Professor Manfred Bischoff

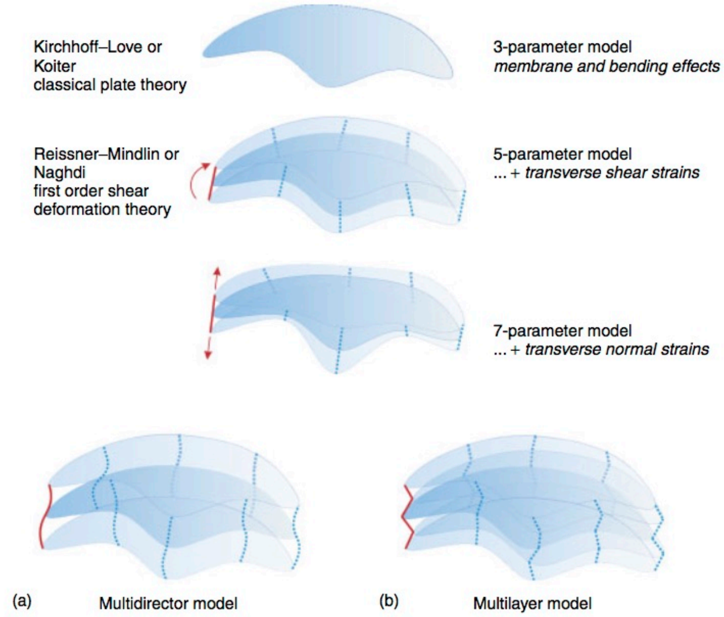

Figure 22. Low- and higher-order as well as layer-wise plate and shell models.

From: M. Bischoff, W. A. Wall, K.-U. Bletzinger and E. Ramm, "Models and finite elements for thin-walled structures", Chapter 3 in Encyclopedia of Computational Mechanics, Edited by Erwin Stein, Rene de Borst and Thomas J.R. Hughes. Volume 2: Solids, Structures and Coupled Problems, John Wiley & Sons, 2004

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Non-linear computational structural mechanics
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Finite element technology
Structural optimization
Multifield and multiscale problems
Contact problems
Computational material modeling

About Myself:

Born 1968 in Freudenstadt, Black Forest
1987 Abitur at the Kepler-Gymnasium in Freudenstadt
1987/88 Military Service at Panzerbrigade 14 in Neustadt and Stadtallendorf
1988 - 1993 Student of Civil Engineering, University of Stuttgart
1993 Diploma in Civil Engineering (Dipl.-Ing.)
1993 - 1999 Research Associate at the Institute of Structural Mechanics (Institut für Baustatik), Prof. Dr.-Ing. E. Ramm, University of Stuttgart

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Nov 2000 - Mar 2001 Post-Doc at the Institute of Structural Mechanics, University of Stuttgart

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Since April 2006 Head of the Institute of Structural Mechanics (Institut für Baustatik und Baudynamik), University of Stuttgart

2000 EUROMECH European Young Scientist Award

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"Models and Finite Elements for Thin-Walled Structures". Chapter 3 in Encyclopedia of Computational Mechanics Published Online: 15 November 2004, doi: 10.1002/0470091355.ecm026

INTRODUCTION:

1.1 Historical Remarks

Thin-walled structures like plates and shells are the most common construction elements in nature and technology. This is independent of the specific scale; they might be small like cell membranes and tiny machine parts or very large like fuselages and cooling towers. This preference to apply walls as thin as possible is a natural optimization strategy to reduce dead load and to minimize construction material. In addition to the slenderness, the advantageous effect of curvature is utilized in shell structures allowing to carry transverse loading in an optimal way, a design principle already known to the ancient master builders. Their considerable heuristic knowledge allowed them to create remarkable buildings, like the Roman Pantheon (115–126) and the Haghia Sophia (532–537) in Constantinople, still existing today. It was not before the Renaissance that scientists began to mathematically idealize the structural response, a process that we denote nowadays as modeling and simulation.

Already, Leonardo da Vinci (1452–1519) stated (Codex Madrid I) a principle that later on emerged to a beam model. The subsequent process, associated with names like Galileo (1564–1642), Mariotte (1620–1684), Leibniz (1646–1716), Jakob I Bernoulli (1654–1705), Euler (1707–1783), Coulomb (1736–1806), and Navier (1785–1836), led to what we call today Euler–Bernoulli beam theory (Timoshenko, 1953; Szabo, 1979). This development was driven by the ingenious ideas to condense the complex three-dimensional situation to the essential ingredients of structural response like stretching, bending, torsion, and so on, and to cast this into a manageable mathematical format. The inclusion of transverse shear deformation is attributed (1859) to Bresse (1822–1883) and extended (1921) to dynamics by Timoshenko (1878–1972), whose name has established itself as a common denomination for this model. Extensions to further effects like uniform and warping torsion, stability problems, cross-sectional distortion, and further refinements, for example, including higher-order kinematics, follows in the nineteenth and twentieth century.

The development of the theory of masonry arches and vaults had its own history, also starting with Leonardo da Vinci (for a detailed elaboration on this subject confer Benvenuto (1991)). The primary aspect in this context was the description of failure mechanisms, a problem investigated up to the present time (see e.g. the valuable work of Heyman). Also, Robert Hooke's (1635–1703) 'Riddle of the Arch' has to be referred to, phrased in a Latin anagram 'Ut pendet continuum flexile, sic stabit contigum inversum rigidum' (literally translated: As the flexible cable hangs, the inverted arch stands). It constitutes a form-finding principle for arches and shells (Mainstone, 1975), which became known as the inverted chain and membrane principle, often applied in the rehabilitation of the cupola of St. Peter in Rome, Rondelet's French Pantheon, Gaudi's work in Catalonia up to modern shell designs by Otto and Isler are based on this principle (Ramm and Reitinger, 1992).

The history of the development of two-dimensional plate theories has its own peculiarities (Timoshenko, 1953; Szabo, 1979). Inspired by Chladni's (1756–1827) experiments with vibrating plates, Jakob II Bernoulli (1759–1789) formulated a grid model of overlapping beams, neglecting the twisting mode. This was corrected by others later on. The related competition proposed by the French Academy and Sophie Germain's (1776–1831) various trials to win the prize and the involvement of Lagrange (1736–1813) became famous. They and others like Poisson (1781–1840) and Navier derived the proper differential equation; however, they still had some shortcomings in their result, in particular, with respect to the involved elastic constants. Kirchhoff (1824–1887) finally removed all doubts in 1850 (Kirchhoff, 1850) and is credited as the founder of modern plate theory. It took almost a century before E. Reissner (1913–1996) (Reissner, 1944; Reissner, 1945) and Mindlin (1906–1987) (Mindlin, 1951) extended the model including the role of transverse shear deformations. Innumerable modifications and extensions, like anisotropy, large deformation (v. Kármán plate theory), higher-order theories, and so on, have been derived over the years.

It is interesting that the initial derivation of a shell formulation was also motivated primarily by vibration problems. Euler developed in 1764 a model to simulate the tones of bells, cutting the axisymmetric structure into rings, applying curved beam models and leaving out the meridional effects. Also, here it took over a century before a consistent theory of thin shells had been derived by Love (1888) (August E. H. Love, 1863–1940). It is based on Kirchhoff's method and thus became known as the Kirchhoff–Love model. For a description of the subsequent emergence of this shell model and the related controversies among Love and his contemporaries on the role of the boundary conditions of both the membrane and the bending part (in particular Lord Rayleigh (1842–1919) and Lamb (1849–1934)), we refer to the article by Calladine (1988), which is worth reading. The need for detailed solutions has driven research in the first half of the twentieth century. Names like H. Reissner, Meissner, Geckeler, Flügge, Vlassov, Novozhilov have to be mentioned, to name just a few; later on further refinements have been introduced by E. Reissner, Gol'denveizer, Koiter, Naghdi, and many others. The inclusion of transverse shear deformations sometimes linked to the name of Naghdi today mostly is referred to as a Reissner–Mindlin formulation, in recognition of their extended plate theories.

The series of names in connection with shell formulations could be continued forever; there are very few topics in structural mechanics where so many investigations have been published. Even for experts, it is hardly possible to have an overall view on the number of special finite element models developed so far. This is a strong indication for the complexity of the involved mechanics on the one hand and their practical relevance on the other hand.

It is obvious that the early developments of theories for thin-walled structures were governed primarily by the main applications in those times, namely, buildings in architecture. Since the industrial revolution, the picture changed completely: now other applications, for example, in mechanical engineering, in vehicle and aerospace industry, in biomechanics, and so on, became dominant and the driving force for further developments.

Large displacements, rotations and strains, buckling, composites, material nonlinearities, coupled problems, multiscale and multiphysics, solution methods, and higher-order formulations are a few keywords for problems that have been extensively investigated in the last few years. The finite element method as a discretization concept is absolutely predominant. An interesting example as to how the finite element developments have influenced the selection of specific structural models is the early shift from Kirchhoff–Love formulations to those with Reissner–Mindlin kinematics for plate and shell elements. It is motivated mainly by the reduced compatibility requirements, although from the practical point of application, the Kirchhoff–Love model is often sufficient.

level of sophistication, we should not forget the main driving force of our ancestors: concentration on the essentials and reduction to the principal mechanical behavior of thin-walled structures (Ramm and Wall, 2004).

1.2. Overview

This paper concentrates on the mathematical modeling of nonlinear mechanics of thin-walled structures in view of associated finite element formulations. This means that we will primarily focus on formulations for structural models as prerequisite for derivation of finite elements, rather than specific ‘elementology’. The main emphasis is put on shells, including the special case of flat plates, turning into shells anyway in the nonlinear regime. The derivations are kept as general as possible, including thick and layered shells (laminated or sandwich structures), as well as anisotropic and inhomogeneous materials from the outset. Throughout Section 4.4, we will specify the corresponding restrictions and assumptions to obtain the classical 5-parameter shell formulation predominantly used for standard shell problems in the context of finite element analysis.

In most part of the text, we restrict ourselves to static problems within the framework of geometrically nonlinear elasticity, neglecting time dependence and inertia effects. The extension into the materially nonlinear area is a straightforward procedure. It is believed that this does not mean a too strong restriction in view of the underlying motivation.

It is a well cultivated tradition to let review articles start with the remark that a complete overview of existing methods and appropriate literature is utterly impossible. The multitude of existing concepts, methods, and implementations, as well as scientific papers, text books, and yet other review articles would effectively prohibit an exhaustive overview. J. E. Marsden and T. J. R. Hughes remark in what they call the ‘disclaimer’ of their famous book on Mathematical Foundations of Elasticity (Marsden and Hughes, 1983) that

‘This book is neither complete nor unbiased. Furthermore, we have not mentioned many deep and highly erudite works, nor have we elucidated alternative approaches to the subject. Any historical comments we make on subjects prior to 1960 are probably wrong, and credits to some theorems may be incorrectly assigned.’

Although the present paper is neither a book nor covers such a broad field like the textbook by Marsden and Hughes (1983), it clearly shares the quoted property. We therefore directly head toward the ideas and inspirations driving the authors during the compilation of the paper at hand.

Motivations for concerning oneself with the present subject are many. They might be of purely scientific nature or driven by the need to find the necessary level for the mechanical content of a model or to have a reliable element as a tool for certain applications one might have in mind. Interest in the mathematical formulation and resulting numerical properties of finite elements for thin-walled structures may also arise when simply applying certain finite element formulations available in scientific or commercial codes. While trying to provide useful information for practitioners and users of commercial finite element codes, this treatise clearly addresses a readership with a scientific background, both things not being mutually exclusive anyway.

When developing and applying a finite element formulation for thin-walled structures, one comes across a couple of questions. Which mechanical effects should be included and which can be neglected? Is it better to start from a shell theory or develop continuum-based elements along the lines of the degenerated solid approach? And what about geometrically exact models? Which simplifications are useful – and admissible? Which consequences does the formulation have for the finite element model? Which parameterization of degrees of freedom are sensible for the applications one has in mind? Should drilling degrees of freedom be included in a shell formulation or not? There are many, many more questions.

It is in this spirit that we try to give an overview of the various decisions that one implicitly makes when incomplete, it should not cover only a mere register of umpteen different plate and shell finite elements along with their alleged pros, cons, and limitations; to be even more specific, this aspect will be very limited in the present contribution.

By doing this, we carefully separate model decisions and the finite element formulation. The former addresses those approximations that are made while formulating the continuous theory. The latter is concerned with additional approximation errors, coming into play along with discretization and finite element formulation. While these numerical errors eventually vanish with mesh refinement, the model errors, inherent to the theory, persist. Distinguishing this is crucial for a sophisticated determination of feasible methods and a competent interpretation of numerical results.

References: The list of references is very long and would require a lot of editing to conform to the format of this bibliography.

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Dominik Schillinger, Vissarion Papadopoulos, Manfred Bischoff and Manolis Papadrakakis, "Buckling analysis of imperfect I-section beam-columns with stochastic shell finite elements", Computational Mechanics, Vol. 46, No. 3, 2010, pp. 495-510, doi: 10.1007/s00466-010-0488-y
ABSTRACT: Buckling loads of thin-walled I-section beam-columns exhibit a wide stochastic scattering due to the uncertainty of imperfections. The present paper proposes a finite element based methodology for the stochastic buckling simulation of I-sections, which uses random fields to accurately describe the fluctuating size and spatial correlation of imperfections. The stochastic buckling behaviour is evaluated by crude Monte-Carlo simulation, based on a large number of I-section samples, which are generated by spectral representation and subsequently analyzed by non-linear shell finite elements. The application to an example I-section beam-column demonstrates that the simulated buckling response is in good agreement with experiments and follows key concepts of imperfection triggered buckling. The derivation of the buckling load variability and the stochastic interaction curve for combined compression and major axis bending as well as stochastic sensitivity studies for thickness and geometric imperfections illustrate potential benefits of the proposed methodology in buckling related research and applications.