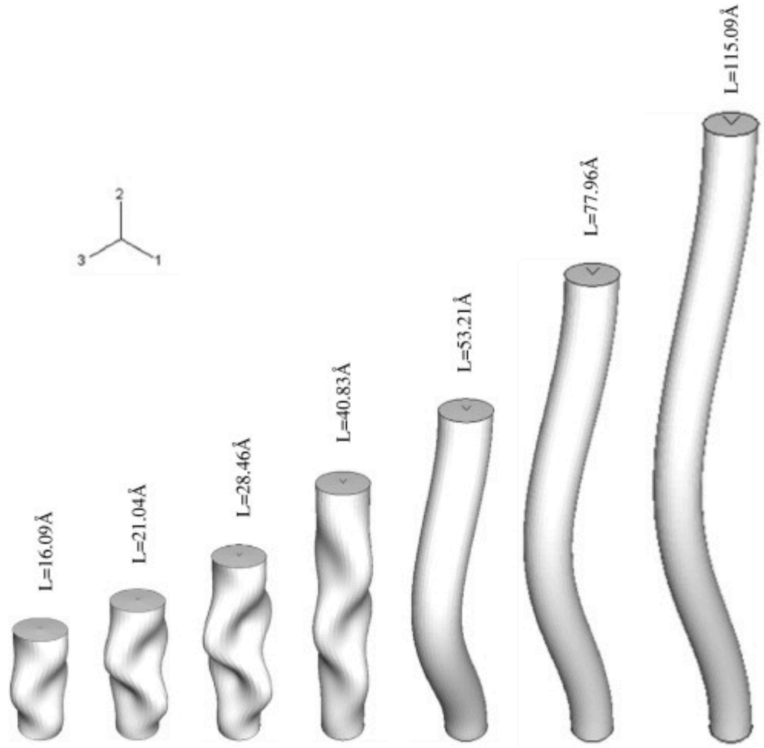
**Professor Chien Ming Wang**




From: "Sanders shell model for buckling of single-walled carbon nanotubes with small length-to-diameter ratios", by N. Silvestre, C.M. Wang, et al, Composite Structures, Vol. 93, No. 7, 2011, pp. 1683-1691

See:
http://www.eng.nus.edu.sg/civil/people/cvewcm/wcm.html
http://www.joykeyan.com/en/Scholar-134.html
http://rdap02pxdu.dev.oclc.org:6251/identities/lccn-n88-672735


Director of Engineering Science Programme and
Department of Civil & Environmental Engineering
National University of Singapore


**Qualifications:**

B.Eng. (First Class Honours), Monash University, Australia 1978
M.Eng.Sc., Monash University, Australia 1980
Ph.D., Monash University, Australia 1982
C.Eng., Institution of Structural Engineers 1998
Fellow of Institution of Engineers Singapore
Fellow of Institution of Structural Engineers

**Biography:**

C.M. Wang is a Professor of Civil and Environmental Engineering at the National University of Singapore (NUS). He graduated from Monash University in Civil Engineering with a First Class Honours in 1978 and was awarded a M.Eng.Sc. and a Ph.D. degree from the same university in 1980 and 1982, respectively. Professor Wang is currently the Director for the Engineering Science Programme, NUS Faculty of Engineering. He is also the Adjunct Professor in the Department of Civil Engineering, Monash University, Australia.

Professor Wang is a Chartered Engineer, a Fellow of the Academy of Engineering Singapore, a Fellow of the Institution of Engineers Singapore and a Fellow of the Institution of Structural Engineers. He is presently the Chairman of the IStructE Singapore Division. He serves in the Steering Committees for ICOTA and APCOM. He was a member of the General Council of the Asian Pacific Association of Computational Mechanics (APACM) and a member-at-large of the Structural Stability Research Council, USA and a member of the ISSC Committee V.4 Offshore Renewable Energy.

His research interests are in the areas of structural stability, vibration, optimization, plated structures and Mega-Floats. His recent grants are secured for research in the areas of very large floating structures, underground structures and carbon nanotubes. He is the author or co-author of over 400 scientific publications, reviewer of many international journals in mechanics, editor of several conference proceedings such as the proceedings on optimization techniques and applications and on computational mechanics and special issues of journals and co-editor of two volumes on Analysis and Design of Plated Structures and a book on Very Large Floating Structures. He is an Editor-in-Chief of the International Journal of Structural Stability and Dynamics and the IES Journal Part A: Civil and Structural Engineering and an Editorial Board Member of Engineering Structures, Advances in Applied Mathematics and Mechanics, International Journal of Applied Mechanics and Ocean Systems Engineering. Moreover, he has co-authored three books "Vibration of Mindlin Plates", "Shear Deformable Beams and Plates: Relationships with Classical Solutions" and "Exact Solutions for Buckling of Structural Members". The first two books were published in 1998 and 2000, respectively, by Elsevier Science while the latest book is published by CRC Press in July 2004.

Professor Wang research papers on flexural-torsional buckling of monosymmetric I-beams have been cited in structural stability textbooks (Bazant and Cedolin 1991, Trahair and Bradford 1991) and his buckling formulas for these beams have been adopted in the American Aluminium Specification and in the design of crane runaway beams according to the Australian design code AS4100 Steel Structures. His paper entitled "Recent Elastic Buckling Formulas and Design Charts for Straight Members and Plates" bagged the IES/IStructE Best Structural paper award 1993. His proposed "Shooting-Optimization Technique", for solving two-point boundary value problems, has been applied by many researchers to solve all kinds of problems such as variable arc-length beam problems (Prof S Chucheepsakul from Thailand, Prof T Huang from USA), biofilm problems (Prof Steven from Canada), undersea cables (Prof Friswell from UK), and fibre problems (Profs Lawryshyn and Kuhn USA). His work on the automation of the Ritz method for plate analysis has drawn much interest from the research community. Researchers such as Prof JN Reddy (USA), Prof AW Leissa (USA), Prof S Dickinson (Canada), Prof YK Cheung (Hong Kong), Prof PA Laura (Argentina) and Prof MA Bradford (Australia) have adopted the method for their plate analyses. His work on developing relationships between the solutions of thick plate theories and the classical thin plate theory has drawn many complimentary reviews. Interestingly, his work on thick annular plates have been used by Israeli scientists to determine the elastic properties of membrane skeleton of living cells which may be modelled as thick plates!

Professor Wang has contributed to the development and application of nonlocal continuum mechanics for predicting the bending, vibration and buckling behaviour of nanostructures, especially carbon nanotubes. Presently he is doing research on refining the nonlocal beam and cylindrical shell models for better prediction of the mechanical responses of carbon nanotubes. The study also involves calibrating the small length scale parameter in the nonlocal models by using Molecular Dynamic Simulations and experimental results.

More recently, Prof Wang conducted cutting-edge research, developed and promoted the use of pontoon-type very large floating structures (VLFS) technology in Singapore and elsewhere. These VLFS lie on the sea surface like giant plates on water, creating valuable land that help in easing congestion in coastal cities and improving the quality of people's life. The advantages of VLFS over traditional land reclamation include their environmental friendliness (does not pollute the water or destroy the marine ecosystem in the seabed and being easily removed or expanded), the cost effectiveness in dealing with deep water and soft seabed, providing useful interior spaces, and are not affected by earthquakes. VLFS have been deployed as floating oil storage facilities, bridges, restaurants, amusement facilities, emergency base, and piers/berths. While conducting research and development of a super large floating container terminal, Prof Wang invented the gill cells (compartments within the floating structure with holes or slits at the bottom floor to allow water in and out freely) to minimize differential deflections and bending stresses in unevenly loaded VLFS. An International PCT Application No. PCT/SG2005/000356 was filed and the application was published on 19 April 2007. Since then, the invention has been patented in Japan, United States and China. This invention can potentially be applied in very large floating structures, mooring buoys, spars, and semi-submersibles. Prof Wang also filed for a patent on offshore floating bunker supply base which will save bunkering costs for both bunker supplier and ship owners as well as precious anchorage space in Singapore waters and a stand-alone offshore fuel storage facility for storing large amounts of fuel or other petrochemicals. Such a floating fuel storage facility will help to solve the land crunch problem faced by Singapore to provide land space for oil tank farms. Prof Wang co-edited the first book on Very Large Floating Structures (published by Taylor and Francis) and wrote more than 30 papers on VLFSs or related to the subject. He has been invited to give keynote lectures and short courses on VLFSs in Japan, India, Australia, Norway, Germany, Thailand, Malaysia and Singapore. He is the principal investigator for several research and industrial projects on VLFSs that amounts to over S$750,000. He was the consultant for the floating platform at Marina Bay and the JTC Corporation assessor for the tender documents on the floating fuel storage facility. Prof Wang's current VLFS studies include the research and development of connector system for large floating concrete structures, hydrodynamic interaction between floating modules, anti-motion devices for VLFS and floating platform for OTEC.

Professor Wang is actively involved in undergraduate teaching and was formerly the Vice-Dean for Undergraduate Programs and chaired the Engineering Undergraduate Programs Advisory Committee (EUPAC), the Faculty Accreditation and Benchmarking Committee (FABC) and the Engineering Learning, Teaching and Education (ELTEC) in the Faculty. He has also served in the University Committee on Educational Policy (UCEP) and the Board of Undergraduate Studies (BUS). Although he has stepped down from being the Associate Director of the Centre for Development of Teaching and Learning (CDTL) at the National University of Singapore from 1998-2001, he is still serving CDTL as a CDTL Affiliate. He recently chaired the International Conference on Teaching and Learning in Higher Education, 1-3 December 2004, Singapore. He assisted the PE Board and IES in drafting the accreditation manual for the Engineering Accreditation Board of Singapore. He is also an external examiner for the Diploma in Offshore Engineering, Ngee Ann Polytechnic and the MSc(Civil Engineering) programme in Universiti Kebangsaan Malaysia.

Professor Wang is the first recipient of the NUS Faculty of Engineering and University Innovative Teaching Awards 1997/1998 for his innovative use of simple and novel real-life examples to bring across abstract and difficult concepts of mechanics. He was also awarded the Civil Engineering Department and the University Teaching Excellence Awards 1998/1999. He has been listed in the 100 Best Teachers in NUS 2002.

Professor Wang has chaired and been invited to serve in international scientific committees of many conferences that include the International Conference on Optimisation Techniques and Applications (ICOTA), Asia-Pacific Conference on Computational Mechanics (APCOM), Conference on Structural Stability and Design, International Conference on Computing in Civil and Building Engineering (ICCCBE), International Conference on Advances in Structural Engineering and Mechanics (ASEM), the International Conference on Enhancement and Promotion of Computational Methods in Engineering Science (EPMESC) and the International Symposium on New Perspectives for Shell and Spatial Structures (IASS-APCS). He has been invited to speak in a number of conferences and was the keynote speaker for the First International Conference on Advances in Structural Engineering and Mechanics, 23-25 August 1999, Korea (Paper title: Deducing thick plate solutions from classical thin plate solutions) the International Symposium on Ocean Space Utilization Technology, 28-31 January 2003, Tokyo (Paper title: Sea space utilization in Singapore), the Third International Conference on Structural Stability and Dynamics, 19-22 June 2005, Kissimmee, Florida (Paper title: Relationships between buckling stresses / vibration frequencies of Mindlin and Kirchhoff plates). The sixth International Conference on Advances in Steel Structures, 16-18 December 2009, Hong Kong (Paper title: Hydroelastic analysis of the large floating plateform at Marina Bay in Singapore), the Twelveth East-Asia-Pacific Conference on Structural Engineering and Construction, 26-28 January 2011, Hong Kong (Paper Title: Very large floating structures: Applications, research and development), the Fourth International Conference on Structural Stability and Dynamics, 4-6 January 2012, Jaipur, India (Paper Title: Novel solution to mitigate hydroelastic response of very large floating structures).

**Honours & Awards:**

Faculty of Engineering Innovative Teaching Award 2007/2008
IES Outstanding Volunteer Award 2007/2008
Lewis Kent Award 2009
Monash University Postgraduate Scholarship 1979-1982
IES/IStructE Best Structural Paper Award 1993
Engineering Faculty Innovative Teaching Award 1997
University Innovative Teaching Award 1997/1998
Department of Civil Engineering Teaching Excellence Award 1998/1999
University Teaching Excellence Award 1998/1999
Listed in the top 100 NUS Excellent Teachers 2001/2002
Department of Civil Engineering Teaching Honors List Award 2003/2004.
Listed in the Marquis Who's Who in the World, 1998-present
Listed in the Marquis Who's in Science and Engineering, 1996-present
Visiting Scientist, Japan Society for the Promotion of Science (JSPS), 2000, 2002.
Editor-in-Chief of International Journal of Structural Stability and Dynamics
Member of Editorial Board of Engineering Structures, 2006 - present.
Member of Editorial Board of the Journal of Computational Structural Engineering, 2000-present

**Courses Taught (perhaps several times) Since Academic Year 2000:**

Design Project 1

Mechanics and Waves
Major Design Project
Plastic Analysis of Structures
Statics & Mechanics of Materials
Plate & Shell Structures (wef AY2003/04
Engineering Professionalism
Statics

**List of Publications:**
See: http://www.eng.nus.edu.sg/civil/people/cvewcm/wcm.html

**Selected Publications:**

C.M. Wang (1), Y.Y. Zhang (2), Y. Xiang (3), J.N. Reddy (4)
(1) Department of Civil Engineering and Engineering Science Programme, National University of Singapore, Singapore 117576, Singapore
(2) School of Mechanical Engineering and Automation, Fuzhou University, 350108, P. R. China; School of Engineering, University of Western Sydney, Penrith South DC, NSW 1797, Australia
(3) School of Engineering, University of Western Sydney, Penrith South DC, NSW 1797, Australia
(4) Department of Mechanical Engineering, Texas A&M University, College Station, TX 777843-3123
**"Recent Studies on Buckling of Carbon Nanotubes"**, Appl. Mech. Rev., Vol. 63, No. 3, May 2010, 030804 (18 pages), doi:10.1115/1.4001936
ABSTRACT: This paper reviews recent research studies on the buckling of carbon nanotubes. The structure and properties of carbon nanotubes are introduced to the readers. The various buckling behaviors exhibited by carbon nanotubes are also presented herein. The main factors, such as dimensions, boundary conditions, temperature, strain rate, and chirality, influencing the buckling behaviors are also discussed, as well as a brief introduction of the two most used methods for analyzing carbon nanotubes, i.e., continuum models and atomistic simulations. Summary and recommendations for future research are also given. Finally, a large body of papers is given in the reference section. It is hoped that this paper provides current knowledge on the buckling of carbon nanotubes, reviews the computational methods for determining the buckling loads, and inspires researchers to further investigate the buckling properties of carbon nanotubes for practical applications.

Wang, C.Y., Zhang, Y.Y., Wang, C.M. and Tan, V.B.C., **"Buckling of Carbon Nanotubes: A Literature Survey"**, Journal of Nanoscience and Nanotechnology, Vol. 7, No. 12, December 2007 , pp. 4221-4247, doi: 10.1166/jnn.2007.924
ABSTRACT: This survey paper comprises 5 sections. In Section 1, the reader is introduced to the world of carbon nanotubes where their structural form and properties are highlighted. Section 2 presents the various buckling behaviors exhibited by carbon nanotubes that are discovered by carbon nanotube researchers. The main factors, such as dimensions, boundary conditions, temperature, strain rate and chirality, influencing the buckling behaviors are discussed in Section 3. Section 4 presents the continuum models, atomistic simulations and experimental techniques in studying the buckling phenomena of carbon nanotubes. A summary as well as recommendations for future research are given in Section 5. Finally a large body of papers, over 200, is given in the reference section. It is hoped that this survey paper will provide the foundation knowledge on carbon nanotube buckling and inspire researchers to advance the modeling, simulation and design of carbon nanotubes for practical applications.

Y Y Zhang (1), C M Wang (2), W H Duan (3), Y Xiang (4) and Z Zong (5)
(1) School of Mechanical Engineering and Automation, Fuzhou University, Fuzhou, Fujian Province 350108, People's Republic of China
(2) Engineering Science Programme, Faculty of Engineering, National University of Singapore, Kent Ridge, 119260, Singapore
(3) Department of Civil Engineering, Monash University, Clayton, Victoria, Australia
(4) School of Engineering, University of Western Sydney, Penrith South DC, NSW, Australia
(5) Department of Naval Architecture, Dalian University of Technology, People's Republic of China
"Assessment of continuum mechanics models in predicting buckling strains of single-walled carbon nanotubes", Nanotechnology Vol. 20, No. 39, 2009, 395707, doi: 10.1088/0957-4484/20/39/395707
ABSTRACT: This paper presents an assessment of continuum mechanics (beam and cylindrical shell) models in the prediction of critical buckling strains of axially loaded single-walled carbon nanotubes (SWCNTs). Molecular dynamics (MD) simulation results for SWCNTs with various aspect (length-to-diameter) ratios and diameters will be used as the reference solutions for this assessment exercise. From MD simulations, two distinct buckling modes are observed, i.e. the shell-type buckling mode, when the aspect ratios are small, and the beam-type mode, when the aspect ratios are large. For moderate aspect ratios, the SWCNTs buckle in a mixed beam–shell mode. Therefore one chooses either the beam or the shell model depending on the aspect ratio of the carbon nanotubes (CNTs). It will be shown herein that for SWCNTs with long aspect ratios, the local Euler beam results are comparable to MD simulation results carried out at room temperature. However, when the SWCNTs have moderate aspect ratios, it is necessary to use the more refined nonlocal beam theory or the Timoshenko beam model for a better prediction of the critical strain. For short SWCNTs with large diameters, the nonlocal shell model with the appropriate small length scale parameter can provide critical strains that are in good agreement with MD results. However, for short SWCNTs with small diameters, more work has to be done to refine the nonlocal cylindrical shell model for better prediction of critical strains.

X. Q. He (1), C. Qu (2), Q. H. Qin (3) and C. M. Wang (4)
(1) Department of Building and Construction City University of Hong Kong, Hong Kong bcxqhe@cityu.edu.hk
(2) Department of Mechanics, Tianjin University Tianjin, 300072, China
(3) Department of Engineering Australian National University Canberra, Australia
(4) Engineering Science Programme and Department of Civil Engineering National University of Singapore, Kent Ridge, Singapore 119260
"Buckling and Postbuckling Analysis of Multi-Walled Carbon Nanotubes Based on the Continuum Shell Model", International Journal of Structural Stability and Dynamics Vol. 7, No. 4 (2007) pp. 629–645
ABSTRACT: Buckling and postbuckling behaviors of multi-walled carbon nanotubes (MWCNTs) under a compressive force are studied. MWCNTs are modeled by Donnell's shallow shell nonlinear theory with the allowance of van der Waals (vdW) interaction between the walls. It is shown herein that the buckling load decreases while the buckling strain increases as the innermost radius of MWCNT increases. For the postbuckling behavior, the shortening-load curves show an initial steep gradient that gradually level up when the radius of the innermost tube changes from a small value to a large value. However, the deflection-load curves are almost level for various radii of MWCNTs. In addition, the analytical results showed that the shortening-load curves are almost linear but the deflection-load curves are nonlinear and the stability of MWCNTs can be enhanced by adding tubes.

Y.Y. Zhang (1), V.B.C. Tan (1) and C.M. Wang (2)
(1)Department of Mechanical Engineering, National University of Singapore, Kent Ridge, Singapore 117576, Singapore

(2) Engineering Science Programme and Department of Civil Engineering, National University of Singapore, Kent Ridge, Singapore 117576, Singapore
"Effect of strain rate on the buckling behavior of single- and double-walled carbon nanotubes", Carbon, Vol.45, No. 3, March 2007, pp. 514-523, doi:10.1016/j.carbon.2006.10.020
ABSTRACT: Molecular dynamics simulations are performed on single- (SWCNTs) and double-walled carbon nanotubes (DWCNTs) to investigate the effects of strain rate on their buckling behavior. The Brenner's second-generation reactive empirical bond order and Lennard-Jones 12-6 potentials are used to describe the short range bonding and long range van der Waals atomic (vdW) interaction within the carbon nanotubes, respectively. The sensitivity of the buckling behavior with respect to the strain rate is investigated by prescribing different axial velocities to the ends of the SWCNTs and DWCNTs in the compression simulations. In addition, the effects of vdW interaction between the walls of the DWCNTs on their buckling behavior are also examined. The simulation results show that higher strain rates lead to higher buckling loads and buckling strains for both SWCNTs and DWCNTs. A distinguishing characteristic between SWCNTs and DWCNTs is that the former experiences an abrupt drop in axial load whereas the axial load in latter decreases over a finite, albeit small, range of strain after buckling initiates. The buckling capability of DWCNT is enhanced in the presence of vdW interaction. DWCNTs can sustain a higher strain before buckling than SWCNTs of similar diameter under otherwise identical conditions.

N. Silvestre (1), C.M. Wang (2), Y.Y. Zhang (3) and Y. Xiang (3)
(1) Department of Civil Engineering & Architecture, ICIST-IST, Technical University of Lisbon, Portugal
(2) Engineering Science Programme, National University of Singapore, Kent Ridge, Singapore
(3) School of Engineering, University of Western Sydney, New South Wales, Australia
"Sanders shell model for buckling of single-walled carbon nanotubes with small aspect ratio", Composite Structures, Vol. 93, No. 7, June 2011, pp. 1683-1691, doi:10.1016/j.compstruct.2011.01.004
ABSTRACT: In this paper, the buckling behaviour of single-walled carbon nanotubes (CNTs) is revisited by resorting to Donnell and Sanders shell models, which are put in parallel and shown to lead to very distinct results for CNTs with small aspect ratio (length-to-diameter). This paper demonstrates inability of the widely used Donnell shell theory while it shows the validity and accuracy of the Sanders shell theory in reproducing buckling strains and mode shapes of axially compressed CNTs with small aspect ratios. The results obtained by the later shell theory are close to molecular dynamics simulation results.The Sanders shell theory could capture correctly the length-dependent buckling strains of CNTs which the Donnell shell theory fails to achieve. In view of this study, researchers should adopt the Sanders thin shell theory from hereon instead of the Donnell theory when analyzing CNTs with small aspect ratios.