

Advances in Shell Buckling: Theory and Experiments*

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In a recent feature article in this journal, coauthored by Gert van der Heijden, I described the static-dynamic analogy and its role in understanding the localized post-buckling of shell-like structures, looking exclusively at integrable systems. We showed the true significance of the Maxwell energy criterion load in predicting the sudden onset of “shock sensitivity” to lateral disturbances. The present paper extends the survey to cover nonintegrable systems, such as thin compressed shells. These exhibit spatial chaos, generating a multiplicity of localized paths (and escape routes) with complex snaking and laddering phenomena. The final theoretical contribution shows how these concepts relate to the response and energy barriers of an axially compressed cylindrical shell.

After surveying NASA’s current shell-testing programme, a new nondestructive technique is proposed to estimate the “shock sensitivity” of a laboratory specimen that is in a compressed metastable state before buckling. A probe is used to measure the nonlinear load-deflection characteristic under a rigidly applied lateral displacement. Sensing the passive resisting force, it can be plotted in real time against the displacement, displaying an equilibrium path along which the force rises to a maximum and then decreases to zero: having reached the free state of the shell that forms a mountain-pass in the potential energy. The area under this graph gives the energy barrier against lateral shocks. The test is repeated at different levels of the overall compression. If a symmetry-breaking bifurcation is encountered on the path, computer simulations show how this can be suppressed by a controlled secondary probe tuned to deliver zero force on the shell.

Keywords: Maxwell load; shell buckling theory; shell buckling experiments; shock sensitivity; localization; imperfection sensitivity; stability; rods.

1. Introduction

Early in the 20th century the pioneering use of thin metal shells as load-carrying components in aircraft and rockets stimulated engineers to look in detail at two well-defined archetypal problems of elastic buckling. These were the complete spherical shell subjected to uniform external pressure, and the cylindrical shell subjected to uniform axial compression. In careful laboratory tests, both of these were found to be collapsing violently at about

one quarter of the classical buckling loads, P_C , predicted by small-deflection linear theory. In response to this discrepancy, von Karman and Tsien [1939, 1941] made approximate Rayleigh–Ritz analyses to demonstrate that, for both problems, there exists a very unstable, subcritical post-buckling path of periodic equilibrium states. This falls rapidly from P_C and eventually stabilizes at a fold (limit point) at what they termed the *lower buckling load*, P_L . They suggested that this load might be a useful

*Based on the opening lecture at the IDEAS Workshop, “Investigating Dynamics in Engineering and Applied Science”, celebrating Gábor Stépán’s 60th birthday, July 3–5, 2014, Budapest.

Advances In Shell Buckling Theory And Experiments

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Advances In Shell Buckling Theory And Experiments:

Recent Advances in Experimental Mechanics E.E. Gdoutos, 2007-05-08 This book contains 71 papers presented at the symposium on Recent Advances in Experimental Mechanics which was organized in honor of Professor Isaac M Daniel The symposium took place at Virginia Polytechnic Institute and State University on the June 23-28 2002 in conjunction with the 14 US National Congress of Applied Mechanics The book is a tribute to Isaac Daniel a pioneer of experimental mechanics and composite materials in recognition of his continuous original diversified and outstanding contributions for half a century The book consists of invited papers written by leading experts in the field It contains original contributions concerning the latest developments in experimental mechanics It covers a wide range of subjects including optical methods of stress analysis photoelasticity moiré etc composite materials sandwich construction fracture mechanics fatigue and damage nondestructive evaluation dynamic problems fiber optic sensors speckle metrology digital image processing nanotechnology neutron diffraction and synchrotron radiation methods The papers are arranged in the following nine sections Mechanical characterization of material behavior composite materials fracture and fatigue optical methods nondestructive evaluation neutron diffraction and synchrotron radiation methods hybrid methods composite structures and structural testing and analysis

Advances in Steel Structures (ICASS '99) Siu-Lai Chan, J.G. Teng, 1999-12-01 These two volumes of proceedings contain 9 invited keynote papers and 126 contributed papers to be presented at the Second International Conference on Advances in Steel Structures held on 15-17 December 1999 in Hong Kong The conference is a sequel to the International Conference on Advances in Steel Structures held in Hong Kong in December 1996 The conference will provide a forum for discussion and dissemination by researchers and designers of recent advances in the analysis behaviour design and construction of steel structures The papers to be presented at the conference cover a wide spectrum of topics and were contributed from over 15 countries around the world They report the current state of the art and point to future directions of structural steel research

Asymptotic Methods in the Buckling Theory of Elastic Shells P. E. Tovstik, Andrei L. Smirnov, 2001

- 1 Equations of thin elastic shell theory
- 1 Elements of surface theory
- 2 Equilibrium equations and boundary conditions
- 3 Errors of 2D shell theory of Kirchhoff Love type
- 4 Membrane stress state
- 5 Technical shell theory equations
- 6 Technical theory equations in the other cases
- 7 Shallow shells
- 8 Initial imperfections
- 9 Cylindrical shells
- 10 The potential energy of shell deformation
- 11 Problems and exercises

- 2 Basic equations of shell buckling
- 1 Types of elastic shell buckling
- 2 The buckling equations
- 3 The buckling equations for a membrane state
- 4 buckling equations of the general stress state
- 5 Problems and exercises

- 3 Simple buckling problems
- 3 1 Buckling of a shallow convex shell
- 3 2 Shallow shell buckling modes
- 3 3 The non uniqueness of buckling modes
- 3 4 A circular cylindrical shell under axial compression
- 3 5 A circular cylindrical shell under external pressure
- 3 6 Estimates of critical load
- 3 7 Problems and examples

- 4 Buckling modes localized near parallels
- 4 1 Local shell buckling modes
- 4 2 Construction algorithm of buckling modes
- 4 3

Buckling modes of convex shells of revolution 4 4 Buckling of shells of revolution without torsion 4 5 Buckling of shells of revolution under torsion 4 6 Problems and exercises 5 Non homogeneous axial compression of cylindrical shells 5 1 Buckling modes localized near generatrix 5 2 Reconstruction of the asymptotic expansions 5 3 Axial compression and bending of cylindrical shell 5 4 The influence of internal pressure 5 5 Buckling of a non circular cylindrical shell 5 6 Cylindrical shell with curvature of variable sign 5 7 Problems and exercises 6 Buckling modes localized at a point 6 1 Local buckling of convex shells 6 2 Construction of the buckling mode 6 3 Ellipsoid of revolution under combined load 6 4 Cylindrical shell under axial compression 6 5 Construction of the buckling modes 6 6 Problems and exercises 7 Semi momentless buckling modes 7 1 Basic equations and boundary conditions 7 2 Buckling modes for a conic shell 7 3 Effect of initial membrane stress resultants 7 4 Semi momentless buckling modes of cylindrical shells 7 5 Problems and exercises 8 Effect of boundary conditions on semi momentless modes 8 1 Construction algorithm for semi momentless solutions 8 2 Semi momentless solutions 8 3 Edge effect solutions 8 4 Separation of boundary conditions 8 5 The effect of boundary conditions on the critical load 8 6 Boundary conditions and buckling of a cylindrical shell 8 7 Conic shells under external pressure 8 8 Problems and exercises 9 Torsion and bending of cylindrical and conic shells 9 1 Torsion of cylindrical shells 9 2 Cylindrical shell under combined loading 9 3 A shell with non constant parameters under torsion 9 4 Bending of a cylindrical shell 9 5 The torsion and bending of a conic shell 9 6 Problems and exercises 10 Nearly cylindrical and conic shells 10 1 Basic relations 10 2 Boundary problem in the zeroth approximation 10 3 Buckling of a nearly cylindrical shell 10 4 Torsion of a nearly cylindrical shell 10 5 Problems and exercises 11 Shells of revolution of negative Gaussian curvature 11 1 Initial equations and their solutions 11 2 Separation of the boundary conditions 11 3 Boundary problem in the zeroth approximation 11 4 Buckling modes without torsion 11 5 The case of the neutral surface bending 11 6 The buckling of a torus sector 11 7 Shell with Gaussian curvature of variable sign 11 8 Problems and exercises 12 Surface bending and shell buckling 12 1 The transformation of potential energy 12 2 Pure bending buckling mode of shells of revolution 12 3 The buckling of a weakly supported shell of revolution 12 4 Weakly supported cylindrical and conical shells 12 5 Weakly supported shells of negative Gaussian curvature 12 6 Problems and exercises 13 Buckling modes localized at an edge 13 1 Rectangular plates under compression 13 2 Cylindrical shells and panels under axial compression 13 3 Cylindrical panel with a weakly supported edge 13 4 Shallow shell with a weak edge support 13 5 Modes of shells of revolution localized near an edge 13 6 Buckling modes with turning points 13 7 Modes localized near the weakest point on an edge 13 8 Problems and exercises 14 Shells of revolution under general stress state 14 1 The basic equations and edge effect solutions 14 2 Buckling with pseudo bending modes 14 3 The cases of significant effect of pre buckling strains 14 4 The weakest parallel coinciding with an edge 14 5 Problems and exercises

Thin-shell Structures; Theory, Experiment and Design California Institute of Technology, 1974 The book describes the status of the theoretical and experimental understanding of the mechanics of thin walled shell structures as known in the 1970 s The

distinctive feature of this book is in its emphasis on experimental evaluation of the theories and on practical concerns for shell design The book is the edited proceedings of the Symposium on Thin Shell Structures Theory Experiment and Design which was held in Pasadena California from June 29 to 30 1972 Author Recent Developments in the Theory of Shells Holm Altenbach, Jacek Chróścielewski, Victor A. Eremeyev, Krzysztof Wiśniewski, 2019-09-25 This book commemorates the 80th birthday of Prof W Pietraszkiewicz a prominent specialist in the field of general shell theory Reflecting Prof Pietraszkiewicz's focus the respective papers address a range of current problems in the theory of shells In addition they present other structural mechanics problems involving dimension reduced models Lastly several applications are discussed including material models for such dimension reduced structures **Stability Analysis of Plates and Shells**, 1998

Developments in Theoretical and Applied Mechanics Grover L. Rogers, S. C. Kranc, E. G. Henneke, Edmund G. Henneke, 1970 Buckling of Cylindrical Shells with Axisymmetric Toroidal Initial Imperfections Clark E. Beck, AIR FORCE FLIGHT DYNAMICS LAB WRIGHT-PATTERSON AFB OHIO., 1973 Some recent advances in thin shell buckling theory which tend to explain the discrepancy between experiment and theory are reviewed The results of a digital computer study to determine the effect of three discrete axisymmetric imperfections on the buckling load of two specific circular cylindrical shells are presented and discussed The shells were 40 inches long with wall thicknesses of 0.02 inch and radii of five and ten inches Initial imperfection amplitudes considered were 0.005, 0.01 and 0.02 inch Autho Applied Mechanics Reviews, 1996

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Developments in Pressure Vessel Technology, 1983 Developments in Analysis and Design Using Finite Element Methods B. Kumar, B. H. V. Topping, 1999 Contains a selection of papers presented at The Seventh International Conference on Civil and Structural Engineering and The Fifth International Conference on the Applications of Artificial Intelligence to Civil and Structural Engineering held concurrently from 13-15 September 1999 at Oxford England **Calculation of the Load Carrying Capacity of Initially Slightly Imperfect Thin Walled Circular Cylindrical Shells of Finite Length** K. Y. Narasimhan, Stanford University. Department of Aeronautics and Astronautics, Nicholas J. Hoff, 1967 The nonlinear partial differential equations of von Karman and Donnell governing the deformations of initially imperfect cylindrical shells are reduced to a consistent set of ordinary differential equations A numerical procedure is then developed for the solution of these equations together with the associated boundary conditions This method is used to determine the number of waves at buckling as well as the load carrying capacity of imperfect cylindrical shells of finite length subjected to uniform axial compression in the presence of the least amount of restraint along the simply supported boundaries It is found that details of

the boundary conditions have little effect on the number of waves into which the shell buckles around the circumference This number is determined essentially by the length to radius and radius to thickness ratios The absence of an edge restraint to circumferential displacements reduces the classical value of the buckling load by a factor of about two as compared to the classical value On the other hand shells with these boundary conditions are less sensitive to initial imperfections in the shape and thus the maximal load supported in the presence of unavoidable initial deviations can be the same for shells with and without a restraint to circumferential displacements along the edges Author **A Collection of Technical Papers** ,1980

Progress Report on Research Supported by Grants from the Defense Research Board of Canada University of Toronto. Institute for Aerospace Studies,1985 **Technical Paper - Florida Engineering and Industrial Experiment Station** University of Florida. Engineering and Industrial Experiment Station,1966 **Proceedings of the Seventh International Conference on Experimental Stress Analysis, Haifa, Israel, 23-27 August, 1982** ,1982 *Science Progress* ,1906 Includes book reviews

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Table of Contents Advances In Shell Buckling Theory And Experiments

1. Understanding the eBook Advances In Shell Buckling Theory And Experiments
 - The Rise of Digital Reading Advances In Shell Buckling Theory And Experiments
 - Advantages of eBooks Over Traditional Books
2. Identifying Advances In Shell Buckling Theory And Experiments
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Advances In Shell Buckling Theory And Experiments
 - User-Friendly Interface
4. Exploring eBook Recommendations from Advances In Shell Buckling Theory And Experiments

- Personalized Recommendations
 - Advances In Shell Buckling Theory And Experiments User Reviews and Ratings
 - Advances In Shell Buckling Theory And Experiments and Bestseller Lists
5. Accessing Advances In Shell Buckling Theory And Experiments Free and Paid eBooks
 - Advances In Shell Buckling Theory And Experiments Public Domain eBooks
 - Advances In Shell Buckling Theory And Experiments eBook Subscription Services
 - Advances In Shell Buckling Theory And Experiments Budget-Friendly Options
 6. Navigating Advances In Shell Buckling Theory And Experiments eBook Formats
 - ePub, PDF, MOBI, and More
 - Advances In Shell Buckling Theory And Experiments Compatibility with Devices
 - Advances In Shell Buckling Theory And Experiments Enhanced eBook Features
 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Advances In Shell Buckling Theory And Experiments
 - Highlighting and Note-Taking Advances In Shell Buckling Theory And Experiments
 - Interactive Elements Advances In Shell Buckling Theory And Experiments
 8. Staying Engaged with Advances In Shell Buckling Theory And Experiments
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Advances In Shell Buckling Theory And Experiments
 9. Balancing eBooks and Physical Books Advances In Shell Buckling Theory And Experiments
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Advances In Shell Buckling Theory And Experiments
 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
 11. Cultivating a Reading Routine Advances In Shell Buckling Theory And Experiments
 - Setting Reading Goals Advances In Shell Buckling Theory And Experiments
 - Carving Out Dedicated Reading Time
 12. Sourcing Reliable Information of Advances In Shell Buckling Theory And Experiments

- Fact-Checking eBook Content of Advances In Shell Buckling Theory And Experiments
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
- Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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