

## A FRESH LOOK AT THE BUCKLING OF CONCRETE SHELL ROOFS

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### ABSTRACT

There have been a number of spectacular past collapses of shell structures. For doubly curved roof shells subjected to uniformly distributed load this paper describes recent work examining one of the potential catastrophic failure modes, that of collapse due to buckling instability. Buckling behaviour will be reassessed by means of a combination of classical shell buckling theory and its extension to the reduced stiffness theory. Of particular interest will be the identification of those membrane and bending stiffness components that provide the most significant contributions to the shell buckling resistance. This will then allow identification of the various factors most likely to weaken the shells resistance to buckling. Each of the factors will be shown to have potentially vital effects on the shells ability to develop the all important membrane stiffness in both the pre- and post-buckling modes. It will be shown how the loss of this membrane stiffness is accompanied by a redistribution of the shells internal resistance in which bending stiffness provides an increasingly important contribution.

### INTRODUCTION

The structural efficiency and the aesthetic qualities of shells have long been recognised. From the early use of masonry vaulting to the more recent exploitation of strong materials, to achieve daringly slender clear spans in excess of 250 m, engineers and architects have been quick to exploit this inherent efficiency of shell behaviour. However, the rush to take advantage of the potential offered by reinforced concrete shell roofs during the mid-decades of the 20th century came to a fairly abrupt end by the late 1960's, partly as a result of a number of catastrophic collapses (Tedesko, 1980). There are signs that a new generation of designers is again becoming aware of the potential offered by the use of these shell roofs.

Although the few recorded, and even more unrecorded, failures of shell roofs were due to a complex interaction of a number of factors, in most, the development of non-linear buckling instabilities played a significant role. In many cases the lack of attention to edge and particularly corner support conditions, was to result in a transfer of the intended membrane behaviour to a greater dependence on bending. Accompanying the high bending strains there was often an acceleration of the growth of visco-plastic distortions, eventually leading to buckling collapse. It is perhaps the availability of powerful numerical procedures for analysing the complexities of geometry, support, and non-linear behaviour that are encouraging designers to again exploit the benefits of shell action. However it is now well known that small changes in geometry, support and loading conditions, in the form of imperfections, can have disproportionate effects on the load carrying capacity of shell structures. If numerical (finite element) analyses are being used to inform shell design, it is important that the potentially disastrous effects, arising from a wide range of imperfection types, are

# Concrete Shell Buckling

**Zdenek P Bazant, Luigi Cedolin**



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**Concrete Shell Buckling** Egor P. Popov, Stefan J. Medwadowski, 1981  
Medwadowski, 1981-01-01 *Buckling of Shell Roofs* Cement and Concrete Association, London, 1964 **Concrete Shell Buckling. A Symposium Held Within the Framework of the 1979 American Concrete Institute Fall Convention, Washington, D.C** E.P. Popov, S.J. Medwadowski, 1981 **Concrete Shell Buckling**, 1981 **Buckling of Reinforced Concrete Shell Structures** Peter H. Griggs, 1968 *Buckling of Shells for Engineers* L. Kollar, E. Dulacsha, 1984-06-06  
Good No Highlights No Markup all pages are intact Slight Shelfwear may have the corners slightly dented may have slight color changes slightly damaged spine **Buckling Stability of Inflated Fabric-reinforced Concrete Shells** Florence Joan Hasiuk, 1986 **Inelastic Behaviour of Plates and Shells** Luiz Bevilacqua, Raul Feijoo, Roger Valid, 2012-12-06  
During the last ten years a considerable volume of information has been accumulated regarding the inelastic behaviour of materials The increasing number of communications published in specialised journals and also the frequency of meetings in these fields indicates a considerable research effort aimed at such topics as plasticity creep fatigue visco plasticity and the like This fact encouraged a group of Brazilian researchers stimulated enthusiastically by Professor P Germain to submit a proposal for a Symposium on the Inelastic Behaviour of Plates and Shells to the General Assembly of IUTAM Brazil had recently joined IUTAM and the Brazilian Association of Mechanical Sciences was eager to host an IUTAM meeting In the selection of the subject it was taken into account besides a promising number of original contributions the interest to be raised amongst the Brazilian researchers and engineers in order to maximise the participation of the host country The recent steps taken in this country towards the development of the aerospace industry the construction of nuclear power plants and the offshore exploration of petroleum have required an intensification of research activities in several fields structural behaviour of plates and shells being one of the most important Therefore the suggested theme would attract the interest of a significant group of Brazilian researchers and engineers and match the necessity for exchanging experience among leading scientists working in those fields *Stability Of Structures: Elastic, Inelastic, Fracture And Damage Theories* Zdenek P Bazant, Luigi Cedolin, 2010-08-16 A crucial element of structural and continuum mechanics stability theory has limitless applications in civil mechanical aerospace naval and nuclear engineering This text of unparalleled scope presents a comprehensive exposition of the principles and applications of stability analysis It has been proven as a text for introductory courses and various advanced courses for graduate students It is also prized as an exhaustive reference for engineers and researchers The authors focus on understanding of the basic principles rather than excessive detailed solutions and their treatment of each subject proceed from simple examples to general concepts and rigorous formulations All the results are derived using as simple mathematics as possible Numerous examples are given and 700 exercise problems help in attaining a firm grasp of this central aspect of solid mechanics The book is an unabridged republication of the 1991 edition by Oxford

University Press and the 2003 edition by Dover updated with 18 pages of end notes *Structural Modeling and Experimental Techniques, Second Edition* Harry G. Harris, Gajanan Sabnis, 1999-03-30 *Structural Modeling and Experimental Techniques* presents a current treatment of structural modeling for applications in design research education and product development Providing numerous case studies throughout the book emphasizes modeling the behavior of reinforced and prestressed concrete and masonry structures *Structural Modeling and Experimental Techniques* Concentrates on the modeling of the true inelastic behavior of structures Provides case histories detailing applications of the modeling techniques to real structures Discusses the historical background of model analysis and similitude principles governing the design testing and interpretation of models Evaluates the limitations and benefits of elastic models Analyzes materials for reinforced concrete masonry and steel models Assesses the critical nature of scale effects of model testing Describes selected laboratory techniques and loading methods Contains material on errors as well as the accuracy and reliability of physical modeling Examines dynamic similitude and modeling techniques for studying dynamic loading of structures Covers actual applications of structural modeling This book serves students in model analysis and experimental methods professionals manufacturing and testing structural models as well as professionals testing large or full scale structures since the instrumentation techniques and overall approaches for testing large structures are very similar to those used in small scale modeling work

*Buckling of a Point Supported Liner Shell Inside a Concrete Containment* Thomas Charles Esselman, 1973 **Buckling of Reinforced Concrete Spherical Shells** Mallela Ramaiah, 1977 *Buckling of Shell Roofs* Cement and Concrete Association, 1963 **Perspectives in Civil Engineering** Jeffrey S. Russell, 2003-01-01 This report contains 27 papers that serve as a testament to the state of the art of civil engineering at the outset of the 21st century as well as to commemorate the ASCE's Sesquicentennial Written by the leading practitioners educators and researchers of civil engineering each of these peer reviewed papers explores a particular aspect of civil engineering knowledge and practice Each paper explores the development of a particular civil engineering specialty including milestones and future barriers constraints and opportunities The papers celebrate the history heritage and accomplishments of the profession in all facets of practice including construction facilities special structures engineering mechanics surveying and mapping irrigation and water quality forensics computing materials geotechnical engineering hydraulic engineering and transportation engineering While each paper is unique collectively they provide a snapshot of the profession while offering thoughtful predictions of likely developments in the years to come Together the papers illuminate the mounting complexity facing civil engineering stemming from rapid growth in scientific knowledge technological development and human populations especially in the last 50 years An overarching theme is the need for systems level approaches and consideration from undergraduate education through advanced engineering materials processes technologies and design methods and tools These papers speak to the need for civil engineers of all specialties to recognize and embrace the growing interconnectedness of the global infrastructure

economy society and the need to work for more sustainable life cycle oriented solutions While embracing the past and the present the papers collected here clearly have an eye on the future needs of ASCE and the civil engineering profession

*Proceedings of the Second Symposium on Concrete Shell Roof Construction* Oslo Symposium on Concrete Shell Roof Construction. 2d,1958     Inelastic Buckling of Plain and Reinforced Concrete Columns, Plates, and Shells George Campbell Ernst,Joseph J. Hromadik,Arvin R. Riveland,1953     **Bulletin of the International Association for Shell and Spatial Structures** International Association for Shell and Spatial Structures,1989     Buckling of a Thin Cylindrical Liner Shell Supported in Concrete with Flexible Stud Type Anchors Robert J. Gratzinger,1973     World Congress on Shell and Spatial Structures F. del Pozo,L. M. Ortega,J. L. Alcalá,1979

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