

STRUCTURAL ANALYSIS AND OPTIMIZATION OF CONCRETE SPHERICAL AND GROINED SHELLS

Ivana Mekjavić, Srećko Pićulin

Subject review

An understanding of successful shells of the past combined with modern structural analysis methods can aid engineers in designing efficient thin shell-concrete structures. This paper presents structural analyses and the optimization study of several notable concrete shells around the world. The finite element analysis using Sofistik software was found to give results close to those from shell theory and to be more powerful when complicated real-life examples were presented. In structural optimization of the concrete spherical and groined shells an attempt is made to reduce overall tensile stress, deflection and reinforcement to the system while changing the limits of the structure's shape. The structural optimization study of these shells shows that a distributed concrete thickness reduces shell stresses, deflections and reinforcements.

Keywords: concrete shells, groined shell, spherical shells, structural analysis, structural optimization

Statika analiza i optimizacija betonskih sfernih i svodastih ljusaka

Pregledni članak

Razumijevanje ranijih uspješnih ljusaka kombinirano sa suvremenim metodama proračuna konstrukcija može pomoći inženjerima u projektiranju efikasnih tankih betonskih ljusakastih konstrukcija. U ovom radu je prikazana statička analiza i optimizacija nekoliko značajnih betonskih ljusaka u svijetu. Analiza pomoću metode konačnih elemenata upotrebom programa Sofistik dala je rezultate bliske onima prema teoriji ljusaka te se pokazala mogućnošću za prikazane složene izvedene primjere. Pri optimizaciji konstrukcije betonskih sfernih i svodastih ljusaka nastojalo se reducirati ukupno vlačno naprezanje, progib i armatura u sustavu uz mijenjanje granica oblika konstrukcije. Optimizacija konstrukcije ovih ljusaka pokazala je da raspodijeljena debljina betona reducira naprezanja, progibe i armaturu ljusaka.

Keywords: betonske ljuske, optimizacija konstrukcije, sferne ljuske, statička analiza, svodaste ljuske

1 Introduction Uvod

Analytical procedures of thin shell analysis generally require the solution of ordinary or partial differential equations, which are not usually obtainable for complex structures. Hence, numerical methods are relied upon, such as the finite element method, for acceptable solutions. Engineering judgment and experience may be guides as reliable as analytical procedures based on simplifying assumptions. Factors such as size, geometry of the shell, especially the type and amount of curvature, boundary conditions, and load distribution must be considered collectively by the designer in the choice of analytical procedures.

The widespread use of large-scale computer programs for structural analysis has reduced reliance on classical methods, provided insight into previously unsolved problems and held out the hope for automatic optimized design.

Design by membrane theory provided essentially a correct basis for design in the hands of experienced shell designers; but bending theory gotten from computer-based numerical solutions gives the inexperienced engineer the opportunity to explore the behaviour of various different forms.

2 Comparison between shell theory and finite-element analysis for a spherical dome

Usporedba teorije ljusaka i metode konačnih elemenata za sfernu kupolu

A comparison of a spherical dome was made between

the Sofistik finite element analysis results and shell theory equations using an example found in [1].

The rigidly supported spherical dome of Fig. 1 is analyzed for uniform gravity load over the dome surface. The parameters of the problem are: $r = 28,80$ m (94,5 ft), constant shell thickness $h = 10,2$ cm (4 in), $\alpha = 28^\circ$, parallel circle radius at springing $r_s = r \sin \alpha = 13,49$ m (44,25 ft), Poisson's ratio $\nu = 1/6 = 0,167$, $q = 2,55$ kN/m² (dead load) + $1,76$ kN/m² (live load) = $4,31$ kN/m² (90 psf). Concrete class is C30/37, concrete strength is $f_{ck} = 30$ N/mm² and modulus of elasticity $E = 32000$ N/mm².

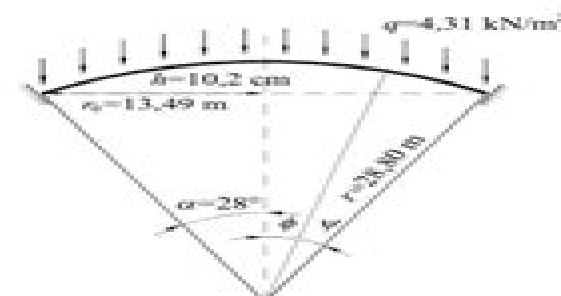


Figure 1 Fixed spherical dome for comparison between finite element analysis and analytic example

Slika 1. Sferna kupola na opetnim osloncima za usporedbu između metode konačnih elemenata i analitičkog primjera

The forces were computed on the basis of the membrane theory, where meridional force is

Structural Analysis Of Shells

RJ Shavelson



Structural Analysis Of Shells:

Structural Analysis of Shells E. H. Baker, L. Kovalevsky, F. L. Rish, 1972 Design and Analysis of Shell Structures M. Farshad, 2013-03-09 Shell structures are widely used in the fields of civil mechanical architectural aeronautical and marine engineering Shell technology has been enhanced by the development of new materials and prefabrication schemes Despite the mechanical advantages and aesthetic value offered by shell structures many engineers and architects are relatively unacquainted with shell behaviour and design This book familiarizes the engineering and architectural student as well as the practicing engineer and architect with the behaviour and design aspects of shell structures Three aspects are presented the Physical behaviour the structural analysis and the design of shells in a simple integrated and yet concise fashion Thus the book contains three major aspects of shell engineering 1 physical understanding of shell behaviour 2 use of applied shell theories and 3 development of design methodologies together with shell design examples The theoretical tools required for rational analysis of shells are kept at a modest level to give a sound grasp of the fundamentals of shell behaviour and at the same time an understanding of the related theory allowing it to be applied to actual design problems To achieve a physical understanding of complex shell behaviour quantitative presentations are supplemented by qualitative discussions so that the reader can grasp the physical feeling of shell behaviour A number of analysis and detailed design examples are also worked out in various chapters making the book a useful reference manual This book can be used as a textbook and or a reference book in undergraduate as well as graduate university courses in the fields of civil mechanical architectural aeronautical and materials engineering It can also be used as a reference and design analysis manual for the practicing engineers and architects The text is supplemented by a number of appendices containing tables of shell analysis and design charts and tables *Structural Shell Analysis* Johan Blaauwendraad, Jeroen H. Hoefakker, 2013-09-06 The mathematical description of the properties of a shell is much more elaborate than those of beam and plate structures Therefore many engineers and architects are unacquainted with aspects of shell behaviour and design and are not familiar with sufficiently reliable shell theories for the different shell types as derived in the middle of the 20th century Rather than contributing to theory development this university textbook focuses on architectural and civil engineering schools Of course practising professionals will profit from it as well The book deals with thin elastic shells in particular with cylindrical conical and spherical types and with elliptic and hyperbolic paraboloids The focus is on roofs chimneys pressure vessels and storage tanks Special attention is paid to edge bending disturbance zones which is indispensable knowledge in FE meshing A substantial part of the book results from research efforts in the mid 20th century at Delft University of Technology As such it is a valuable addition to the body of shell research literature of continuing importance This work can be used for university courses It also shows professionals how to perform manual calculations of the main force flow in shell structures and provides guidance for structural engineers estimating stresses and deformations *Structural Analysis Exam Study Guide*

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Theory of Shell Structures C. R. Calladine,1983 This book attempts to bring the essence of shell structures within the grasp of engineers It tackles the fundamental question of how bending and stretching effects combine and interact in shell structures from a physical point of view and shows that this approach leads to an understanding of the structural mechanics of shells in general

Structural Analysis of Shells H. van Koten,1997 **Computer Oriented Analysis of Shell Structures** Richard F. Hartung,1971 **Structural Analysis with the Finite Element Method.**

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Theory of Matrix Structural Analysis J. S.

Przemieniecki, 1985-01-01 This classic text begins with an overview of matrix methods and their application to the structural design of modern aircraft and aerospace vehicles Subsequent chapters cover basic equations of elasticity energy theorems structural idealization a comparison of force and displacement methods analysis of substructures structural synthesis nonlinear structural analysis and other topics 1968 edition

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web junior soldiers totally his prep course the totally his preparation course is an introductory course designed to help children learn the junior soldier promise both

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web soldier believes we re going to learn the junior soldier promise as well one part of the junior soldier promise is by his help i will be his loving and obedient child and will

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web children who join the salvation army as junior soldiers make the following promise i know that jesus is my saviour from sin i have asked him to forgive my sins and i will

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web home resources discipleship resources activate share helping children explore their personal faith journey and understand what it means to be a junior soldier of the