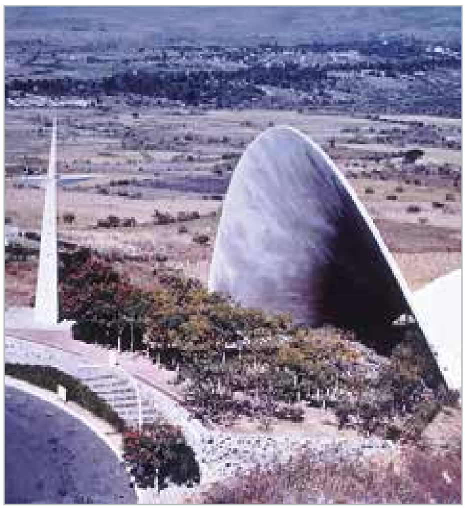
Structural Design of Concrete Shells in Seismic Areas Using HyperWorks



Examples of shell structures: Oceanografic, Felix Candela, Valencia, Spain. Courtesy of Felipe Gabaldón

Key Highlights

Industry:
University/Research, Architecture Engineering Construction

Challenge:
Structural optimization to design expressive structures that can safely be employed in seismic areas

Altair Solution:
Investigate shell structures under earthquake actions

Benefits:
- Predict structure behavior
- Understanding of form/earthquake response relation
- Reduction of stress concentrations

About Princeton and Form Finding Lab

Princeton University is a vibrant community of scholarship and learning that stands in the nation's service and in the service of all nations. Chartered in 1746, Princeton is the fourth-oldest college in the United States. Princeton is an independent, coeducational, nondenominational institution that provides undergraduate and graduate instruction in the humanities, social sciences, natural sciences and engineering.

As a world-renowned research university, Princeton seeks to achieve the highest levels of distinction in the discovery and transmission of knowledge and understanding. At the same time, Princeton is distinctive among research universities in its commitment to undergraduate teaching. Today, more than 1,100 faculty members instruct approximately 5,200 undergraduate students and 2,600 graduate students. The University's generous financial aid program ensures that talented students from all economic backgrounds can afford a Princeton education.

The Form Finding Lab at Princeton University, USA is a research group that focuses on structural systems that derive their strength from their curved shape dictated by the flow of forces. As a result these structures can be extremely thin, cost-effective and CO2 reducing and, arguably convey an esthetic quality. More information about the group and its research can be found here http://formfindinglab.princeton.edu/

The director of the Form Finding Lab is Sigrid Adriaenssens, PhD, structural engineer specialized in the form finding of structural surfaces. She is Assistant Professor at the

Keywords: Seismic analyses, Concrete Shells, Structure Form Finding, Optimization

Princeton University Success Story

"The versatility of the HyperWorks suite, supported by Altair's team of optimization experts proved to be a great asset for this research. The computational efficiency of the software permitted a great amount of simulations to run simultaneously, and the built-in optimization methods proved to be powerful tools to explore the structures' behavior"

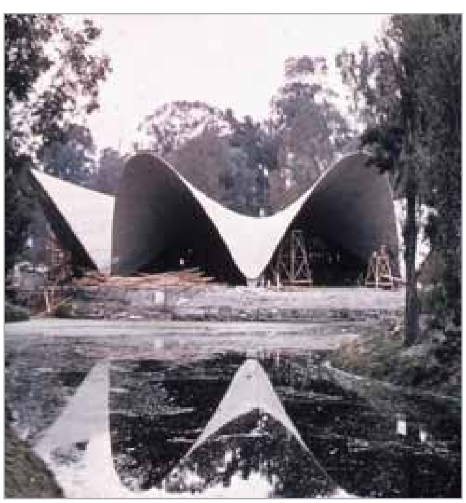
Tim L. Michiels, MSc, PhD student
Civil Engineering, Form Finding Lab
Princeton University

Department of Civil and Environmental Engineering at Princeton University, USA, Adriaenssens holds a PhD in lightweight structures from the University of Bath, UK, and previously worked as a project engineer for Jane Wernick Associates, London, and Ney + Partners, Brussels, Belgium.
She has authored 2 books and more than 40 peer-reviewed journal publications in the field. She is the co-chair of IASS Working Group 5 on Shells and the co-editor of the International Journal of Space Structures. Her current research interests include passive, active and adaptive structures.

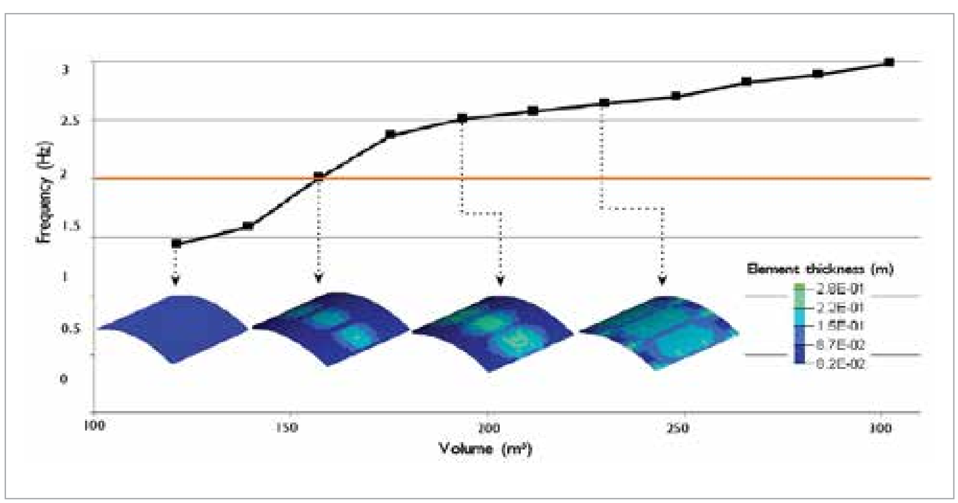
Tim Michiels is a PhD candidate in the Form Finding Lab of Princeton University where he researches the behavior of shell structures subjected to natural disasters such as earthquakes. He further develops methods to design resilient shell structures using sustainable materials such as rammed earth and adobe. Tim received his bachelor's and master's degrees in Civil Engineering from KU Leuven (Belgium) and obtained a master's degree in historic preservation from the Raymond Lemaire International Centre for Conservation. Before arriving at Princeton, Tim worked for the Getty Conservation Institute, researching how to protect historic earthen buildings against earthquakes and conducting field projects in Morocco and Peru.

Shell structures for seismic areas

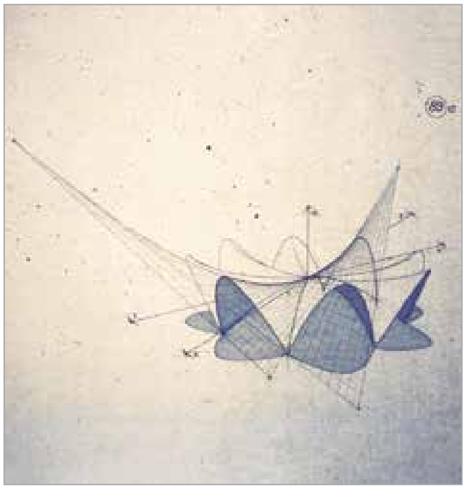
News broadcasts showing images of collapsed buildings, ravaged roads and torn-apart cities regularly remind us about the destructive power of earthquakes. While decades of research have greatly improved the understanding of these cataclysmic events, building professionals and researchers continuously try to adapt



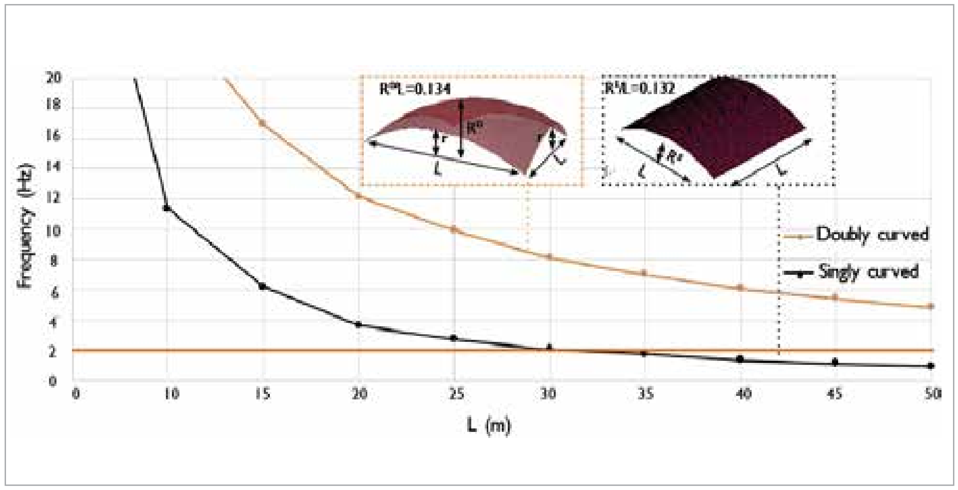
Las Manantiales Restaurant in Mexico City



Built-in optimization methods in OptiStruct were employed to find better thickness distributions of shells and thus improve their vibrational properties



Los Manantiales, Xochimilco, Mexico City



These graphs show how the vibrational properties of singly curved and doubly curved shell structures are influence by the span and the form of the shell structure.

and employ the most sophisticated numerical methods to improve the behavior of buildings during a seismic event in order to safeguard their occupants.

Researchers at the Form-Finding Lab of Princeton University, for example, are exploring the design of elegant and expressive structures that can safely be employed in seismic areas. They focus on shell structures, which are very thin, curved and typically large span structures made out of a wide range of materials ranging from steel and glass, to concrete and even bricks or mud.

These shell structures have empirically shown their excellent performance during earthquakes, as exemplified by the undamaged survival of the shells by the acclaimed shell builder Félix Candela during the great 1985 Mexico City earthquake. Powerful computational tools, however, are needed to analyze the behavior of these structures under earthquake loading.

Optimization driven design approach

The researchers of the Form-Finding lab resorted to HyperWorks, Altair's advanced simulation software suite, to perform their simulations and analyses. The suite was used to investigate the effects of a shell's shape on a buildings' performance during an earthquake and to simulate the influence of thickness variations on the response due to shaking caused by the earthquake.

Geometries could readily be imported from other CAD-software into HyperMesh, and after inserting further model properties, the effects of different earthquakes could be simulated using HyperWorks' integrated OptiStruct solver. The resistance and behavior during earthquakes could thus be predicted for a series of geometries. Additionally, the built-in optimization tools in OptiStruct allowed not only to search for a better overall shape within the given constraints, but could also be used to predict the regions of the shell's localized thickness where changes would provide the shell with the desired vibrational properties.

As such, the HyperWorks suite was used to obtain a global understanding of how the form of a shell structure influences its response to an earthquake. The overall shape of a shell, and in particular its curvature, was shown to have a major influence on the vibrational properties and thus earthquake behavior. By increasing curvature, and thus the corresponding stiffness of the shell, the fundamental frequencies of the structures increased, ensuring that their vibration modes were triggered less by earthquakes. While thickness distribution was shown to be only of secondary importance, sizing optimization was nevertheless a useful tool to reduce stress concentrations. These understandings can greatly further the design of safe new shells in earthquake areas.

Computational efficiency and optimization

The versatility of the HyperWorks suite, supported by Altair's team of optimization experts proved to be a great asset for this research. The computational efficiency of the software permitted a great amount of simulations to run simultaneously, and the built-in optimization methods proved to be powerful tools to explore the structures' behavior. The help to discover the range of possibilities within the software packets of Altair's technical experts were readily available to discuss and work with Princeton's research team. Their contributions ranged from providing help with building the models, to introducing the team to other available optimization methods and even writing a customized script for interpreting certain data.

Finally, the researchers plan to continue this investigation by applying the understandings of how form influences the flow of earthquake forces in shells to real structures, such as the ones of Félix Candela. Furthermore they anticipate using the gathered data to design prototype shell structures from innovative and low-cost materials that can resist earthquakes.

All images courtesy of the Félix and Dorothy Candela archive at Princeton University

Visit the HyperWorks library of
Success Stories
at www.altairhyperworks.com

About Altair

Altair is focused on the development and broad application of simulation technology to synthesize and optimize designs, processes and decisions for improved business performance. Privately held with more than 2,600 employees, Altair is headquartered in Troy, Michigan, USA and operates more than 45 offices throughout 24 countries. Today, Altair serves more than 5,000 corporate clients across broad industry segments. To learn more, please visit www.altair.com.

About HyperWorks®

Performance Simulation Technology

HyperWorks is an enterprise simulation solution for rapid design exploration and decision-making. As one of the most comprehensive, open-architecture CAE solutions in the industry, HyperWorks includes best-in-class modeling, analysis, visualization and data management solutions for linear, nonlinear, structural optimization, fluid-structure interaction, and multi-body dynamics applications.

www.altairhyperworks.com

Altair

Altair Engineering, Inc., World Headquarters: 1820 E. Big Beaver Rd., Troy, MI 48083-2031 USA
Phone: +1.248.614.2400 • Fax: +1.248.614.2411 • www.altair.com • info@altair.com