Earthquake Testing of a Building Fully Outfitted with Nonstructural Components and Systems

Non-Technical Highlight:

What is the outcome or accomplishment?

For the first time ever, a full-scale, 5-story reinforced concrete building outfitted with a broad array of nonstructural components and systems (NCSs) was tested at the University of California, San Diego in spring 2012. The building included a fully functional elevator, prefabricated metal stairs, partition walls, ceilings, synthetic stucco and precast concrete cladding exterior facades; as well as mechanical, electrical and plumbing systems and medical equipment. The building-nonstructural system was subjected to simulated earthquake shaking, first while supported on rubber isolators and subsequently while fixed to the base of the world's largest outdoor shake table. This project, coined "***BNCS***" (**B**uilding **N**onstructural **C**omponents and **S**ystems), brings together a consortium of over 45 industry sponsors from around the world, state and federal government funding entities, and four Universities, to collaborate with the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). The unified goal of this multi-disciplinary group is to minimize future earthquake-induced losses associated with damage to nonstructural components and systems.

What is the impact?

Nonstructural components and systems encompass more than 80% of the cost of construction of a modern building. Over the past three decades, the majority of earthquake-induced direct losses in buildings have been attributed to damage to these non-load bearing elements. This project will improve seismic design methodologies and construction practices for these important components, leading to increased confidence in their performance and functionality during future earthquakes.

What explanation/background does the lay reader need to understand the significance of this outcome?

To perform their intended function, buildings are outfitted with a broad range of items, none of which contribute to the buildings primary load bearing resistance. These items, termed *nonstructural components and systems* (NCSs) in the design literature, may be broadly categorized as mechanical, electrical and plumbing systems; architectural components; and building contents. Past earthquakes have exposed the vulnerability of NCSs, demonstrating that when subjected to even moderate shaking levels, damage to these items can result in significant direct and indirect economic losses, in addition to exposing occupants to hazardous conditions.

Complicated by the many configurations, detailing variations and connection types to the building, the design of NCSs largely rests outside of the building structural engineers' domain. Rather it is supported by mechanical, plumbing, electrical, and other engineering specialties and associated construction trades. In many instances however, few to no seismic engineering standards exist. This largely stems from lack of knowledge of their behavior during earthquake motions.

This landmark project is developing improved analysis and design tools for nonstructural components and systems with the goal of minimizing future earthquake-induced losses to society at large associated with damage to these highly vulnerable, yet critically important items supporting the functionality of buildings.

Technical Highlight

A full-scale, 5-story reinforced concrete building is outfitted with a broad array of nonstructural components and systems (NCSs), including a fully functional elevator, prefabricated metal stairs, partition walls, ceilings, synthetic stucco and precast concrete cladding exterior facades; as well as mechanical, electrical and plumbing systems and medical equipment. The test building-nonstructural system was subjected to simulated earthquake shaking, first while supported on rubber isolators and subsequently while fixed to the base of the world's largest outdoor shake table at the University of California, San Diego in spring 2012. This project brings together a consortium of over 45 industry sponsors from around the world, state and federal government funding entities, and four Universities, to collaborate with the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). This is the first time a building with such a complex array of realistic, full-scale, and operational NCSs has been seismically tested on a shake table.

This project will produce a one of a kind experimental dataset, which will allow the profession to better understand the seismic behavior of nonstructural components and systems within buildings. These data will be used to evaluate the capabilities of current tools, and as needed, develop new tools for simulating the response of building-nonstructural systems; while also supporting comparison and improvement of current design codes and construction practices.

Does this highlight represent potentially transformative research? Yes

This research is transformative in that it will for the first time allow tests of complex systems, which look closely at their multidisciplinary issues, using facilities that are fully equipped to investigate, in a controlled environment, the effects of earthquakes on building system performance. It will develop improvements to existing and new design methodologies for nonstructural components and systems that will be superior to current design methods. Many of the NCSs included in this test program have never been tested at full-scale, in a dynamic building environment as proposed in this program; including in particular a fully functional elevator, prefabricated metal stairs, partition walls, ceilings, synthetic stucco and precast concrete cladding exterior facades; as well as mechanical, electrical and plumbing systems and medical equipment.

Photographs of (left) structural skeleton during façade installation (North & West elevation) and (right) completed building façade (West and South elevation) at the NEES@UCSD shake table.

What is the intellectual merit of this activity?

Research is lacking at the system level that incorporates the structure, the NCSs and addresses issues such as detrimental kinematic and dynamic interaction between systems components. Experimental data will be generated to validate advanced nonlinear simulation platforms used for performance-based seismic design, and will be evaluated in socio-economic terms for ease of interpretation and comparison.

What are the *broader impacts* of this activity?

What may be the benefits of the proposed activity to society?

Outcomes from this work will have broad and immediate impacts on performance-based design of NCSs, including fire protection systems, through the efforts of a parallel fire following earthquake payload project. The project team includes key industry members leading design development and code writing committees, to ensure successful infusion of the project findings into practice. As a result of this work, the benefits to society will be the enhancement of earthquake safety and reduction in earthquake-induced direct and indirect losses associated with nonstructural systems within buildings.

How well does the activity advance discovery and understanding while promoting teaching, training, and learning?

This project involves 45 industry partners, four Universities, and state and federal funding entities. Eight Ph.D. students and four master's students are being trained and conducting their thesis work as a part of this project. In addition, the project provides a training ground for the local carpenters union and via the Research Experience for Teachers (RET) program of the NSF supports education of primary school level teachers. Knowledge gained in the project will be taught in earthquake engineering courses at each of the Universities.

Will the results be disseminated broadly to enhance scientific and technological understanding and if so, how?

The results and findings will be presented in technical conferences, published in refereed journals, and communicated to code committees. A regulatory committee provides oversight of the project to maximize its potential for implementation to design codes.

Please describe how the NEES Network played a valuable and integral role in the implementation and success of this research project.

The testing of a 5-story full-scale reinforced concrete building outfitted with nonstructural components and systems would not be possible without the NEES shake table at UCSD. These tests are the central ingredient to this research program, providing an invaluable data set for not only the research group and its partners, but also to the community at large, to understand how complete building systems perform during earthquakes. The NEES cyberinfrastructure provides efficient tools for the project team to communicate and share test data.

Award Title
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Claudia Marin, Howard University
Brian Meacham, Worcester Polytechnic Institute (non-NSF supported Fire Payload PI)

NEES Sites at which research occurred: UCSD (with instrumentation support of UCLA)

For additional information on this project: http://bncs.ucsd.edu/index.html