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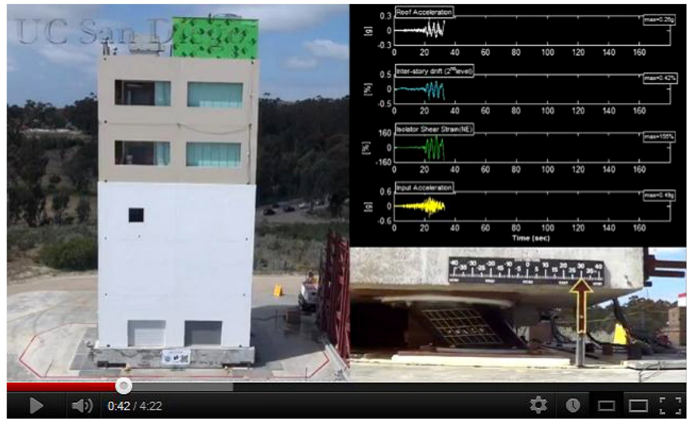
SeismicWaves

How the National Earthquake Hazards Reduction Program Is Advancing Earthquake Safety

Putting It All Together

The Building Nonstructural Components and Systems (BNCS) Earthquake and Post-Earthquake-Fire Tests

During April–May 2012, an unprecedented series of tests was conducted on the largest outdoor shake table in the world, located at the University of California, San Diego (UCSD) Englekirk Structural Engineering Research Center. A full-scale building fully outfitted with a variety of common nonstructural components and systems (NCS) was subjected to realistic earthquake ground motions to examine in detail the seismic performance of NCS. These landmark tests generated a one-of-a-kind set of experimental data that will be used to reduce damage to NCS in future earthquakes. The tests were the centerpiece of an ongoing, multiyear project led by researchers from UCSD, San Diego State University, Howard University, and Worcester Polytechnic Institute.



Excerpt from [video on BNCS test](#) conducted in April 2012. Left side shows test building on UCSD shake table. Upper right shows instruments tracking motion parameters captured by building sensors. Lower right shows base isolator flexing under the building (vertical arrow measures lateral movements). Courtesy of BNCS Project Core Team.

As better building codes and standards have made the load-bearing, structural systems in new buildings safer and less susceptible to collapse, damage to their nonstructural systems has emerged as a dominant source of potential earthquake-related losses in them. NCS include a building's mechanical, electrical, and plumbing systems, architectural components, and contents. Recent earthquakes have shown that even moderate levels of ground shaking can produce NCS damage that exposes occupants to hazardous conditions, is costly to repair, and results in building downtime and indirect losses.

A Unique Testing Facility

The UCSD Large High-Performance Outdoor Shake Table (LHPOST) is one of 14 experimental facilities supported by the National Science Foundation (NSF, one of the four Federal agencies participating in the National Earthquake Hazards Reduction Program) as part of its nationwide George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). NSF also supports the use of these facilities through its annual NEES research grant awards, one of which has partially funded the BNCS project.[1]

The LHPOST is capable of subjecting the largest test specimens to accurate reproductions of some of the strongest earthquake ground motions ever recorded. The shaking administered in the BNCS tests was patterned upon ground motions recorded in the magnitude (M) 6.7 Northridge, CA, earthquake of 1994, the M7.9 temblor near Alaska's Denali National Park in 2002, the M8.0 earthquake near Pisco, Peru in 2007, and the M8.8 Chile earthquake of 2010.

A Real Building, Packed with Learning Potential

The building constructed on the NEES shake table at UCSD was a five-story, reinforced-concrete structure. In addition to a full-height metal stairway and a functioning passenger elevator, the building contained a variety of NCS needed for multiple building uses. Utility equipment was concentrated on the first floor, while the second floor housed home-office and laboratory environments with anchored and unanchored contents. On the third floor, a computer server room contained two racks of servers, one functional, the other non-functional.

Both the fourth and fifth floors were devoted to hospital functions, with an intensive care unit on the former and a surgical suite on the latter. Hospitals need

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[1] See NSF award number 0936505 at www.nsf.gov/awardsearch/showAward.do?AwardNumber=0936505.

to remain operational following earthquakes to care for injured survivors, and to do so, must learn how to better protect the kinds of unique and sensitive equipment that were represented on these floors.

The building also featured partial mechanical, electrical, and plumbing subsystems, several types of ceilings, and two types of exterior facade. The building's NCS were largely donated and installed by the project's nearly 40 industry partners using installation methods commonly applied in practice. Often several types of NCS, or varying installation methods common in practice, were included in order to compare their seismic performance. During the shake-table tests, the responses of the structure and its NCS were recorded by a GPS system, more than 80 digital cameras, and approximately 500 analog sensors installed throughout the building. A portion of this instrumentation was deployed by the mobile NEES laboratory based at the University of California, Los Angeles.

A Three-Phased Test Protocol

Although NCS had been tested on shake tables in the United States and Japan before the BNCS tests, prior tests had involved more limited inventories of NCS, had not involved full-scale buildings, or had not focused primarily on NCS performance. The BNCS testing not only focused on the responses of a variety of common NCS, it installed those components in a full-scale building to examine the dynamic interactions between and within structural and nonstructural systems that can only be reproduced accurately at full scale.

In the first phase of testing, the building was shaken while mounted on large rubber bearings called base isolators. Previous research had shown that base isolation could be effective in reducing damaging lateral motions in buildings during earthquakes, and consequently, in significantly increasing the likelihood that buildings can remain operational. By measuring the responses of the building and its NCS, the BNCS tests affirmed and quantified these benefits.

In the second phase of testing, the base isolators were removed and the test building was, like most buildings constructed today, anchored directly to the ground (i.e., the shake table). The building was then shaken as strongly, and later more strongly, than it had been while it was supported on base isolators. This enabled the researchers to monitor the NCS under progressively greater displacements and accelerations, even to the point where some were damaged or failed. The responses of the NCS with and without base isolation will be used to enhance the accuracy of analytical models used to predict NCS performance under alternative building designs.

In the final tests, the researchers started controlled fires in the building to study fire and smoke behavior and impacts in earthquake-damaged environments. Although fire sprinklers and other typical fire protection measures had been incorporated into the building's NCS, this testing confirmed that shaking damage to NCS can exacerbate post-earthquake fire hazards. This was the first time that the post-earthquake fire performance of full-scale building systems had been recorded.

As the wealth of BNCS test data is further analyzed, it will influence building design and construction in many ways. The data are yielding new findings about the effects of earthquake shaking and post-earthquake fires on structural and nonstructural systems. Project participants will be disseminating these findings through a variety of educational and outreach initiatives. These efforts are expected to enhance NCS-related modeling tools, educational programs, and standards and practices in the fields of performance-based building design and construction, NCS design and installation, and building codes and standards development. Additional information about these activities and the tests is available at http://bncs.ucsd.edu/index.html. All BNCS test data will be archived in the NEEShub Project Warehouse at http://nees.org/warehouse/welcome.