October 2009

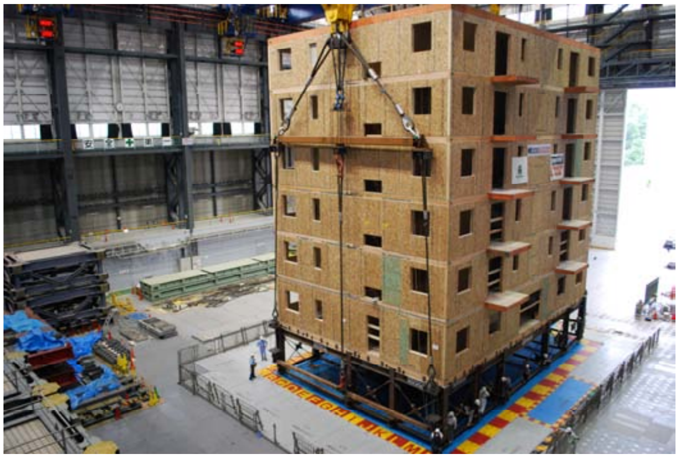
SeismicWaves

How the National Earthquake Hazards Reduction Program Is Advancing Earthquake Safety

Can Wood Buildings Safely Grow Taller in Seismic Regions?

The NEESWood Project Provides a Definitive Answer

This past summer in rural Japan, the largest building ever seismically tested was subjected to the maximum credible earthquake for Los Angeles on the world's biggest shake table. This "capstone" test of the tallest wood-frame building ever tested marked the culmination of the NEESWood research project. The project was launched in the fall of 2005 with ongoing support from the National Science Foundation (NSF) and NSF's George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES).[1] Since then, NEESWood researchers have marshaled academic, industry, and international collaboration to successfully produce and validate a new design methodology that has major implications for wood-frame construction in seismic regions of the United States and around the world.



The capstone test structure is moved onto the E-Defense shake table in Japan on June 22, 2009. Photo courtesy of John van de Lindt, Colorado State University.

Competing with Steel and Concrete

Wood-frame buildings generally cost less to construct than do structures made with steel or concrete, and wood is heavily used for low-rise construction (four stories or less). In earthquake-prone regions, however, building codes have generally excluded wood framing from the market for mid-rise (five- to seven-story) structures. This is because not enough has been known about how such buildings respond to strong earthquake ground motions.

NEESWood researchers have sought to learn more about the seismic behavior of wood-frame structures and to use this knowledge to develop improved design methods and tools. Their objectives have been to enable the construction of safe and economical mid-rise wood buildings—and the mitigation of earthquake damage among low-rise wood structures—in seismically active regions.

Led by Principal Investigator Dr. John van de Lindt of Colorado State University, the research team includes co-principal investigators from the University at Buffalo (UB), University of Delaware, Rensselaer Polytechnic Institute (RPI), and Texas A&M University. A number of technical collaborators from government and industry have also participated in the project, contributing products, product-testing data, funding, materials, and services. Of particular note are the Simpson Strong-Tie Company, the U.S. Forest Products Laboratory, FPInnovations, and Japan's National Research Institute for Earth Science and Disaster Prevention (NIED).

New Design Philosophy Needed

In recent damaging earthquakes such as California's 1994 Northridge event, traditional engineering design procedures have been effective in limiting building collapses and loss of life, but have proven less effective in limiting building damage and ensuring that immediate re-occupancy is possible following the earthquake. These conclusions were reinforced by the first major NEESWood experiment in 2006. In this "benchmark" test led by Co-Investigator Dr. Andre Filiatrault, researchers subjected a full-scale, two-story wood-frame townhouse to a simulation of the Northridge earthquake produced by twin shake tables at UB's NEES laboratory. The result was damage that, although not life-threatening, was substantial and costly.

The benchmark test yielded reliable data on the seismic performance of wood buildings designed in accordance with prevailing building codes. NEESWood researchers used these data to further enhance software that they were developing, the Seismic Analysis Package for Woodframe Structures (SAPWood). This tool, in turn, enabled them to more accurately predict how changes in the design of wood buildings would affect the buildings' seismic performance, and supported their efforts to create a new method for designing these structures.

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[1] Funding has been provided under NSF grant awards CMMI-0529903 and CMMI-0402490.

A Performance-Based Approach

In recent years, performance-based seismic design (PBSD) has gained acceptance as an effective approach for designing structures to meet multiple performance objectives. Seeking to limit both damage and casualties, NEESWood researchers embraced this approach for their design methodology.

Recognizing that many engineers may not have access to the computer-modeling capabilities needed for complex PBSD "whole-structure" analyses, NEESWood researchers led by Dr. David Rosowsky of RPI developed a simpler PBSD procedure as the basis for their methodology. This "direct displacement-based design" procedure was built upon the results of earlier work by NEESWood investigators and others, including the finding that damage severity in wood structures correlates strongly with the amount of lateral displacement (drift) brought about by earthquake ground motions.

Ultimate Verification in Japan

NEESWood researchers used this new PBSD procedure to design a seven-story, mixed-use building for the project's capstone tests. The structure had a steel-frame ground floor designed for two retail shops topped by a six-story, wood-frame condominium tower containing 23 one- and two-bedroom residential units. Innovative and economical design features included steel special moment frames for the first floor and, for the condominium tower, Anchor Tiedown Systems from the Simpson Strong-Tie Company and midply wood shear-wall systems developed by Canada's FPInnovations-Forintek Division.

The investigators planned a series of shake-table tests to learn how this mid-rise wood structure, representative of those in the western United States, would respond to potentially damaging seismic forces, and to determine whether structures designed using the new PBSD methodology could meet performance objectives established during the design process. There was only one tri-axial shake table in the world large enough to accommodate the capstone tests. This was Japan's E-Defense (Earth-Defense) facility, which NIED opened in 2005, 10 years after the devastating Kobe earthquake that provided the impetus for its development. Located near Kobe, the facility was made available to U.S. researchers under a 2005 agreement between NSF and Japan's Ministry of Education, Culture, Sports, Science, and Technology that called for research collaboration and shared access to the NEES and E-Defense facilities.

Most of the materials needed to construct the capstone building were shipped to Japan from the United States in early 2009. Japanese workers led by Maui Homes LLC assembled the building at the E-Defense facility in consultation with NEESWood researchers, and capstone testing was conducted on June 30, July 6, and July 14. Some 300 sensors and 50 optical tracking devices installed in and around the structure captured a wealth of data on the building's performance.

The simulated ground motions produced by the shake table were amplifications of the Northridge earthquake. The final test on July 14 subjected the structure to the strongest shaking, which, at 180 percent of Northridge levels, is expected to occur, on average, only once every 2,500 years, and is more powerful than that which new buildings must be designed to withstand in Los Angeles.

The building remained suitable for continued occupancy throughout all of the testing, with only minor, nonstructural damage sustained, consisting primarily of cracks in drywall around windows and doors. The tests confirmed that it is possible to design and construct safe, durable, and economical mid-rise (and low-rise) wood-frame buildings in seismic areas. They also verified that this can be done using the NEESWood PBSD approach, supported by the freely available SAPWood software.

The NEESWood project has made seminal contributions to the seismic design of wood structures, to the application of PBSD to such structures, and to engineers' understanding of the general seismic behavior of these types of structures. On July 14, Dr. John van de Lindt commented that based on the project outcomes, he anticipates substantial movement over the next few years toward building-code approval of mid-rise wood-frame construction in seismic regions of the United States. Further information about the project is available from NSF at www.nsf.gov/news/newsmedia/neeswood/index.jsp, and from the project Web site at www.engr.colostate.edu/NEESWood/index.shtml.