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nehrp SeismicWaves

How the National Earthquake Hazards Reduction Program Is Advancing Earthquake Safety

Ensuring That When the Ground Starts Shaking, Bridges Can Bend Without Breaking

"[The bridge] felt like it was oscillating a little bit, and we saw the road rise up in front of us before we fell."

"The feeling is kind of a free-fall feeling at [an] amusement-park ride."

Those were the comments of two survivors of the Mississippi River bridge collapse that occurred in Minneapolis on August 1, 2007.[1] Although earthquakes were not involved in that tragedy, they have destroyed highway bridges in the recent past. The Loma Prieta earthquake of 1989 collapsed a freeway viaduct in Oakland, California, killing 42 motorists, and in 1994, the Northridge earthquake irreparably damaged 10 bridges in Southern California.

The Minneapolis collapse again spotlighted the costly and potentially tragic consequences of bridge failures. The disaster claimed 13 lives and is expected to cost nearly $400 million. Earthquake-related bridge failures can be doubly disastrous, since they not only endanger drivers during the quake, but also hamper emergency response and recovery efforts afterwards.

Since the 1970s, however, engineers have made considerable progress in learning how to reduce the vulnerability of the nation's more than 600,000 bridges to earthquake damage. Now, a major research project funded by the National Science Foundation (NSF, a NEHRP agency) through grant award CMMI-0420347 is further advancing these efforts (http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0420347).

A Groundbreaking Investigation

This project is being carried out by the University of Nevada, Reno (UNR) in cooperation with several other universities in the United States and abroad. It is enabling researchers to test, for the first time ever, the seismic performance of entire four-span bridges along with the performance of individual bridge components.

During an earthquake, the parts of a bridge interact in complex ways with each other and with the foundation soils surrounding the footings and abutments (the supports at each end of the bridge). These interactions determine the performance of the entire bridge system, which is the primary focus of the UNR project.

To test complete bridge systems, the researchers are building large-scale models of bridges in the laboratory at UNR and subjecting them to simulated earthquake ground motions. The project is studying three such models that are being made with differing materials and design details at about one-fourth the size of real bridges. The first bridge model, a conventional reinforced-concrete structure about 110 feet long, was tested at UNR in February 2007. After the test, Principal Investigator Mehdi "Saiid" Saiidi commented that "a great deal of useful data have been obtained that will tell us for the first time the interaction among different components of a bridge system . . . [and] allow for detailed study of numerous aspects of bridge response compared to how they are envisioned in design codes. Practicing engineers are very likely to take the results to heart because this was a complete bridge system of large scale."

Over the next two years, the researchers plan to test two more bridge models that incorporate innovative seismic-resistant features. Reinforced-concrete piers will be strengthened with outer layers made from fiber-reinforced polymer composites; columns will be made more resilient with built-in isolators designed to absorb and damp down seismic forces; and column-footing connections will be toughened with new "superelastic" nickel titanium rods and bendable concrete.

Model bridge tested at UNR NEES facility, February 2007. Courtesy of UNR

[1] Quotes from Kelly Kahle and Melissa Hughes, reported by ABC News on August 2, 2007, in "Bridge Collapse Survivors Tell Their Tales." Retrieved from http://abcnews.go.com/GMA/Story?id=3439611 on October 9, 2007.

NEES-Enabled Collaboration

Researchers at other universities are collaborating with the UNR team as part of this project and under accompanying NSF-funded projects made possible by the UNR bridge tests. This shared approach—as well as large-scale bridge testing—has been facilitated by the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). Established in 2004, NEES is a unique network of earthquake engineering experimental facilities developed and maintained with NSF funding. These laboratories, located at UNR and 14 other universities across the country, are linked through an extensive information technology infrastructure that includes a variety of software tools designed for remote collaboration and computer modeling. NEES Consortium, Inc., located in Davis, California, coordinates the operation of these 15 facilities (http://www.nees.org).

The facility at UNR (http://nees.unr.edu) has three identical shake tables (each 4.3 meters by 4.5 meters in table size) that make the site uniquely suited for testing the large-scale, four-span bridge models involved in this project. Four-span bridges have three supporting piers, each of which can be placed on a separate shake table at UNR. In addition, the shake tables are biaxial, enabling project staff to incorporate both lengthwise and lateral shaking into the tests (with abutment motions added via hydraulic jacks), something never before done with complete bridges.

Researchers at the University of California, San Diego (UCSD) are using the large high-performance outdoor shake table at the UCSD NEES facility to study the seismic performance of full-scale bridge abutments. This work is contributing to the design of the abutments used in the UNR tests. Meanwhile, engineers at Florida International University are fabricating, testing, and modeling the innovative piers that will be incorporated into UNR's bridge models. The many sensors that are being used to monitor and record the performance of bridge components during UNR's tests include fiber-optic systems installed by researchers from the University of Illinois, Chicago, and new wireless monitors developed by engineers at Stanford University.

Project staff at UNR and at the University of California, Berkeley, are using NEES OpenSees software to predict and simulate the performance of UNR's bridge models. Earthquake engineers at Japan's Tokyo Institute of Technology are collaborating on the design of the isolators that will be tested in the bridge columns at UNR, and University of Kansas researchers are using non-invasive photogrammetric methods to better understand and control damage caused when bridge components are pushed beyond the limits of their elasticity. The superelastic rods designed to strengthen column-footing connections on the bridge models are being developed and tested by researchers from the Georgia Institute of Technology.

Freeway bridge collapse, Northridge earthquake, 1994.
Credit: Mehmet Celebi, USGS

By pooling the diverse expertise of these and other researchers and universities, this collaborative project is benefiting earthquake engineering and the future safety of the motoring public. The project is providing invaluable hands-on training for many earthquake engineering students. It is breaking new ground in seismic research on bridges—and advancing related knowledge, sensor technology and damage detection methods, design approaches, analytical tools, and experimentation—by utilizing the unique resources provided by NEES. Project findings will help to improve the design criteria and seismic codes used to ensure better bridge performance in future earthquakes.

Additional information can be found on the project website at http://nees.unr.edu/4-spanbridges/.