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SeismicWaves

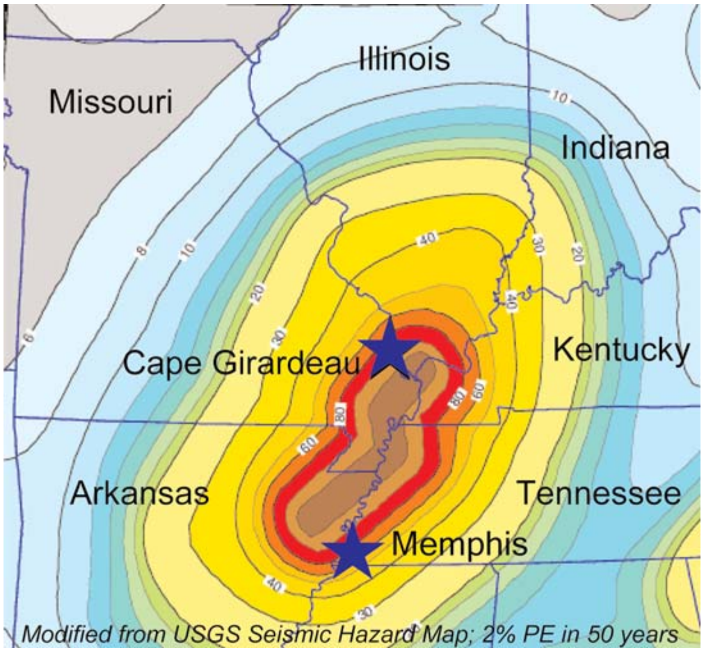
How the National Earthquake Hazards Reduction Program Is Advancing Earthquake Safety

Keeping Up Bridges in the New Madrid Seismic Zone

During the winter of 1811–1812, three of the most powerful earthquakes in U.S. history occurred in the region now known as the New Madrid Seismic Zone (NMSZ). The fault system that generated these historic quakes extends for 150 miles along both sides of the Mississippi River from the southern tip of Illinois to near Memphis, Tennessee.

Today, the 125,000-square-mile area considered most at risk from NMSZ seismicity contains 12 million residents and some 200 cities. With the region bisected from north to south by the Mississippi River, bridges are some of the most important and seismically vulnerable segments of the area's transportation network. Yet the majority of bridges in the region were designed with little or no seismic consideration.[1]

Federal and State agencies have begun to examine and respond to this vulnerability in recent decades, prompted not only by greater understanding of seismic hazards in the NMSZ, but also by growing appreciation of the impact that bridge failures could have on emergency response and recovery efforts and on local, regional, and national commerce. Efforts undertaken have included incorporating seismic design into new bridges, assessing and addressing the need to retrofit existing bridges, and installing seismic monitoring systems on selected bridges.



Map of the NMSZ showing the locations of the Emerson and I-40 bridges. Adapted from a map prepared by University of Illinois researchers Youssef Hashash and Scott Olson.

Monitoring how bridges respond to earthquakes is crucial to bridge safety because it provides the data needed to guide design and retrofit efforts. Although data are available from bridges monitored in other regions, these data are not necessarily applicable to bridges in the NMSZ. Differences in the soils and bedrock that overlie faults mean that the same type of bridge can behave differently in Missouri, for example, than in California. However, two major monitoring projects are beginning to generate the kinds of area-specific data needed to better protect bridges in the NMSZ.

The Emerson Bridge Project

The Bill Emerson Memorial Bridge carries traffic over the Mississippi River between Cape Girardeau, Missouri, and East Cape Girardeau, Illinois. Construction of the bridge was completed in December 2003. The 4,000-foot-long structure was designed to last for 100 years and to withstand a major NMSZ earthquake. As the only four-lane river crossing between St. Louis and Cairo, a distance of about 130 miles, the Emerson bridge would be critically important to response and recovery efforts following such an event.

Instrumentation of the bridge was carried out in two phases. First, 84 seismic sensors were installed on the piers, deck, and towers of the bridge, as well as in the ground at "free-field" locations near the bridge on both sides of the river. Structural and free-field vibrations are transmitted via wireless antennas to a central recording system housed near the bridge, and from there, in real time, to data users through a broadband Internet connection. This portion of the monitoring system, completed in December 2004, was developed by the U.S. Geological Survey (USGS, a NEHRP agency) under a contract from MCEER (one of three national earthquake engineering research centers supported by the National Science Foundation, a NEHRP agency) with financial support from the Federal Highway Administration (FHWA) and the Missouri Department of Transportation (MoDOT), which owns the system.

[1] Jamie Padgett, "Retrofitted Bridge Fragility Curves for Assessing the Consequences of an Earthquake Event," Mid-America Earthquake Center *Student Leadership Council Online Magazine* V, no. 1 (July 2005), http://mae.ce.uiuc.edu/graduate/slc_online_magazine_2005_july.html.

In 2007, a state-of-the-art geotechnical ground-failure instrumentation array was added to the monitoring system. This work was designed and implemented by researchers from the University of Illinois at Urbana-Champaign under a grant from the USGS Advanced National Seismic System (ANSS). Earlier studies had found that the floodplain under the eastern portion of the bridge includes a layer of sandy soil approximately 40 feet thick that is susceptible to liquefaction during a significant earthquake. This additional array, consisting of piezometers that measure water pressure in soil and micromachined electromechanical sensor-based systems that measure soil vibrations and displacements, was designed to record dynamic soil behavior and its effects on the bridge. Of particular interest was soil in the approach embankment on the Illinois side of the bridge, which the Illinois Department of Transportation had modified to mitigate liquefaction.

Emerson bridge nears completion in 2003 (bridge in the background has since been demolished). Photo courtesy of MoDOT, http://www.modot.org/southeast/projects/bridge/index.htm#gallery.

The Emerson bridge instrumentation has already begun to yield data that may prove useful in improving bridge design in the NMSZ and other seismic regions. In a study completed for MoDOT in 2007, researchers from the University of Missouri-Rolla used data recorded by the monitoring system to develop a mathematical model that accurately simulates the behavior of the Emerson bridge during normal traffic conditions and minor earthquakes. They used this model to validate some of the engineering assumptions made in designing the bridge and to assess how the bridge is likely to perform during larger quakes. In the future, as more data are collected, this model can be expanded to further evaluate and enhance bridge-design assumptions; to evaluate how the soil, foundation, and structure interact; to model the bridge's response to greater stresses; and to enable rapid post-earthquake assessments of the bridge.

The Memphis I-40 Bridge Project

The Hernando DeSoto Bridge carries Interstate 40 across the Mississippi River between Memphis, Tennessee, and West Memphis, Arkansas. The bridge was built in 1973 with little seismic protection. It is over 3 miles long, consisting of two tied arch truss spans over the main river channel and numerous approach spans and highway ramps to the east and west.

Recognizing how important the bridge is to transportation and commerce, the FHWA teamed with the Tennessee Department of Transportation (TDOT) and the Arkansas State Highway and Transportation Department in the 1990s to evaluate the seismic readiness of the structure. The agencies found serious deficiencies that could cause the bridge to collapse during a damaging NMSZ earthquake, and subsequently planned a major, phased seismic retrofit for the bridge. They incorporated friction pendulum isolation bearings and other cutting-edge technology into the design that should enable the bridge to withstand, with little or no damage, a magnitude 7.0 earthquake occurring 65 kilometers away at a depth of 20 kilometers.[2] Much of this retrofit work, which got under way in 1999, has since been completed.

Researchers from the Center for Earthquake Research and Information (CERI) at the University of Memphis, in consultation with the USGS, designed a seismic instrumentation system for the bridge that will enable them to monitor the performance of the retrofitted structure and to compare actual and expected performance. CERI has installed this system in phases as the retrofit has progressed. A network of 108 seismic sensors is located on the main spans and western approach spans. These instruments, designed to measure vertical, longitudinal, and transverse bridge motions, were funded by the FHWA and TDOT.

To measure seismic forces impacting the bridge, free-field reference sensors have been installed near the bridge at

[2] Rebecca Jaramilla, "Memphis Braces for a Lot of Shaking," *Public Roads* 67, no. 4 (January/February 2004), http://www.tfhrc.gov/pubrds/04jan/09.htm.

I-40 bridge at Memphis. Photo by Mr. GOP, http://www.city-data.com/picfilesv/picv16314.php.

ground level and at depths of 100 and 200 feet. This equipment was funded by TDOT and ANSS. CERI is maintaining the entire bridge monitoring system, and expects to begin receiving data from the reference sensors in real time later this spring.

As with the Emerson bridge, data from the I-40 bridge will enable researchers to refine models of how the structure responds to seismic events, assess whether the bridge performs as designed, and enhance bridge design practices tailored to the NMSZ. Seismic instrumentation of these two critical bridges, located near the north and south ends of the New Madrid fault, is a major step forward in efforts to improve the design and resiliency of bridges in the NMSZ and in similar regions around the world.

Additional information about the Emerson bridge instrumentation is available from the University of Illinois at https://netfiles.uiuc.edu/olsons/www/emerson/index.htm. The FHWA has published a detailed overview of the I-40 bridge retrofit at http://www.tfhrc.gov/pubrds/04jan/09.htm; for further information on the I-40 bridge instrumentation, contact CERI (http://www.ceri.memphis.edu/). Information about ANSS and its work in structural instrumentation is available from the USGS at http://earthquake.usgs.gov/research/monitoring/anss/documents.php and http://pubs.usgs.gov/fs/2003/fs068-03/.