Risk modeling for bridges simulates multihazard scenarios

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Close-up of damage and temporary repairs to the Miles Glacier Bridge near Cordova, Alaska after the 1984 Good Friday Earthquake. Credit: Historic American Buildings Survey/Historic American Engineering Record

(Phys.org) —Flood and earthquake. Either one of these natural hazards, if severe enough, can topple a highway bridge. Accordingly, bridges are designed and built to withstand both types of trauma. But what happens when nature brings two blows at once?

Such an concurrence may be rare, but it isn't unheard of. In January 2009, a magnitude 4.5 earthquake struck the state of Washington less than three weeks after a major flood event.

Flood-induced scour, the erosion of soil and rock around a bridge's foundation, is one of the common causes of degraded health of a bridge and may lead to bridge failure, says Swagata Banerjee, assistant professor of civil engineering at Penn State. But even where it doesn't cause collapse, scour results in weakness. "The foundation is exposed, and the bridge becomes flexible, and it may not carry as much load," Banerjee says. Then, if an earthquake should come along, the potential for damage is magnified.

Especially in regions where both types of hazard are common, risk planners need to account for this one-two punch, Banerjee says. With a grant from the National Science Foundation, she has developed a risk evaluation framework that integrates seismic and flood hazards, and is currently using her model to evaluate bridges in three flood-prone, seismically active regions: California, Washington state, and the New Madrid seismic zone, encompassing parts of Missouri, Tennessee and Arkansas.

Banerjee is starting her study in California, where she earned a Ph.D. at the University of California at Irvine before coming to Penn State in 2009.

"We selected a few bridges there and requested Caltrans, the California Department of Transportation, to send us design drawings, from which we can build computer models," she says. Incorporating historical flood data for the bridge's location, she then develops a flood hazard curve to determine the peak local discharge for a major flood event. "Based on the discharge we can calculate scour depth," Banerjee says, "and then we perform seismic analysis on the weakened bridge."

So far she has analyzed two California bridges, one that opened in 2009, and the other designed some 30 years earlier. Like 95 percent of highway bridges in the state, both are of concrete construction. "The new bridge responded very well," Banerjee reports. "We saw very minimal effect from the flood event on bridge seismic performance. With the older bridge, however, we did see more damage."

The major difference between the two, she notes, is in their foundations. "The old bridge has a pile foundation," she says. That is, each of the bridge's four piers rests atop a bundle of concrete piles driven into the ground and capped. The new bridge, in contrast, simply extends its piers into the ground.

"The extended pier foundation can take more of the lateral loading that occurs when an earthquake is shaking the ground," Banerjee says. "Caltrans has been moving toward this approach."

Bouncing Back

Besides guiding design for the future, she says, multiple hazard modeling can be useful for determining the cost-efficiency of retrofitting existing bridges. "Also, if you know the damage risk of a given structure you can plan emergency response accordingly," she says.

Her model specifies four damage levels. "Minor damage means only some cracks within the bridge, but no difference in functionality," she explains. "Moderate damage may mean one lane has to close for repairs. Then there's extensive damage, which is really an alarm—it says the bridge will be closed for major repairs. And the final damage state is collapse."

Predicting damage is important for determining resilience, which is the second focus of Banerjee's research. Resilience refers to how quickly a bridge or other structure can return to full function, but there's more to it than that.

"It's a concept beyond the bridge itself," she says. "It involves the whole community."

A structure that fails is part of a larger system, and when that system is a highway network, the impacts ripple widely.

"We talk about direct loss, which is directly related to structural repair or replacement," Banerjee explains. "But we also have to think about indirect loss, from the societal perspective." The latter may include the costs of detouring traffic and increased commuting time, losses of revenue for businesses that are interrupted and of opportunity for workers who can't get to work, and decreased access to essential services, among other things. To get a better handle on these larger costs, she says, she will need to collaborate with economists.

"We can't really do anything about hazard events," Banerjee says. "But we have to make sure that we can respond properly so that we lessen the impact of these events on society.

"This is the concept of resiliency. We are trying to reduce the loss as much as we can."

Provided by Pennsylvania State University

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