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UTC Spotlight

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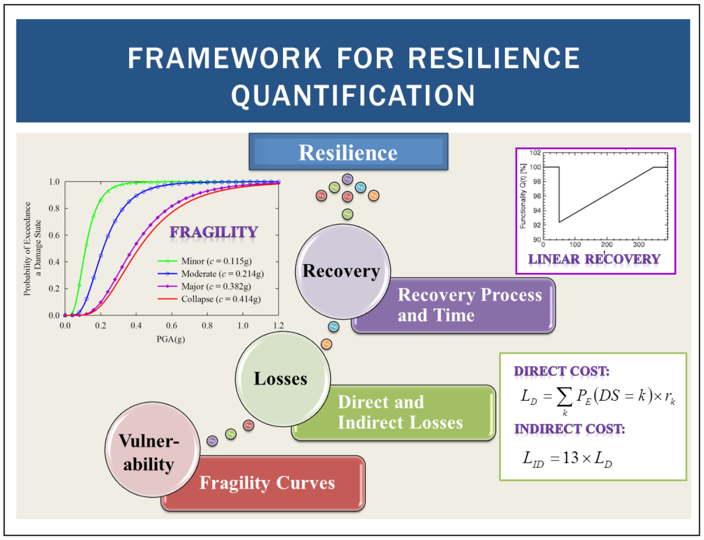
Enhancing Disaster Resilience of Highway Bridges to Multiple Hazards

Disaster resilience is defined by the National Academies as "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events," and that "enhanced resilience allows better anticipation of disasters and better planning to reduce disaster losses – rather than waiting for an event to occur and paying for it afterward" (Cutter et al. 2013). To achieve such enhanced resilience, civil infrastructure systems must not only survive natural disasters, but recover to functional levels within acceptable time and cost limits.

Framework for Estimating Resilience

Resilience is generally quantified as a dimensionless quantity representing the rapidity of the system to revive from a damaged condition to the pre-damaged functionality level. System performance during a natural disaster (commonly referred to as system vulnerability), resulting losses, and post-event system recovery are the three major components used to quantify the disaster resilience of a civil infrastructure system.



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System resilience is an integrated measure of system vulnerability, post-event loss, and recovery. System vulnerability can be expressed with fragility curves; the post-event loss model includes direct and indirect losses; the post-event recovery model provides the time to complete recovery.

The vulnerability model was developed from structural analysis under natural disasters. This model is expressed in the form of fragility curves that provide probabilities of exceeding various performance levels for different hazard intensities.

The loss model incorporates direct and indirect losses from a post-event degraded system over the period of system restoration. The direct loss arises due to system restoration after the event and the indirect loss arises due to post-event disrupted functionality of the system. For highway transportation systems, indirect losses consist of rental, relocation, business interruptions, traffic delay, loss of opportunity, losses in revenue, etc.

The recovery model describes a path following which post-event restoration of systems is expected to take place. This model considers the time required to complete system restoration, which greatly depends on the severity of structural damage of systems due to extreme events.

Enhancement of Seismic Resilience of Highway Bridges

This research includes analytical investigation of the effectiveness of bridge retrofit in enhancing seismic resilience of highway bridges. A reinforced concrete bridge in the La Cienega-Venice Boulevard sector of the Santa Monica (I-10) freeway in Los Angeles, California, is analyzed. During the 1994 Northridge earthquake, this bridge was severely damaged primarily due to shear failure of one bridge pier. Post-event reconnaissance indicated that the failure was initiated from inadequate lateral confinement of bridge piers designed in pre-1971 era. As part of this research, bridge piers are retrofitted with steel jackets assuming the undamaged condition of the bridge prior to the Northridge event. Research outcome showed that applied retrofit resulted in an enhancement of seismic resilience of the bridge from 57.5 to 99.9 percent. A cost-benefit analysis revealed that the applied retrofit technique is also cost effective (Venkittaraman and Banerjee 2013).

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Building resilient highway transportation systems requires enhancement in disaster resilience of constituent bridges. Research has shown that bridge seismic performance can heavily influence the seismic performance of the overall system (Zhou et al. 2010).

Enhancement of Resilience to Multiple Hazards

The study was extended to identify optimal retrofit strategies of highway bridges under a multihazard scenario, which resulted from the occurrence of an earthquake in the presence of flood-induced scour at bridge foundations. Identification of an optimal retrofit strategy is important to reduce the cost of post-disaster system restoration. A multiobjective, evolutionary algorithm is used for this purpose. The two conflicting objectives in this problem are maximizing bridge resilience under the specified multihazard scenario and minimizing the retrofit cost. The impact of various bridge retrofit design options (i.e., column jacketing with steel and composite casings) is studied.

The optimization algorithm evaluates bridge disaster resilience under multihazard conditions by applying all possible retrofit options generated based on the user-specified bounds on design variables. Moreover, the analytical framework calculates the cost of each retrofit option. Results from the optimization process, called Pareto-optimal set, include solutions that are distinct from each other in terms of associated cost, contribution to resilience enhancement, and values of design parameters. This optimal set of solutions offered the best search results for retrofit material and configuration. Obtained optimal solutions facilitate the choice of a bridge retrofit strategy for multihazard condition based on specific preferences on target resilience and retrofit cost (Chandrashekaran and Banerjee 2014).

References

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About This Project

This project, "Optimal Bridge Retrofit Strategy to Enhance Disaster Resilience of Highway Transportation Systems," was conducted at Penn State under the direction of principal investigator Swagata Banerjee, Ph.D. (Swagata@engr.psu.edu).