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CALTRANS DIVISION OF RESEARCH, INNOVATION AND SYSTEM INFORMATION

TRANSFORMING IDEAS INTO SOLUTIONS

Research Results

Geotechnical/ Structures

Generation-2 Seismic Bridge Fragility Models - Production Analytical Components

Develop fragility models for California concrete box-girder bridges.

July 2025

Project Title: Generation-2 Fragility Models for California Highway Bridges

Task Number: 1780

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WHAT WAS THE NEED?

Major earthquakes can severely disrupt transportation networks. Immediately after an earthquake, the California Department of Transportation (Caltrans) emergency managers and decision-makers need to understand field conditions to coordinate the response and dispatch bridge inspection resources. Since 2008, Caltrans has used the ShakeCast alerting system to provide early situational awareness to emergency managers. ShakeCast uses a combination of ground-shaking maps developed in near-real time by the United States Geological Survey, coupled with pre-calculated bridge fragility relationships, to rapidly estimate the bridge damage.

Fragility relationships are statistical models describing the probability that a specific level of shaking will induce varying degrees of bridge damage, ranging from minor spalling of concrete to complete bridge collapse. The first-generation fragility models, developed in the early 1990s, have several limitations that affect their usefulness for emergency response and planning applications. Most importantly, the models do not address substantial variations in bridge performance associated with the full range of bridge types, configurations, and design eras existing in California. In addition, the bridge damage state definitions are not clearly associated with the identification of post-earthquake emergency repair needs and available traffic capacity, and they provide only a qualitative sense of damage for the entire bridge, with minimal details about quantitative engineering metrics or where the damage might be located.

WHAT WAS OUR GOAL?

The overall aim of the project was to develop a new generation of accurate, actionable bridge fragility models for Caltrans' ShakeCast alerting system and to bolster seismic reliability evaluations of California's statewide bridge inventory. This task focused specifically on developing models for concrete box girder bridges.

WHAT DID WE DO?

This project involved a combination of closely coordinated internal and contract research. The internal work was focused on characterizing California's bridge inventory while the contract work involved conducting an extensive program of analytical modeling.

Internal work on bridge-inventory characterization involved development of a new bridge taxonomy to group bridge classes/subclasses according to salient design features relevant to seismic performance. Data from a variety of Departmental information assets were being synthesized to first characterize the range of existing idealized bridge classes, and then to assign individual bridges to a class, thus enabling assignment of fragility models for ShakeCast. Additionally, the capacity of various bridge-component details was characterized as a set of component capacity limit state (CCLS) models. These models characterize component damage as a function of earthquake demands and were developed in consultation with Caltrans' bridge design and maintenance experts.

Analytical modeling work was being completed under contract with the Georgia Institute of Technology. For each idealized bridge class/subclass, representative analytical bridge models were established using ranges of design details compiled through review of applicable bridge plans. Probabilistic seismic demand models (PSDM's) were then developed through a stochastic application of a non-linear finite-element modeling procedure. For each bridge type, a set of up to several hundred simulations were performed using a wide range of earthquake motions and in-class permutations of the representative bridge model.

Once the PSDM's were established, they were combined with applicable capacity models provided by Caltrans to yield component fragility models which characterize component-level damage. The component models were then combined according to the details of a specific bridge type to yield a bridge-system fragility model which is used to characterize operational consequences of bridge damage. The system-level models will serve as the primary basis for ShakeCast alerting and inspection prioritization while the component-level models provide added insight into locations and extent of predicted damage.

The project has now moved to UC Davis under different contract, where work continues on extending the framework to other bridge types. Meanwhile, independent checking and validation of the developed models is underway in preparation for use in ShakeCast.

WHAT WAS THE OUTCOME?

The task has successfully established a robust framework and infrastructures for seismic fragility modeling tailored to California's bridges (see Image 1). This task generally covered the goals, with key accomplishments including: 1) generating uncertainty distributions estimates that match the actual California bridge inventory, such as the column section mixture model has been adopted in multiple studies; 2) developing and publishing important response models for bridge components (including abutments with sacrificial backwalls and lateral seismic behavior of standard pile designs built over different eras); 3) introducing and applying a nonlinear PSDM approach that identifies progressive structural damage; and 4) producing fragility curves in varying levels of detail and for different component groupings (see Image 2).

WHAT IS THE BENEFIT?

Successful development and deployment of improved fragility models into ShakeCast will facilitate a more effective post-earthquake emergency response where incident commanders, decision makers, and field inspectors have excellent situational awareness early in the response-operations timeline. Additionally, these same tools will improve planning capabilities by providing a uniform basis to assess the seismic reliability of California's bridge inventory over a full range of hazard levels. Together, the improved fragility models within ShakeCast will provide for faster post-earthquake emergency response and restoration of network mobility. It will also support planning decisions into the most effective allocations of capital resources for improved seismic safety and a more reliable transportation network.

LEARN MORE

Final Report online access forthcoming.

IMAGES

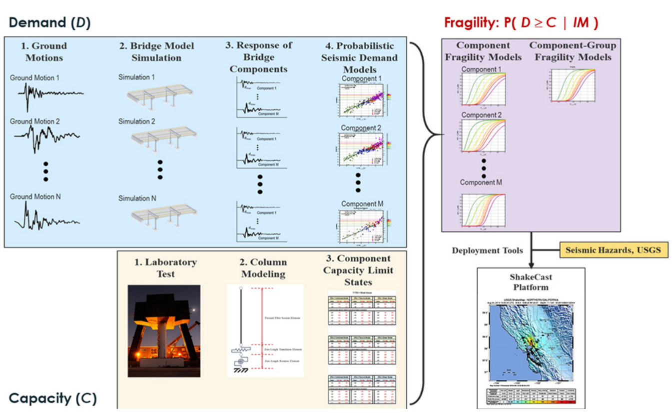

Image 1: Demand is estimated using stochastic methods, i.e., each bridge class and subclass is simulated numerous times to capture how they might perform under a wide range of earthquakes and design variations. Capacity is derived from lab tests and finite-element simulations of real structural components. These demand and capacity distributions are then paired to produce fragility models at varying levels of detail.

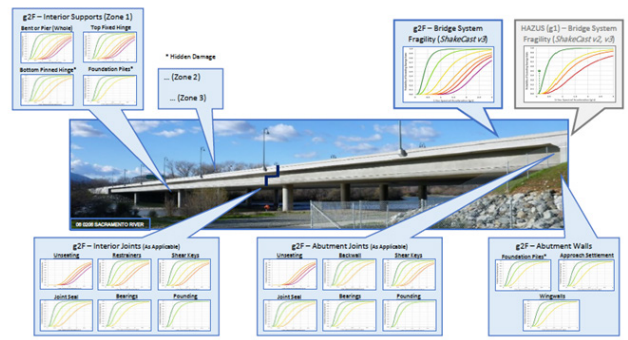

Image 2: The g2F fragility models will be deployed within the ShakeCast earthquake alerting system. Added bridge classes will allow the distinct seismic performance of each to be characterized. The g2F models will also estimate component and component-group level damage in addition to the condition of the overall bridge system.