DRISI

Caltrans Division of Research, Innovation and System Information

Research Notes

Geotechnical/ Structures

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Project Title:
Improved "Generation-2" Bridge Fragility Using Unique California Information

Task Number: 1780

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Generation-2 Bridge Fragility Relationships, Phase 2

Development of Production Models for Concrete Bridges

WHAT IS THE NEED?

Major earthquakes can severely disrupt transportation networks. Immediately after an earthquake, Caltrans emergency managers and decision-makers need to understand eld conditions to coordinate the response and to 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 specic level of shaking will induce varying degrees of bridge damage, ranging from minor spalling of concrete to complete bridge collapse.

The rst-generation fragility models, developed in the early 1990s, have several limitations that aect their usefulness for emergency response and planning Development of Production Models for Concrete Bridges applications. Most importantly, the models do not address substantial variations in bridge performance associated with the full range of bridge types, congurations, and design eras existing in California. In addition, the bridge damage-state denitions are not clearly associated with the identication of post-earthquake emergency repair needs and available trac 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.

Task 1780 is the second phase of Project P266 that builds upon the knowledge and experience gained through an initial end-to-end application of the methodology completed under the phase-one feasibility studies (Task 1755). This new phase will develop and optimize a set of generation-2 fragility models for most concrete bridge classes in California.

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WHAT ARE WE DOING?

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

Internal work on bridge-inventory characterization involves 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 are 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 is being characterized as a set of component capacity limit state (CCLS) models. These models characterize component damage as a function of earthquake demands, and are being developed in consultation with Caltrans' bridge design and maintenance experts.

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

Once the PSDM's are established, they are combined with applicable capacity (CCLS) models provided by Caltrans to yield component fragility models which characterize component-level damage. The component models are 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.

WHAT IS OUR GOAL?

The goal of Project P266 is to develop a new generation of more accurate and more useful bridge fragility models for incorporation into Caltrans' ShakeCast earthquake alerting system and to support seismic reliability evaluations of the state bridge inventory. Task 1780 will complete generation-2 models for most concrete bridge types, representing over 75% of California's bridge inventory.

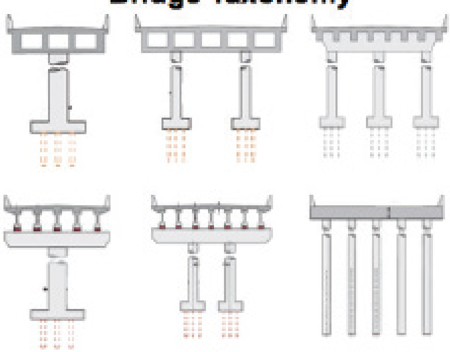

Image: Current fragility models view these bridges and others as essentially the same type - a continuous concrete structure. The new taxonomy considers them separate classes, each having distinct seismic performance.

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.

WHAT IS THE PROGRESS TO DATE?

Task 1780 got underway in August 2013, and has now completed most interim milestones required to begin the production FEM analyses used to create PSDM's for concrete box-girder (BG) bridge classes. Key milestones include envisioning an overall deployment framework, characterization of the CA bridge inventory, development of a manageable production-analysis work plan establishment of quality-control processes, development of bridge-component response models, and conduct of numerical validation exercises.

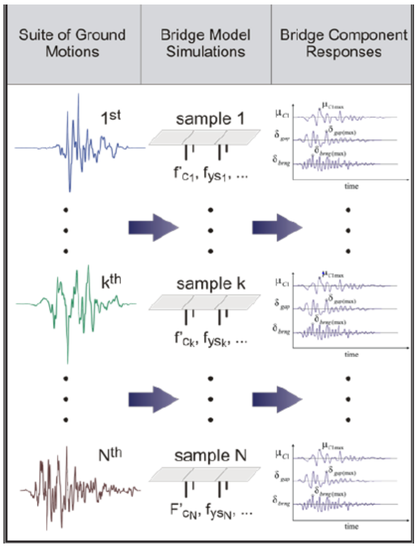

Image: Stochastic method: Each bridge class and subclass is analyzed using multiple simulations to establish seismic performance over a wide range of earthquakes and bridge-class details.

A manageable production-analysis work plan for BG bridges was defined using a combination of analytical sensitivity studies and analysis of the CA bridge inventory. The inventory was classified into "idealized Bridge Systems (IBS)" using a prototype taxonomy ("g2F codes") meant to capture design features contributing to seismic performance. Sensitivity studies identified groups of bridge configurations which yield comparable seismic performance and thus could be combined under a common class. This and additional strategies were used to pare down the 687 identified IBS classes into a manageable set of 176 "Representative Bridge Systems (RBS)" to be analyzed under the BG-base-model work plan. Additional inventory analysis allowed development of a companion adjustment-factor work plan for both skew and bridge height/unbalance.

Quality-control (QC) procedures have been established for the specification, management, and archive of FEM analysis inputs and responses for each RBS class. These QC procedures are founded on the development of a prototype database and fact-sheet document which capture essential details of production analyses including peak responses for tens of engineering parameters for each of over 100,000 individual FEM runs. Adoption of this process will ensure that details of "what's inside" each PSDM model are well documented. Together with report products and sample data files, future researchers will be positioned to reproduce or refine project findings. Departmental information assets including both bridge-inventory and maintenance databases as well as extensive collections of representative bridge plans have been used to develop statistical models for bridge-design details that are characteristic of evolving design practices in each of three seismic-design eras. Initial models have been developed for BG superstructure dimensions, interior supports, abutments, joints, and foundations needed for the FEM analyses. Additionally, a new suite of 320 scaled earthquake ground motions have been developed which provide more balanced coverage of the full column-ductility-demand range needed from PSDM's representing CA seismic hazard.

Numerical validation work has been completed involving both comparisons of independently-conducted bridge-modeling results for an ordinary Caltrans bridge design and additional comparisons to published experimental work. The bridge modeling was conducted both within a deterministic framework familiar to Caltrans designers, then also within a probabilistic framework appropriate for fragility-model development.

Production analyses of BG bridge designs will commence once the numerical validation results and component models have been finalized. Once underway, comparable work plans and component models will be developed and analyses executed in parallel for other concrete bridge types including I-beam, T-beam, and slab designs. Component capacity limit states will also be specified so that component-level fragility models can be computed from the PSDM's, and common combinations of components and limit states for each RBS will be identified so that system-level fragility models can be computed.

IMAGES

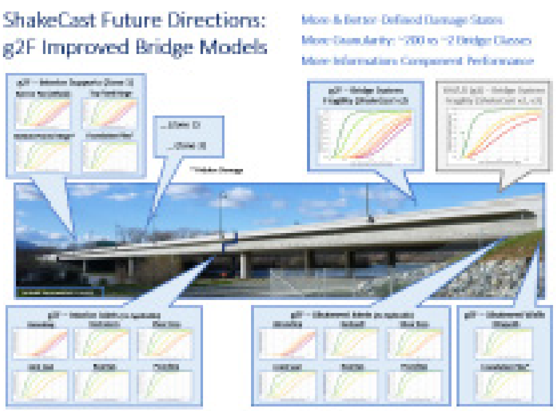

Image 1: The new g2F fragility models will be deployed within the ShakeCast v3 earthquake emergency notification system operated by Caltrans. Added bridge classes will allow the distinct seismic performance of each to be characterized. The g2F models will also estimate component-level damage in addition to the condition of the overall bridge system.

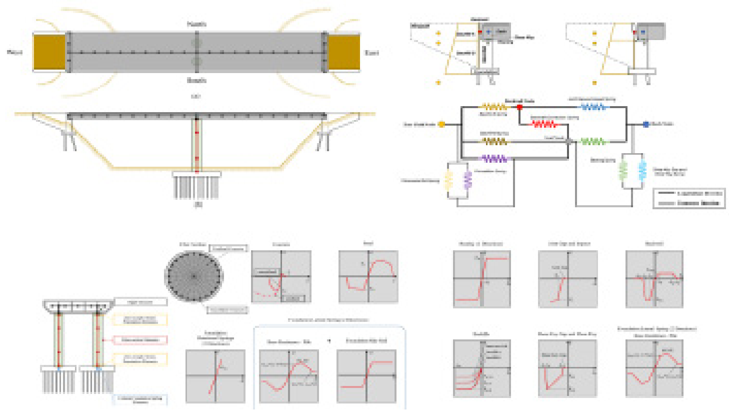

Image 2: Each simulation is performed using nonlinear, time-domain, finite-element analysis. Engineering models of bridge design attributes are selected from statistical models developed for each brodge class.

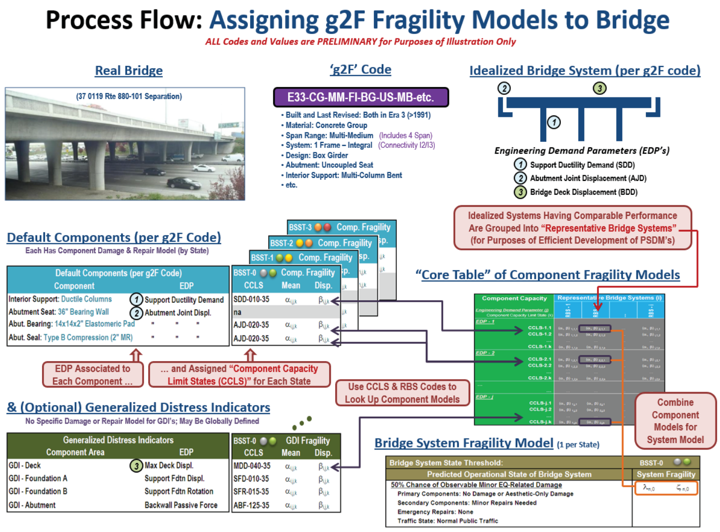

Image 3: Deployment of g2F models within ShakeCast requires that individual bridges in the CA inventory be assigned to a representative class having comparable seismic performance, and that key bridge components are assigned capacity models appropriate to that bridge. Inventory-data analysis and management for classication and model assignment are challenging central aspects for research deployment.