DRISI

Caltrans Division of Research, Innovation and System Information

Research Results

Improving Bridge Fragility Models

Developing new fragility models to rapidly estimate seismic bridge damage more accurately

Geotechnical/ Structures/ Seismic

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Feasibility Studies for Improving Caltrans' Bridge Fragility Relationships

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WHAT IS THE NEED?

Major earthquakes can severely disrupt transportation networks. Immediately after an earthquake, Caltrans emergency managers and decision-makers need to understand field 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 precalculated 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 the vast range of bridge types, configurations, and design eras existing in California. In addition, the bridge damage-state definitions are not clearly associated with post-earthquake emergency repair needs and 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?

This research is the first phase of a multiphase project to explore the feasibility of developing fragility models that better represent California's bridge inventory to improve Caltrans' capability to rapidly estimate earthquake damage for emergency response management and scenario planning. The first phase investigated new methods for bridge classification, damage-state definitions, and numerical modeling to determine whether bridge-performance distinctions can be isolated from what is currently treated as a single bridge class.

WHAT DID WE DO?

Caltrans, in partnership with researchers at the Georgia Institute of Technology and Rice University, explored emerging concepts for developing the next generation of bridge fragility models. The risk-based methodology for characterizing bridge performance over a wide range of hazard levels presented a new approach for Caltrans seismic design experts. To familiarize these practitioners to the methodology's analytical details and ensure that its application could incorporate Caltrans seismic design principles and earthquake experience, frequent and in-depth interactions occurred at the onset of the project between the academic research team and the Caltrans seismic design professionals who were more experienced with practical bridge-design and maintenance matters.

Fragility model development involves strong interdependencies between assumptions adopted and results obtained, so the research required an iterative propose-and-evaluate approach. For example, numerous bridge design characteristics affect seismic performance. The challenge is to identify optimal combinations of characteristics to yield a manageable number of bridge classes and subclasses that have distinct performance results. To expand the bridge taxonomy, the investigation considered characteristics not addressed by previous methods. Fragility models were developed for four common concrete bridge types: integral box girders, integral T-girders, non-integral I-girders, and slab. In addition, separate models were developed for subclasses of each bridge type. The subclasses considered three seismic design eras—prior to 1971, 1971–90, and post 1990—and applicable combinations of other configuration attributes, including abutment type (diaphragm, various seat sizes) and interior support type (single column, multicolumn, pile extension).

Developing a single fragility model for each subclass—for example, a modern era, multicolumn box girder with a diaphragm abutment—involved defining representative ranges of design details for that class by examining bridge plans, performing a suite of 320 nonlinear structural simulations, and then creating statistical models for each engineering metric used to define damage, such as column ductility or hinge displacement. The researchers performed this numerically intensive process for each combination of bridge type, era, and configuration and then evaluated the original taxonomy parameters and damage models in aggregate and how they compared to design experience and laboratory and field observations. During this investigation, both the damage models and bridge taxonomy were refined.

WHAT WAS THE OUTCOME?

The researchers established the feasibility of using the emerging methodology to extend and refine bridge fragility models. After broadly defining the scope of the methodology for Caltrans purposes, an end-to-end iteration through the entire model-development process was completed for a representative range of bridge classes in California. The results revealed distinct performance differences between bridge classes and subclasses that are not captured by earlier methods. This phase also produced sample model formats that are being incorporated into the next generation of ShakeCast.

Caltrans seismic design professionals also became familiar with the methodology while simultaneously orienting the academic research team to the practical details and concerns of bridge engineers. This phase provided key insights on performance trends for various bridge systems as well as the consequences of adopting certain assumptions for damage-state definitions and selecting bridge-taxonomy characteristics. For instance, it was determined that the limit-state definitions used in this iteration were too conservative and need to be modified in future phases. Although the prototypes developed during this phase are not sufficiently mature for deployment, the results will guide the future work of extending, optimizing, and verifying the next generation of fragility models.

WHAT IS THE BENEFIT?

This project demonstrated the feasibility of developing more accurate and useful bridge fragility models. As production models are completed in future phases, they will be incorporated into the ShakeCast earthquake alerting system. The new fragility models will improve Caltrans' earthquake emergency response capabilities by providing incident commanders, decision-makers, and field inspectors with more accurate and detailed information earlier. Additionally, planners can use these capabilities to assess potential transportation-system damage for various earthquake scenarios and proactively develop risk mitigation strategies to minimize adverse impacts to the public and speed regional economic recovery after a major earthquake.

LEARN MORE

For more information:
www.dot.ca.gov/research/researchreports/reports/2012/t1775_final_report_cjr_v2.pdf

IMAGES

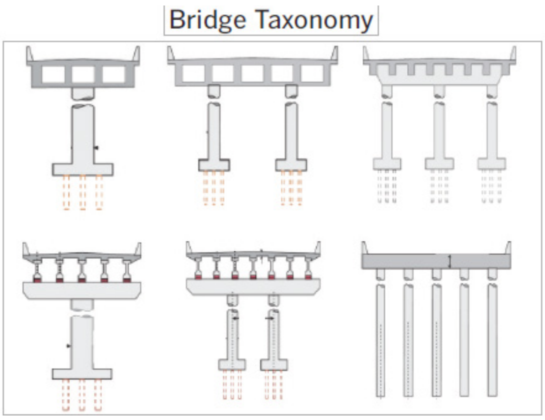

Figure 1: Current fragility models view these bridges and others as essentially the same type—a continuous concrete structure. The new taxonomy considers them separate classes, each having distinct seismic performance.