Research Project Highlight

Probabilistic Performance-Based Optimal Seismic Design of Isolated Bridge Structures

Project # 1107-NCTRCJ

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Start-End Dates:
1/1/2012-8/31/2016

Abstract
The emerging transportation needs in California, together with significant success of high-speed rail systems all through the world, has prompted the initiation of California high-speed rail (CHSR) project. In areas with high seismic activity (e.g., San Francisco and Los Angeles), the seismic risk mitigation of high-speed rail bridges is a topic of major concern to stakeholders, policy makers, and engineers. Seismic isolation offers a promising solution for high-speed rail bridges in high seismic regions. However, its effectiveness in enhancing the seismic performance of CHSR bridges needs to be evaluated reliably based on a comprehensive numerical model of a bridge system considering its various components with their nonlinearities and interactions. Thus, a nine-span CHSR prototype bridge is designed, and a detailed three-dimensional (3-D) nonlinear finite element (FE) model, with soil-foundation-structure and rail-structure interactions, was developed in OpenSees. Using this FE model, seismic responses (including the bridge structural and rail responses) of the prototype bridge with and without seismic isolation were compared deterministically and probabilistically, and the beneficial and detrimental effects of seismic isolation identified. To evaluate the effects of isolator characteristics, a parametric probabilistic seismic demand hazard analysis was performed with respect to key isolator model parameters. For an optimum isolator design that strikes a balance between beneficial and detrimental effects, a probabilistic performance-based optimum seismic design (PPBOSD) framework was proposed and validated with a proof-of-concept example. This framework was applied to seek the optimum seismic isolator design for the CHSR prototype bridge considered. Several well-posed design optimization problems, with different probabilistic objective and constraint functions, were defined and solved. This research illustrates the power of the proposed PPBOSD framework, and investigated the suitability of seismic isolation for CHSR bridges.

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Deliverables

A PEER report summarizing research findings. Several conference and journal papers are published or under review, mainly regarding the following topics: (1) Definition, illustration and validation of the proposed PPBOSD framework; (2) Design and modeling of the CHSR prototype bridge, followed by deterministic and probabilistic demand hazard analysis of bridge with and without seismic isolation; and (3) parametric probabilistic demand hazard analysis and probabilistic performance-based optimum seismic design of seismic isolators for the CHSR prototype bridge.

Research Impact

California high-speed rail (CHSR) bridges will constitute one of the most important components of the transportation infrastructure. Proper design and seismic risk-mitigation of CHSR bridges are essential for the reliable operation of high-speed trains, seismic safety during high intensity earthquake events, and resilience of California communities. For damage-free or low-damage performance objectives, seismic isolation is identified as one of the promising earthquake protection strategies. However, the feasibility and optimality of the design of seismic isolation for CHSR bridges need to be evaluated in a probabilistic framework due to the pertinent sources of uncertainty (e.g., seismic input). Thus, the PEER performance-based earthquake engineering (PBEE) methodology was used with emphasis on the probabilistic demand hazard analysis to evaluate the effects of seismic isolation on the seismic response of a high-speed rail prototype bridge system considered. Considering the conflicting effects of seismic isolation on different key response quantities (e.g., pier drift, deck displacement and acceleration, rail stress) of CHSR bridge systems, the proposed and validated PPBOSD framework was used as a decision-making tool for isolator design in the face of uncertainty, to strike a trade-off between the beneficial and detrimental effects. It was found that seismic isolation can be used to satisfy the seismic design requirements of the considered CHSR prototype bridge in a highly seismic region, and that the isolator characteristics can be optimally tuned to satisfy the probabilistic design objectives and constraints using the proposed PPBOSD framework. This framework can also be used to develop and calibrate simplified and practical probabilistic performance-based seismic design methods for ordinary highway bridges and for building structures. This research work provides significant insight to decision-makers (e.g., structural engineers and stakeholders) on the potential use of seismic isolation for risk mitigation of future CHSR bridges.

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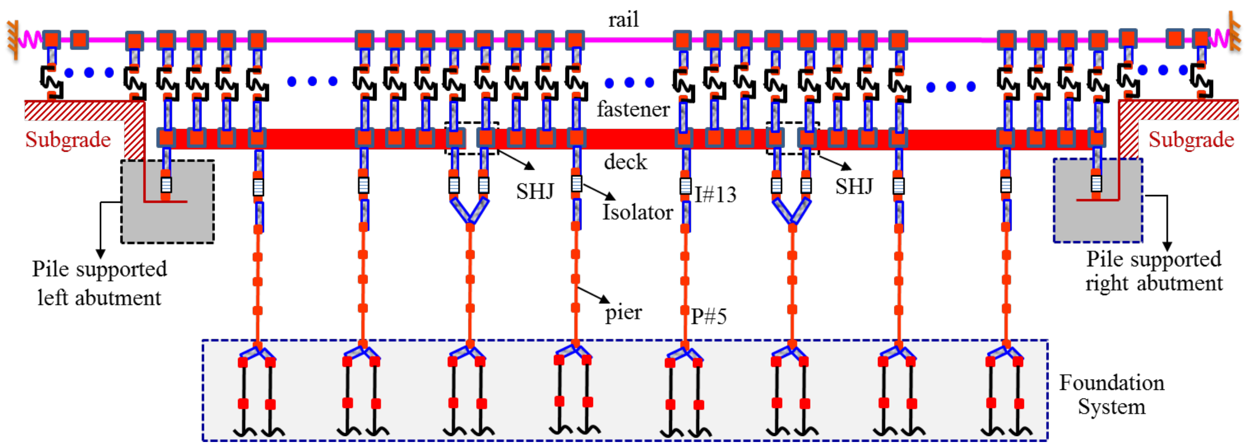
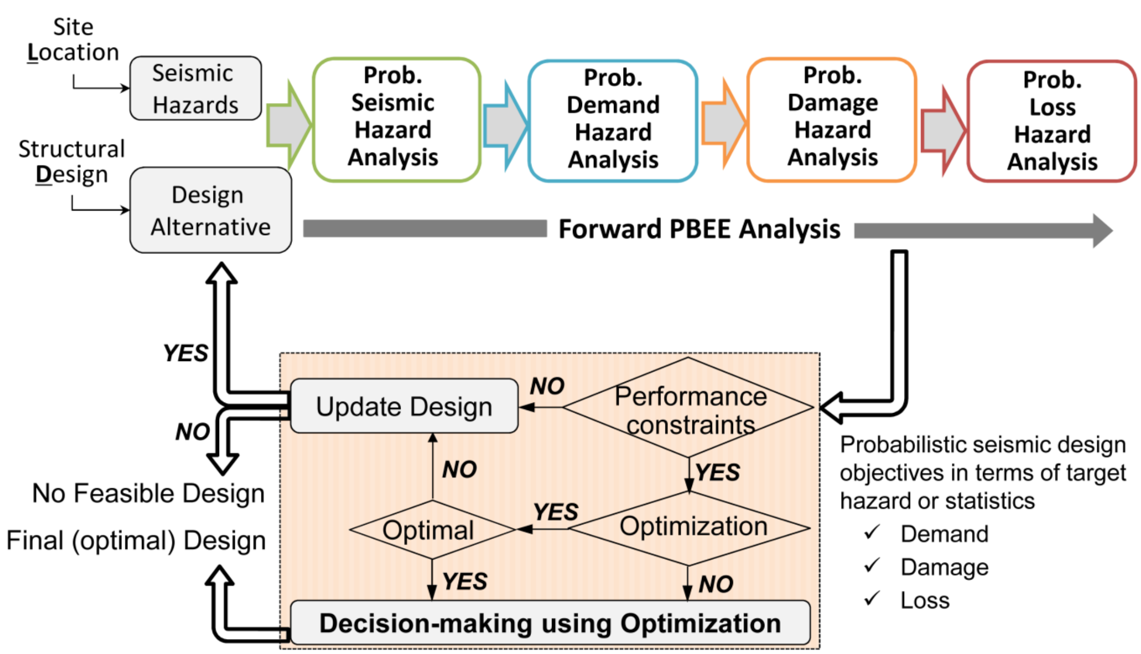
Project Images



a) Elevation view of the comprehensive 3-D nonlinear Finite Element model of the California High-Speed Rail (CHSR) prototype bridge



b) Probabilistic performance-based optimum seismic design (PPBOSD) framework

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