PEER "Research Nuggets"

Title: Seismic Performance of Isolated Bridges Under Beyond-design Basis Shaking

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Motivation: Seismically isolated highway bridges are expected to provide limited service under a safety evaluation-level ground shaking with minimal to moderate damage. The behavior under shaking beyond-design considerations, corresponding to a large return period seismic hazard, is not well understood and could induce significant damage. In these rare events, the seismic isolation system can be subjected to displacement demands beyond its design capacity, resulting in failure of the bearings, structural pounding between the deck and the abutment backwall, or damage to primary structural components such as columns. Improved understanding of the progress of damage and failure in seismically isolated bridges is necessary for performance-based assessment and quantification of the risk of collapse.

Objectives: This study examines the seismic performance of a prototype highway bridge subjected to beyond-design basis shaking. The performance evaluation requires advanced modeling approaches to capture progress of damage and potential failure modes. Thus, a significant effort of this research is towards developing models to capture the limit states of seismically isolated bridges and their primary components under beyond-design basis shaking. In addition, potential mitigation measures, including reconfiguration of bearings and supplemental damping, were examined to improve seismic performance.

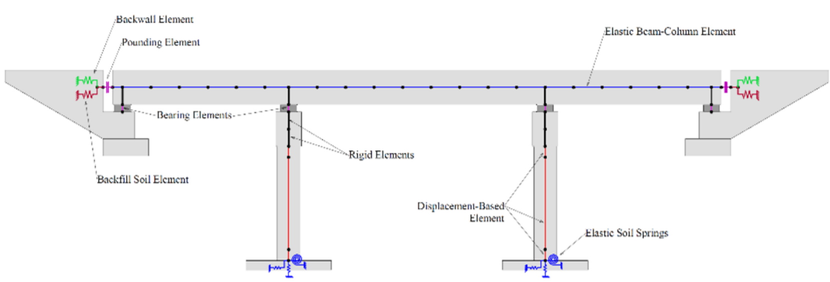
Methodology: State-of-the-art models are employed to account for pounding between deck-to-abutments and the behavior of bearings under large cyclic displacements including any strength degradation and/or hardening. A full nonlinear finite element model of a prototype isolated bridge is developed considering failure modes of the abutment backwall and bearing behavior. Nonlinear time-history analysis is performed using 30 bidirectional ground motions scaled to a design and beyond-design seismic hazard to understand the expected damage. Mitigation strategies considering redistribution of bearing properties and supplemental viscous damping are examined to evaluate their effectiveness in improving the performance of seismically isolated bridges under beyond-design basis shaking.

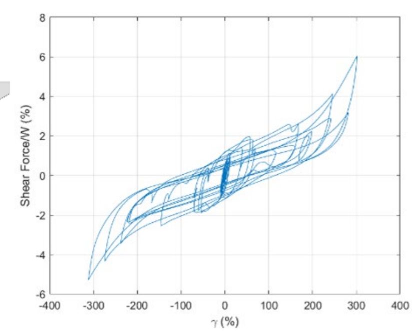
Results: For design-level shaking, the seismically isolated bridge behaves as expected with limited nonlinear behavior at the columns and no expected pounding. For the beyond-design-level seismic hazard, the displacement demands on the isolation system are about twice as large compared to the design-level ground motions. This increase in displacement results in about one-third of the ground motion pairs causing pounding between the deck and abutment. The model indicates a potential for backwall failure in shear and significant permanent deformations of the backfill soil but without achieving its peak strength and full failure. Damage to the abutment is considered sacrificial that can be rapidly repaired. No shear keys or restraints were considered in the transverse direction and in some cases bearing failure can be expected with the potential for unseating.

For beyond-design shaking, the column moment-rotation behavior shows yielding with the increased displacements and resisting forces in the bearings. Importantly, ductility was limited in the column bents and did not achieve the onset of strength degradation considered in the modeling. As the columns yield, their relative contribution to the deck displacement increases, reducing the effectiveness of the isolation system. However, the bearings still accounted for the majority of the deck displacement demands.

To improve the performance of the isolated bridge, two modifications to the bridge were considered and analyzed: The first consists of changing the bearing configuration to reduce the forces transferred to the bent by placing stiffer bearings and engaging hardening earlier at the abutment. This configuration effectively reduced the force demands of the bent, while reductions in the deck displacements were negligible.

Supplemental viscous dampers were also considered as an alternative to improve the performance of the seismically isolated bridge. Targeting 25% additional damping ratio, all the performance parameters observed were significantly improved. No abutment pounding was observed, with limited nonlinear behavior at the columns.





Conclusions: Considering design-level shaking, the isolated bridge performs adequately, as expected, with limited damage and no significant nonlinear behavior in the structural components. For beyond-design shaking, yielding can be expected in the columns. While yielding of the columns reduces the effectiveness of the isolation system, damage to the columns can be maintained at reasonable levels and does not rapidly degrade towards collapse. Pounding between the deck and abutment can be expected resulting in repairable damage to the abutments. The simulations indicate that the collapse failure mode of a seismically isolated bridge for beyond-design shaking is likely bearing failure and potential for unseating in the transverse direction in the absence of lateral restraints.

Keywords: Bridge, Seismic Isolation, Beyond-Design Shaking, Pounding, Elastomeric Bearings