UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

Seismic Performance of Isolated Ordinary Bridges Under Beyond Design Shaking

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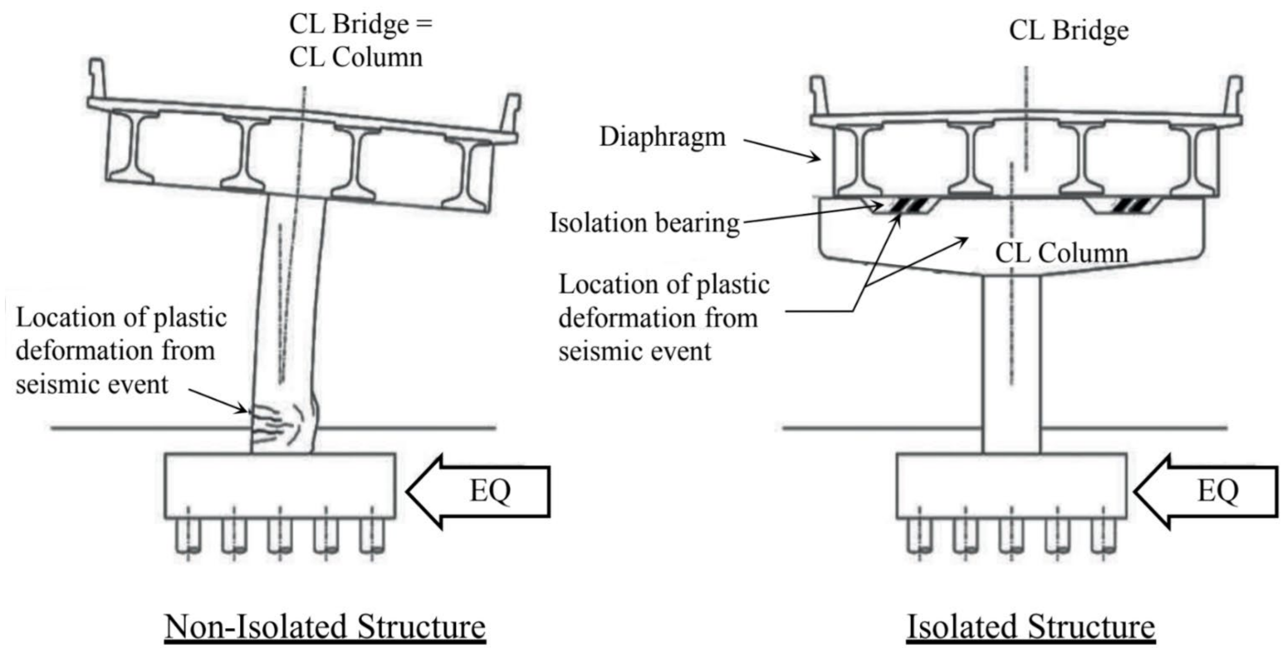
Research Overview

- Seismic isolation has demonstrated to be one of the most effective techniques to mitigation seismic damage in various types of structures including bridges
- Performance and modeling of seismically isolated bridges is well understood for design level motions
- For beyond design basis shaking, failure modes and consequences are not clearly defined

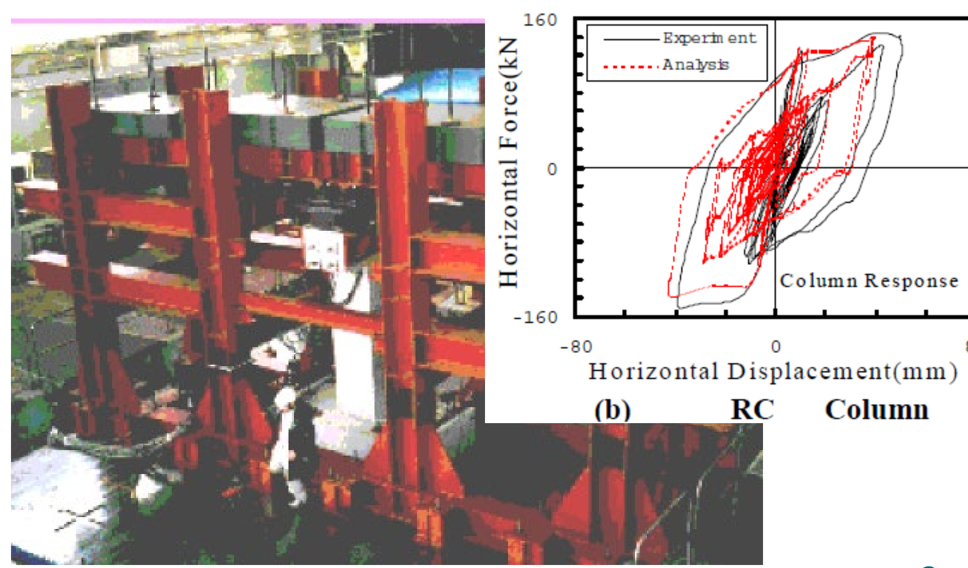


“Seismic Design of Ordinary Bridges with Isolation Bearings”, Caltrans, 2019

Research Overview

- Limited studies examining bridge behavior beyond design considerations
- Test at UNR demonstrated effectiveness of isolation system to 3X design motion leading to localized bearing instability but stable overall response
- Testing in Japan leading to plastic hinge forming in column with energy dissipation shifting from bearing to column

Testing at UNR, Buckle et al. 2017



Adachi et al 2000

Research Objectives

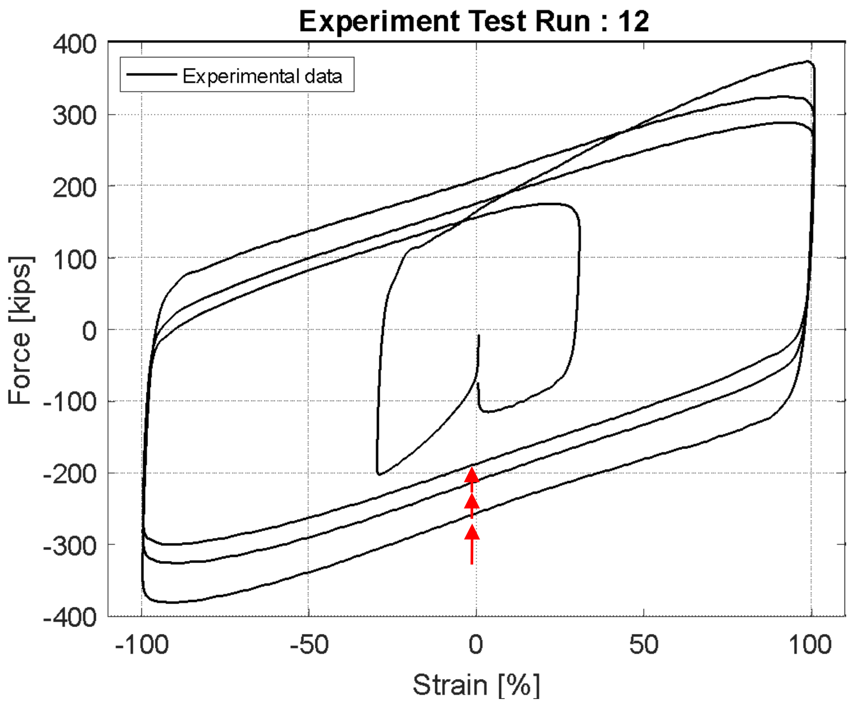
- Develop advanced models of seismically isolated bridge components capable of characterizing response under extreme shaking
  - Lead Rubber Bearing Models: typically modeled with (smooth) bilinear models
  - Impact Models: typically use modified bi-linear model
  - Revisit abutment and deck models for impact

  ➡ Implementation of models in OpenSEES
- Development of prototype bridge models to assess system response
- Damage characterization
  - Determine damage state for bearings and bridge components supplemented by past experiments and research
- Mitigation Measures
  - Effects on supplemental damping, bearing hardening, and restrainers

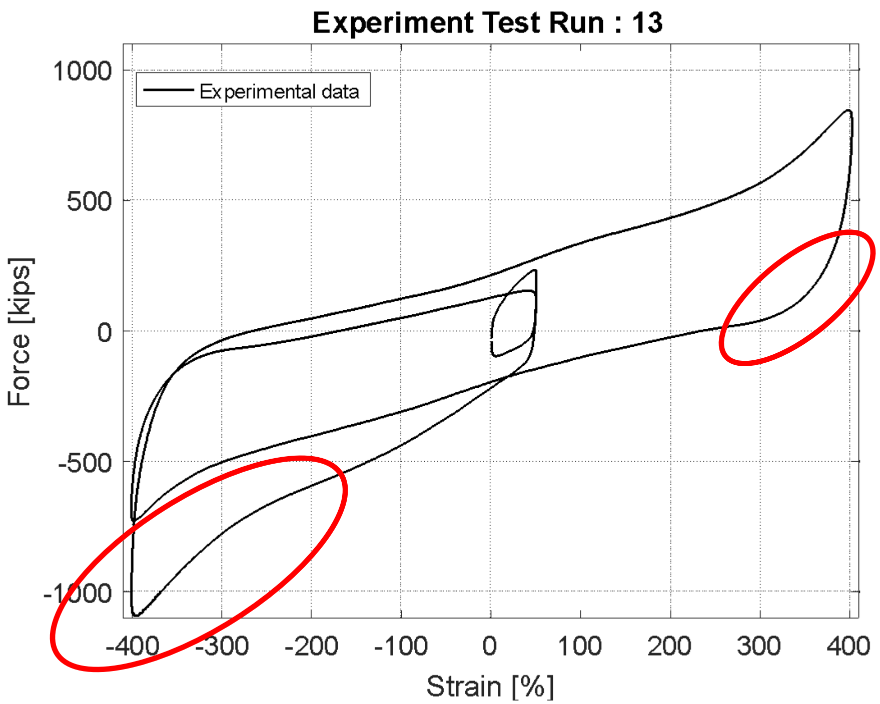
Modeling of Bearings

- Advanced modeling of Lead Rubber Bearings
  - **Strength degradation of lead core due to heating**
  - **Hardening of elastomer induced at large strains**
  - Effects of vertical loads and instability of bearings

Strength Degradation

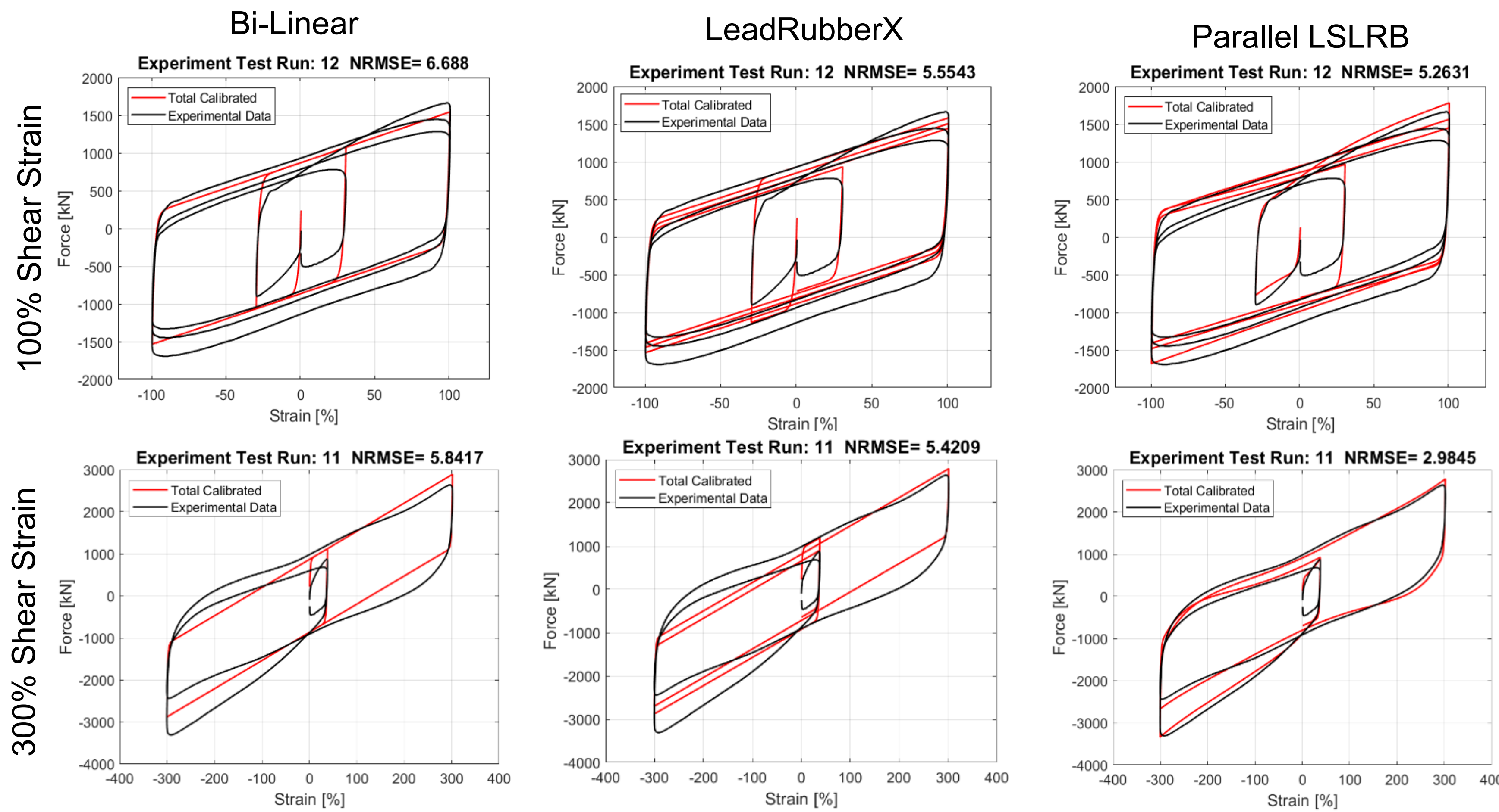


Strain Hardening



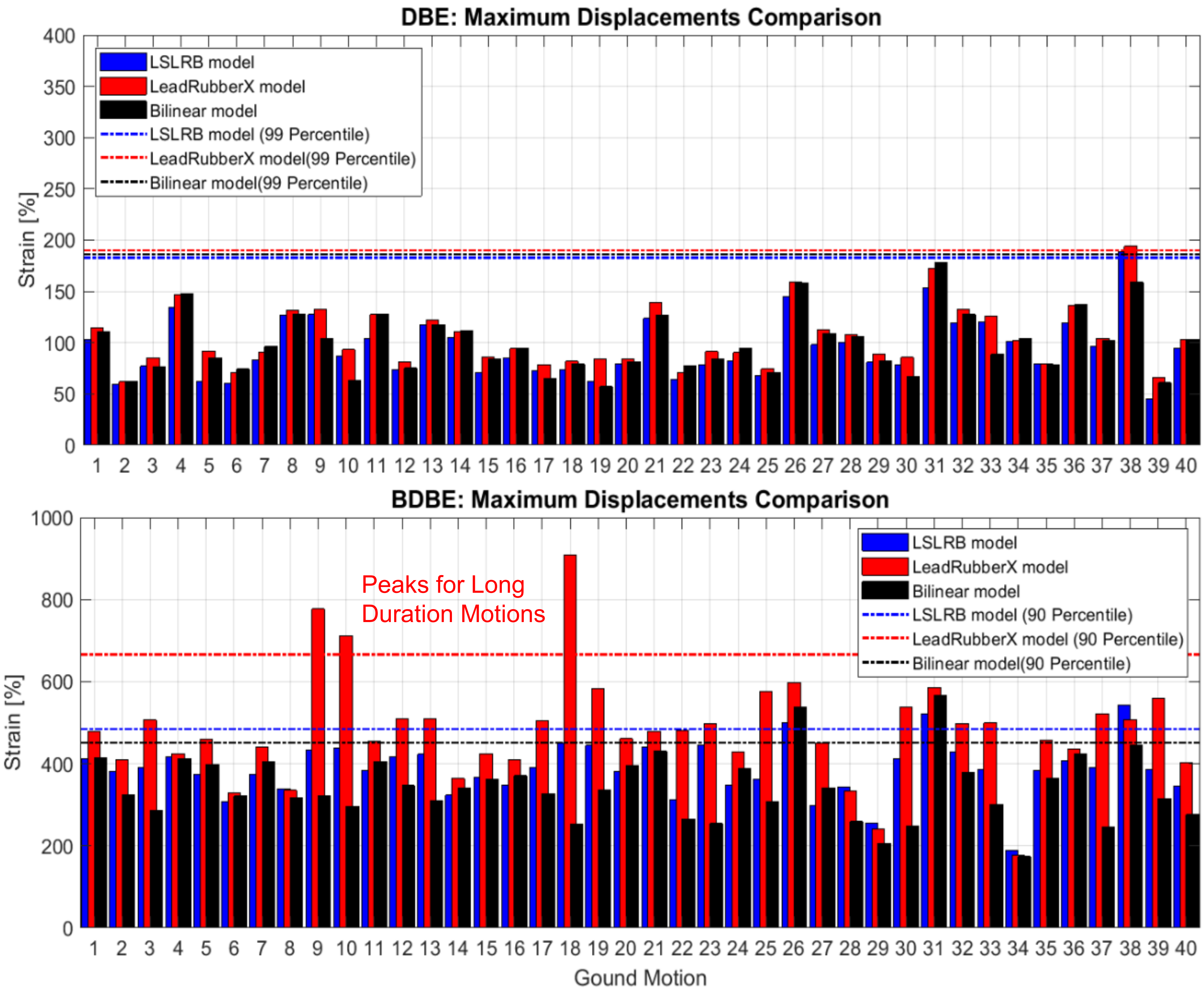
Modeling of Bearings

- Comparison of Bearing Models to Experimental Data
  - Model works well in 1D, need extension to 2D anisotropic behavior



Marquez et al. 2021

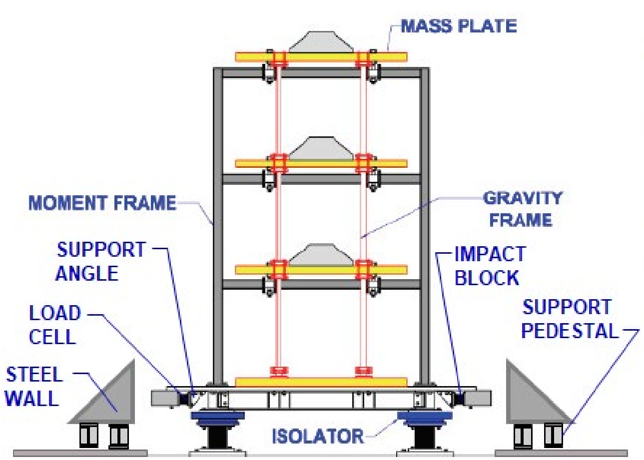
Effects of Bearing Models on SDOF Response

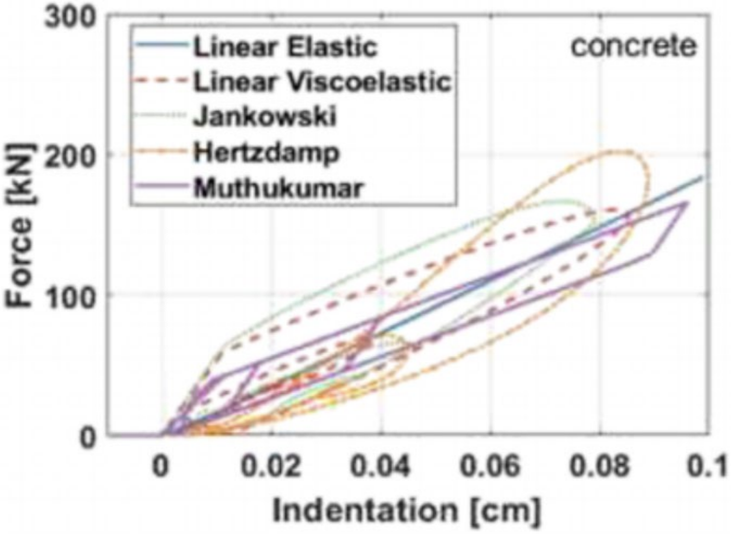


Modeling of Impact

Limited experimental data for verification of impact models

- Contact Model
  - OpenSees *ImpactMaterial* is based on bilinear approximation to Herts contact model and is calibrated to penetration distance
  - Hertz Damped Model was implemented in OpenSees
  - Contact model important for local impact response

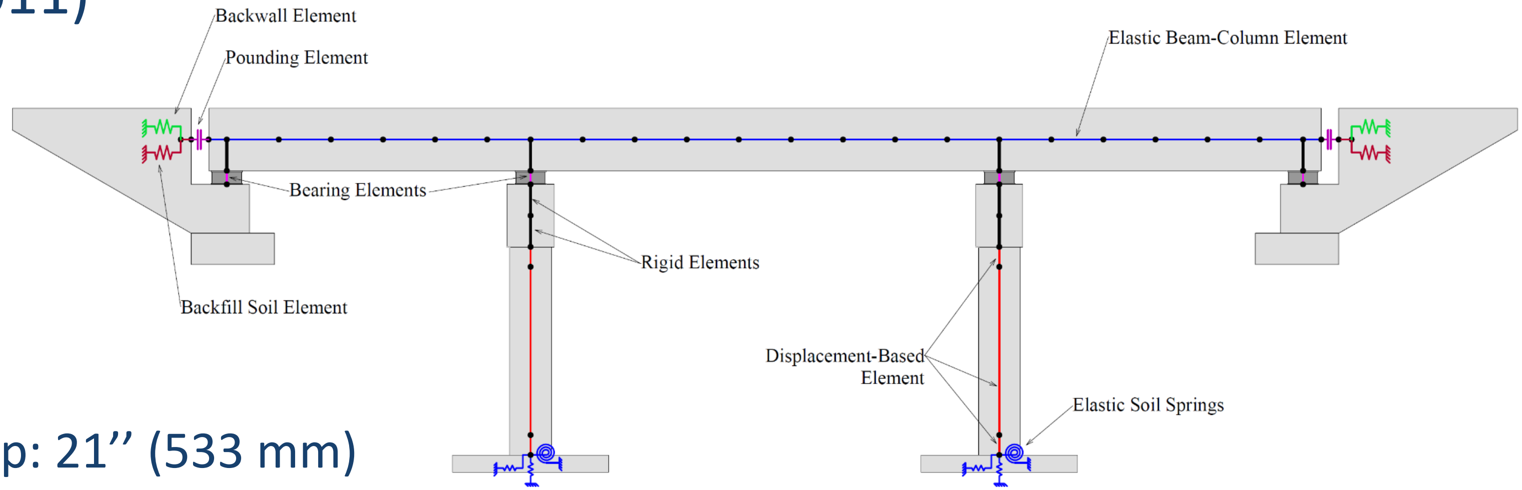




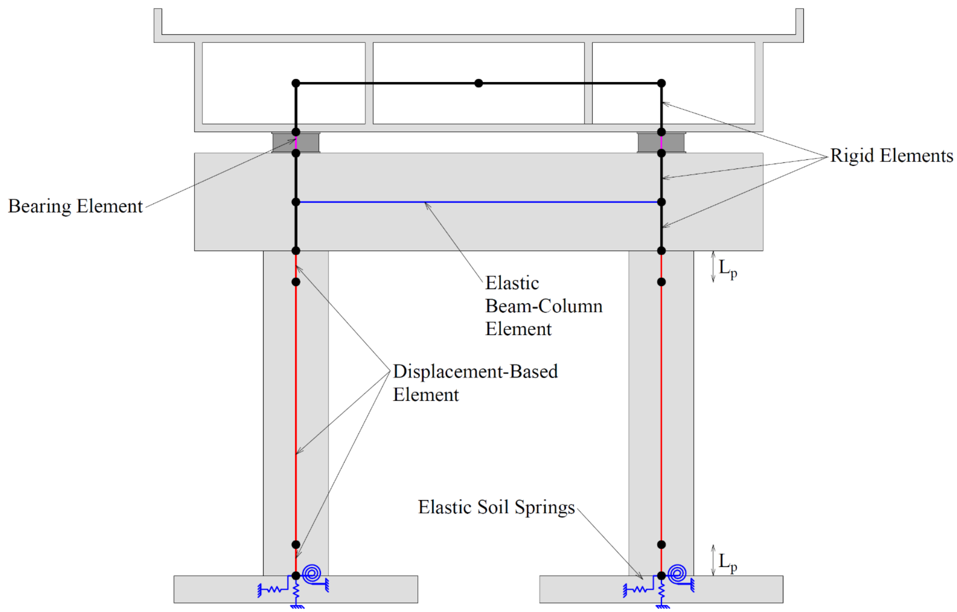
Ref: “Evaluation of uniaxial contact models for moat wall pounding simulations”, P. Hughes & G. Mosqueda, 2019

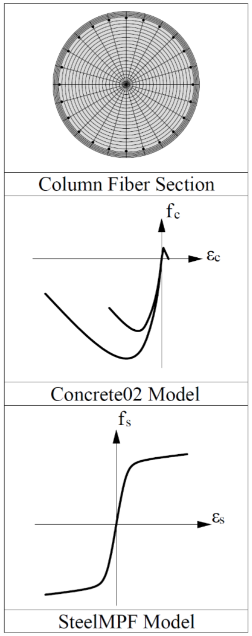
Bridge Model

Prototype model of ordinary seismically isolated bridge (Buckle et al. 2011)



Gap: 21'' (533 mm)

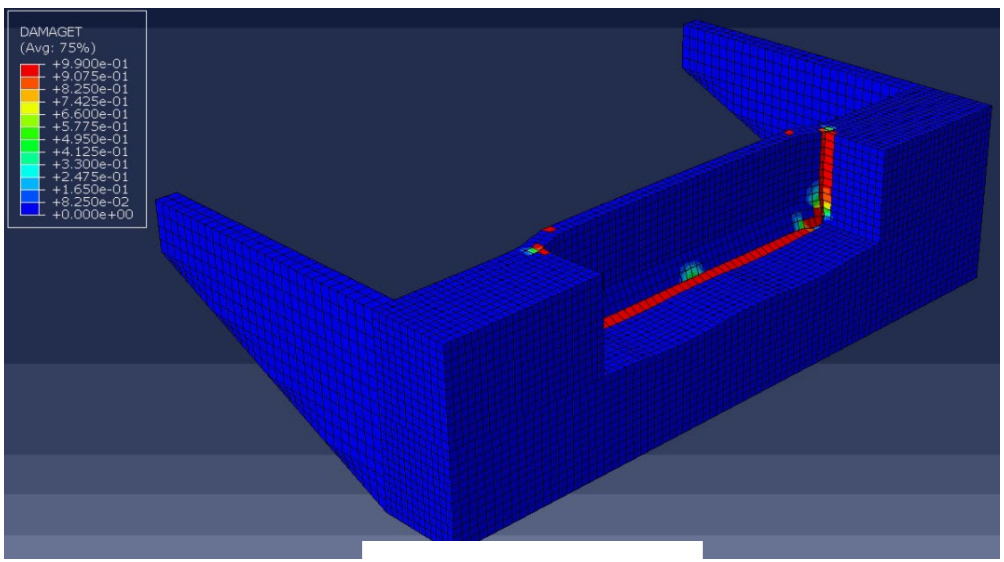


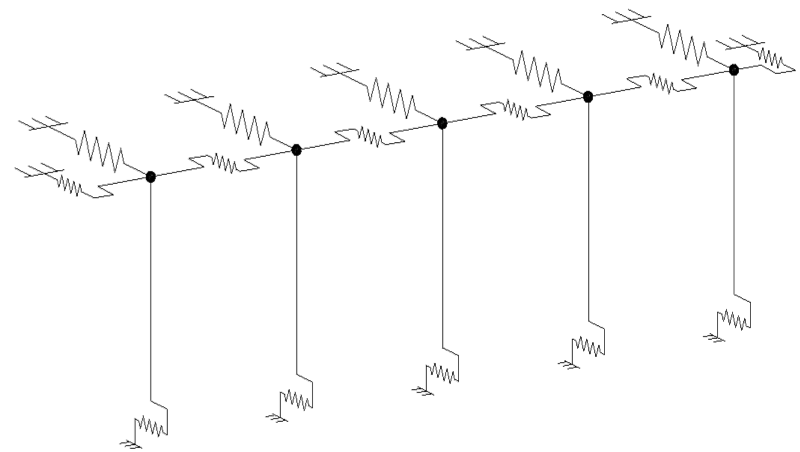


Bridge Model

Abutment model in OpenSees derived from ABAQUS simulations:

- Backfill soil: *Hyperbolic* gap material
- Wall: *TwoNodeLink* element for out-of-plane shear behavior at the base
- Abutment-Deck Contact: *Hertzdamp* contact model



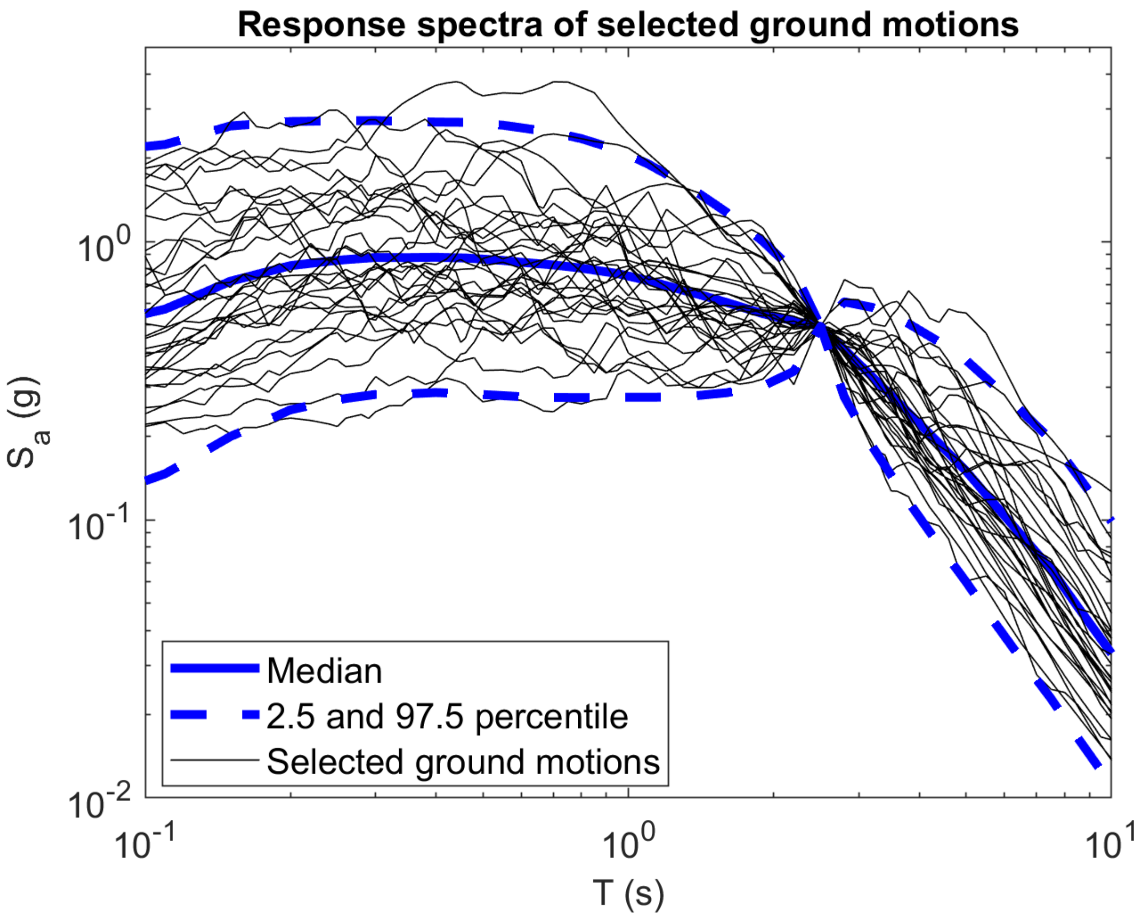


SIMULIA ABAQUS → OpenSees

Bridge Model

Ground Motions:

- 30 bidirectional records for site in Los Angeles
- "Design Level" considers 975 Year return period
- "Beyond Design" considers 2475 years of return period

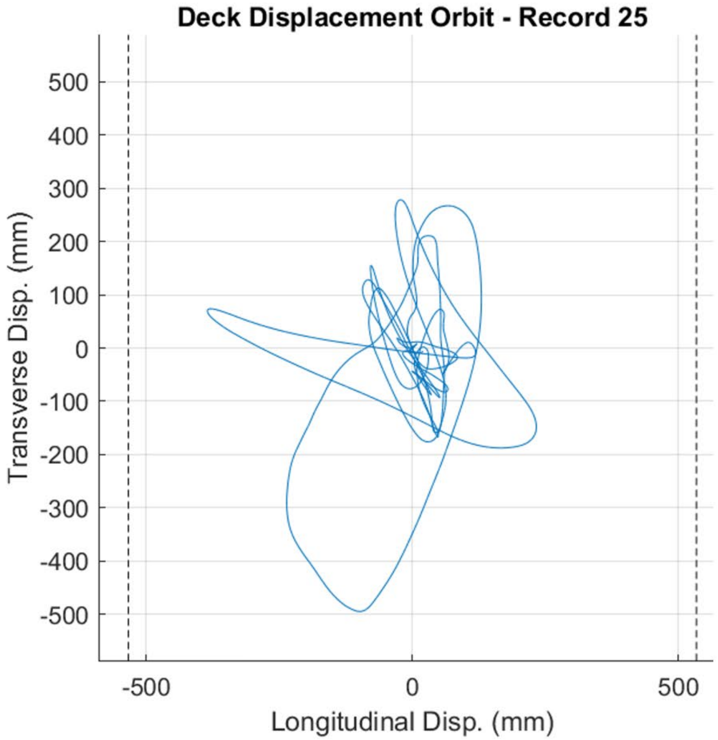


Results

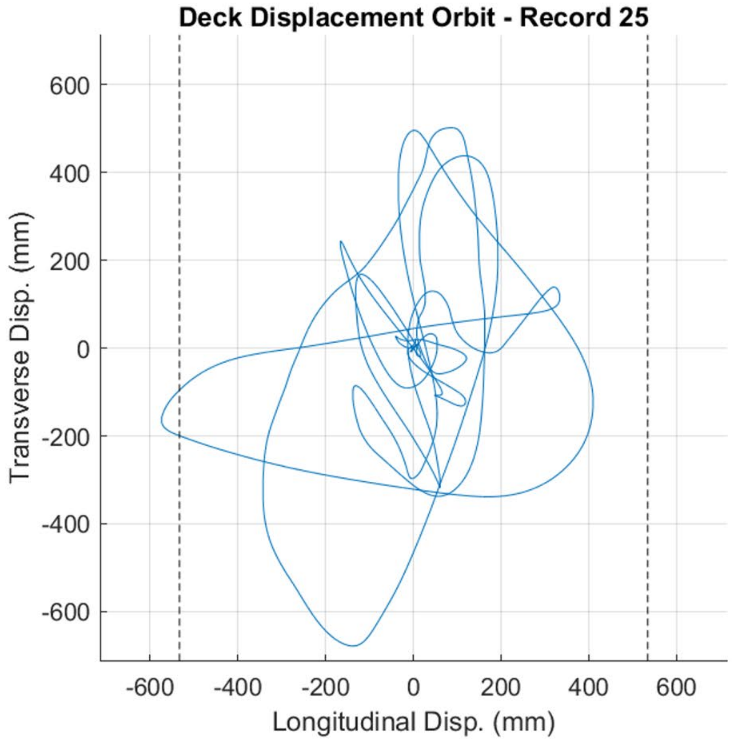
Design vs Beyond Design Level:

- Deck displacement for beyond design is around twice the design level
- No abutment impact for the design level intensity
- 11 out of 30 abutment impact for beyond design intensity

Design Level



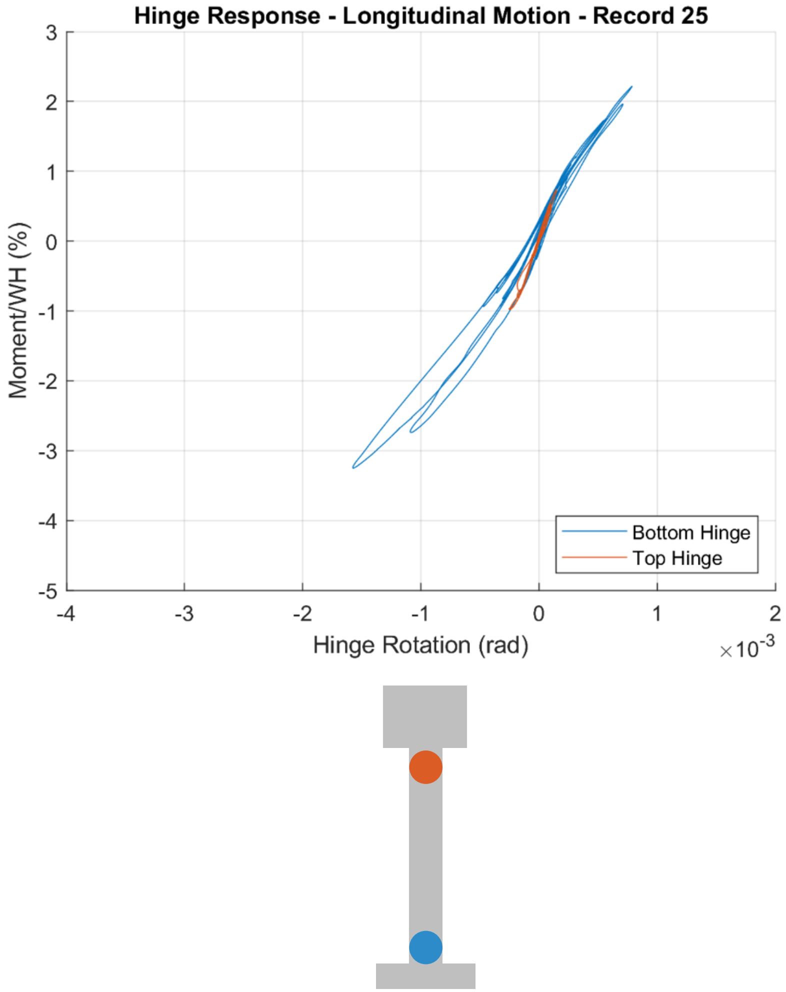
Beyond Design Level

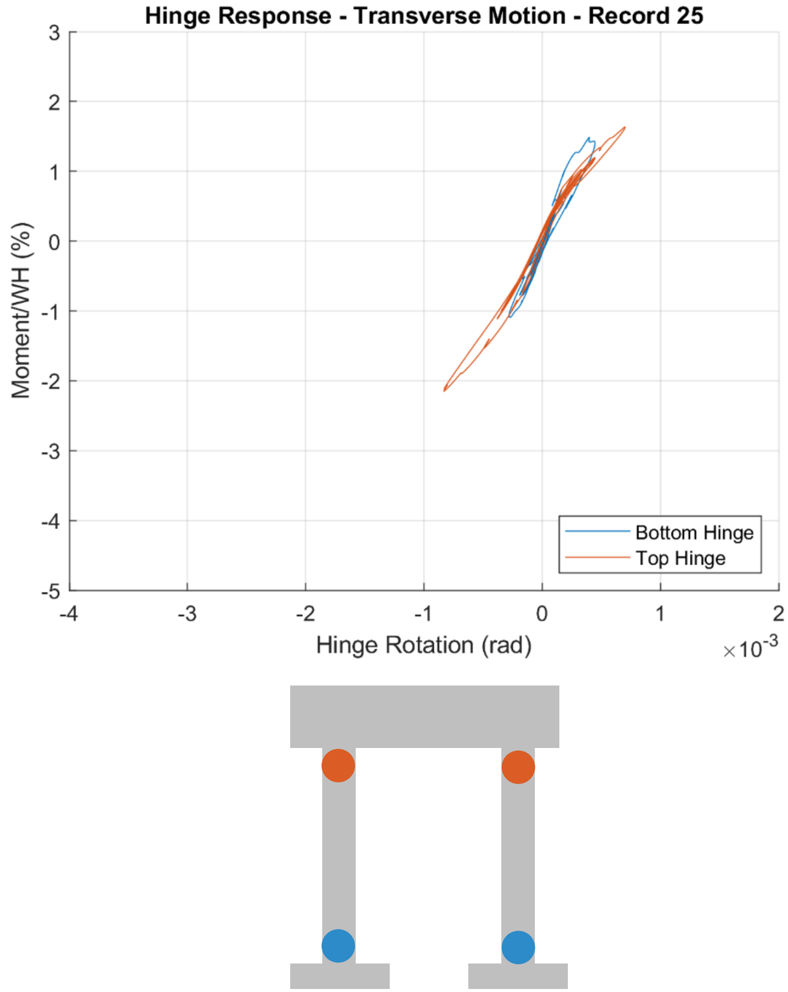


Results

Design vs Beyond Design Level:

- Bent behavior essentially linear for design level

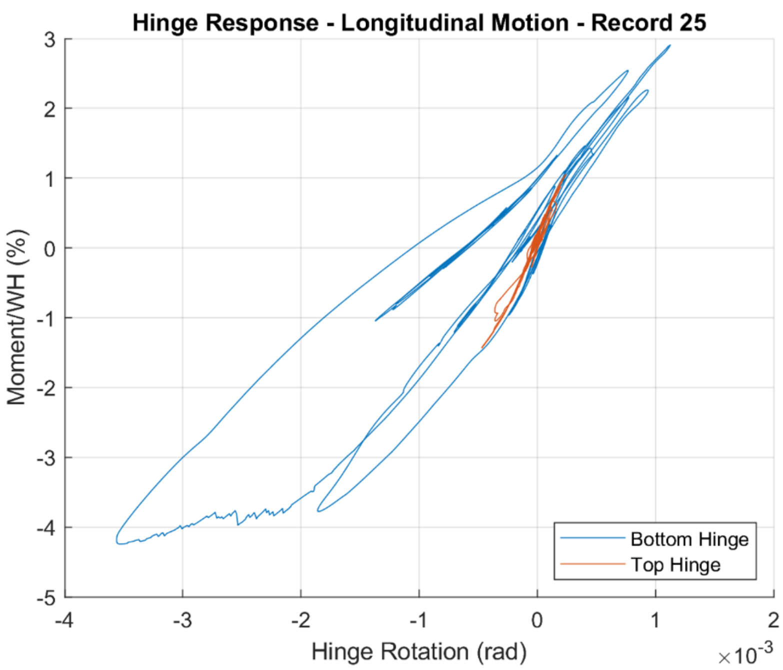


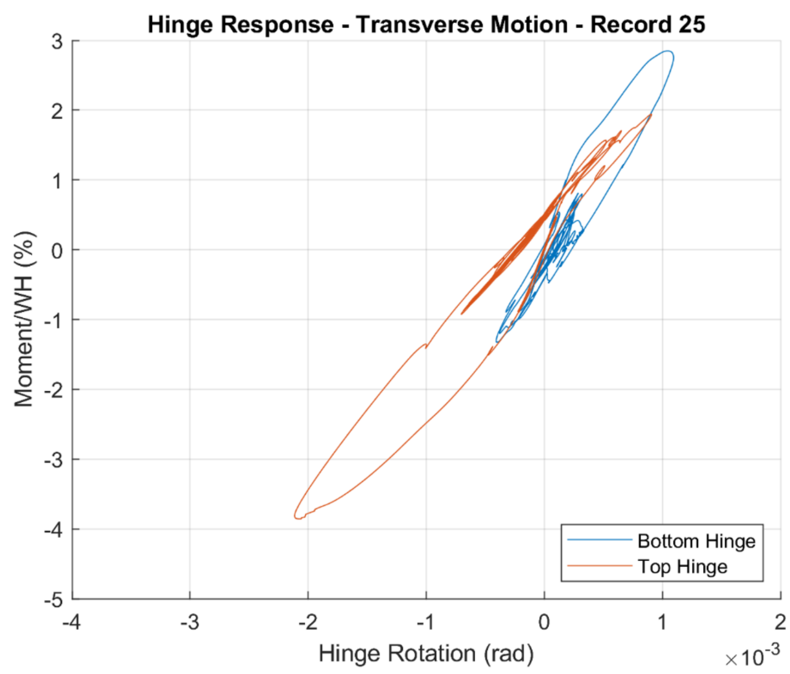


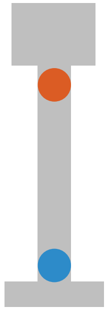
Results

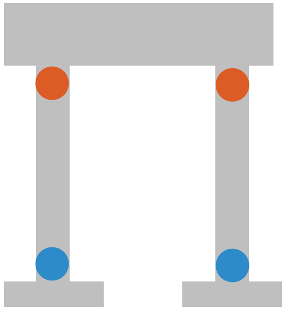
Design vs Beyond Design Level:

- Significant nonlinear behavior observed for beyond design





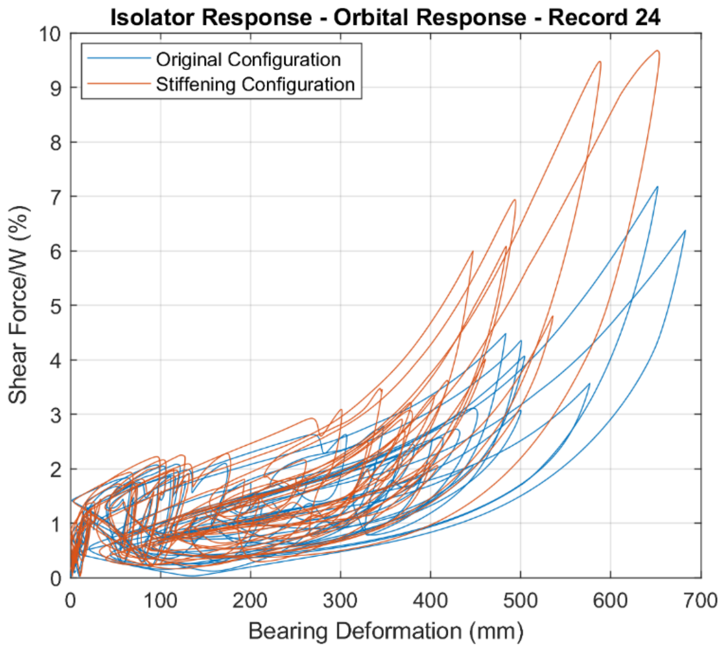




Alternative Designs

- Stiffening Configuration:

  Bearings design is modified to have stiffer bearings at the abutment that engage hardening earlier, more flexible at bents



- Damping Configuration:

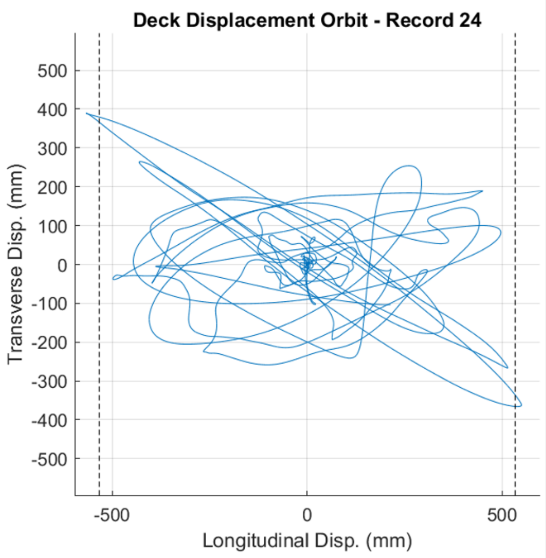
  Viscous dampers are added between abutment and deck, with 25% additional damping

Results

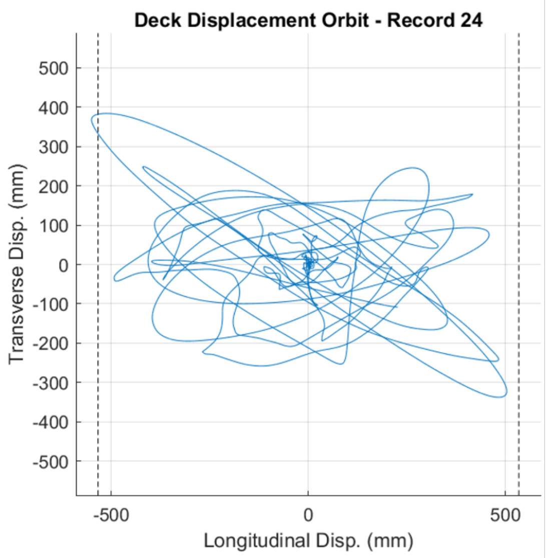
Alternative designs:

- Deck orbital displacement only slightly less for stiffening design
- Displacement reduction of about 40% with added dampers

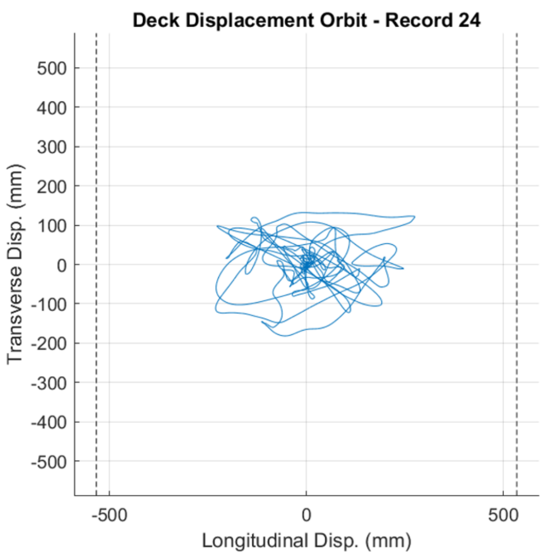
Original Design



Stiffening Design



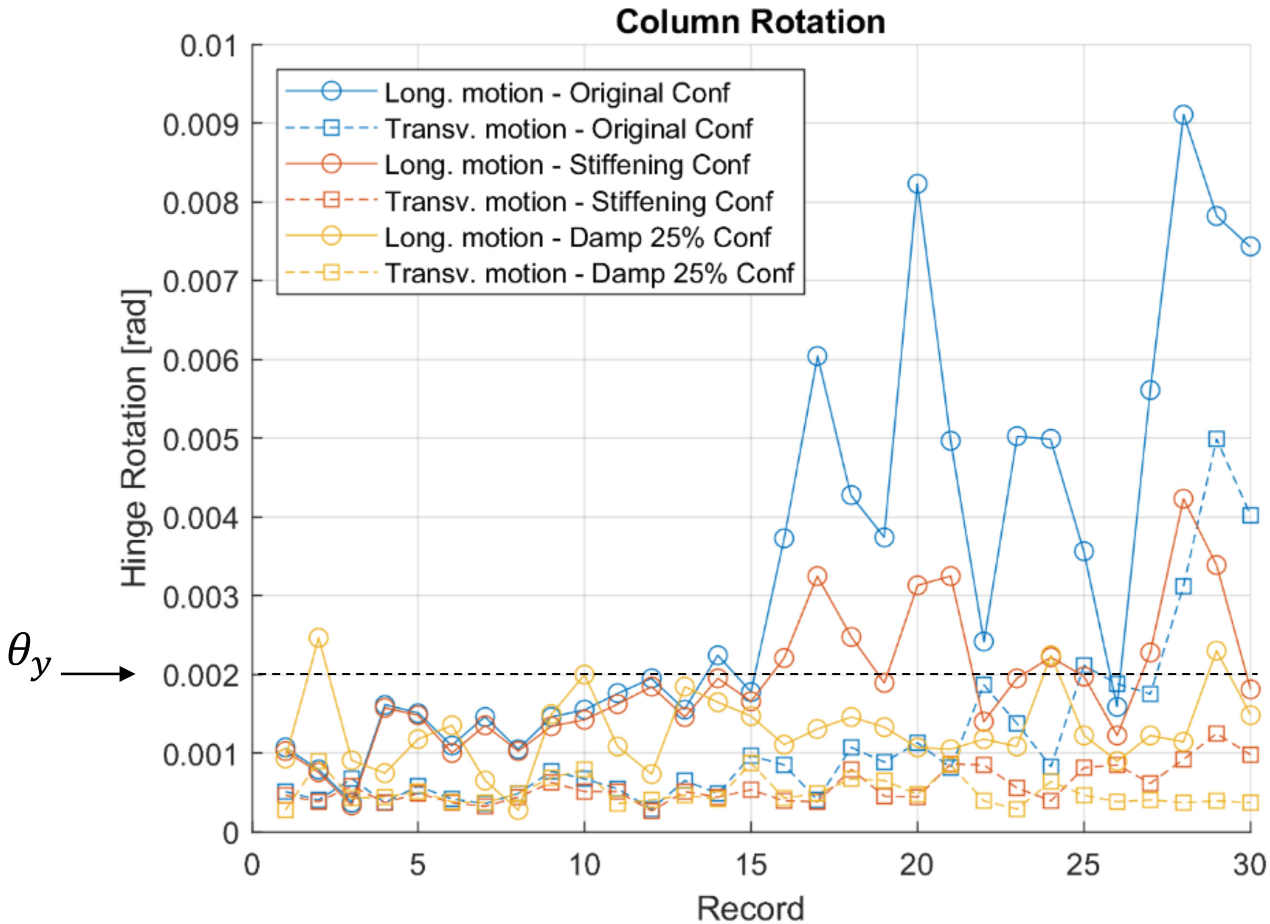
Damping Design



Results

Alternative designs:

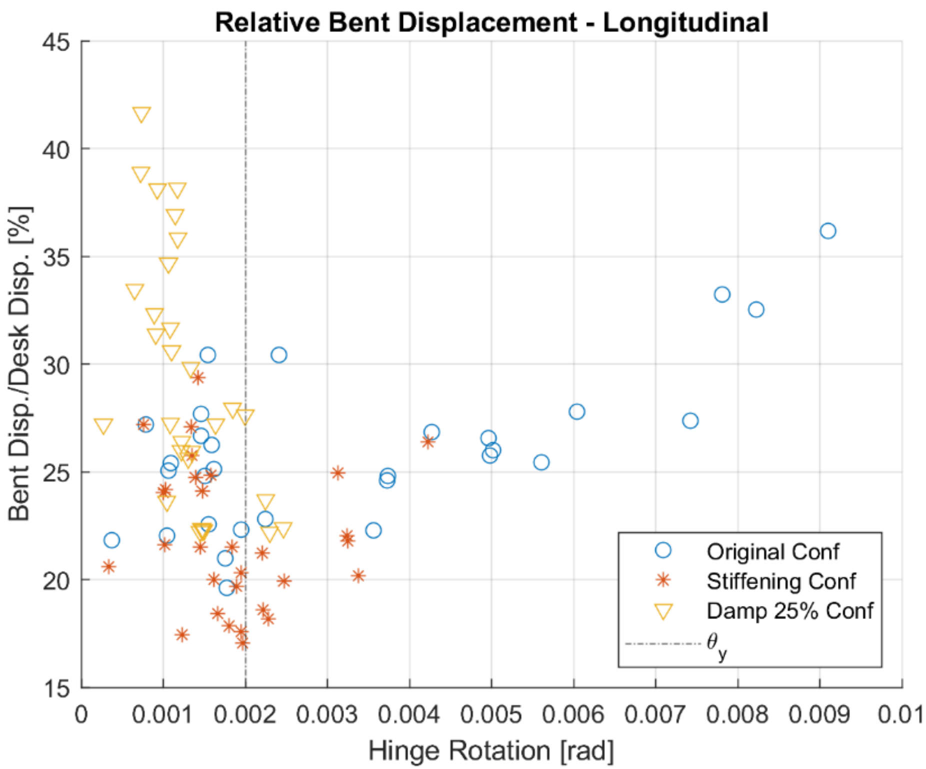
- Both alternative designs reduce the column demands compared with original design

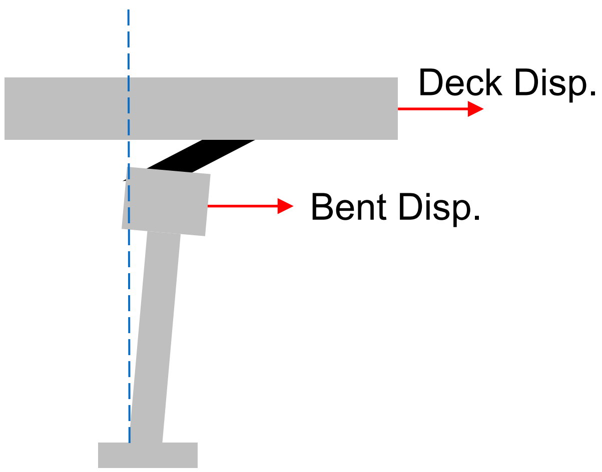


Results

Distribution of demands between isolation and bent:

- For small intensity shaking, bent contribution is high because bearing remains elastic
- For design level demands, bearing yields and bent contribution drops to 20%
- For larger demands, column yields and bent contribution increases





$\frac{\text{Bent Disp.}}{\text{Deck Disp.}}$: Bent displacement contribution ratio

Conclusions

- Design-level shaking: bridge performs as expected
  - Limited nonlinear behavior at the columns, no pounding
  - Maximum shear strain in lead rubber bearings remains within 300% shear strain
- For beyond design-level shaking:
  - Plastic hinges develop at columns, specially in the longitudinal direction
  - 11 of 30 records resulted in pounding to abutment
  - 4 out of 30 ground motions produced a deformation greater than 400% shear strain in bearings without restraints

Conclusions

- Mitigation measures - Stiffer bearings at abutments:
  - The overall deck displacement does not change significantly with similar occurrences of impact
  - Reduces forces at the bent, but increases the bearing shear strain at the abutment
- Mitigation measures – Supplemental viscous dampers:
  - Deck displacement is reduced by about 40% with beyond design motions result in displacement comparable to design-level without dampers
  - Column behaves essentially linear and no pounding observed
- Need for more comprehensive evaluation of different bridge configurations and variability in design paramters

Acknowledgements

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