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Simplified Displacement-Based Analysis of Isolated Bridges on Yielding Piers

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Outline

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1. Background

a. Piers of most isolated bridges are designed to remain elastic in the design earthquake.
b. Performance in a larger-than-design earthquake is not explicitly checked, but the isolators are required to remain stable at a displacement equal to 1.5 times the design displacement.
c. If demand is greater than 1.5 design displacement, the isolator could be structurally damaged or become unstable, leading to unseating of the superstructure.
d. Allowing the column to yield before the displacement capacity of the isolator is exhausted could protect the isolator from damage and the bridge from collapse.
e. Purpose of this project is to investigate feasibility of doing so by
    - Analysis using the direct displacement-based method, and
    - Experiment using shake table testing of quarter-scale, isolated

2. Review of displacement-based analysis of bilinear isolation systems on elastic substructures

Basic steps:

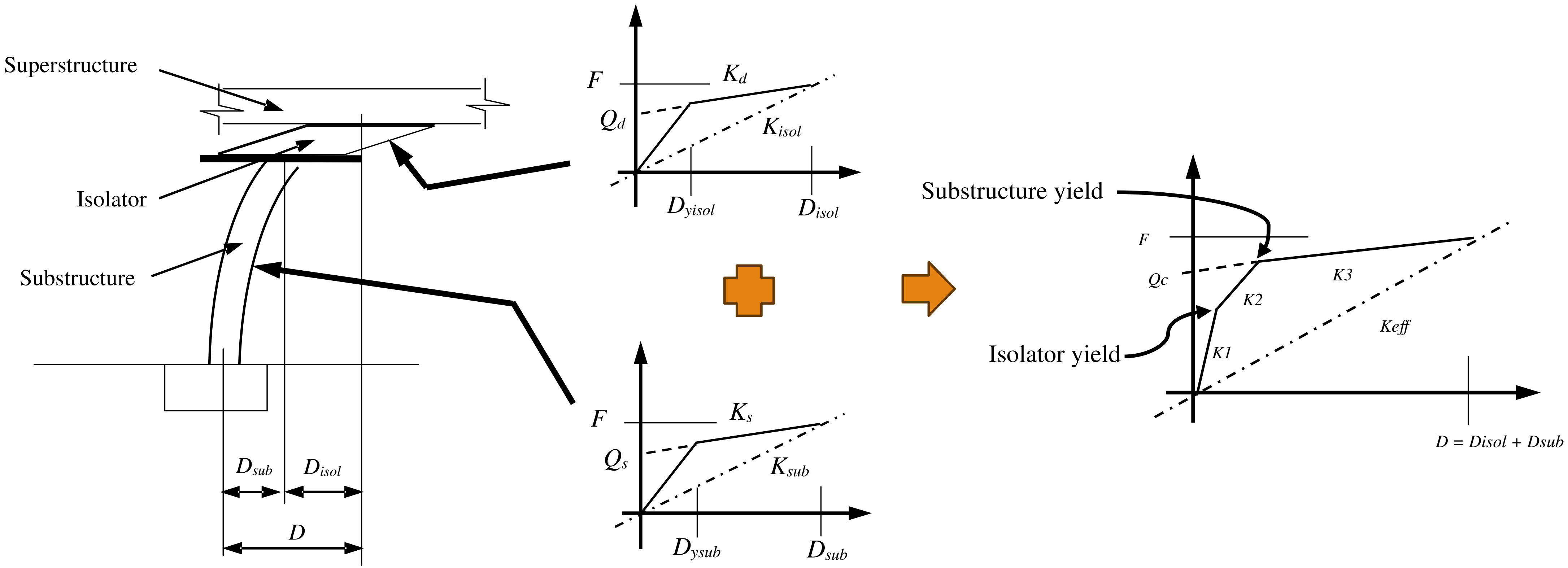
1. Assume isolated bridge is a single-degree-of-freedom system with displacement, D.
2. Calculate effective stiffness of the bilinear system, K_{eff}, at displacement D.
3. Calculate corresponding effective period, T_{eff}.
4. Calculate corresponding effective damping ratio ζ_{eff} and damping reduction factor, B_L.
5. Using a **displacement response spectrum** for the given ground motion, obtain displacement, D, at period T_{eff} and damping ζ_{eff}.
6. Compare displacement with that assumed in step 1. If in agreement go to step 7, otherwise go back to step 2 with an updated D.
7. Calculate component displacements and bridge base shear at system displacement D.

3. Extension to bilinear isolation systems on yielding substructures

Methodology is essentially the same as for an elastic substructure, provided the effective stiffness, K_{eff}, of the combined isolator-substructure system is updated to include the properties of the yielding column.

Implementation using a spreadsheet is still feasible.

3. Effective stiffness, K_{eff}, of a yielding isolator on yielding column



4. Basic equations

Using equilibrium and geometry it can be shown that:

$$K_{eff} = \frac{\gamma K_{sub}}{(1+\gamma)}$$

where:

$$\gamma = \frac{K_{isol}}{K_{sub}} = \frac{(K_d D + Q_d - Q_s)}{(K_{sub} D - Q_d + Q_s)}$$

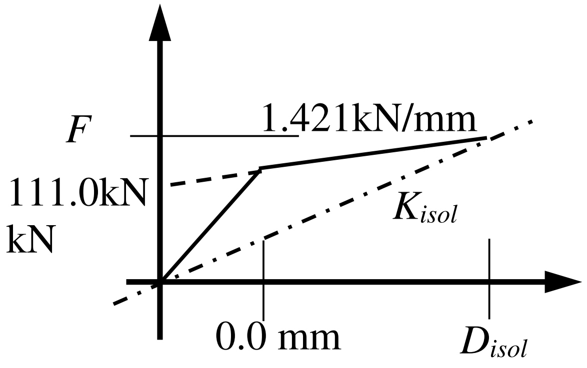
and

$$D = displacement\ of\ superstructure = D_{sub} + D_{isol}$$

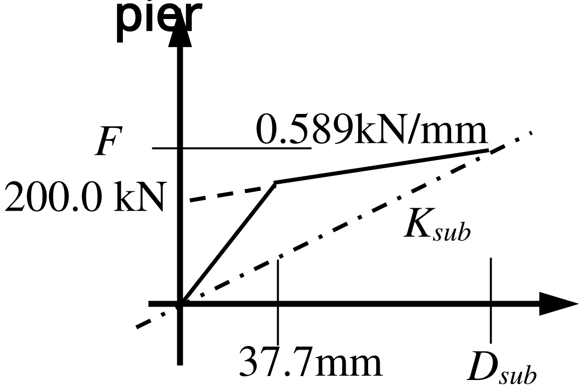
where:

$$D_{isol} = \frac{D}{(1+\gamma)}\ and\ D_{sub} = \frac{\gamma D}{(1+\gamma)}$$

5. Example



Isolator properties at pier

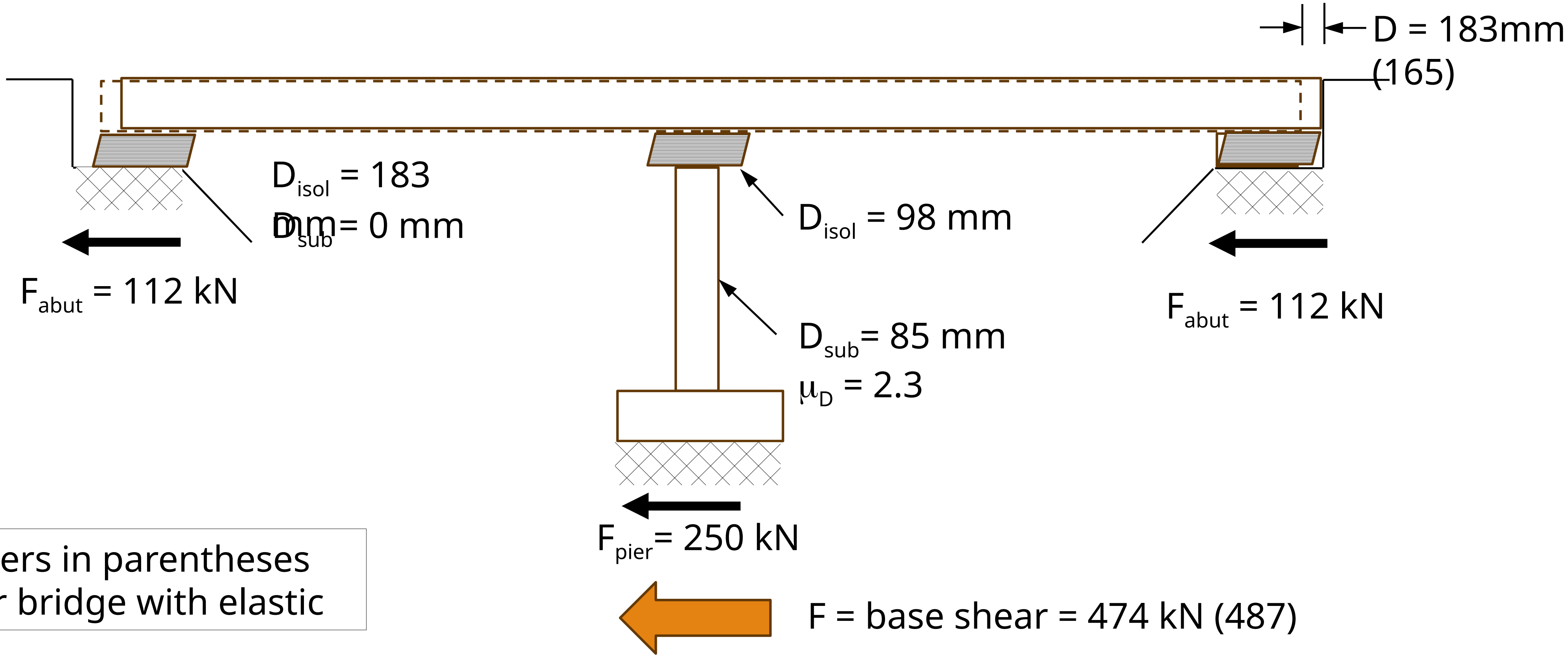


Pier properties

Two-span bridge

Superstructure weight, W = 2,370 kN

5. Example continued



Numbers in parentheses are for bridge with elastic pier

F = base shear = 474 kN (487)

6. Shake table experiments at University of Nevada Reno

- Funded by Caltrans with Principal Investigators:
  - Gilberto Mosqueda, UC San Diego
  - Keri Ryan, UN Reno
- Objective is to evaluate:
  - cost effective design methods by quantifying capacity beyond current code requirements
  - feasibility of protecting seismic isolators from failure by engaging hinging in substructure columns
- Two specimens tested: ¼-scale, two-column pier with four lead-rubber bearings.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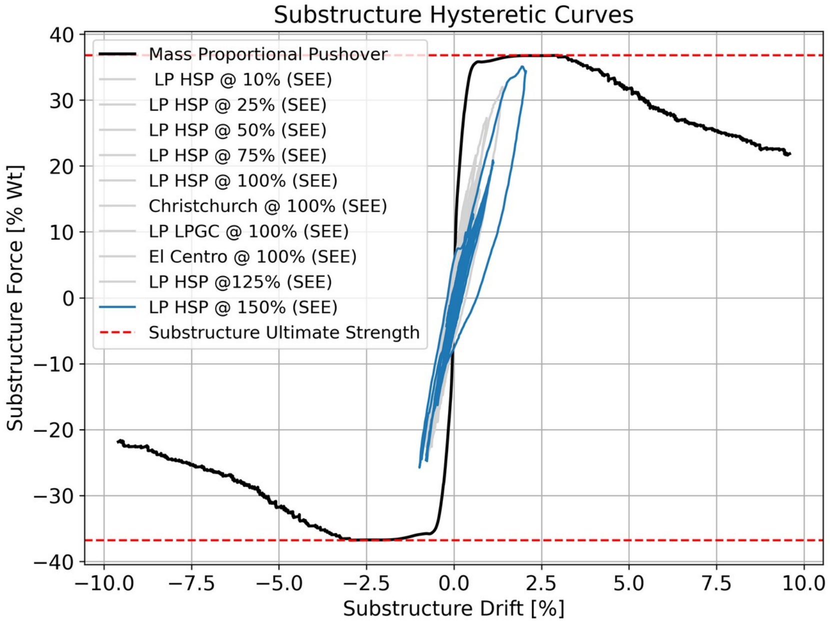
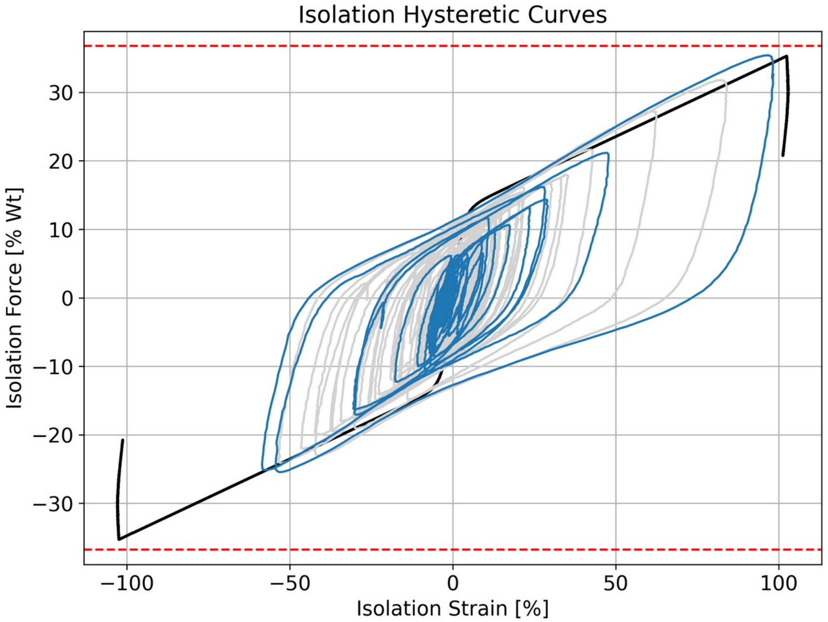
Preliminary results (1/2)

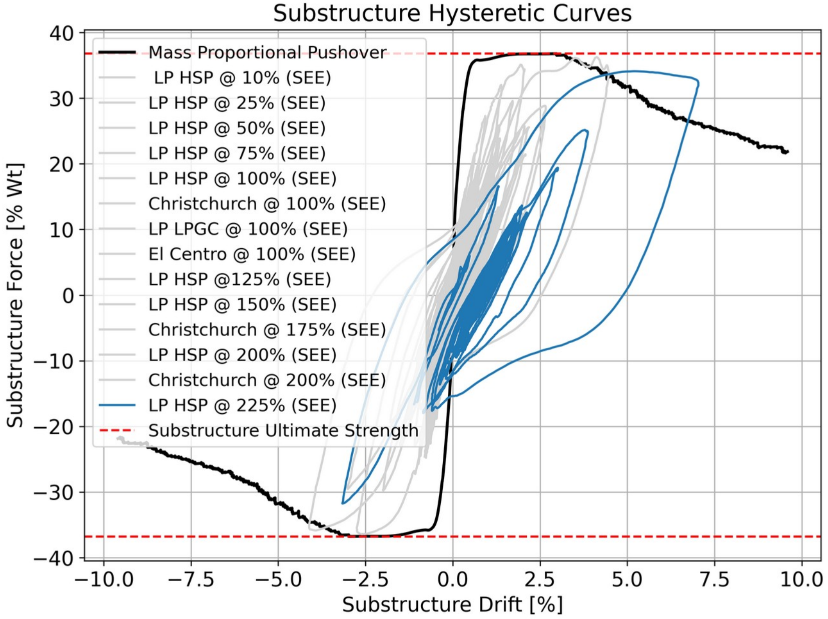
- 1.5 x Design Earthquake– Initiation of damage - limited yielding

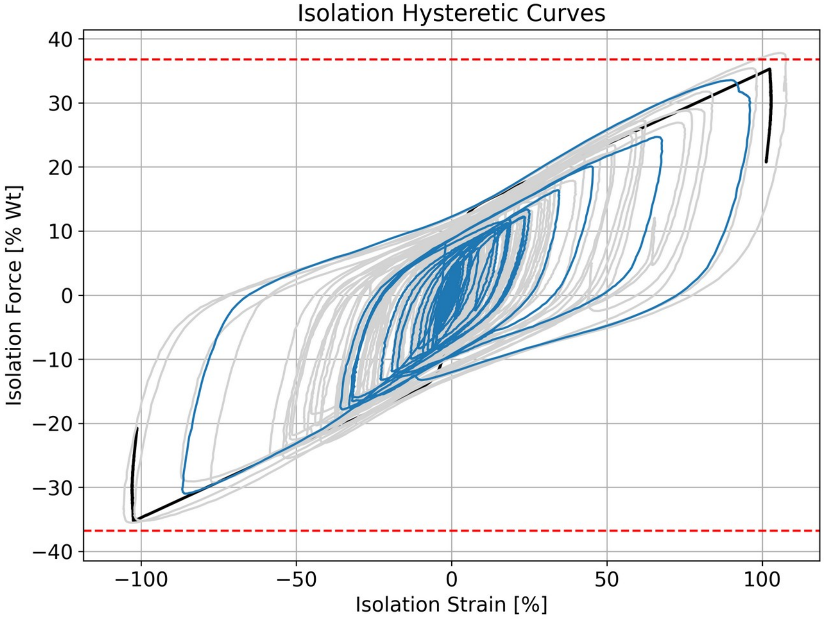




Preliminary results (2/2)

- 2.25 x Design Earthquake – Ductile column response with major damage





7. Conclusions

a. Simplified displacement-based method of analysis is a convenient and efficient tool for exploring consequences of allowing yield in the substructures of isolated bridges.

b. Shake table experiments demonstrated the isolated bridge designed per Caltrans Bridge Design Manual performed as expected, with reserve capacity well beyond design earthquake:

- Essentially elastic behavior up to 1.5 times design earthquake. Yield in columns showed stable progression of damage as shaking increased to over 2 times design level motion Substructure strength can be selected to desired earthquake level and isolation displacement limit.
- Plastic hinging in substructure effectively limits isolator displacements protecting them against structural damage or instability.

Acknowledgements - shake table experiments

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Thank you!