# Seismic Response of Typical Highway Bridges in California to Component Modeling and Characteristics

Bahareh Mobasher[1], Roshanak Omrani[2], Ertugrul Taciroglu[2], Farzin Zareian[1]

1 University of California, Irvine

2 University of California, Los Angeles

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# Outline

- ✓ Introduction
- ✓ Problem statement & Objectives
- ✓ Bridge Modeling
  - Shear keys
  - Backfill passive resistance
- ✓ Analysis/Discussion
  - EDP: Column Drift Ratio, Deck rotation, longitudinal and transverse deck movement
- ✓ Concluding Remarks

# History of bridge seismic design

- ✓ Caltrans (California Department of Transportation) formulated the first code requirements in the United States for seismic design of bridges in **1940.**

The Newhall Pass interchange

Foothill Freeway Interchange

- ➢ Insufficient seat width

  - ✓ Hinge restrainers
  - ✓ Increase the amount of steel spirals and ties in columns
  - ✓ Increase earthquake design force

# History of bridge seismic design

✓ Loma Prieta earthquake, 1989

➢ Collapse of upper deck and support columns.
➢ Local soil effect (Amplified ground motion)
➢ Insufficient hoop reinforcement

✓ Northridge earthquake, 1994.


**Lessons from previous earthquakes:**

✓ Understand seismic behavior of bridges.

✓ Specify important components in bridges.

✓ Update codes and guideline based on the current state-of-the-art.

# Previous Work

PEER 2008/03 - Guidelines for Nonlinear Analysis of Bridge Structures in California
Ady Aviram, Kevin R. Mackie, Bozidar Stojadinovic

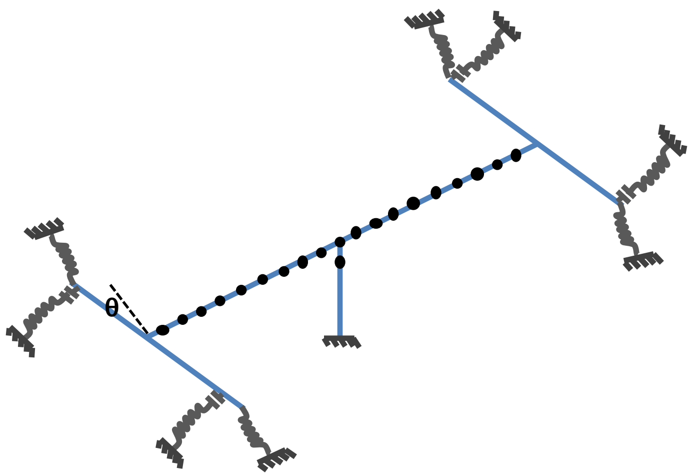
- **Outcomes:**
  - Recommendations for adoption of appropriate model dimension (2D or 3D)
  - Assessment of various plastic hinge modeling options for capturing nonlinear response of bent columns
  - Criteria for selection of analysis methods

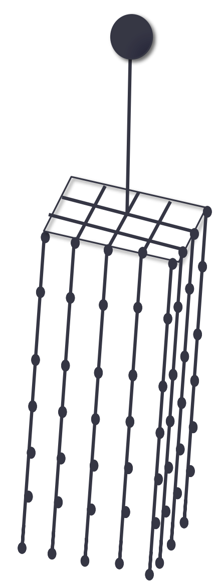
- **Shortcomings:**
  - Linear analysis of soil-structure interaction
  - Simplified (or lack of) models for abutments, foundation, columns, expansion joints, and shear keys
  - Ground motion selection and scaling

# Problem Statement

✓ Current-state-of-research in performance assessment of bridge structures is mostly confined into the two **Structural** and **Geotechnical** domains.

**Structural** ⇄ **Geotechnical**



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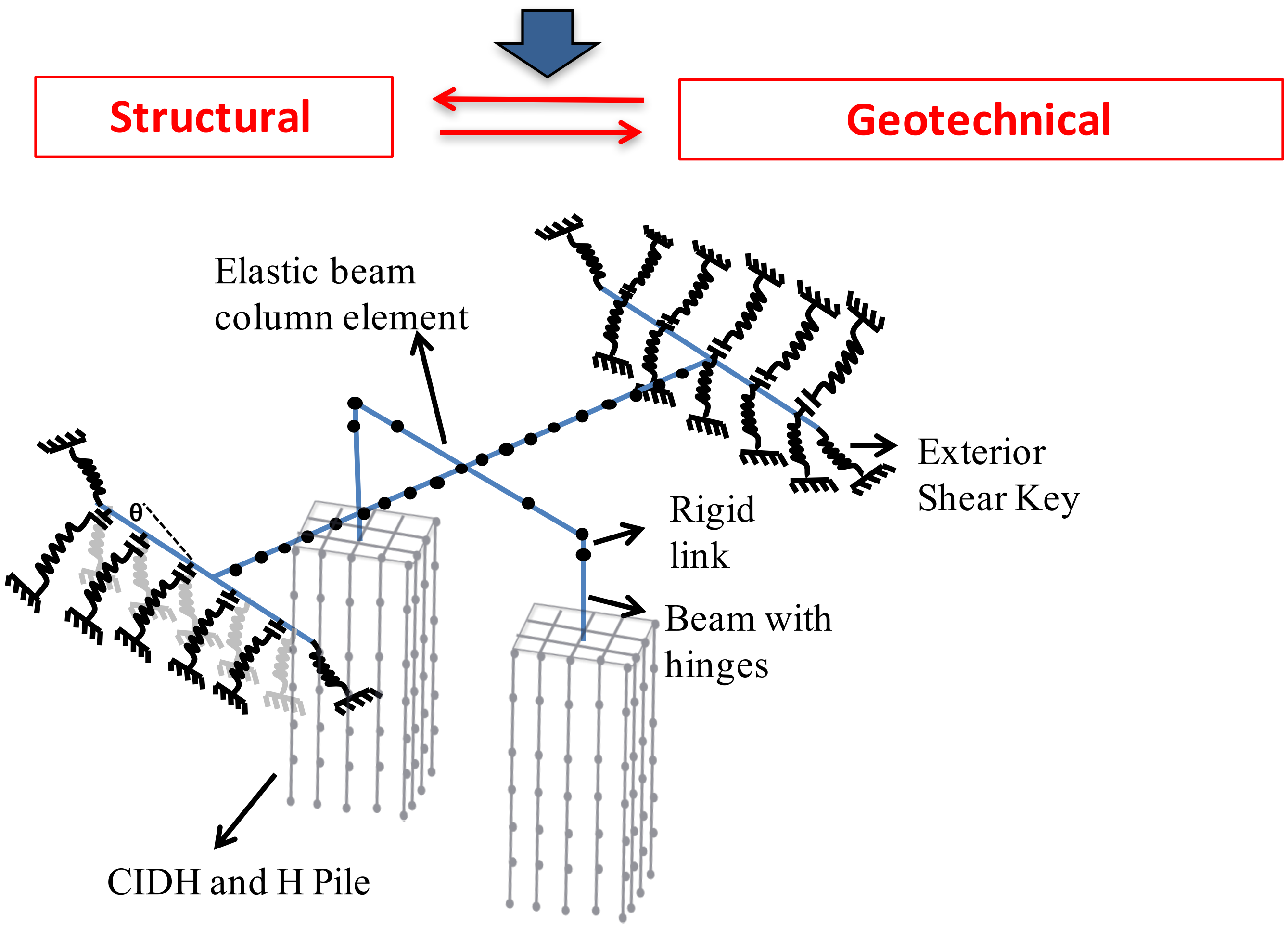
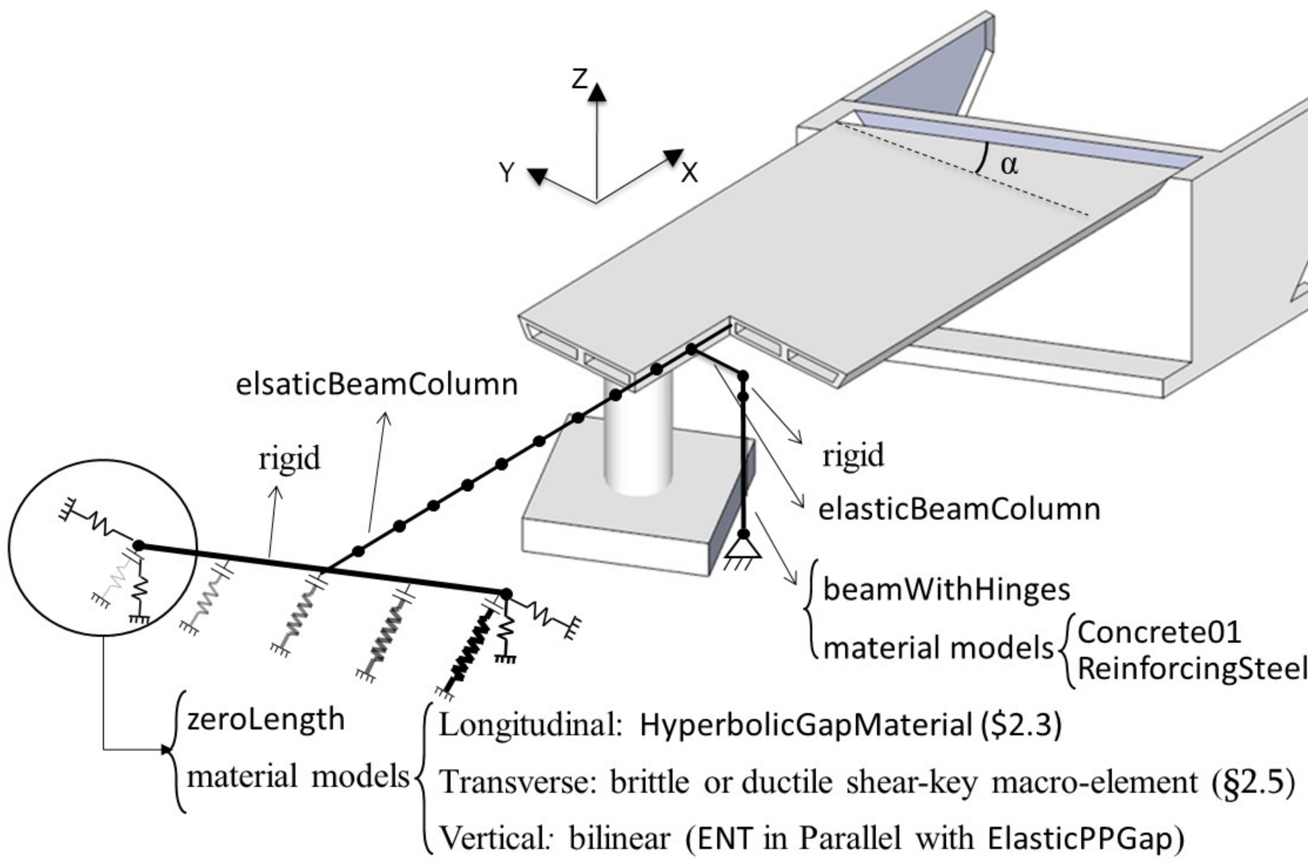


# Problem Statement

✓ There is a gap between the recommended modeling approaches by seismic design guidelines and the current state-of-the-art in bridge component modeling

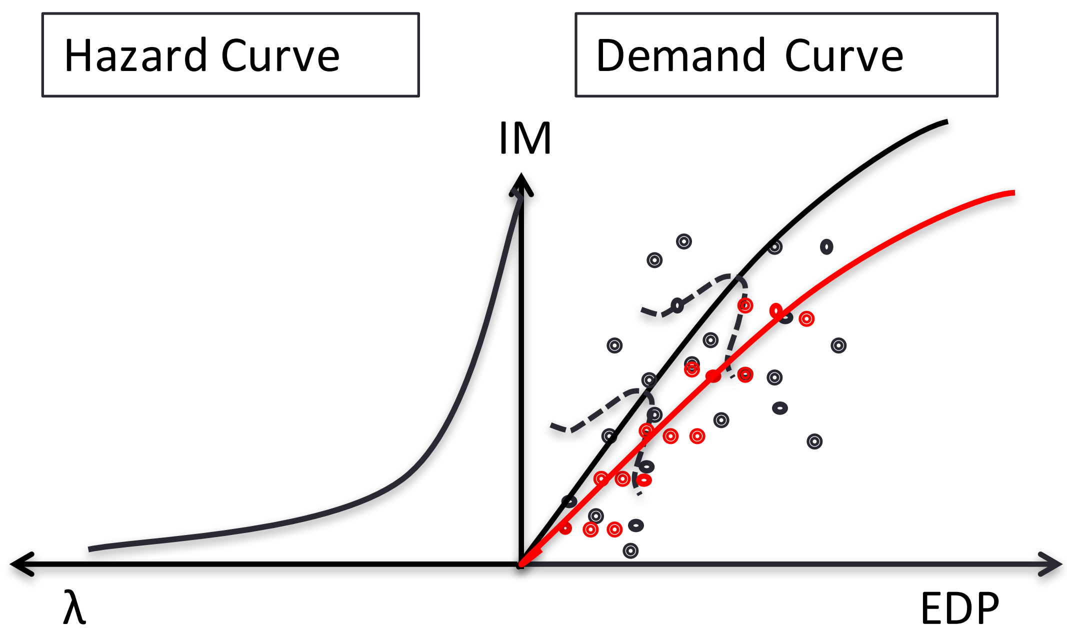
Quantify the advantages (and disadvantages) of utilizing advanced component models, compared with simple ones



# Problem Statement

✓ Current performance base assessment
- Neglects time-dependent effects (i.e., combination of corrosion, and previous seismic damages) conditioned on hazard levels.

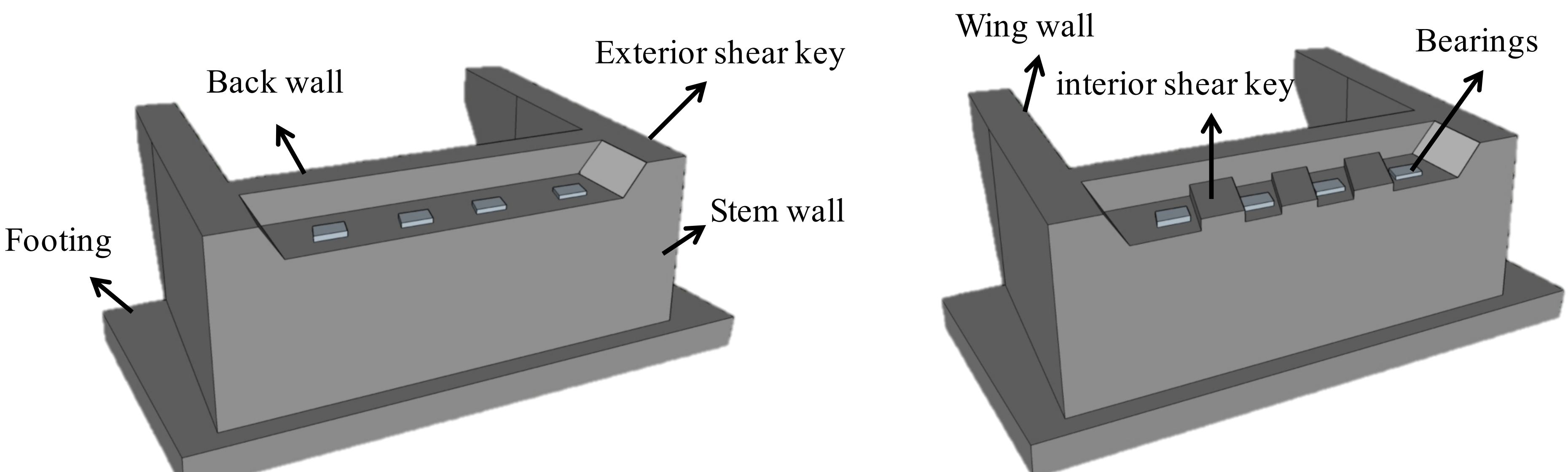
Develop enhanced demand model (EDP|IM)



# Exterior Shear key

- **What is a shear key?**
  - Shear keys are used at bridge abutments to provide transverse support to bridge superstructure.

- **There are two types of shear keys**
  - Exterior shear key.
  - Interior shear key (Interior shear keys are not recommended by Caltrans because of maintenance problems).



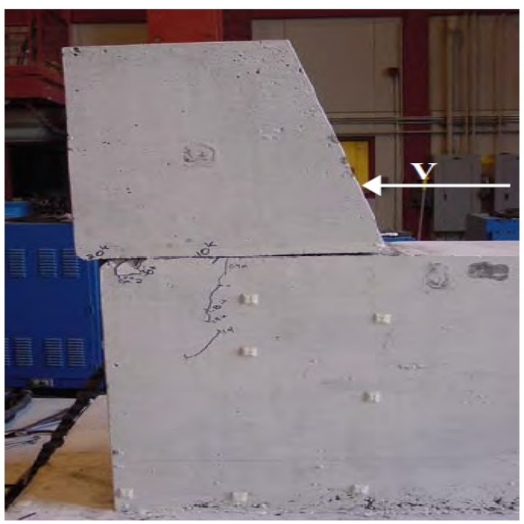

Schematic of typical seat-type abutment

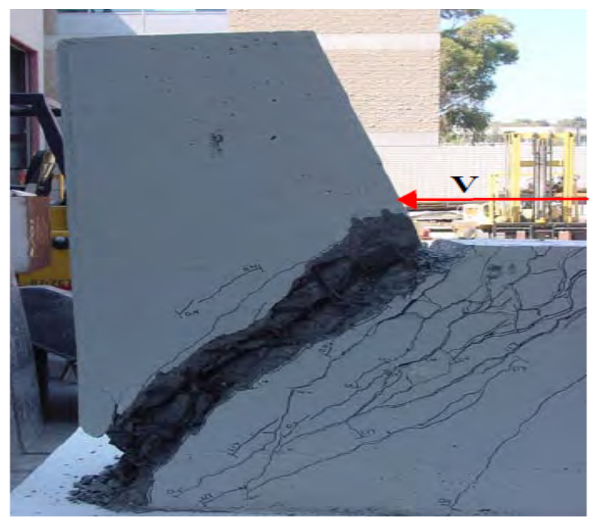
# Exterior Shear key

✓ **The are two kinds of failure mechanism for exterior shear key joints (Bozorgzadeh et al. 2004, Megally et al. 2001).**

- A single horizontal crack that develops at the Interface (sliding shear failure).

- Multiple diagonal cracks along the direction of predominant principal compressive stresses (Strut-and-Tie failure)

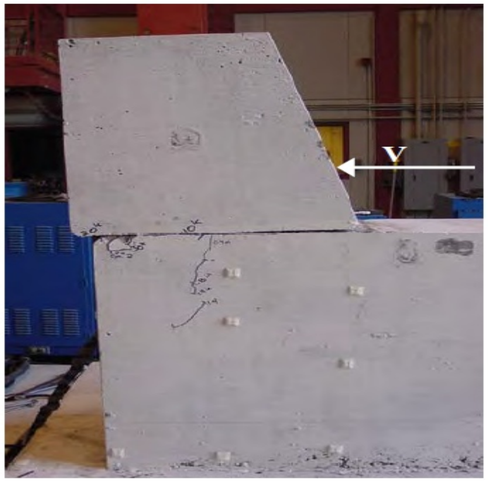


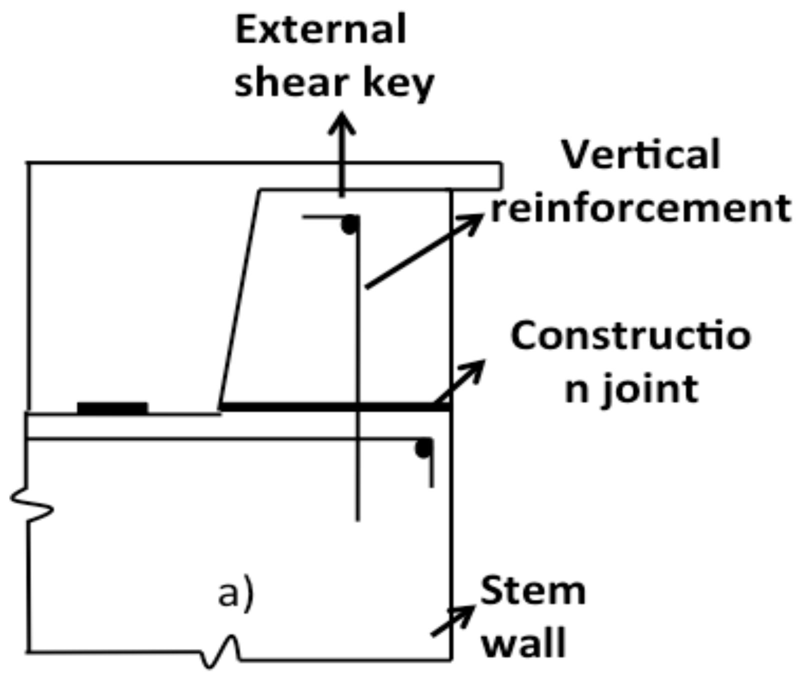




(Bozorgzadeh et al. 2004)

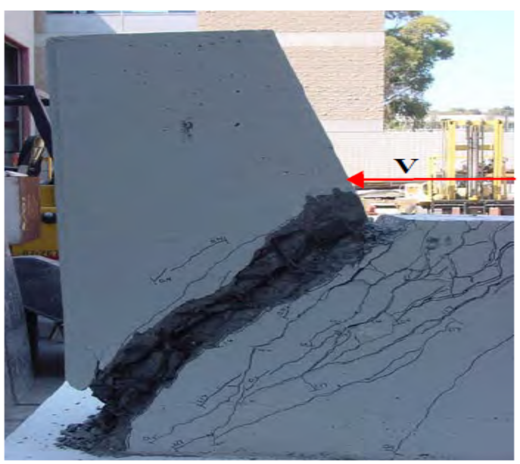
# Design criteria

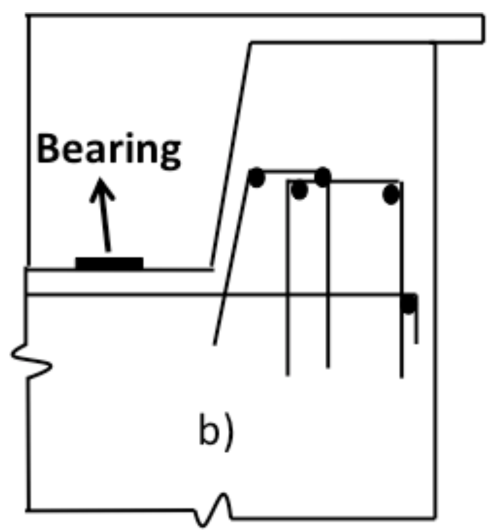
✓Isolated Shear Key (Brittle)




✓Non-isolated Shear Key (Ductile)



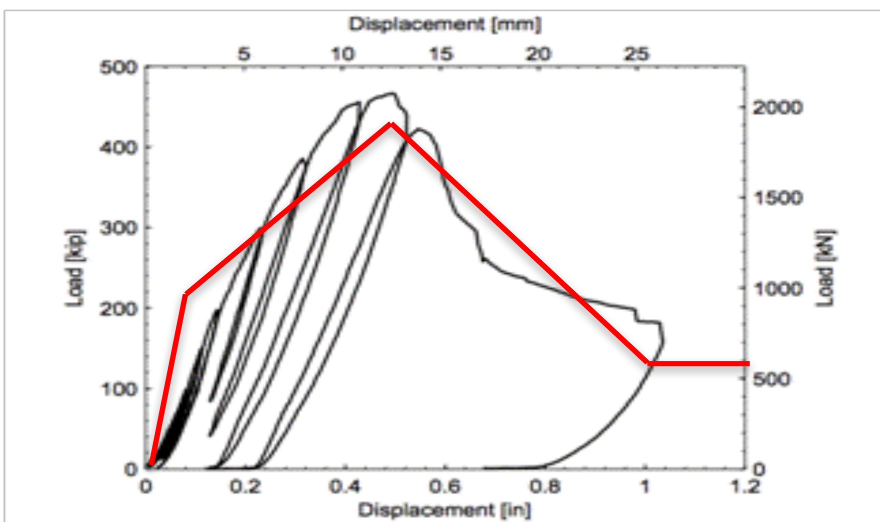



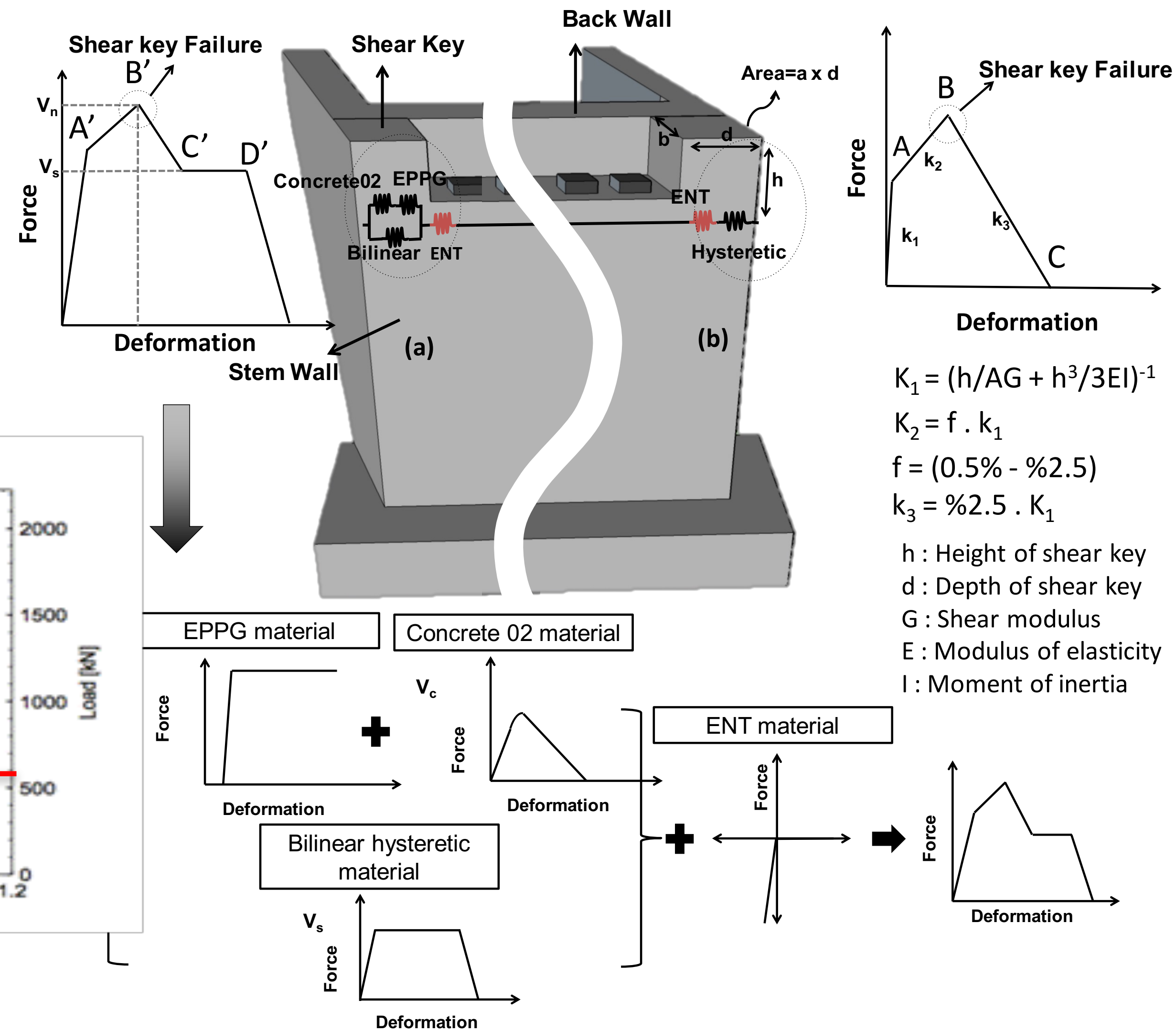
# Shearkey Model

Validated macroelement models for abutment shear keys and seismic response sensitivity of ordinary bridges to shear key behavior. (Engineering Structures)
Bahareh Mobasher , Roshanak Omrani , Ertugrul Taciroglu , Farzin Zareian

**Based on Test Results:**

- ✓ **Bozorgzadeh et al. 2004**
- ✓ **Megally et al. 2001.**




$K_1 = (h/AG + h^3/3EI)^{-1}$

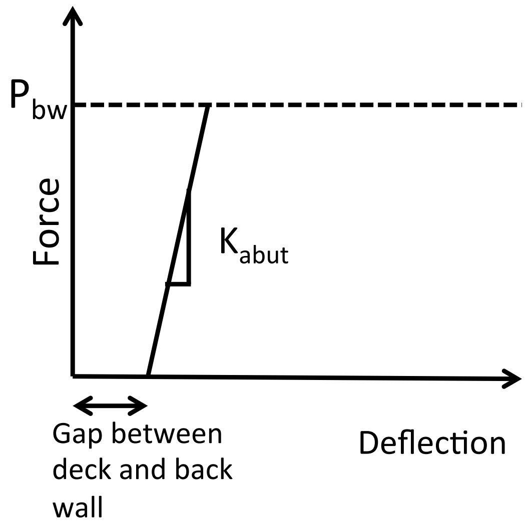
$K_2 = f \cdot k_1$

$f = (0.5\% - \%2.5)$

$k_3 = \%2.5 \cdot K_1$

h : Height of shear key
d : Depth of shear key
G : Shear modulus
E : Modulus of elasticity
I : Moment of inertia

# Backfill Passive Pressure



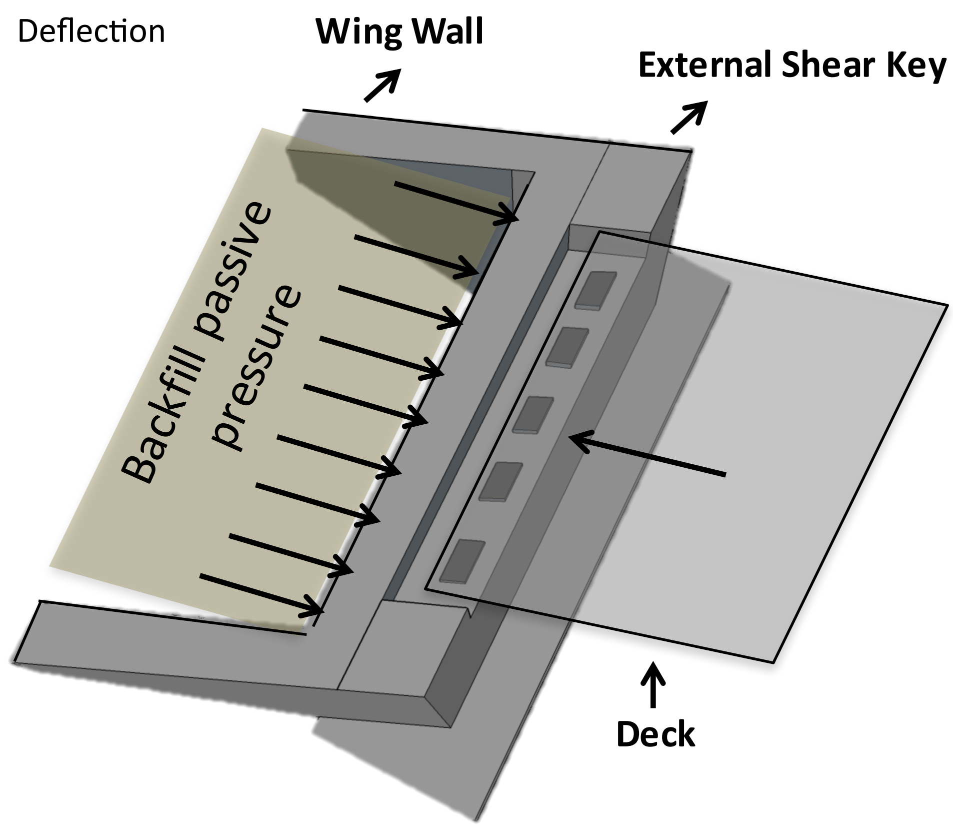

UC Davis (1995); UCLA (2007)

$$k_i \approx \frac{50\ kip/in}{ft}$$

$$k_{abut} = k_i . w . \frac{h_{bw}}{5.5ft} \qquad U.S. unit$$

$$p_{bw} = A_e . 5.0\ ksf . \frac{h_{bw}}{5.5}$$

$$A_e = h_{bw} . w_{bw}$$



# Backfill Passive Pressure

✓ **Abutment backfill soil type classification in California Highway Bridges (Earth Mechanics, Inc. , 2005):**

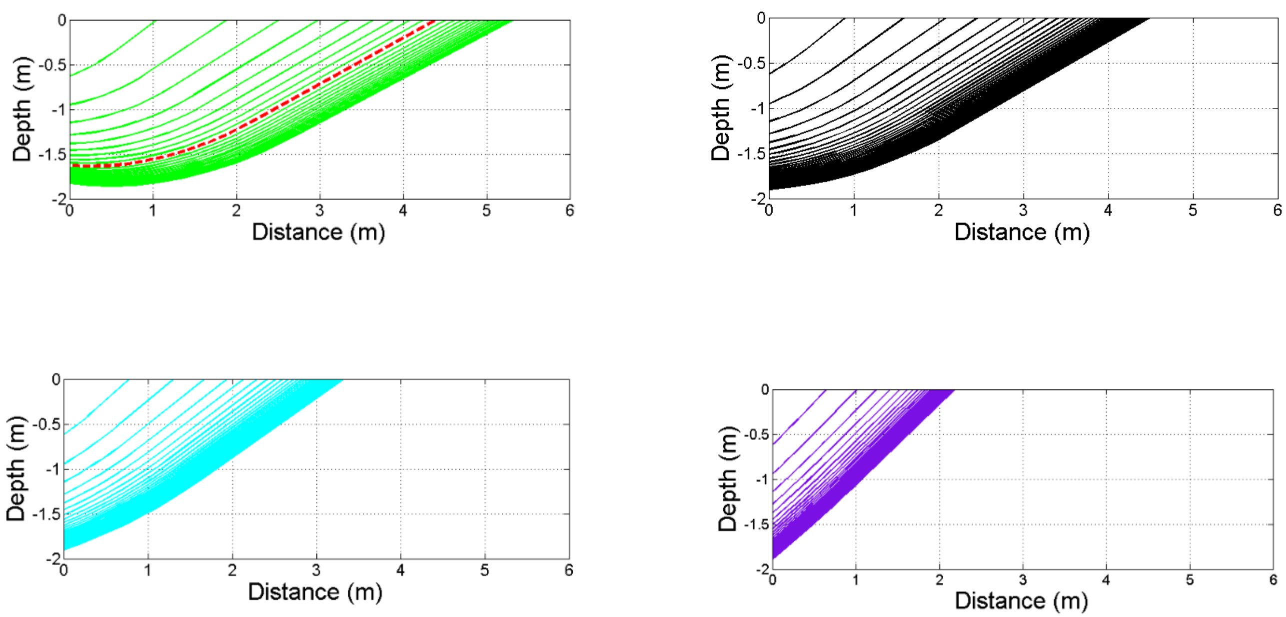
I. Dense to very dense sand with gravel

II. Medium dense silty sands, some with gravel

III. Medium Clayey sands, some with gravel

IV. Stiff-hard clays with fine to coarse-grained sands, some with silts

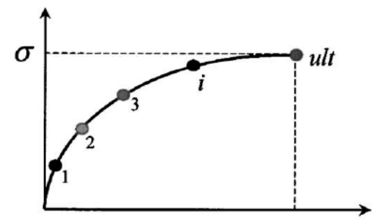
❖ Single force-deformation can not capture different types of soil

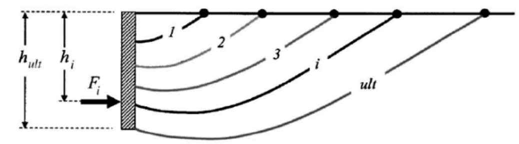



Variability in the Predicted Seismic Performance of a Typical Seat-type Bridge Due to Epistemic Uncertainties in its Abutment Backfill and Shear-key Models. (Engineering Structures)
Roshanak Omrani , Bahareh Mobasher , Farzin Zareian, Ertugrul Taciroglu

# Backfill Passive Pressure

**LSH model** (Shamsabadi et al., **2007**)
Log-Spiral failure surface +
Hyperbolic stress-strain model



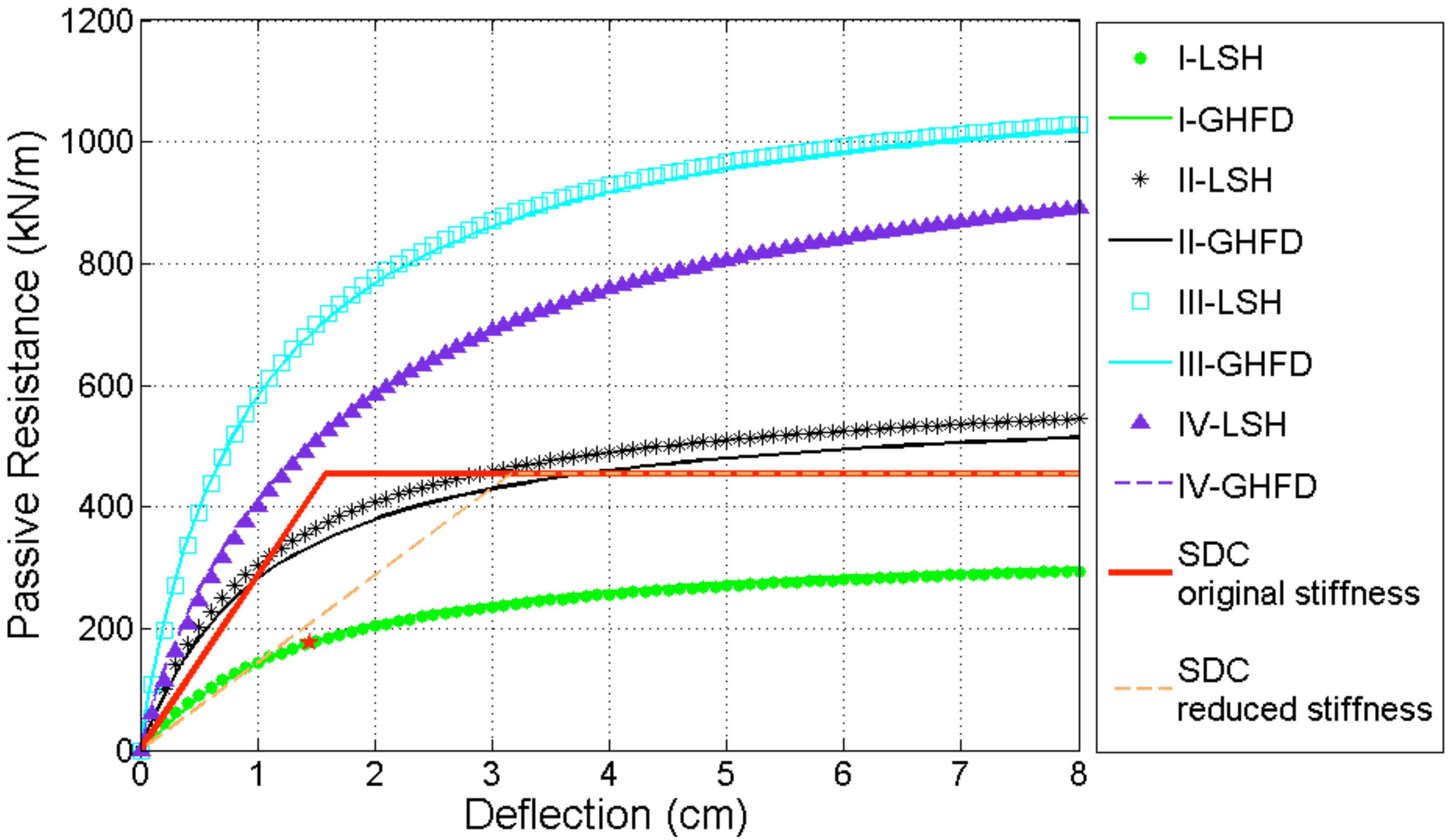

**GHFD model** (Khalili-Tehrani et al., **2011**)
Generalized Hyperbolic Force-Displacement model

$$F(y) = f_\delta \frac{a_r y}{\hat{H} + b_r y} \hat{H}^n, \qquad \hat{H} \equiv \frac{H}{H_r}$$

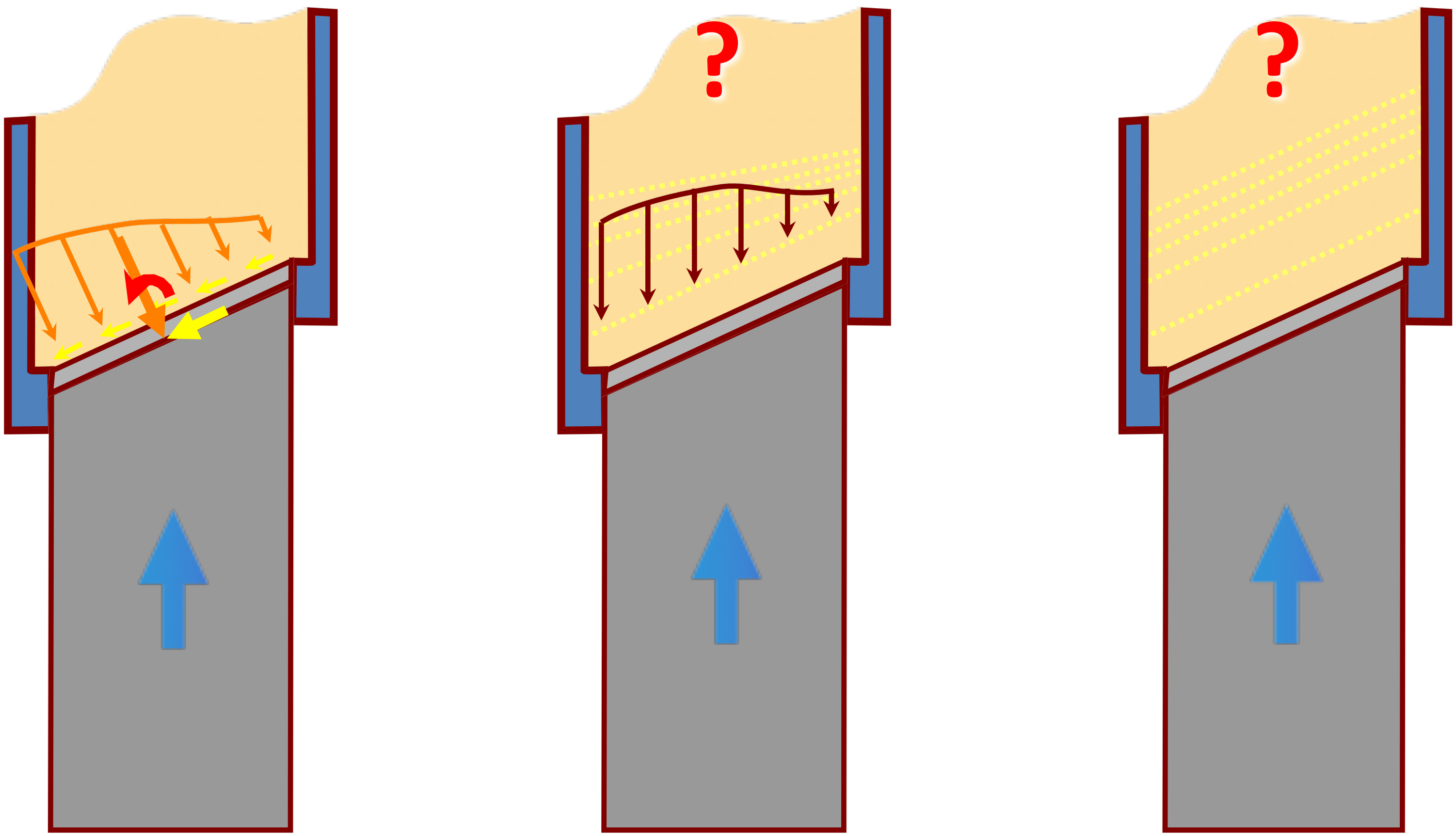
Calibrated for granular and cohesive backfills
utilizing extensive simulations generated by the LSH model.

$a_r, b_r, f_\delta$ ⇐ $c, \phi, \gamma$

# Backfill Passive Pressure



# Skewed Abutment




- ✓ Unseating
- ✓ Shearkey failure
- ✓ Deck Rotation
- ✓ High seismic demands on columns

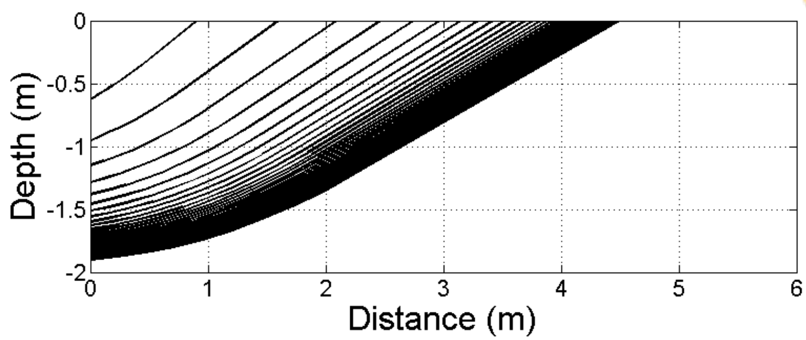
# Skewed Abutment

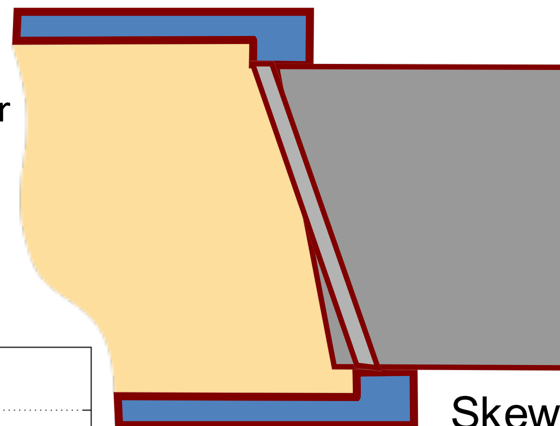
1. Linear passive reduction,

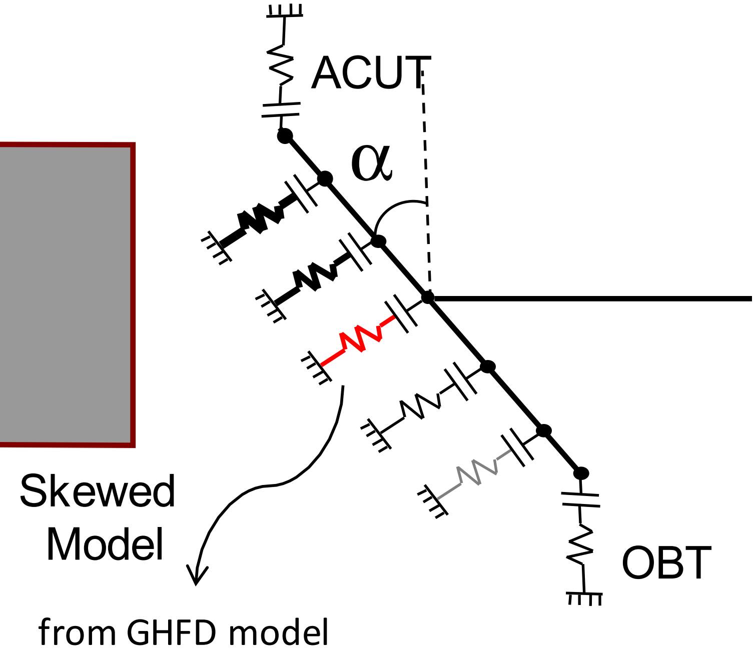
Stiffness/Strength Variation Factor

(Kaviani et al., 2012)

$$\beta = 0.3 \times \frac{\tan\alpha}{\tan 60^\circ}$$

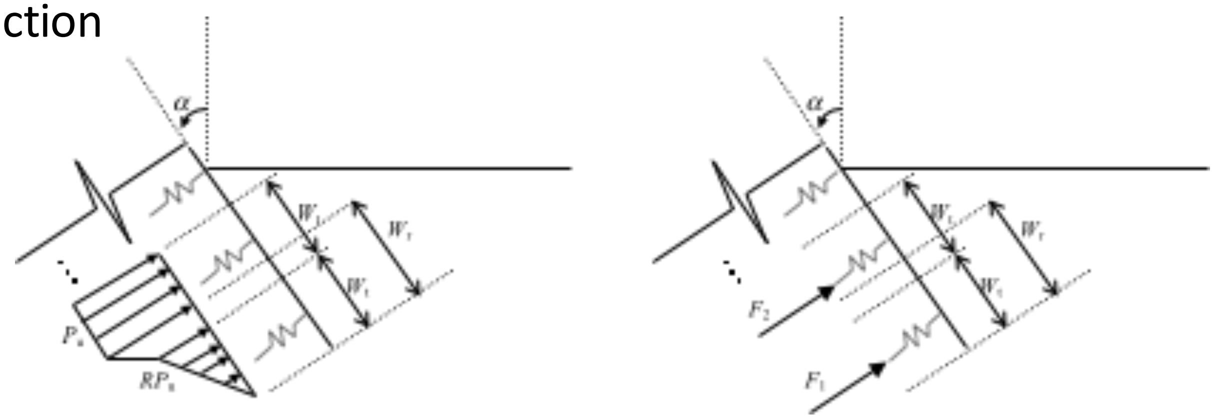





Skewed abutment model (Kaviani et al., 2012).

3. Non-uniform passive reduction



# Skewed Abutment

1. Linear passive reduction, (Kaviani et al., 2012)

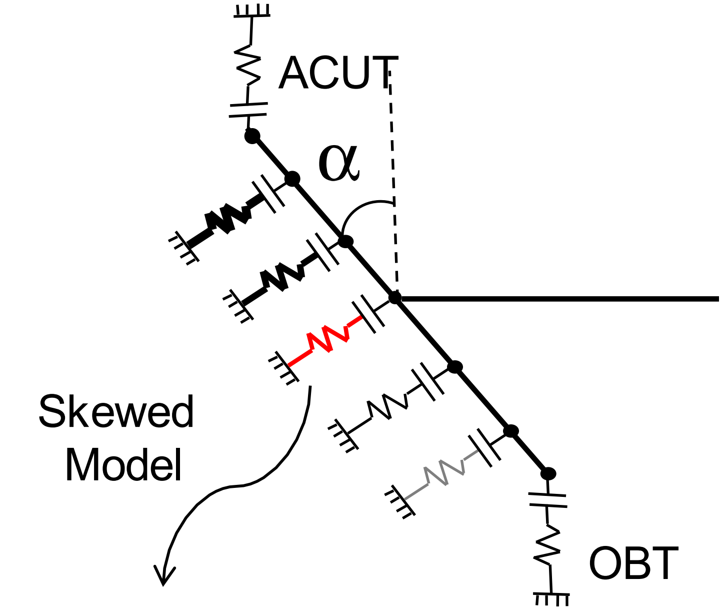
   Stiffness/Strength Variation Factor

$$\beta = 0.3 \times \frac{\tan\alpha}{\tan 60^\circ}$$

2. Uniform passive reduction (Rollins and Jesse (2012), and Marsh et al. (2013) )

   Stiffness/Strength Variation Factor

$$R = 8\times10^{-5}\alpha^2 - 0.0181\alpha + 1$$

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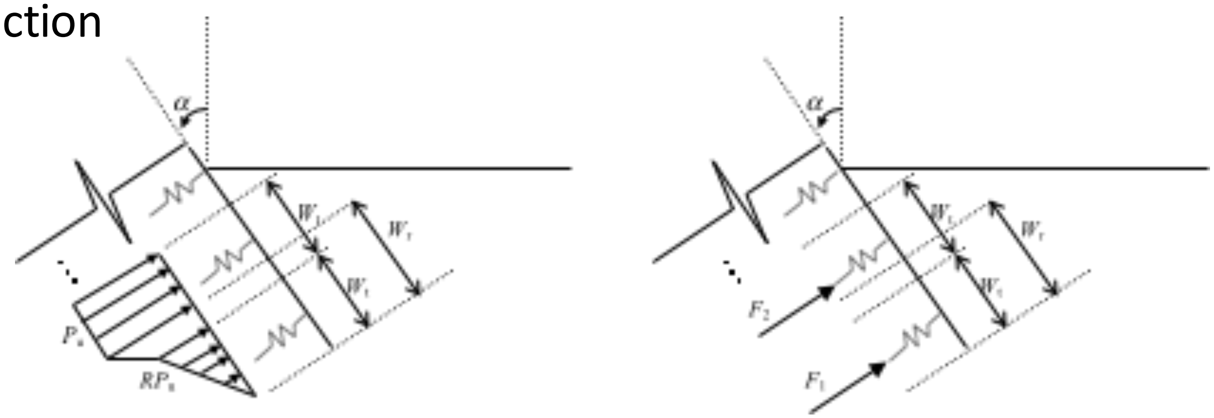
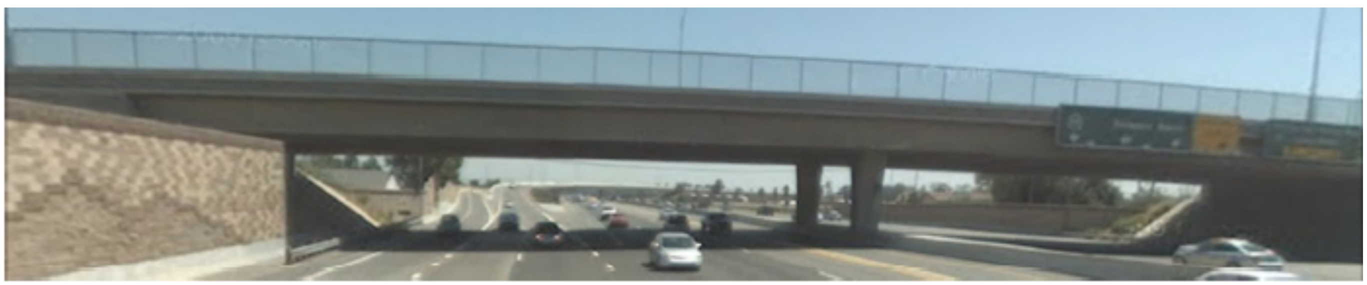


# Selected Bridge

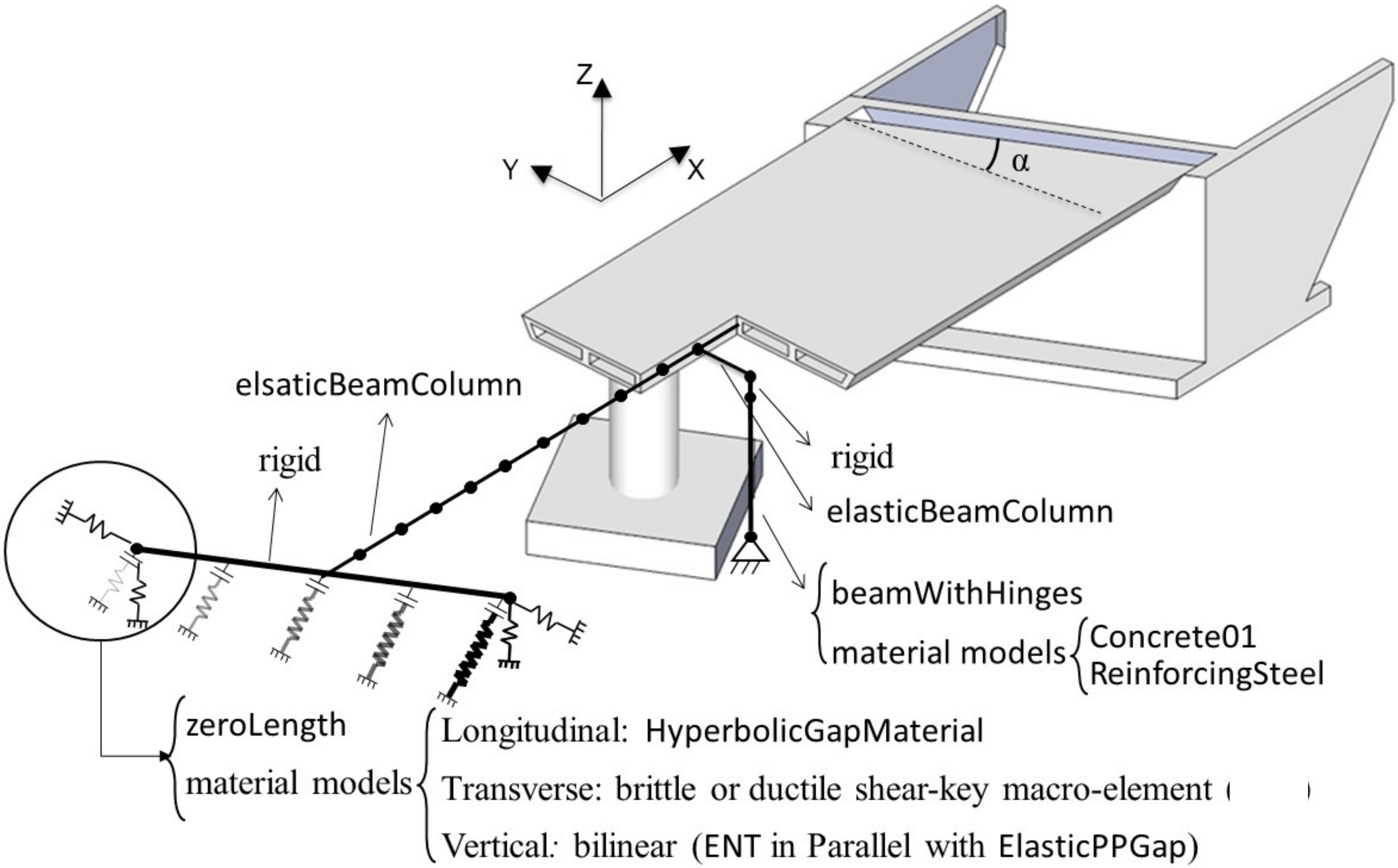
✓ Jack Tone Road Overcrossing (Type A), a bridge with two spans supported on a single-column bent

✓ La Veta Avenue Overcrossing (Type B), a bridge with two spans and a two-column bent

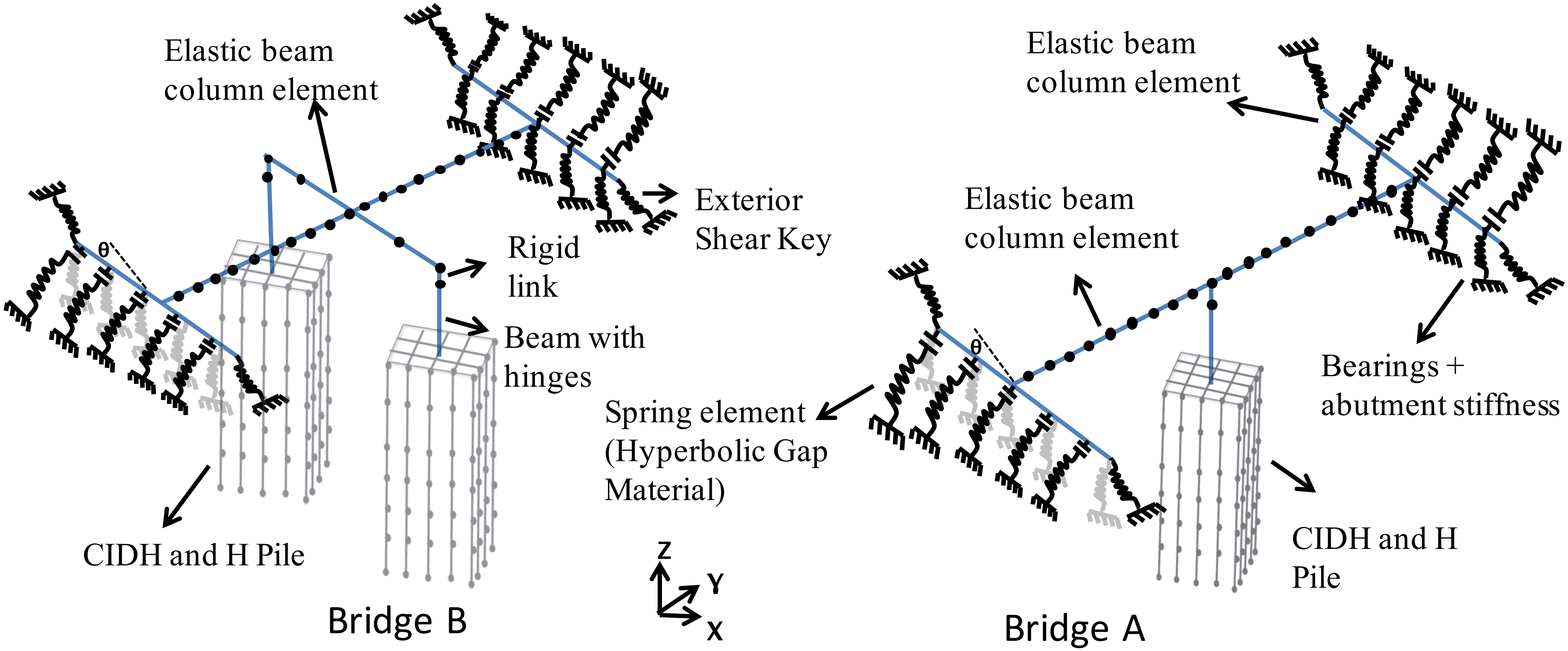


| Bridge Type | Bridge No. | Structure Name | Bridge Length (m) | Width (m) | Year Built |
|---|---|---|---|---|---|
| 2 Span Single Column | 29 0315K | JACKTONE-SB 99 ON-RAMP SEPARAT | 67.2 | 8.3 | 2001 |
| 2 Span Multiple Column | 55 0938 | LA VETA AVENUE OC | 91.4 | 23 | 2001 |

# Selected Bridge

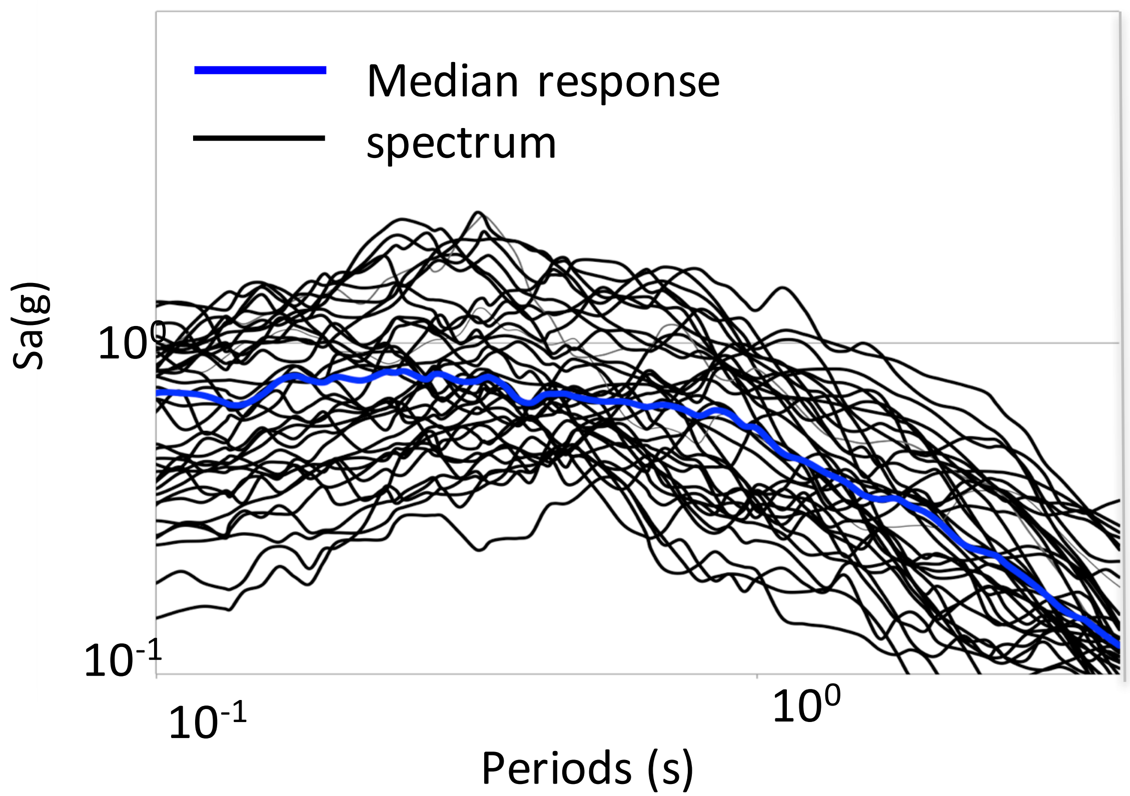


# Selected Bridge



# Ground Motion

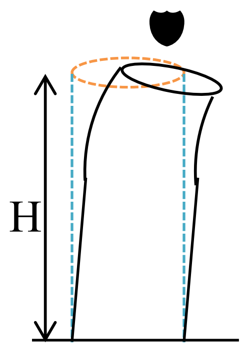
- ✓ Selected bridge is subjected to a set of 40 pulse-like ground motions with two horizontal components, and 21 different incident angles (Baker 2007)




Geometric mean response spectra (FN/FP components) for selected pulse-like records (Shahi and Baker, 2011)

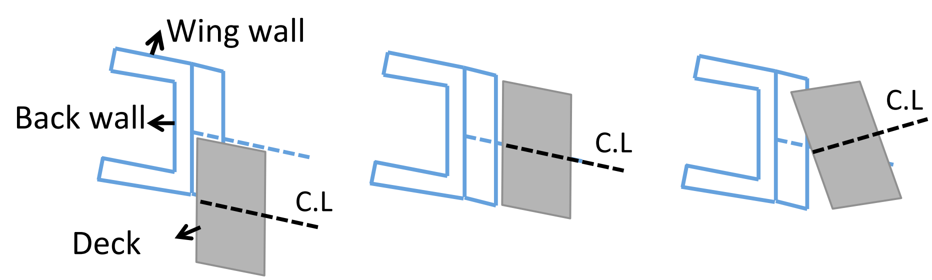
# Collapse criteria

- ✓ Collapse is defined as either the column drift ratio larger than 8% (Hutchinson et al., 2004)
- ✓ The deck displacement relative to the abutment and in longitudinal direction is larger than the seat width (i.e., 30").



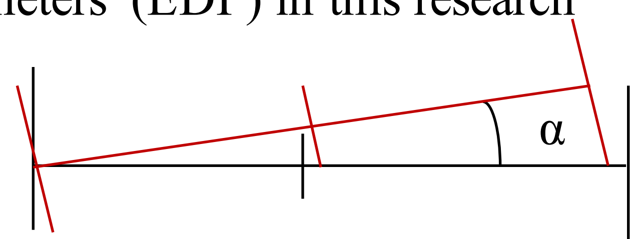

$$(\delta / H).100 \geq 8\%$$

Column drift ratio %

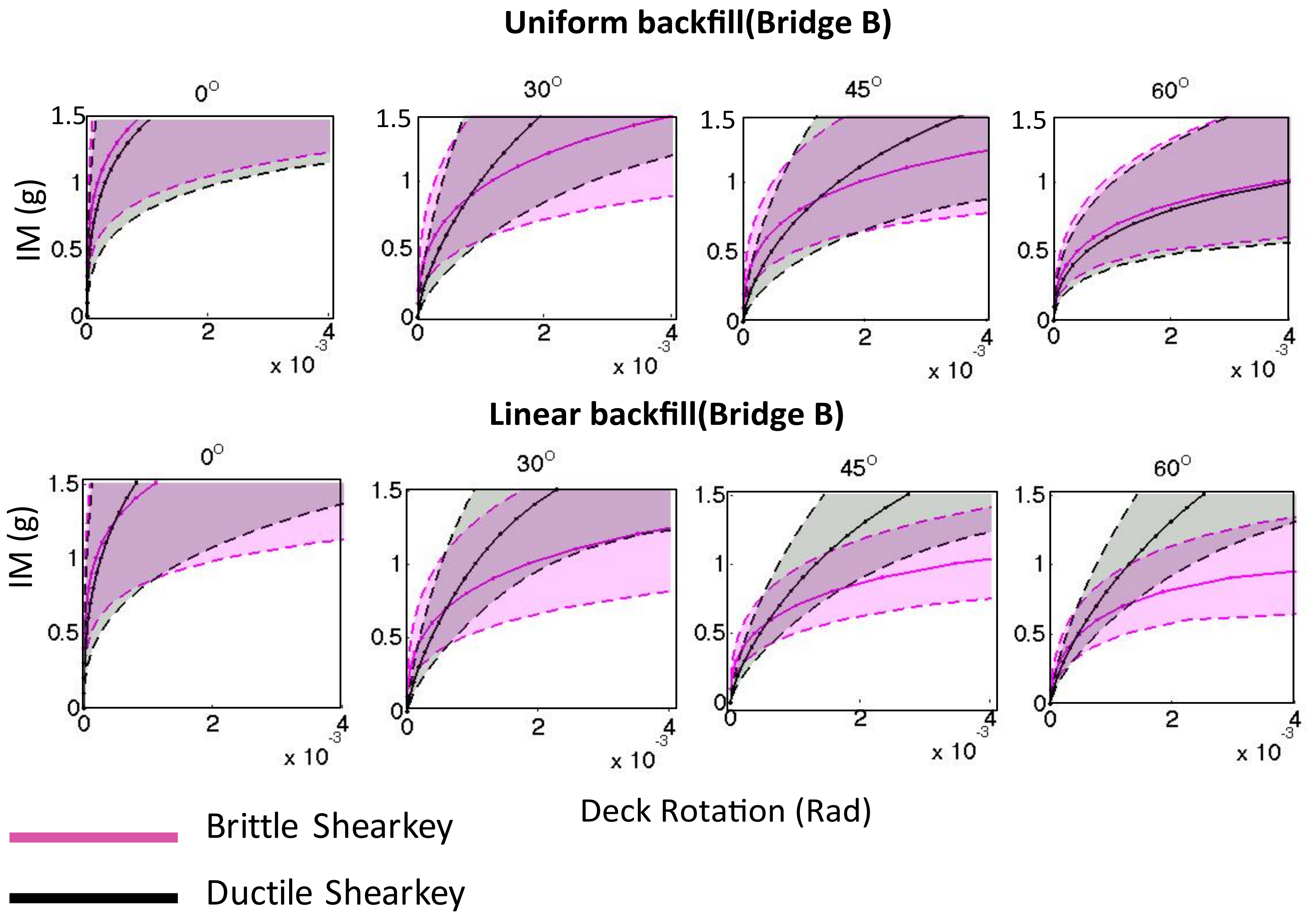



Abutment unseating

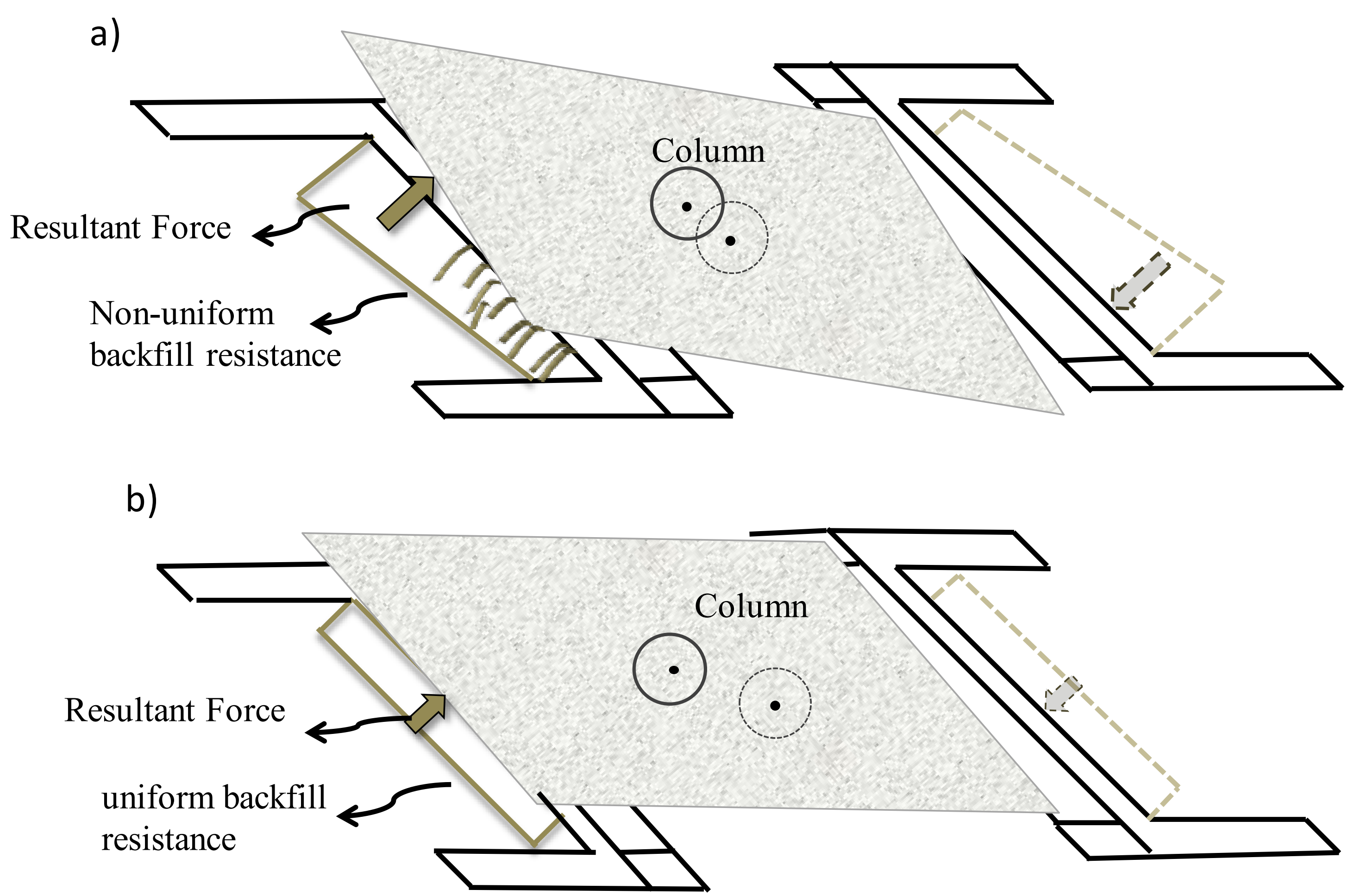
- ✓ Deck rotation, column drift ratio, and deck movement considered as three engineering demand parameters (EDP) in this research



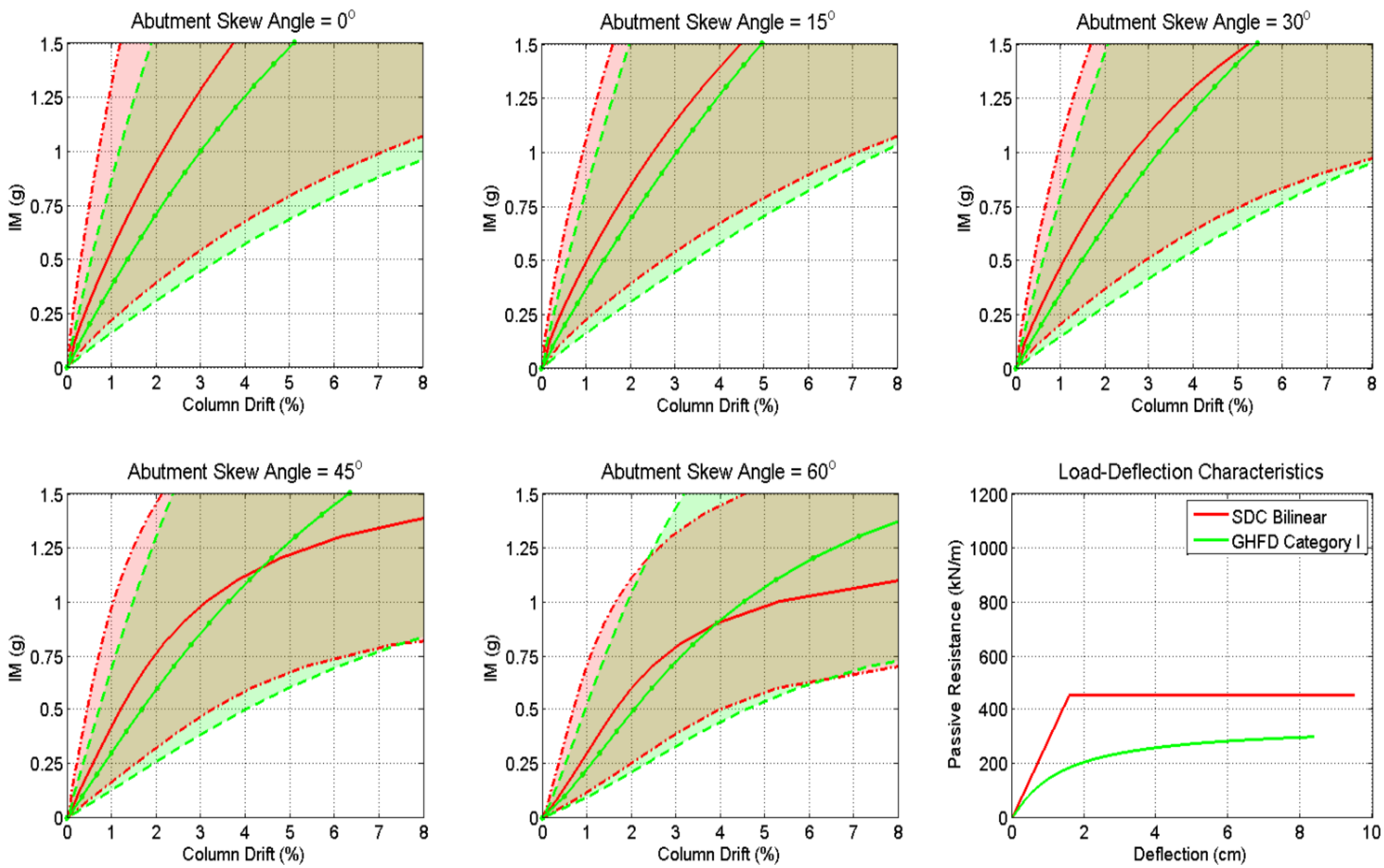
# Shear Keys & Deck Rotation



# Compound Effect of Shear key and Backfill

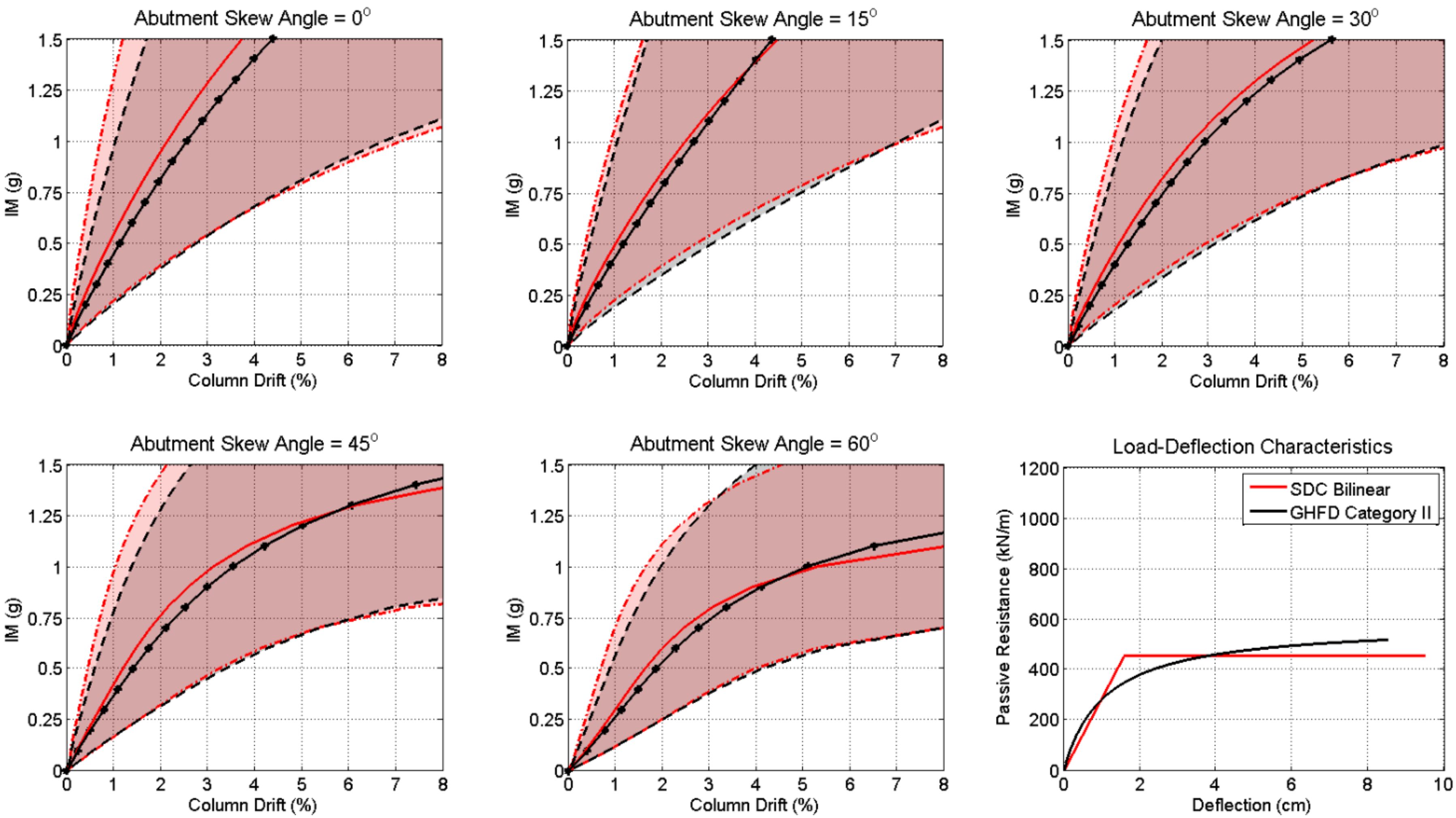


# Backfill Model & Column Drift Ratio



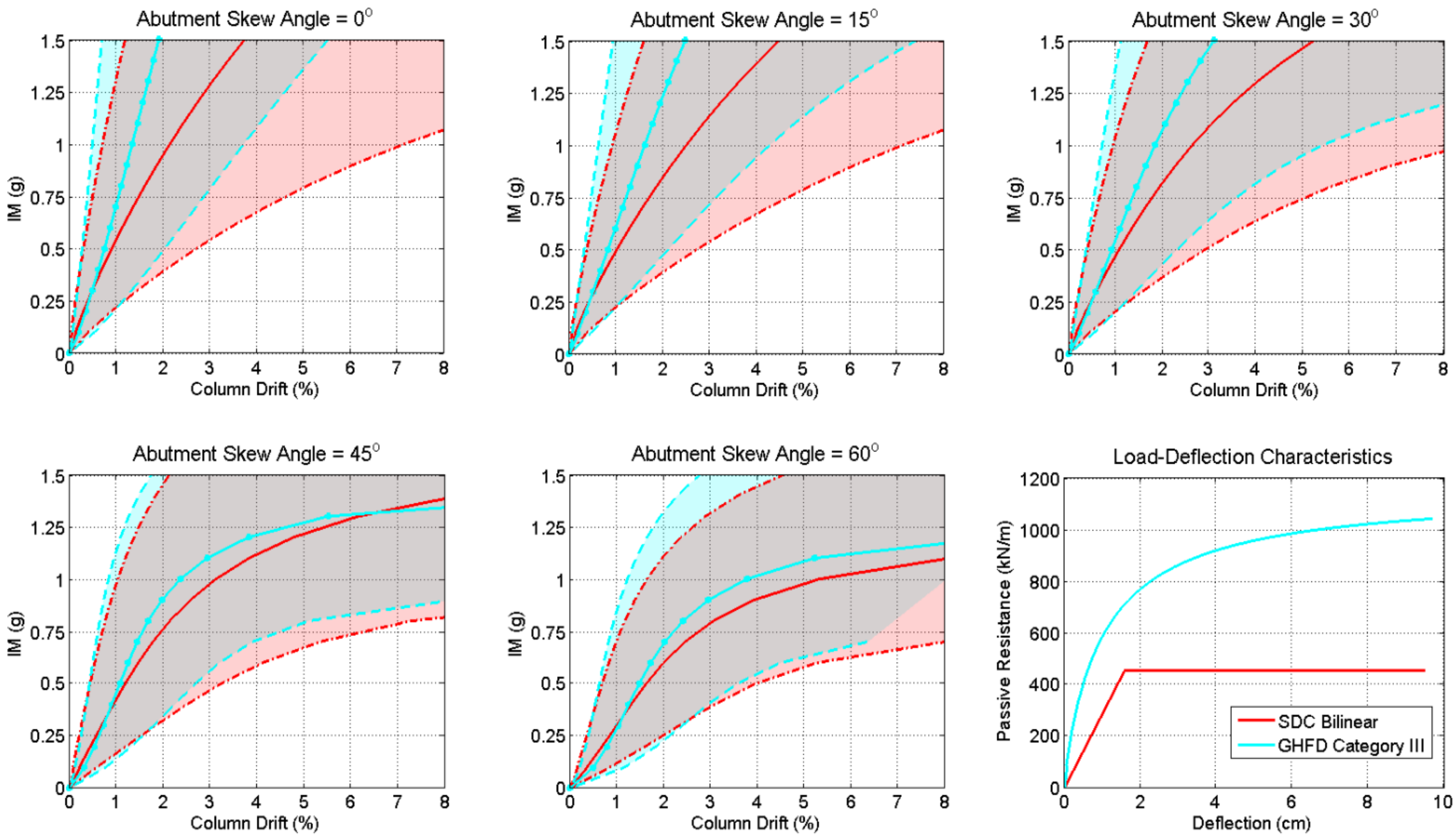

➢ Non-uniform passive reduction, Brittle Shearkey

# Backfill Model & Column Drift Ratio




- Non-uniform passive reduction, Brittle Shearkey

# Backfill Model & Column Drift Ratio

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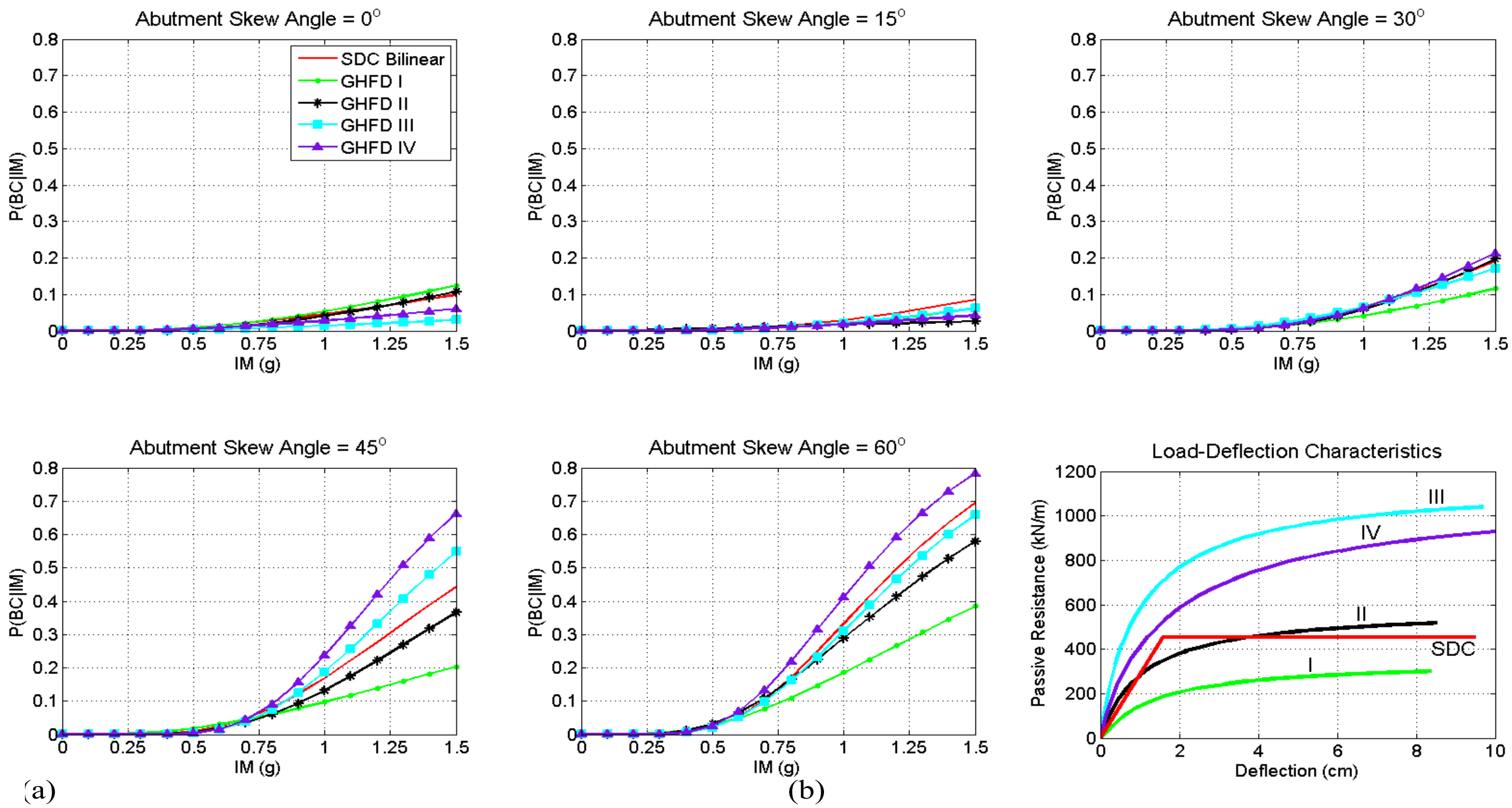
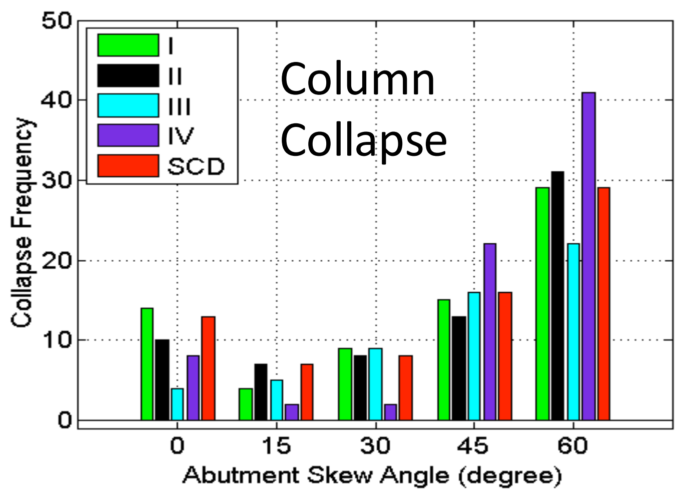
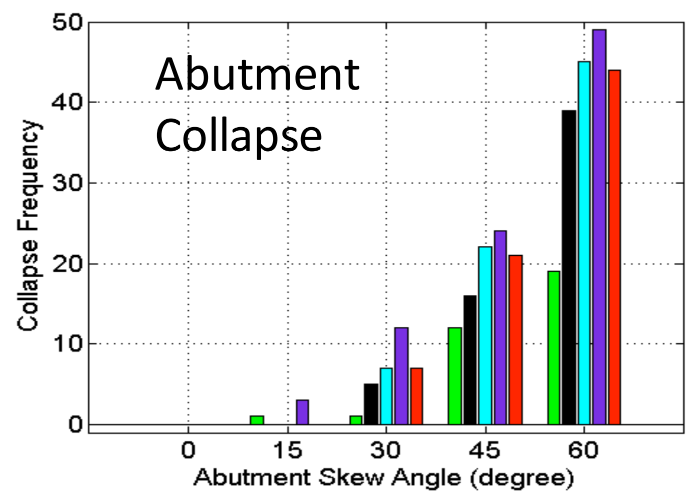
# Compound Effect of Shear key and Backfill

- Non-uniform passive reduction, Brittle Shearkey




- ✓ 0-15°: Column Collapse
- ✓ 30-60°: Unseating



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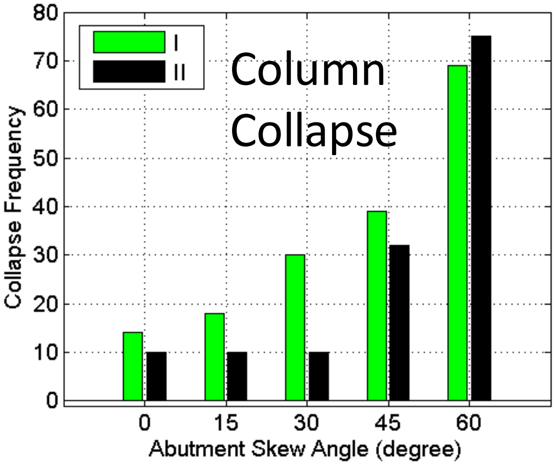


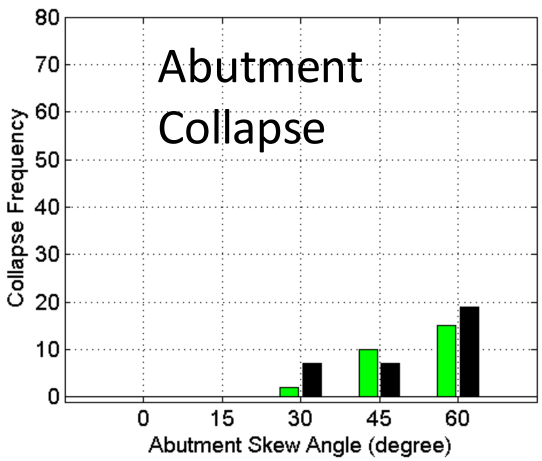


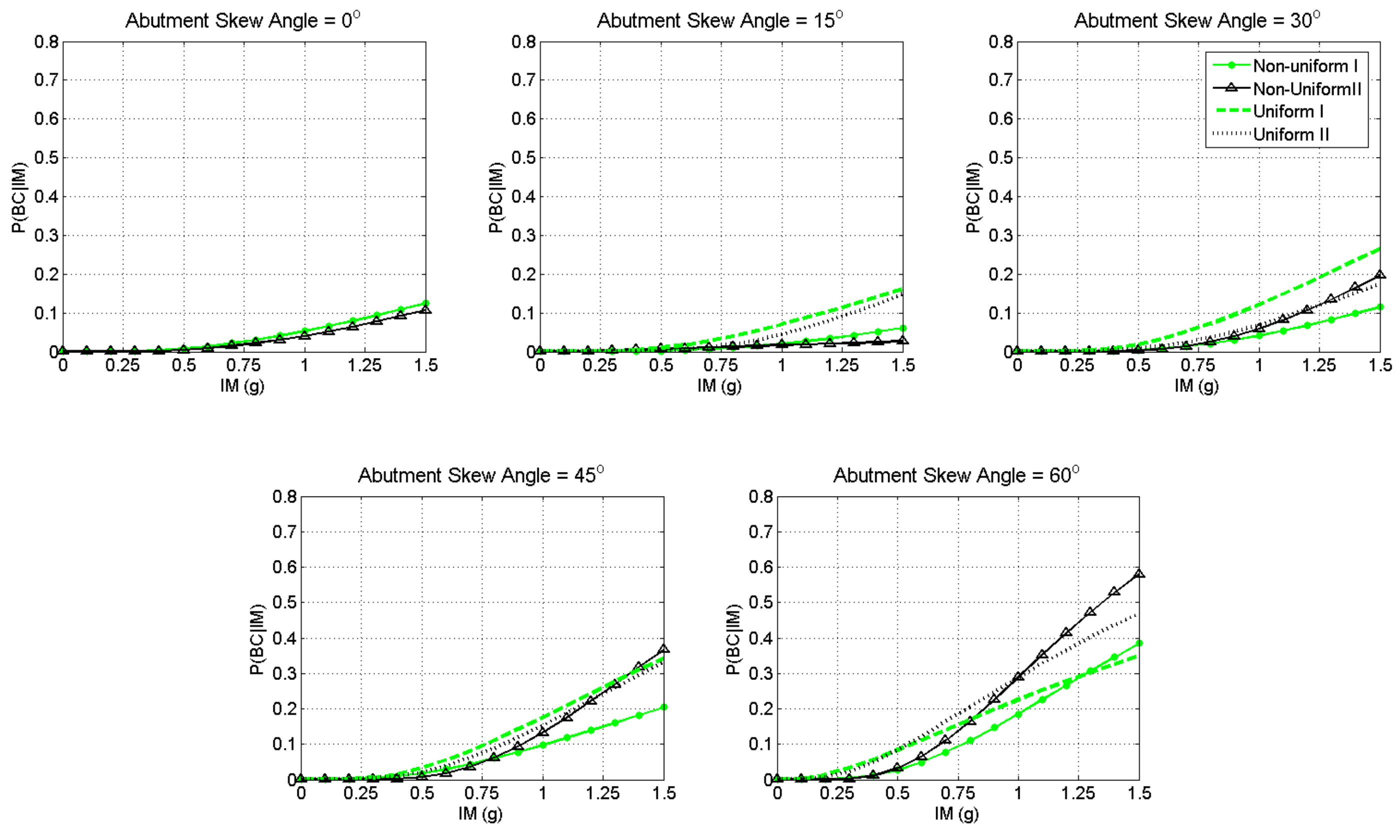

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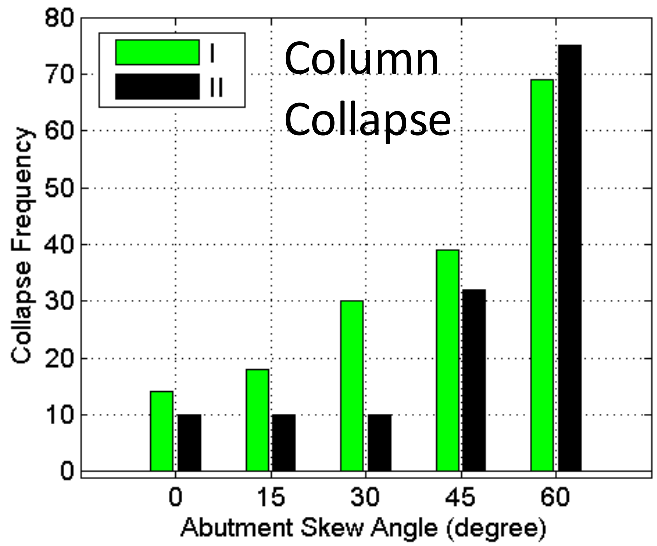
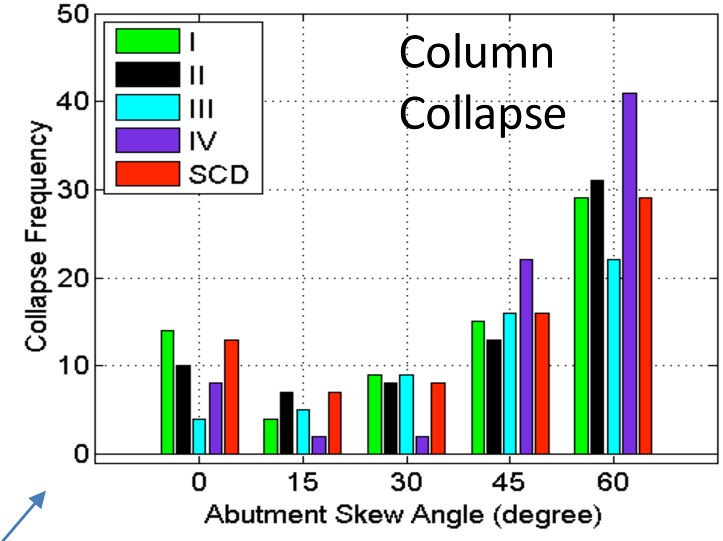
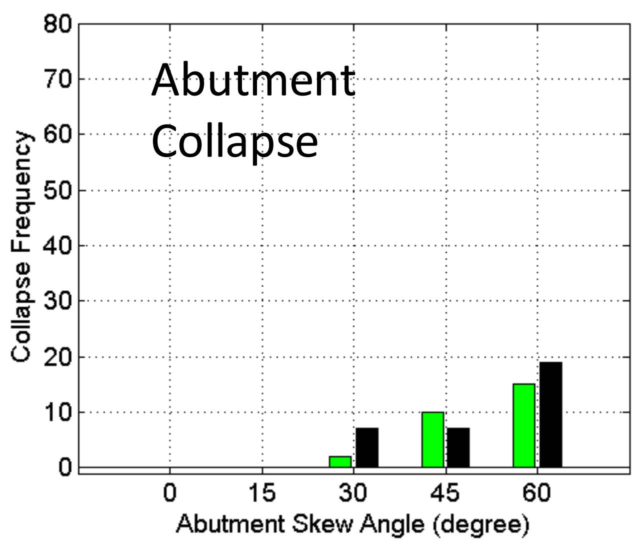
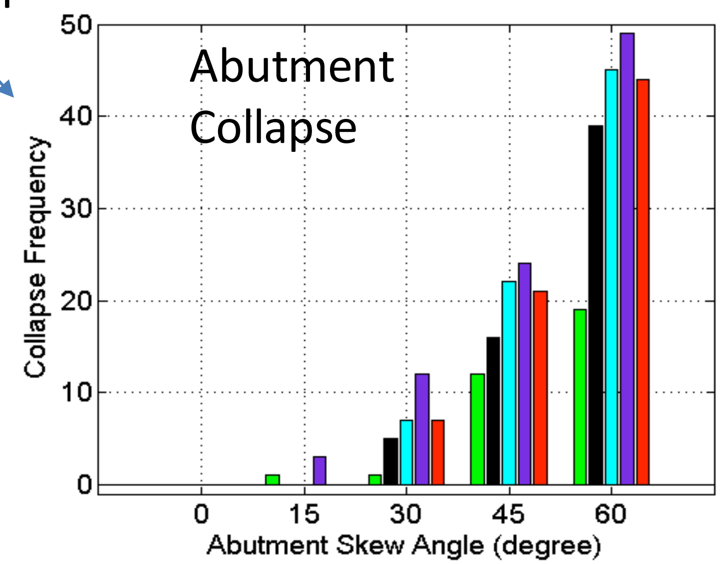



Uniform BF

Non-uniform BF



# Concluding Remarks

1. New Guidelines for Nonlinear Analysis of Bridge Structures in California.
2. In a straight abutment configuration,
   a. Column failure is found to be the major collapse mechanism (at most 10%).
   b. Column drift ratio is significantly affected by the level of passive resistance.

2. At larger skew angles ($30^o$ and above)
   a. Abutment unseating becomes noticeable.
   b. The backfill and shear-key responses are shown to be coupled.
   c. The dynamic equilibrium among the reaction forces define the direction and extent of bridge rotation, and dominance of either of the two failure mechanisms (column failure or abutment unseating).

# Concluding Remarks

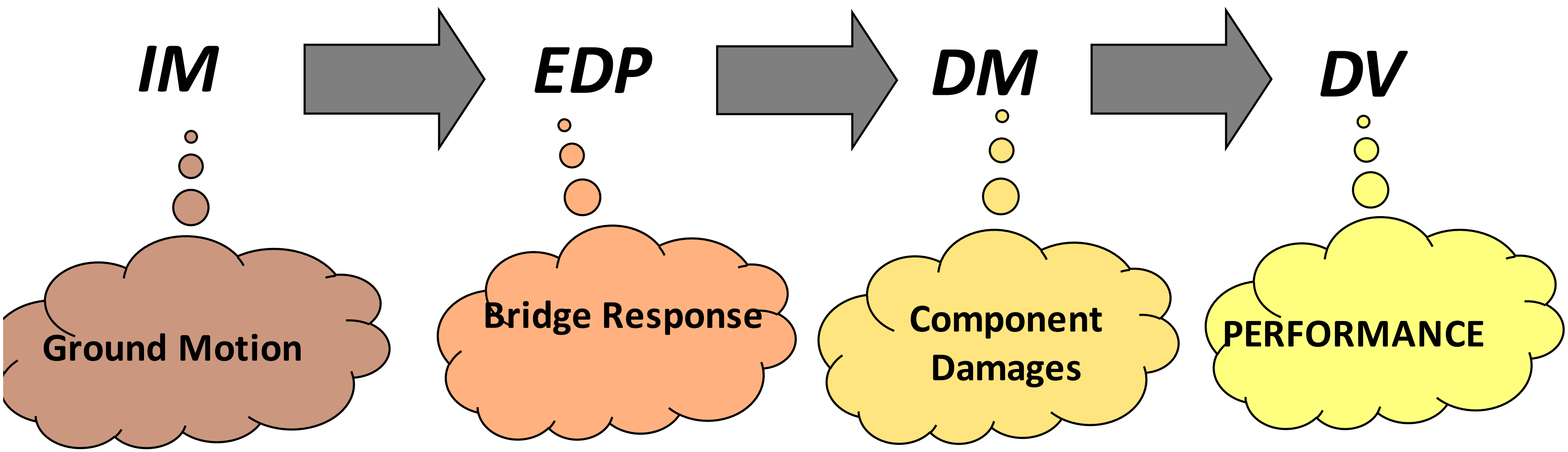
3. The actual force-deformation capacity of shear-keys predominantly controls the coupling between longitudinal and transverse seismic response of the bridge.

4. The methodology employed for reducing the passive resistance of backfill in skewed configuration is shown to significantly affect the collapse mechanism

# Concluding Remarks

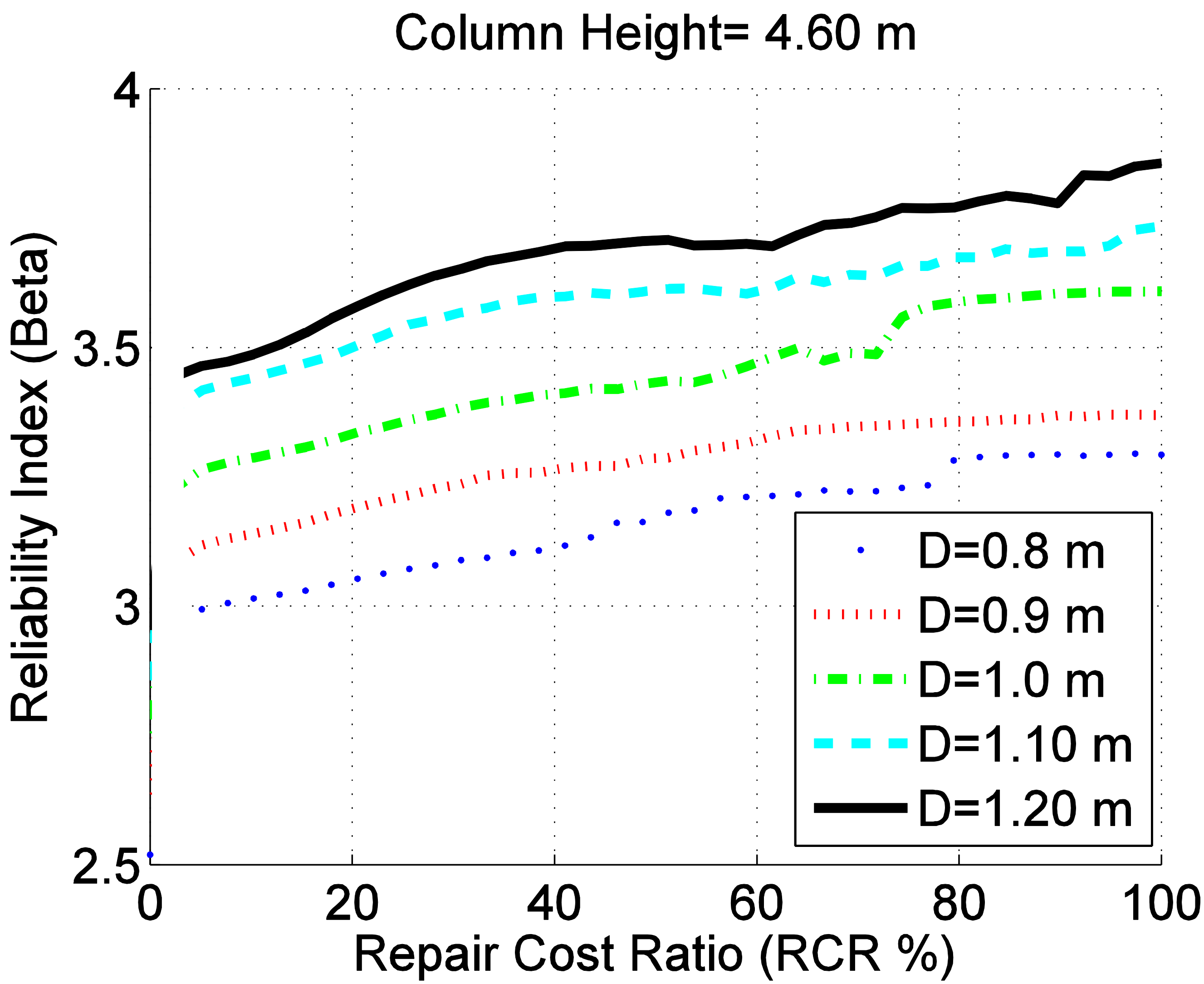
Bridge Design Framework for Target Seismic Loss (Zakeri & Zareian, 2016)

$$\lambda(DV) = \int\int\int G(DV \mid DM) \cdot dG(DM \mid EDP) \cdot dG(EDP \mid IM) \cdot d\lambda(IM)$$



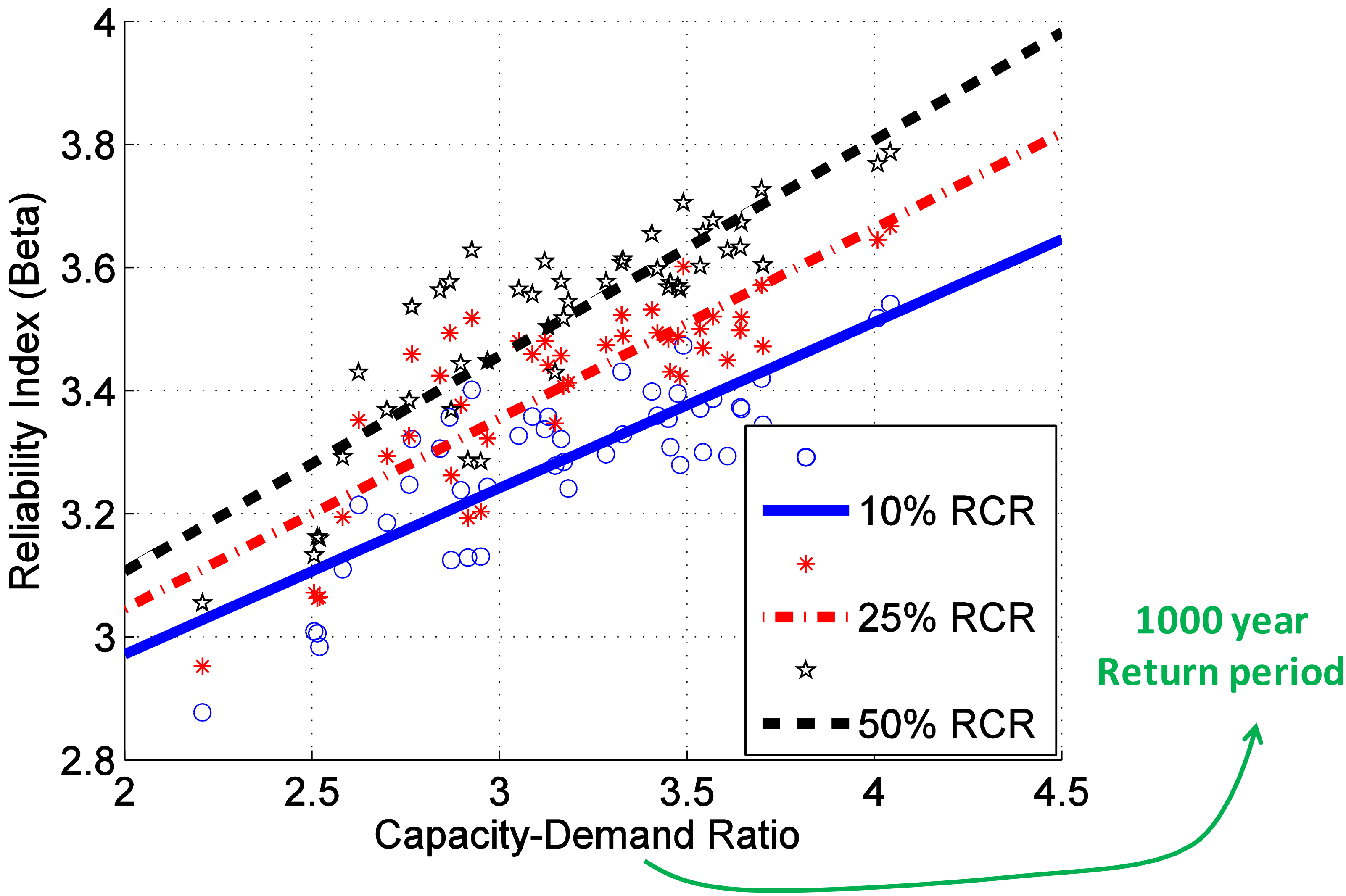
# Concluding Remarks

Bridge Design Framework for Target Seismic Loss (Zakeri & Zareian, 2016)



# Concluding Remarks

Bridge Design Framework for Target Seismic Loss (Zakeri & Zareian, 2016)



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# Thank you