Performance-Based Seismic Assessment of Skewed Bridges:

by
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- PEER Transportation Systems Research Program

TSRP Coordination Meeting

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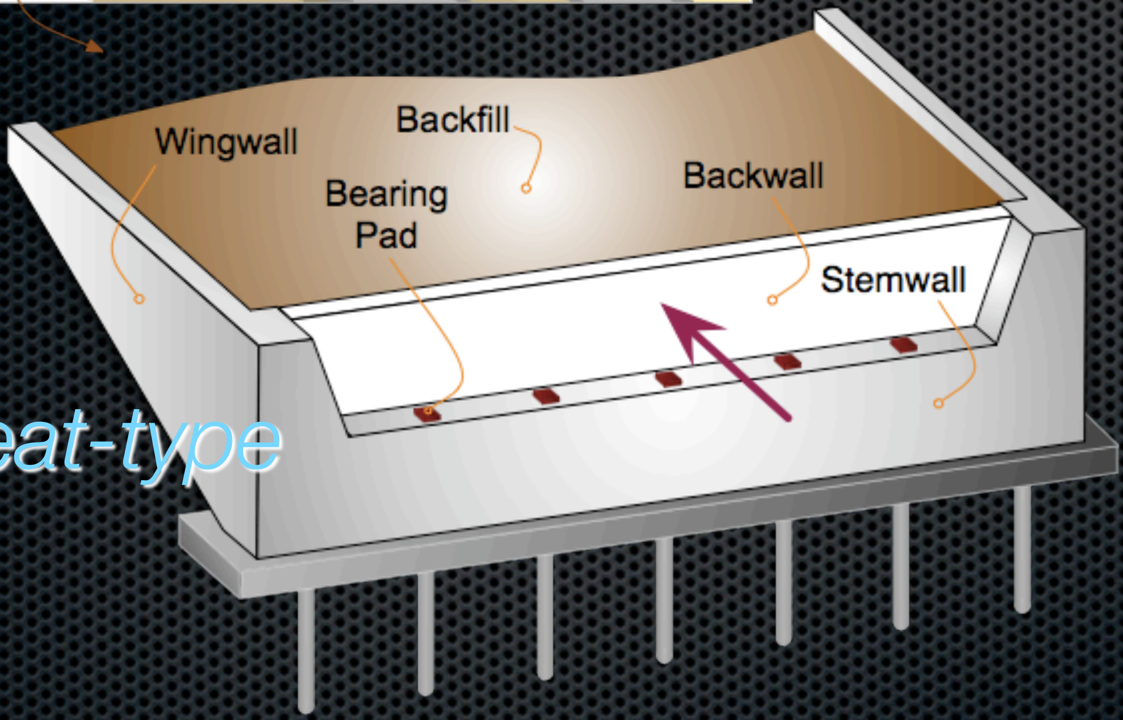
Anoosh Shamsabadi, Caltrans

Outline

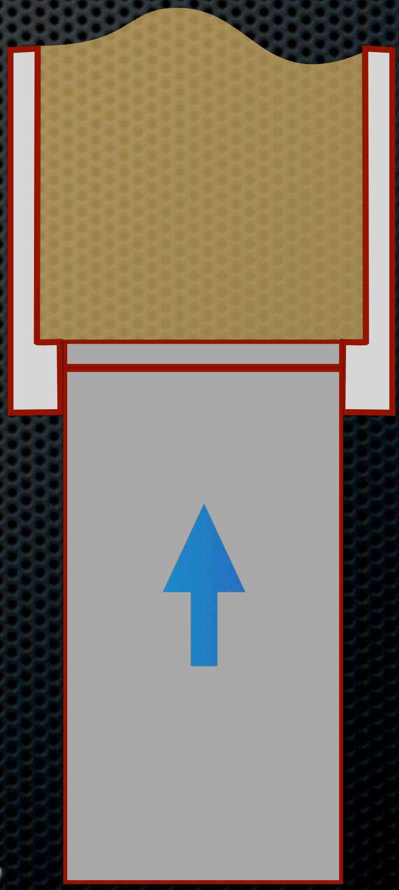
1. Skew bridges & project goals
2. Modeling skew abutment response
3. Developing *NLTH* simulation models for skew bridges
4. Exploring and quantifying skew-bridge response
5. Discussion

Anatomy of an Abutment



Seat-type

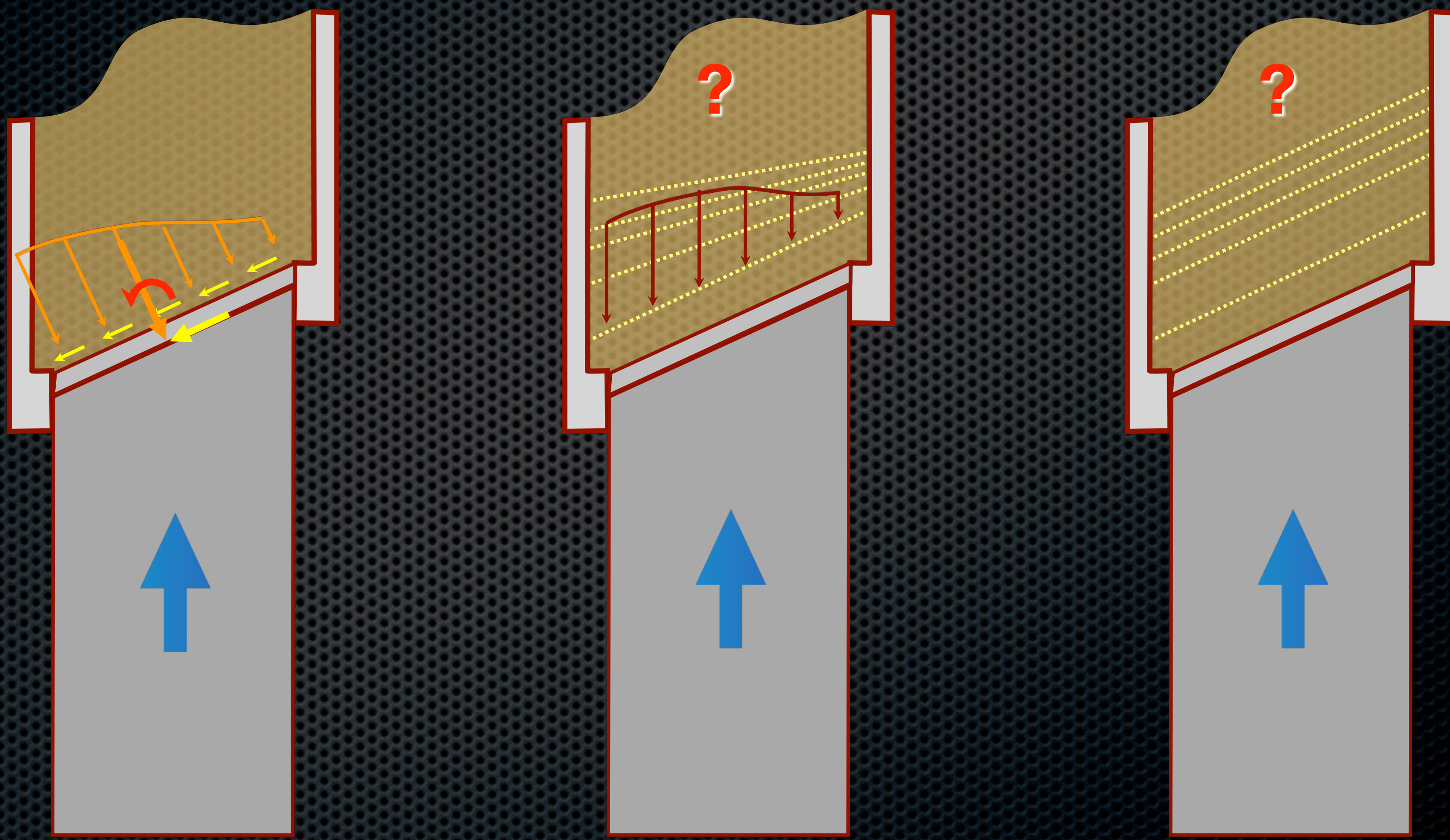
plan view



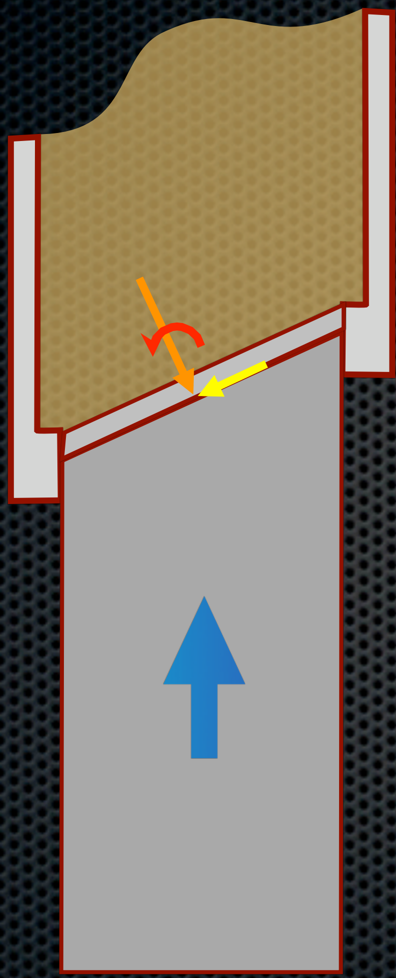
There are also "monolithic abutments"

Skew-angled abutments

Skew happens



Skew Bridge Challenges



- Unseating
- Shear key failure
- Backfill response (near field)
- *Deck rotation (esp. for single span bridges)*
- *High seismic demands on columns*

Project Tasks

1

Develop Macroelement Models for Skew Abutments

2

Develop a Database of Simulation Models for Skew Bridges

3

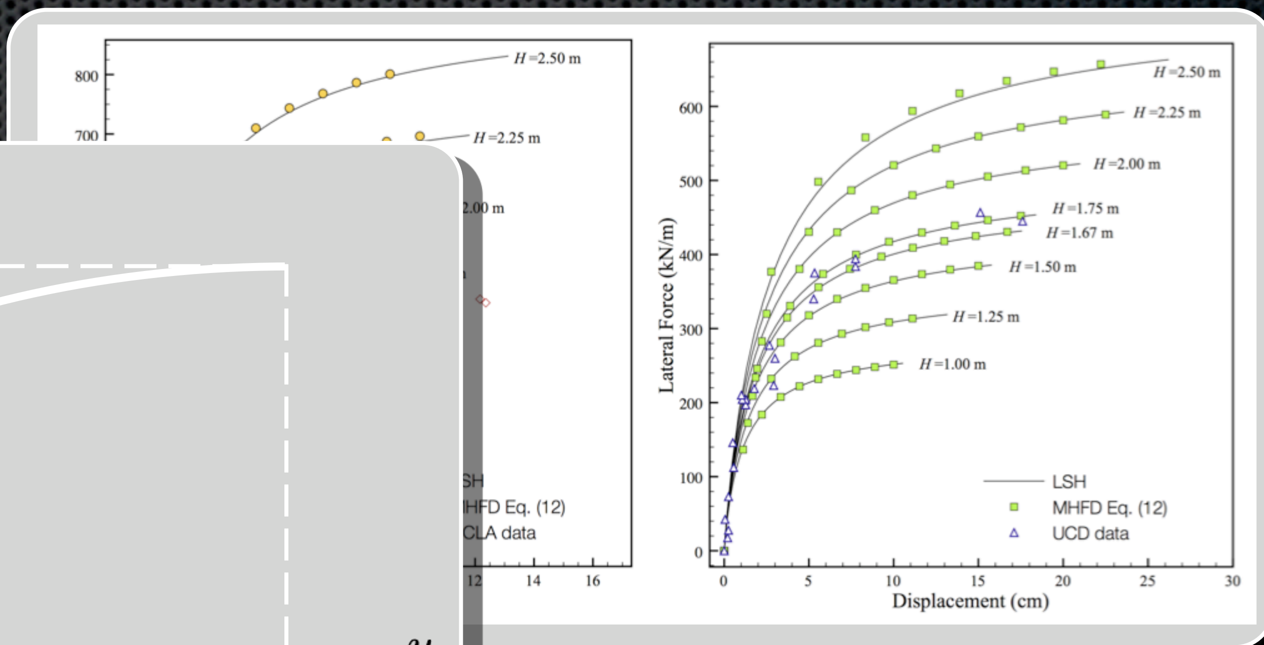
Quantify the Sensitivity of Skew Bridge Response and Damage Metrics to Key Input Parameters

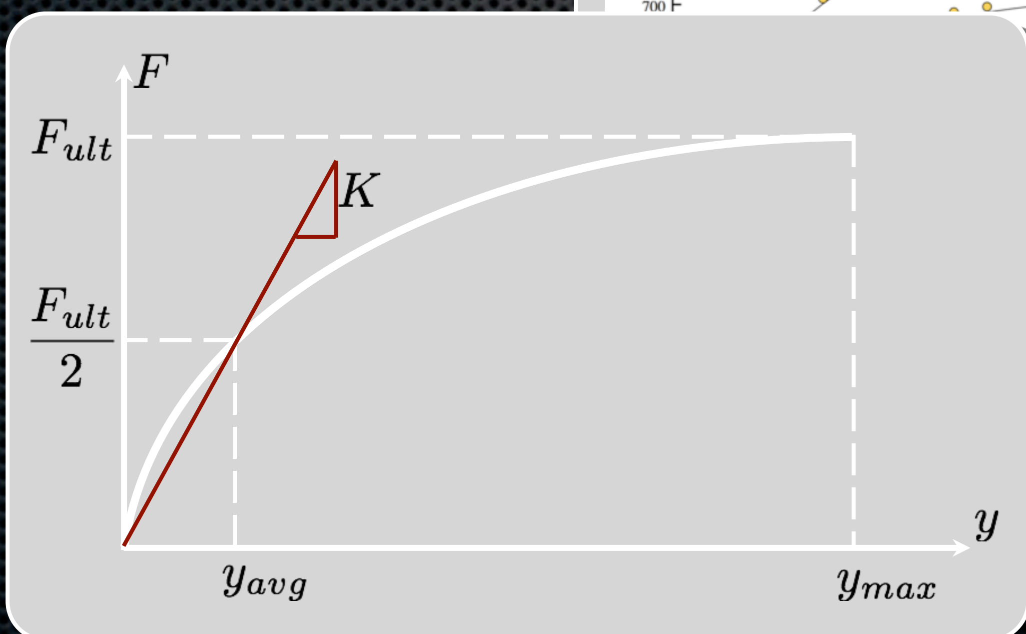
4

Update Caltrans Seismic Design Criteria for Skew-Angled Bridges

Generalized Hyperbolic Force-Displacement (GHFD) Model

- Backwall height-dependence is explicitly modeled
- Model parameters are physical soil properties





Physically Parameterized Backbone Curve

$$F(y) = f_\delta \frac{a_r y}{\hat{H} + b_r y} \hat{H}^n, \quad \hat{H} = \frac{H}{H_r}, \quad a_r = \frac{1}{\beta}(\eta - 1)\alpha, \quad b_r = \frac{1}{\beta}(\eta - 2), \quad f_\delta = \frac{2\delta}{3\phi} + \frac{5}{9}.$$

GHFD Parameters	U.S. Customary Unit System
β	$= \left[670.47 - 269.05(\tan\phi)^{1.23}\right]\varepsilon_{50}$
α	$= \begin{cases} 5.38\gamma + 8.63c & \text{for } \phi = 0 \\ 1.06\left[60.49(\tan\phi)^2 + 5.74\right]\gamma & \text{for } c = 0 \\ \left[60.49(\tan\phi)^2 + 5.74\right]\gamma + \left[34.71(\tan\phi)^{1.79} + 9.37\right]c & \text{otherwise} \end{cases}$
n	$= \begin{cases} 2.0 & \text{for } c = 0 \\ \dfrac{0.13(\tan\phi)^{1.2} + 0.22}{\sqrt{c}} + 0.9 & \text{otherwise} \end{cases}$
η	$= \begin{cases} 15.47 & \text{for } \phi < 5^\circ \text{ and } c \neq 0, \\ 18.10 - 9.38\sqrt{\tan\phi} & \text{for } \phi \geq 5^\circ \text{ and } c \neq 0, \\ 14.36 - 7.49\sqrt{\tan\phi} & \text{for all } \phi \text{ values and } c = 0. \end{cases}$

Physically Parameterized Backbone Curve

GHFD relationship

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Physically Parameterized Backbone Curve

GHFD relationship

backwall-soil friction angle

$$F(y) = f_\delta \frac{a_r y}{\hat{H} + b_r y} \hat{H}^n, \quad \hat{H} = \frac{H}{H_r}, \quad a_r = \frac{1}{\beta}(\eta - 1)\alpha, \quad b_r = \frac{1}{\beta}(\eta - 2), \quad f_\delta = \frac{2\delta}{3\phi} + \frac{5}{9}.$$

Reference Wall height (3.28 ft)

Wall friction correction coefficient

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F: Lateral force (kips/ft)

y: Lateral displacement (in)

c: Soil cohesion (ksf)

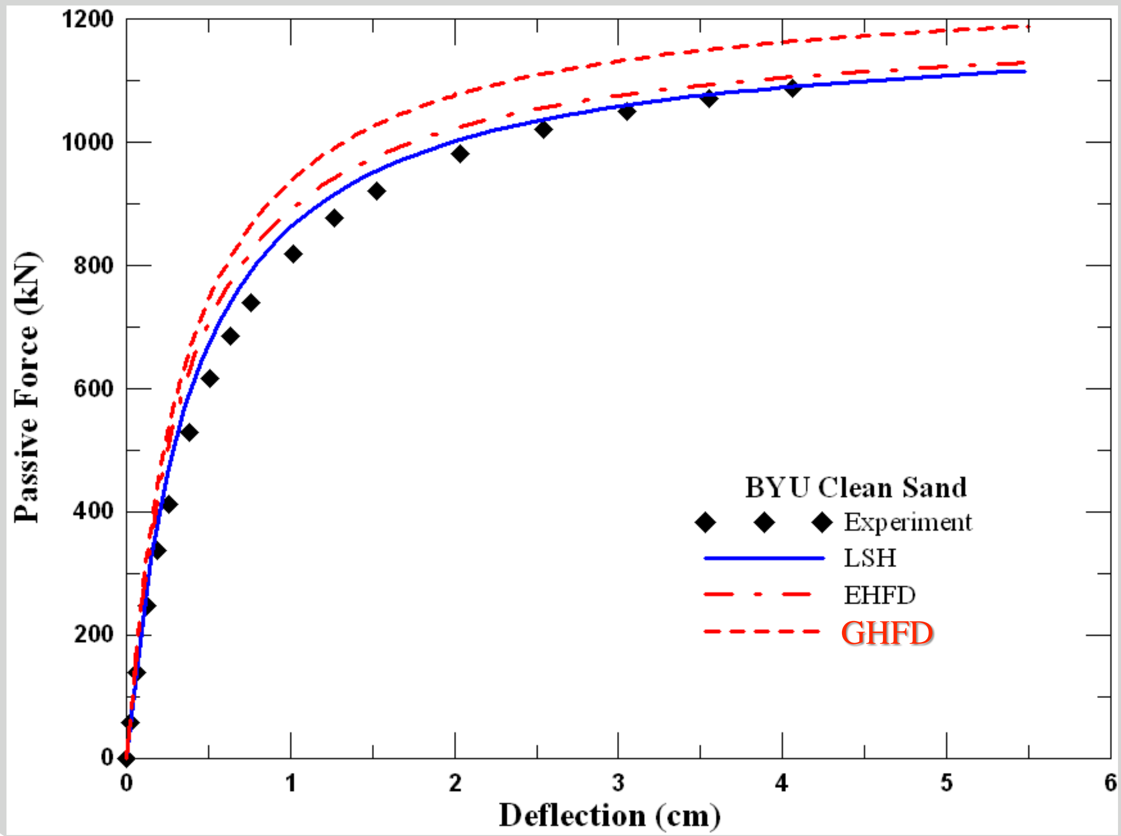
Φ: Internal friction angle (deg)

γ: Unit soil weight (kcf)

ε_{50}: Soil strain at 50% of ultimate stress (triaxial testing)

Model Validation

Experiments	Parameters							
	Backfill Soil					LSH		
	c (kPa)	$\phi°$	γ (kN/m^3)	ε_{50}	ν	$\delta°$	c_a (kPa)	R_f
BYU Clean Sand	3.83	39.0	18.4	0.0020	0.30	30.0	2.49	0.98
BYU Silty Sand	31.0	27.0	19.2	0.0030	0.35	13.0	20.15	0.97
RPI Dense Sand	0.0	39.0	16.2	0.0035	0.35	39.0	0.00	0.95



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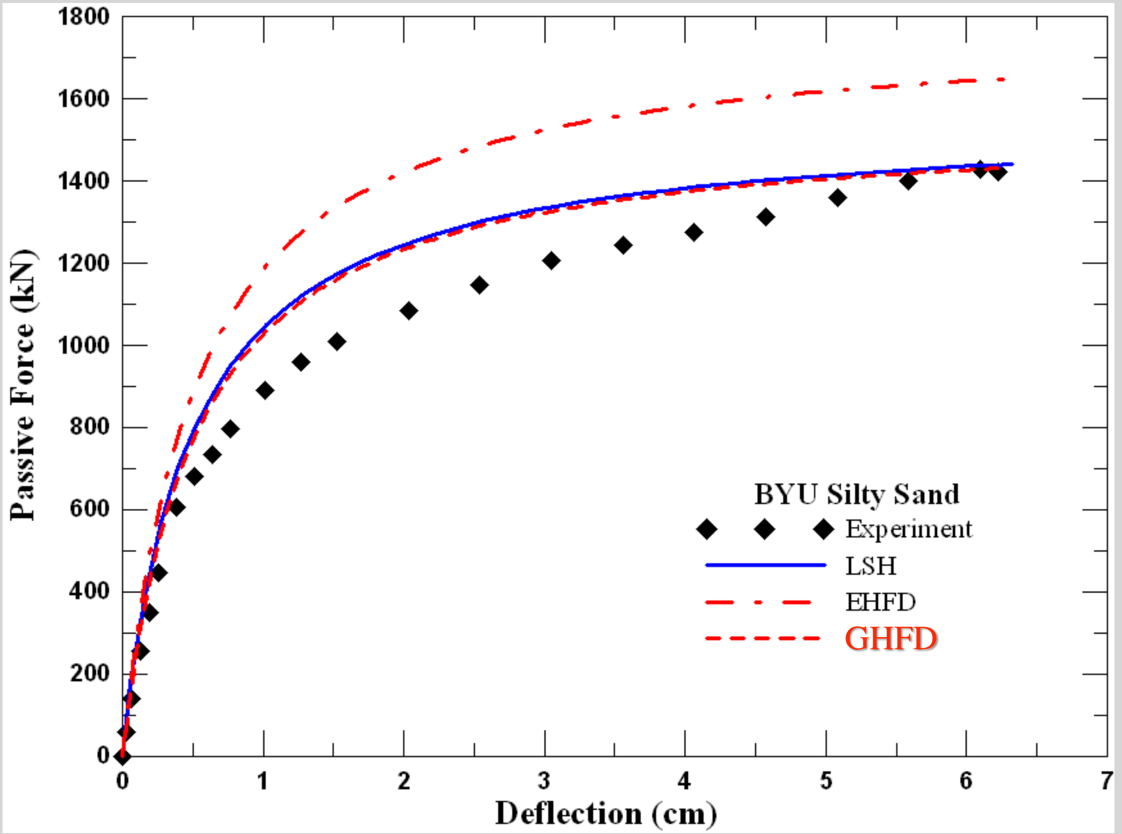

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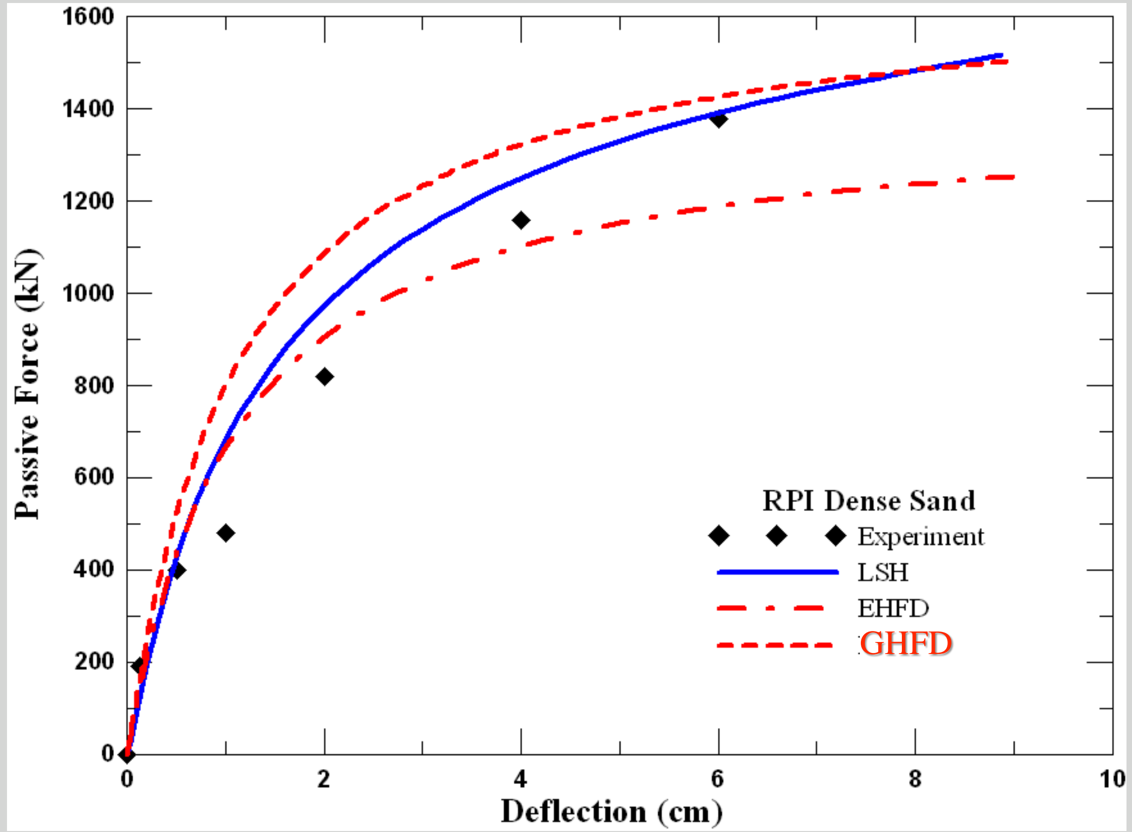

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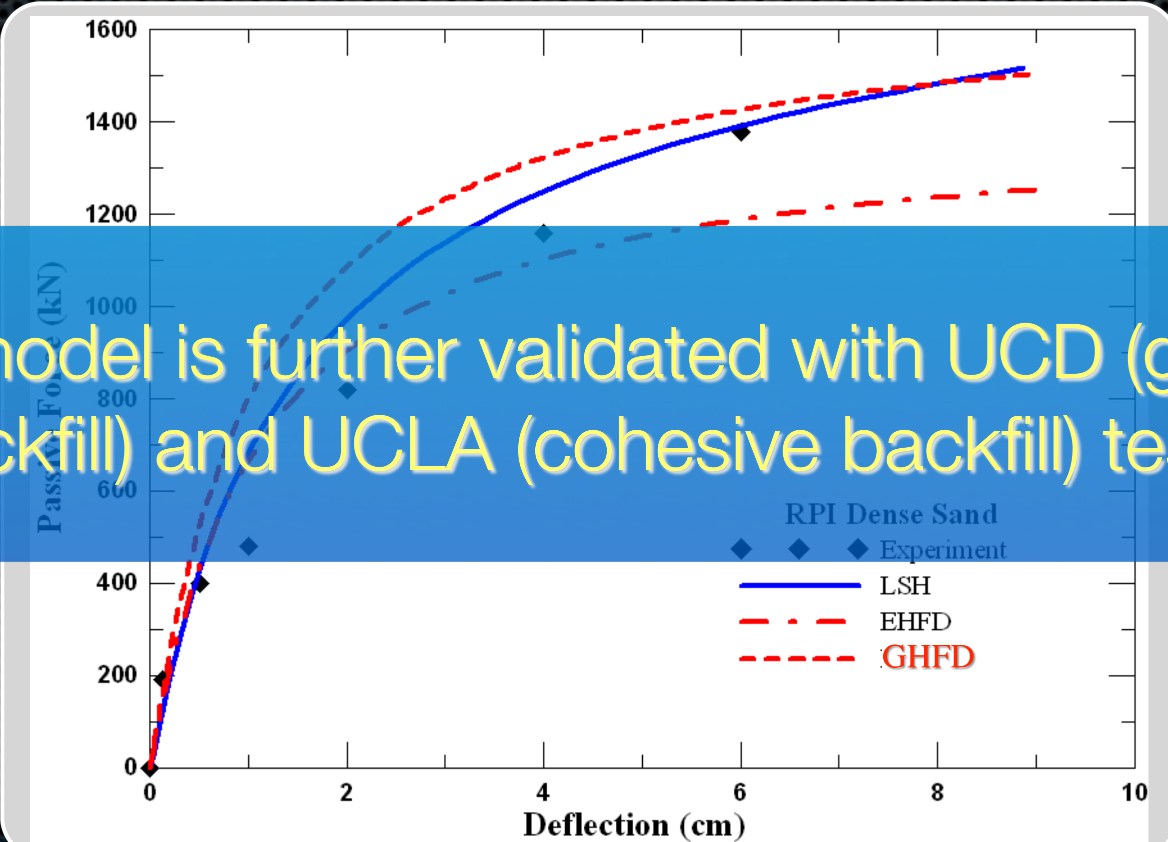
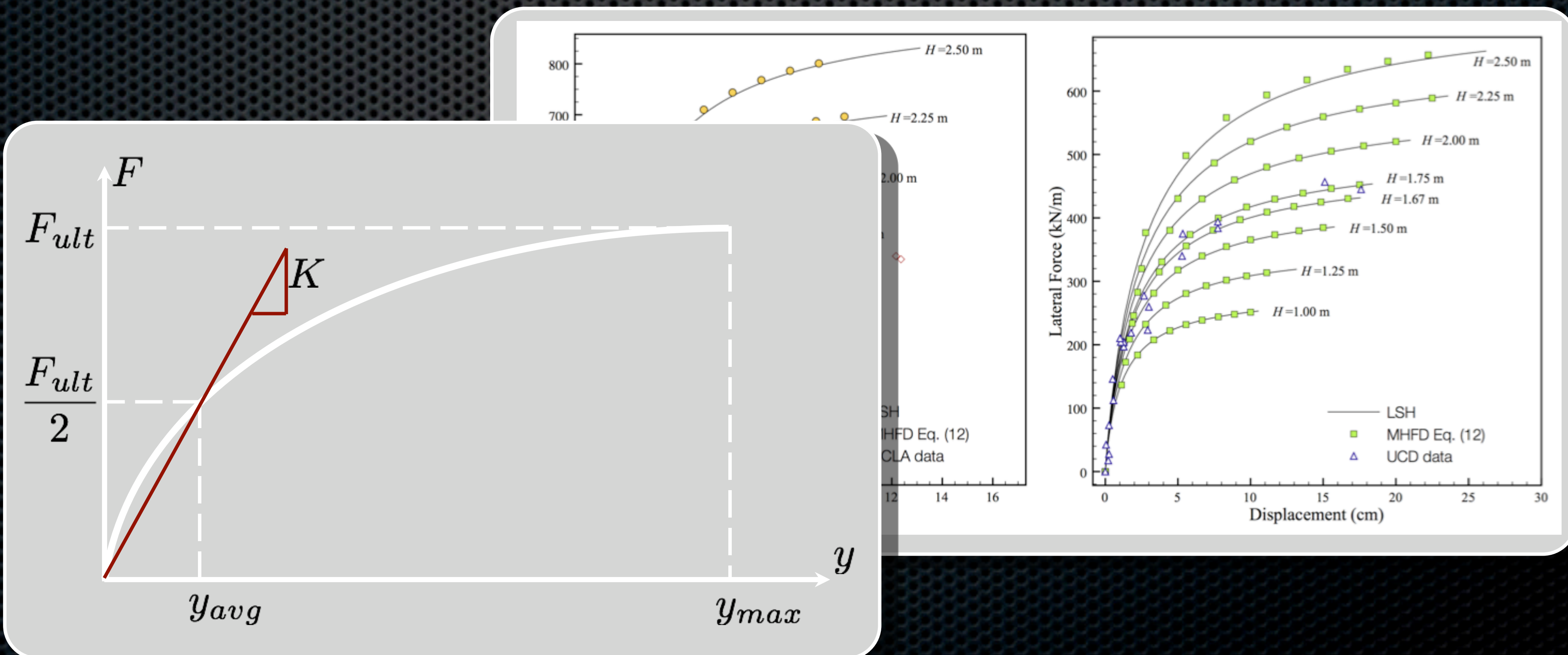


✓ model is further validated with UCD (granular backfill) and UCLA (cohesive backfill) test data

Generalized Hyperbolic Force-Displacement (GHFD) Model

- Backwall height-dependence is explicitly modeled
- Model parameters are physical soil properties



Generalized Hyperbolic Force-Displacement (GHFD) Model

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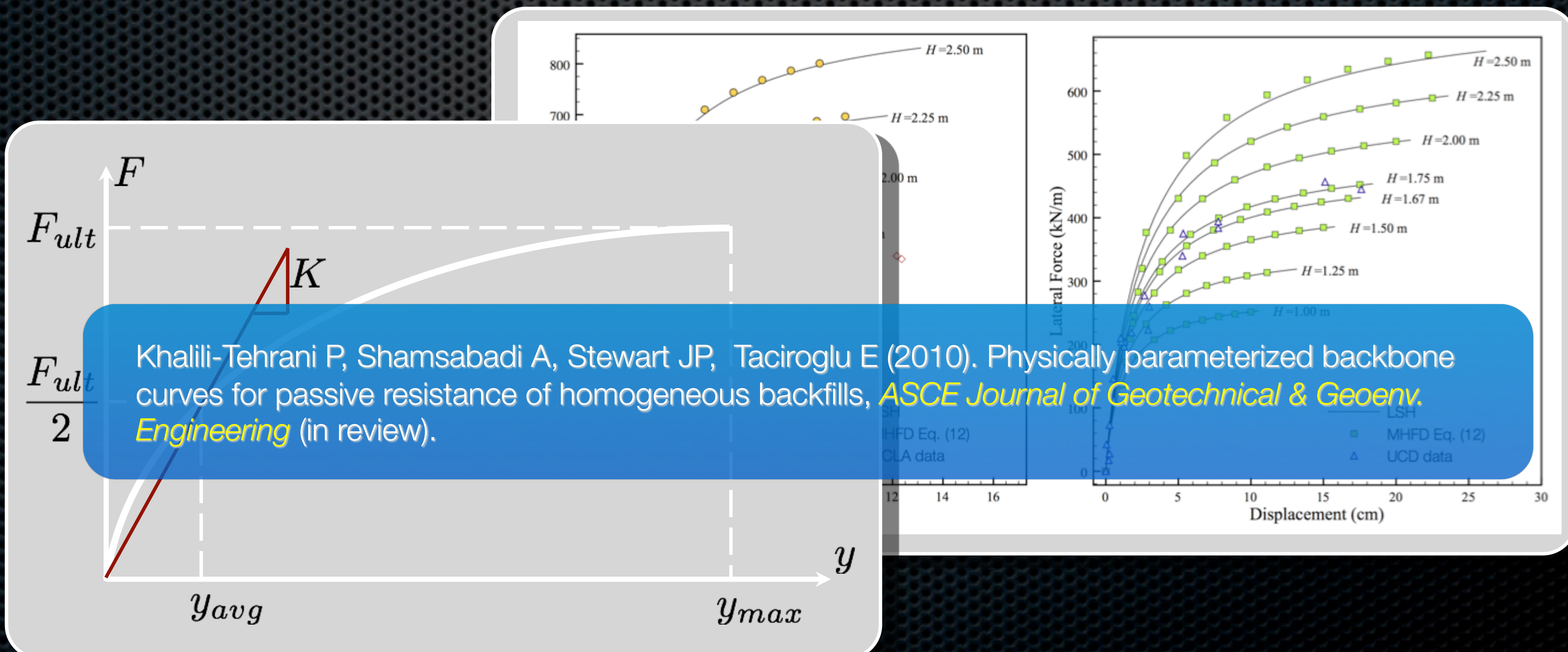
- Suitable for massive computation
- Cited in upcoming Caltrans SDC



Khalili-Tehrani P, Shamsabadi A, Stewart JP, Taciroglu E (2010). Physically parameterized backbone curves for passive resistance of homogeneous backfills, *ASCE Journal of Geotechnical & Geoenv. Engineering* (in review).

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Valid for straight abutments only!

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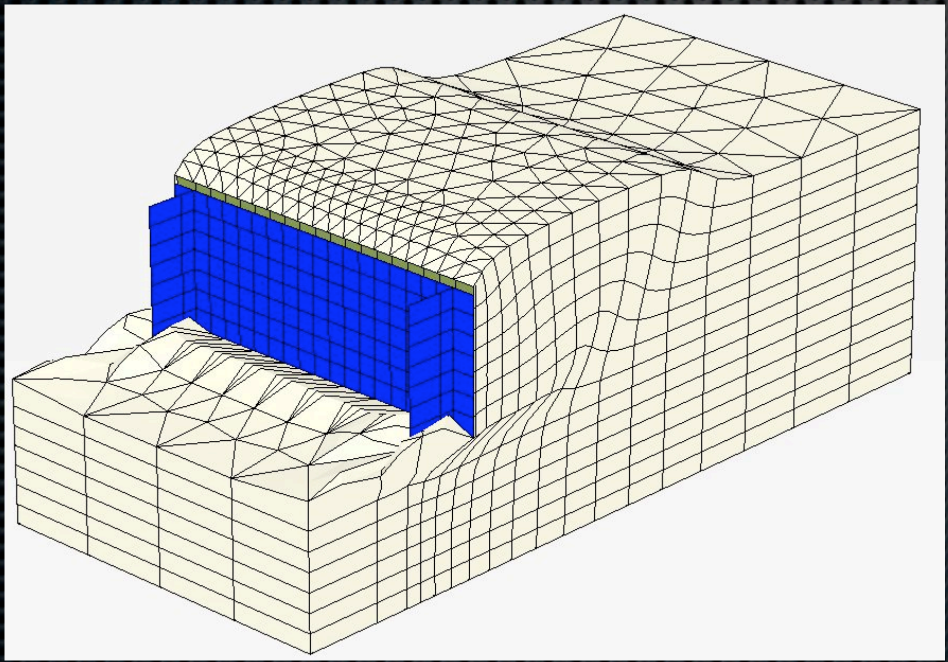
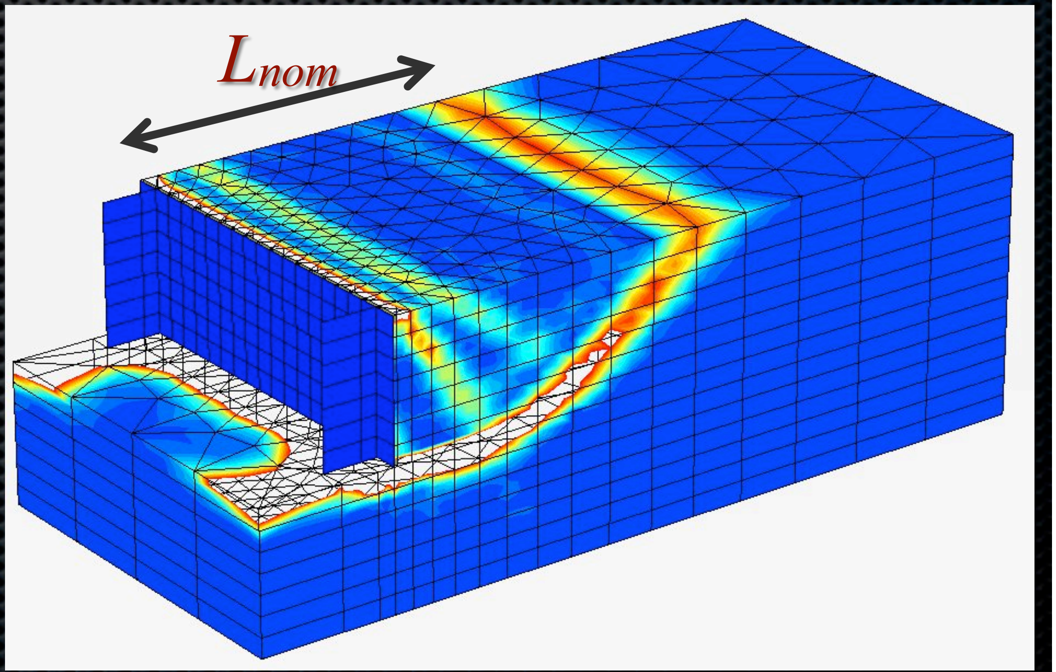
Extension to skew abutments of torsionally stiff bridges

Straight Abutment with UCLA backfill

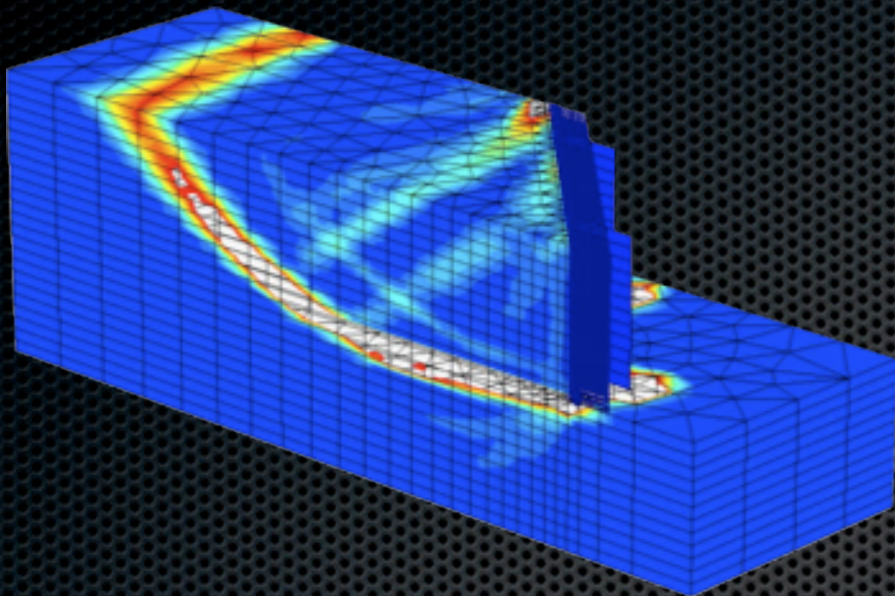
Input parameters for “Hardening Soil” PLAXIS model

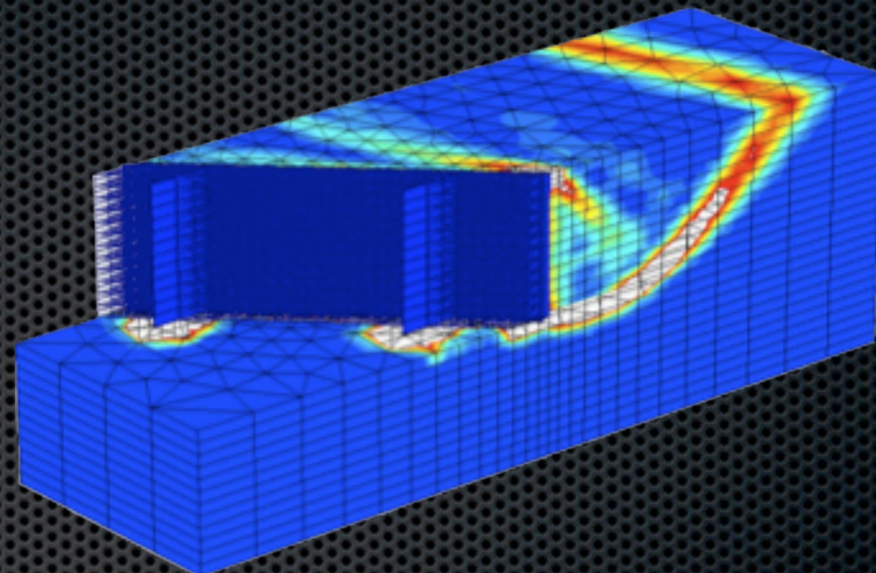
Strength Parameters					Displacement Parameters			
Unit weight, γ (kN/m^3)	Friction angle, ϕ	Cohesion, c (kPa)	Dilatancy angle, ψ	R_{int}	R_f	E_{50}^{ref} (MPa)	E_{ur}^{ref} (MPa)	υ
20.0	40°	14	10°	0.50	0.97	70	140	0.3
20.0	39°	24	9°	0.50	0.97	70	140	0.3

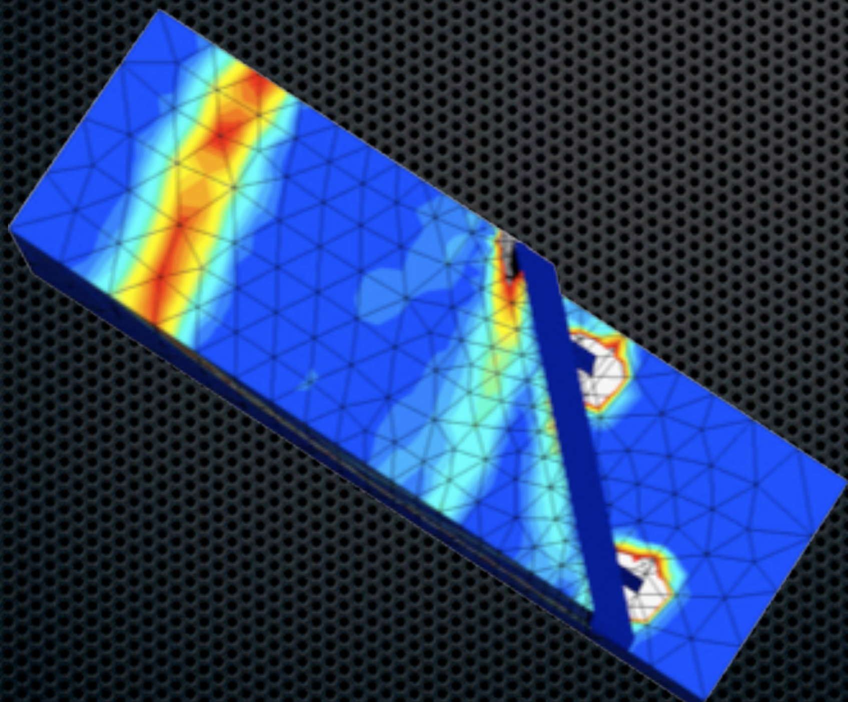


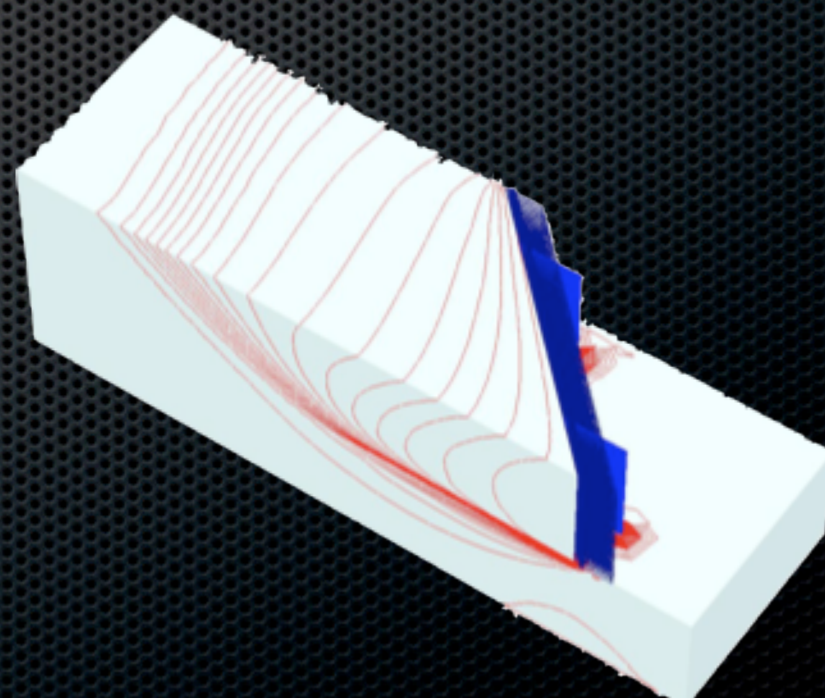


45° skew Abutment with UCLA backfill

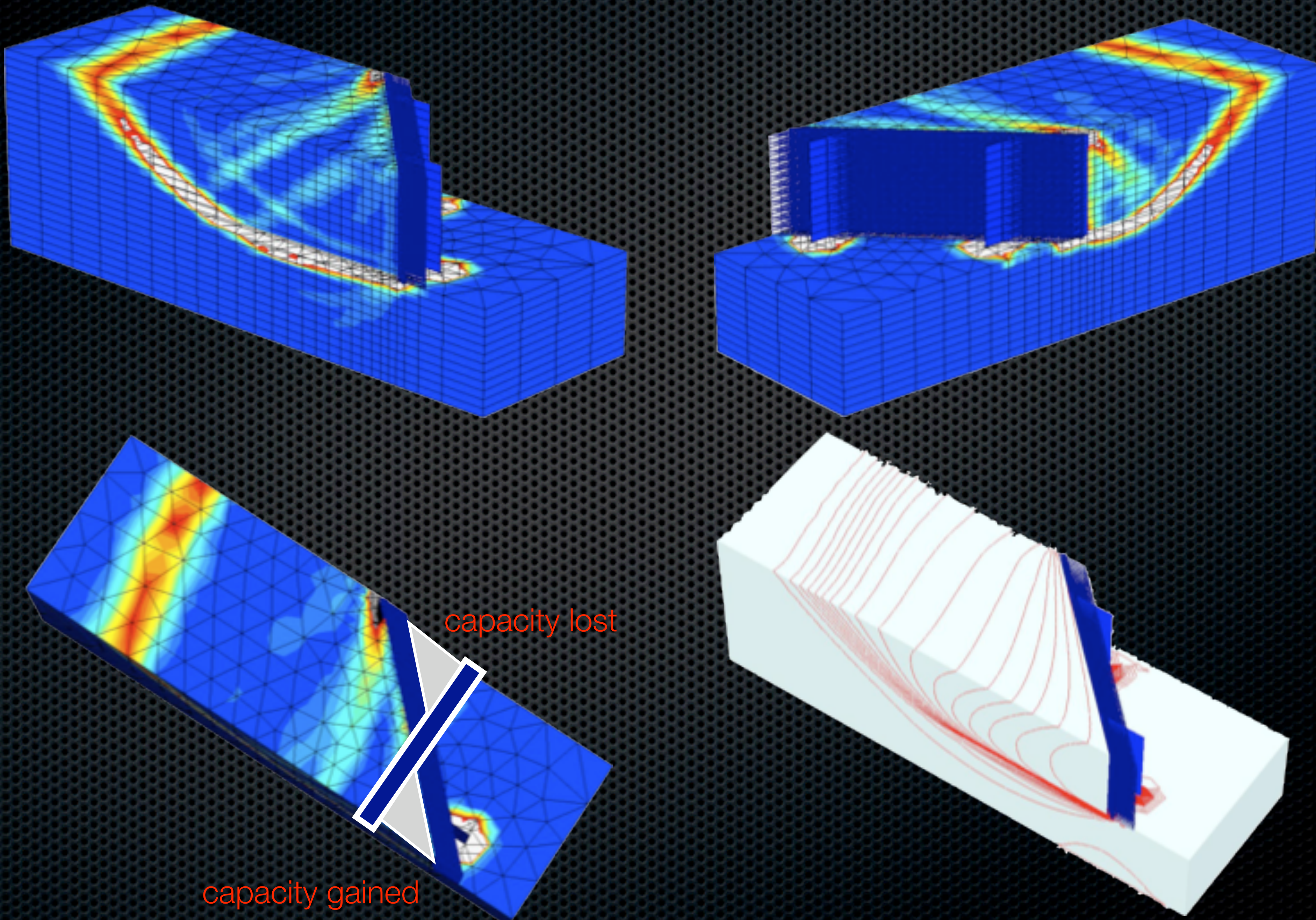




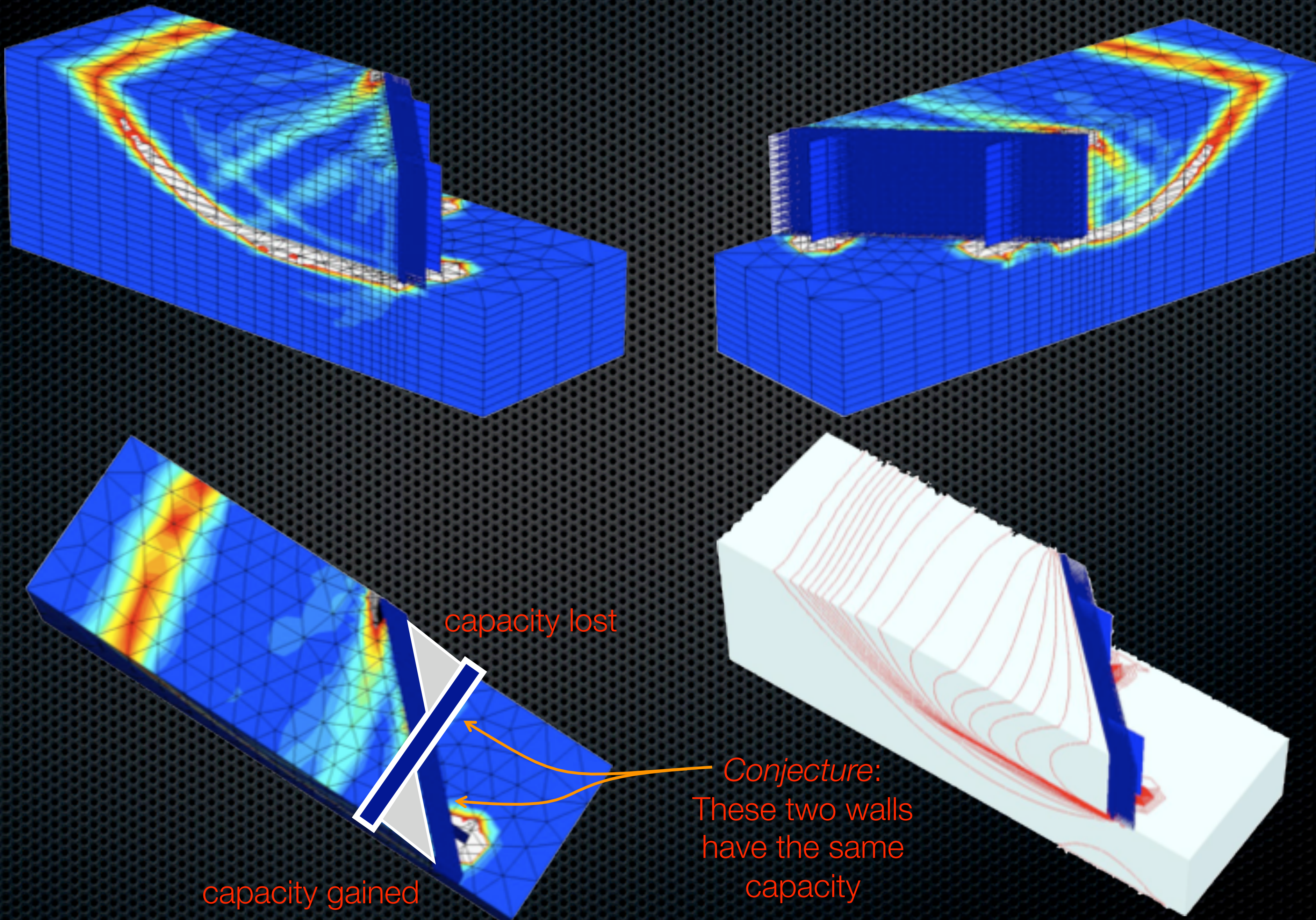




45° skew Abutment with UCLA backfill



45° skew Abutment with UCLA backfill



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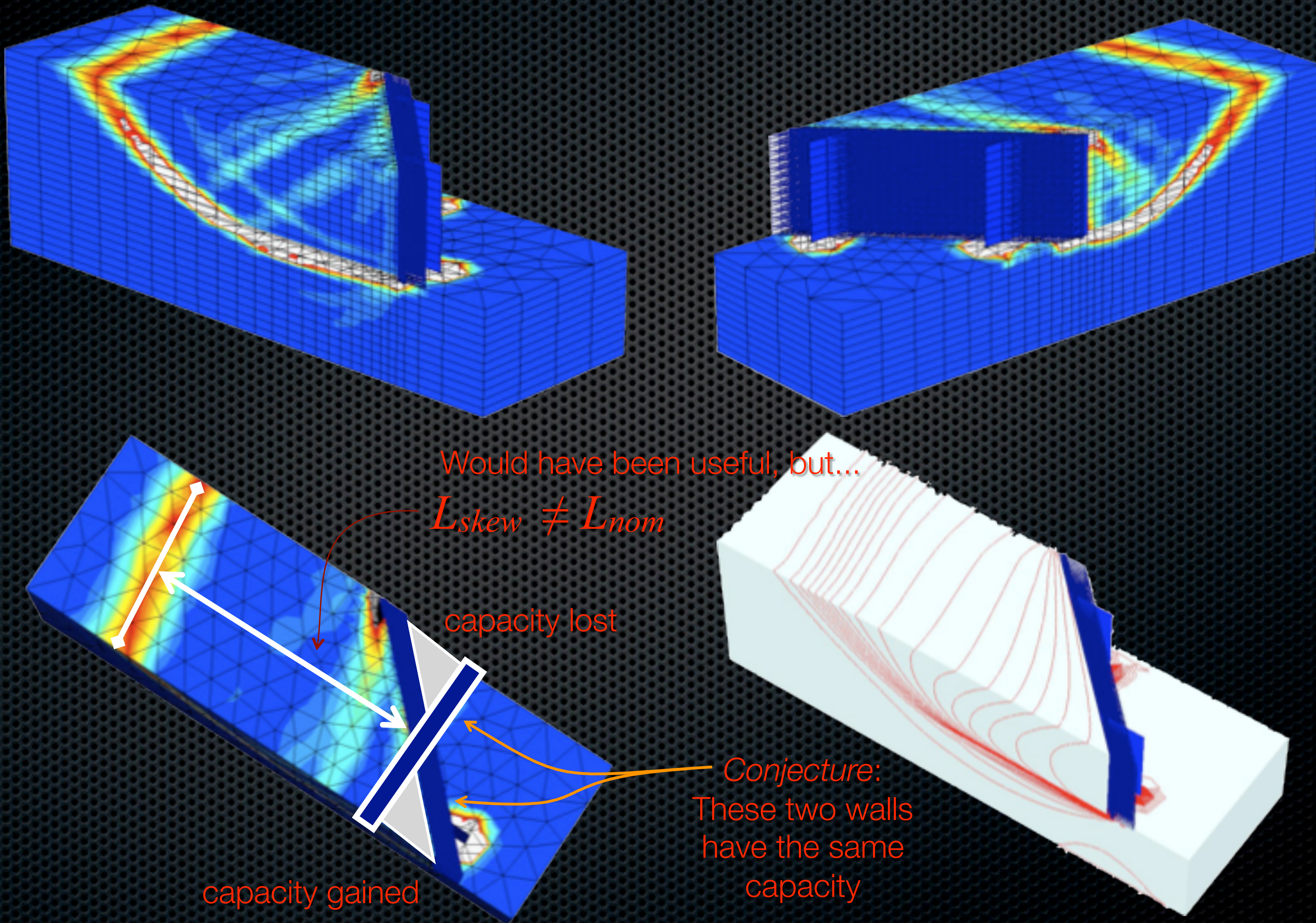
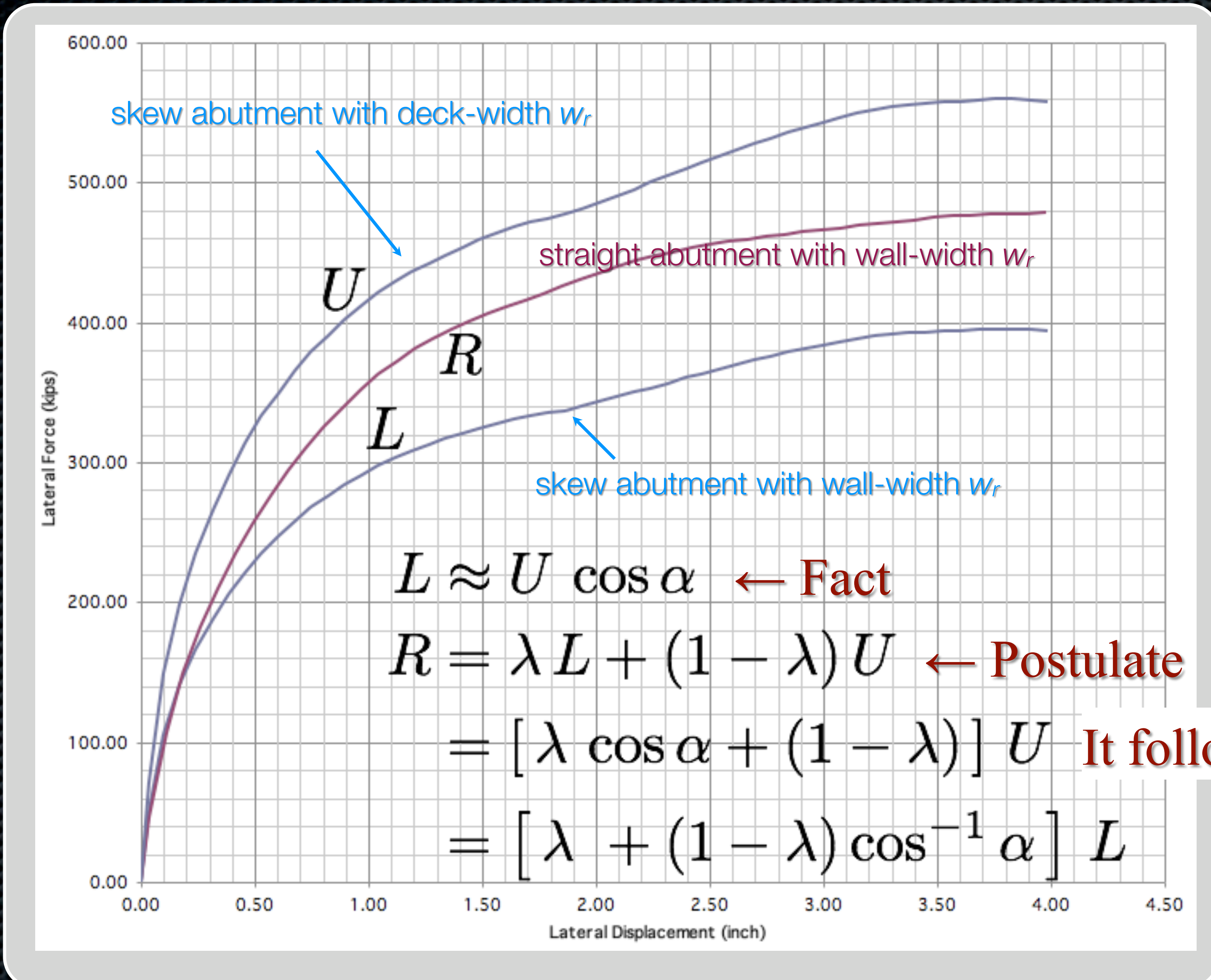


A different line of attack—A thought experiment



$$L \approx U \cos\alpha \quad \leftarrow \text{Fact}$$

$$R = \lambda L + (1-\lambda)\,U \quad \leftarrow \text{Postulate}$$

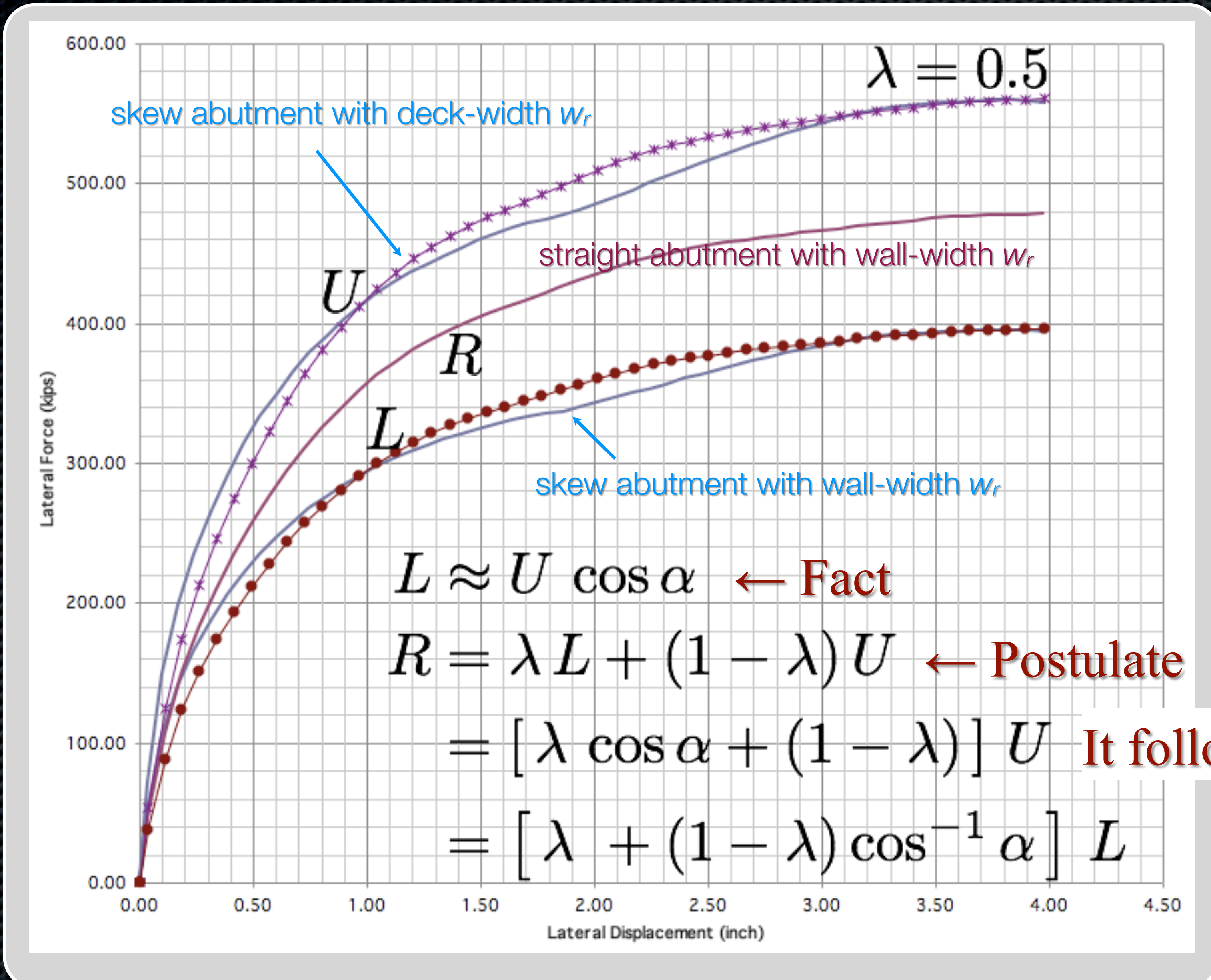
It follows that

$$= [\lambda \cos\alpha + (1-\lambda)]\; U$$

$$= \left[\lambda + (1-\lambda)\cos^{-1}\alpha\right] L$$

Side note: U is higher than R, because, in fact, $L_{skew} > L_{nom}$.

A different line of attack—A thought experiment



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Side note: U is higher than R, because, in fact, $L_{skew} > L_{nom}$.

A different line of attack—A thought experiment

The scaling law for non-rotating skew-abutments

$$L \approx U \cos\alpha$$

$$U = \frac{R}{(\cos\alpha - 1)\lambda + 1}$$

$$L = \frac{R\cos\alpha}{(\cos\alpha - 1)\lambda + 1}$$

GHFD model yields this curve

Thus, given soil properties and backwall height, the skew-angled abutment response (U or L) can be computed (from R).

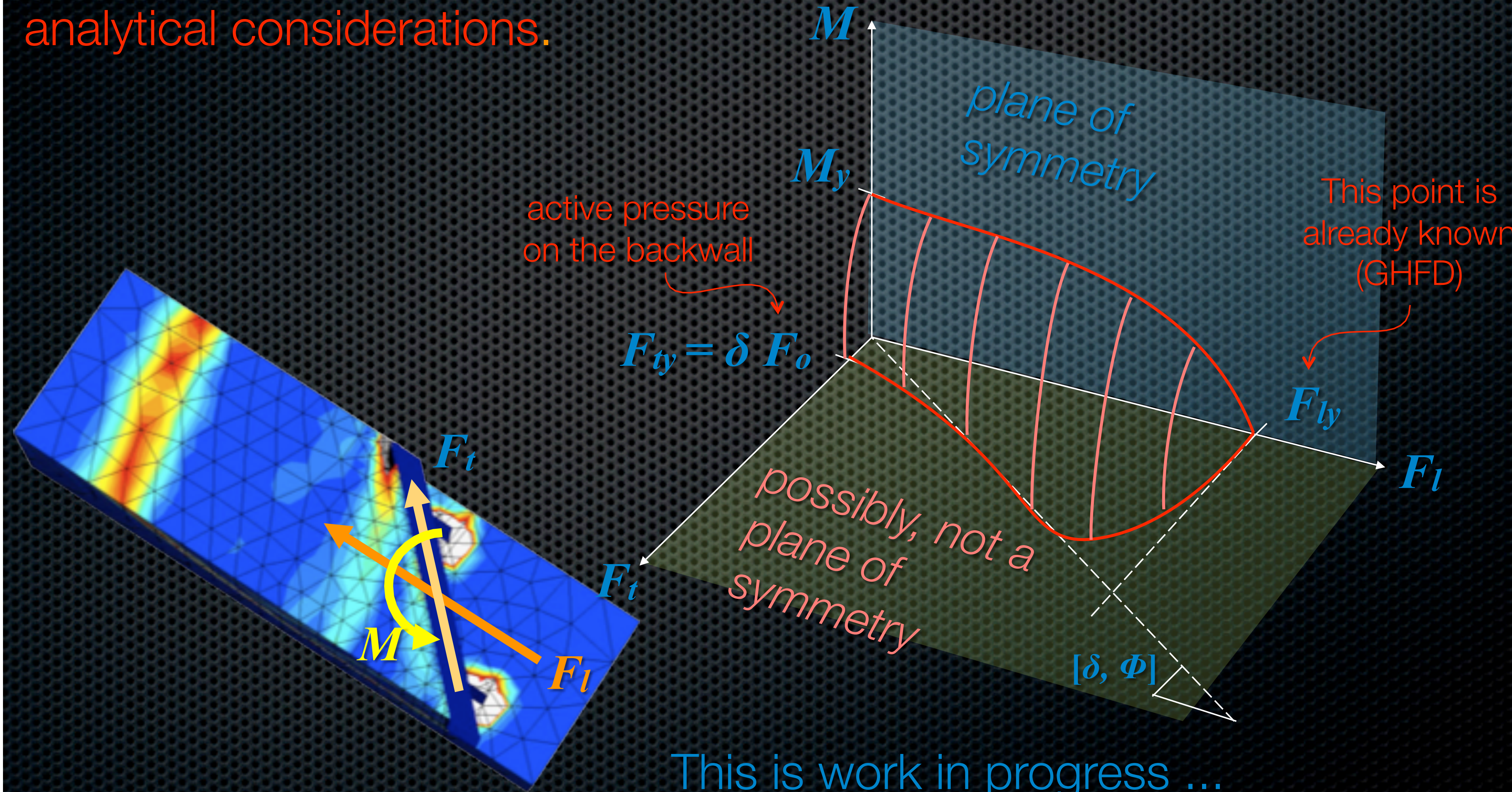
Q: Does scaling work for different skew angles and wider abutments?

A: Yes (*corrections may be needed for extreme skew angles*)!

Extension to skew abutments of torsionally flexible bridges

Development of a physically parameterized yield surface

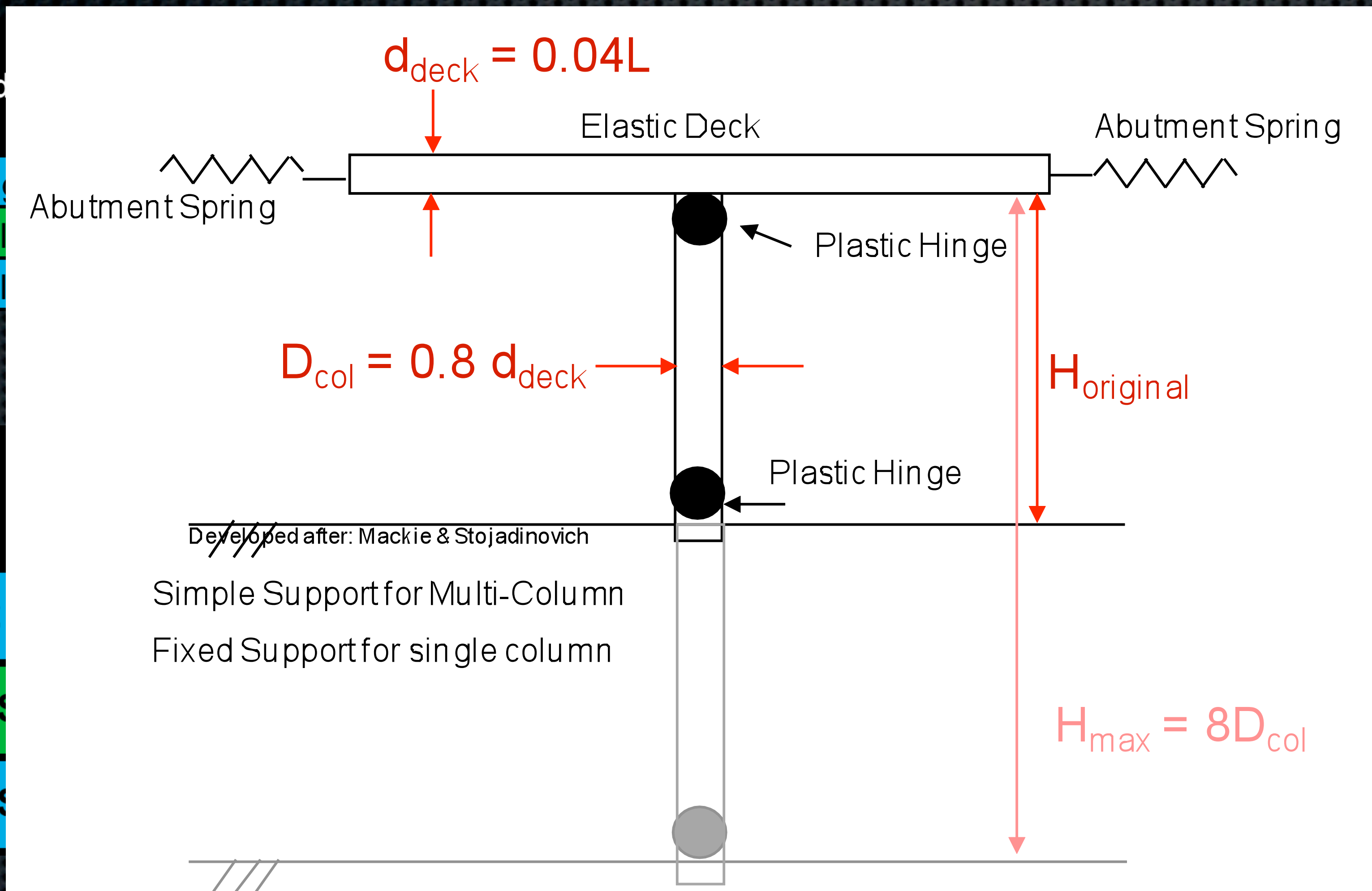
Approach: Develop a three-DOF macro-element through numerical simulations with 3D continuum FE models and analytical considerations.



This is work in progress ...

Bridge Matrix

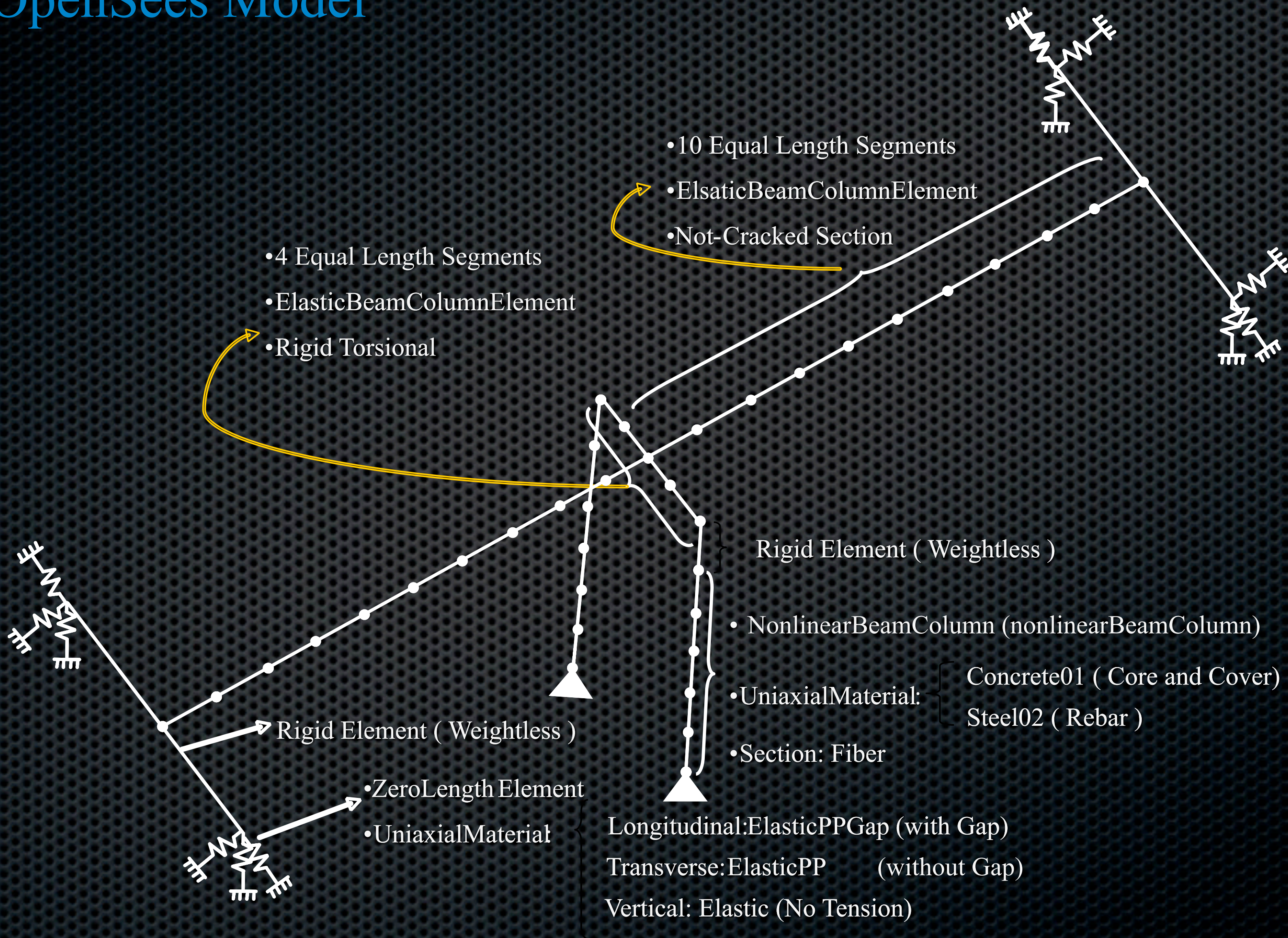
Brid	dth n)	Year Built
2 Span Sin	8.3	2001
2 Span Mul	23	2001
3 Span Mul	23.5	2001



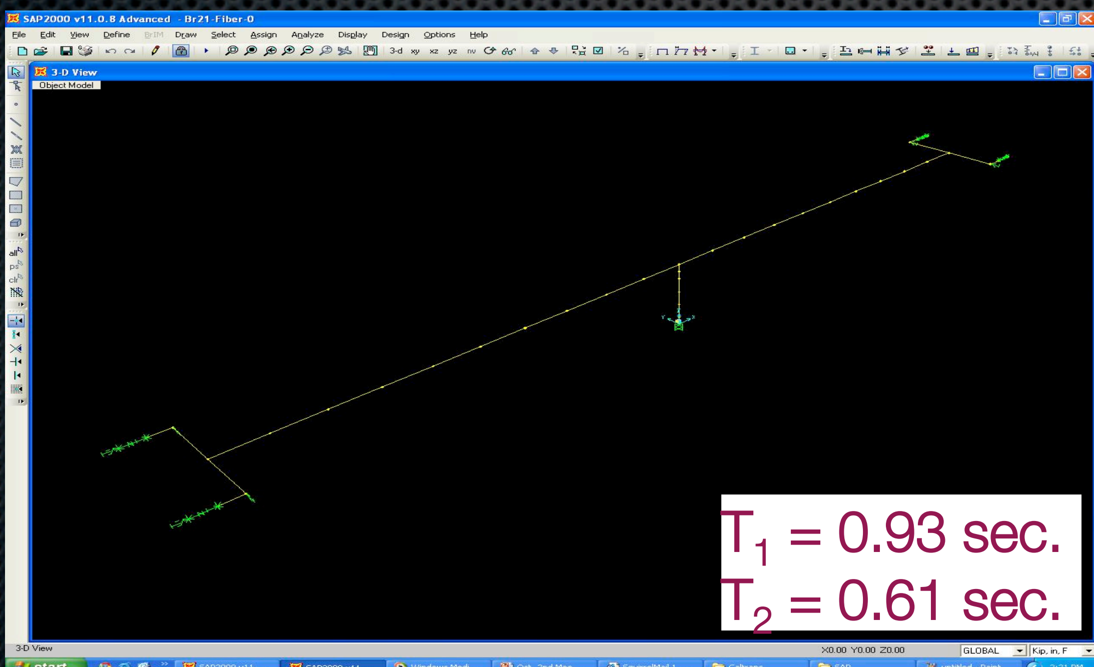
	ric	
	45°	60°
2		
2 S		
3 S		

Bridge Modeling

- OpenSees Model

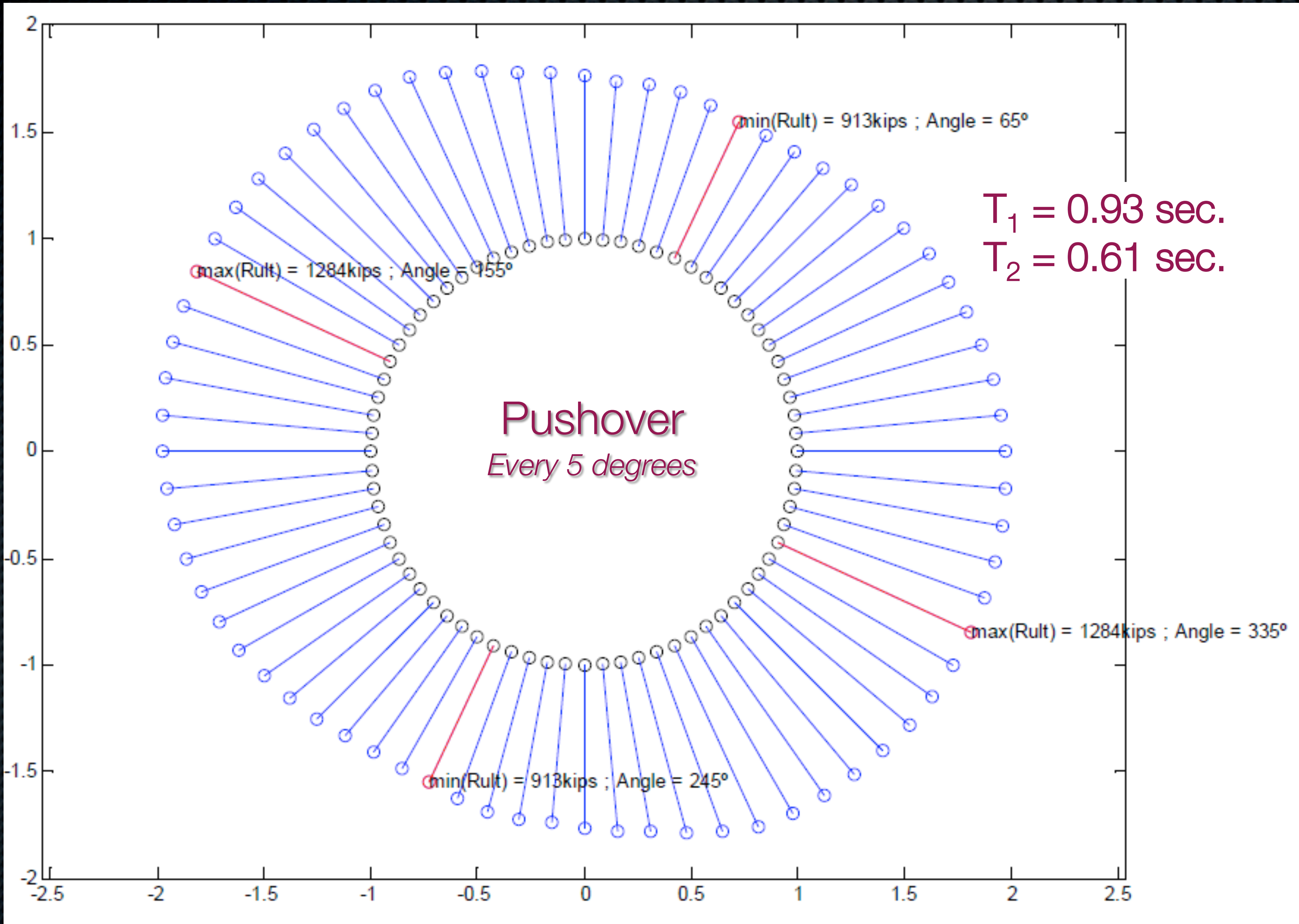


Bridge A: Two Span – Single-Column



- Two Spans: 33.105 m + 34.095 m
- Continuous cast in place prestressed concrete box girder. Half-cap beam integral with the deck
- One reinforced concrete column (1.68 m diameter)
- Reinforced concrete seat type abutments
- Steel piles

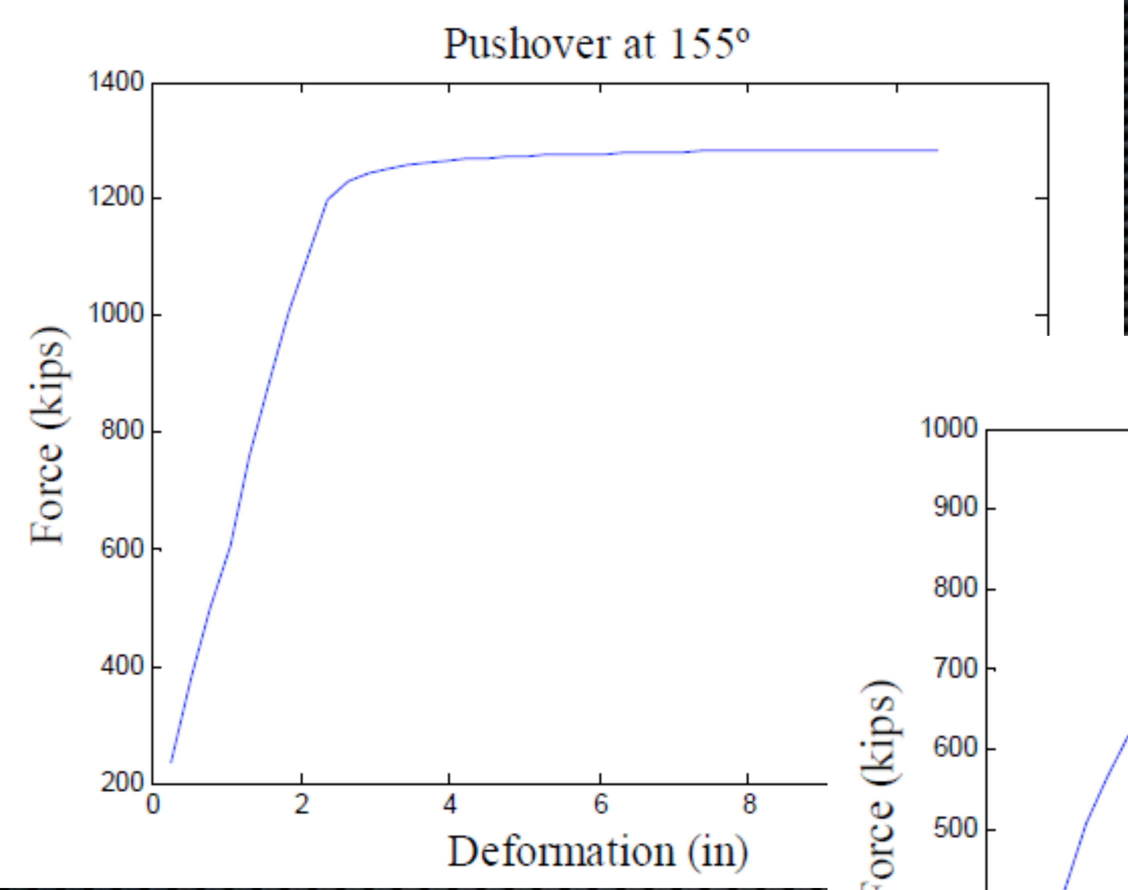
Bridge A: Two Span – Single-Column

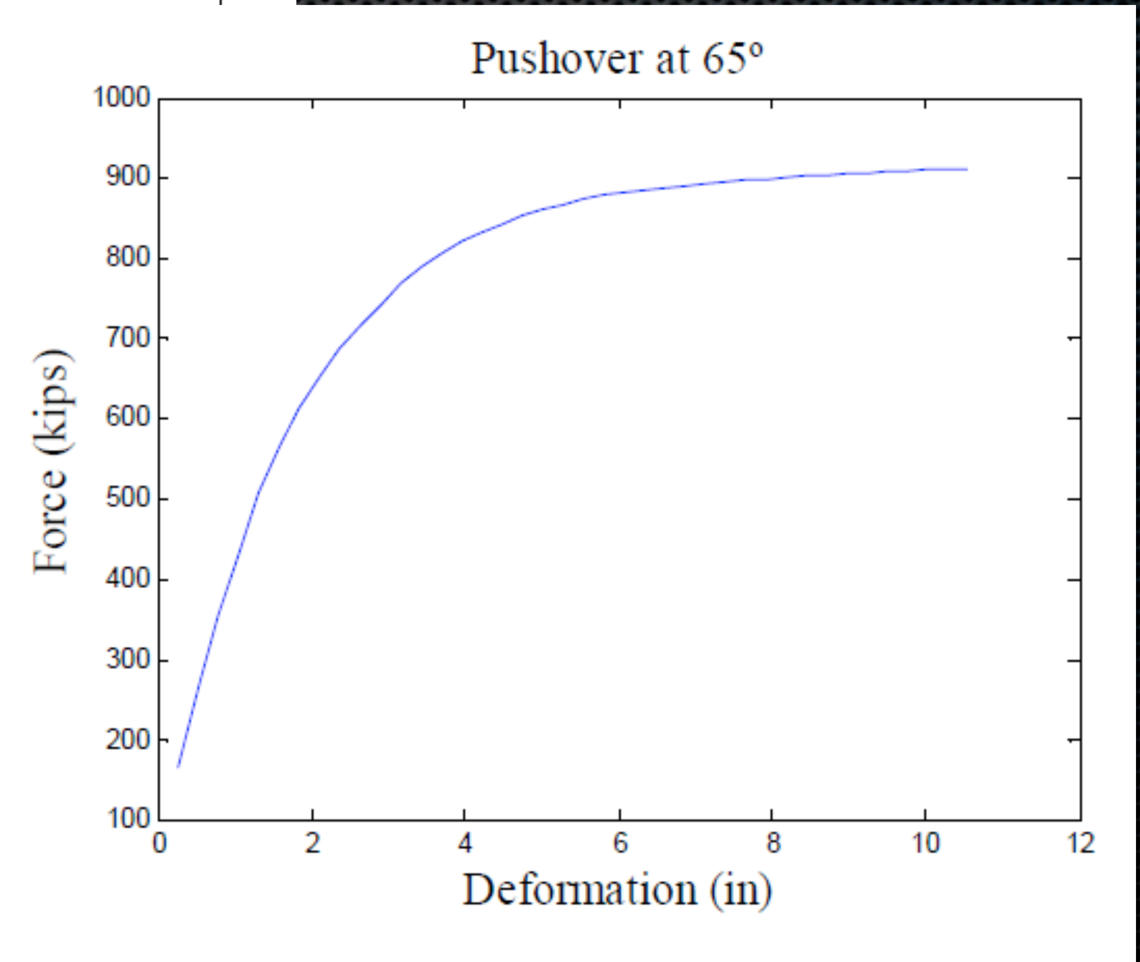


T_1 = 0.93 sec.

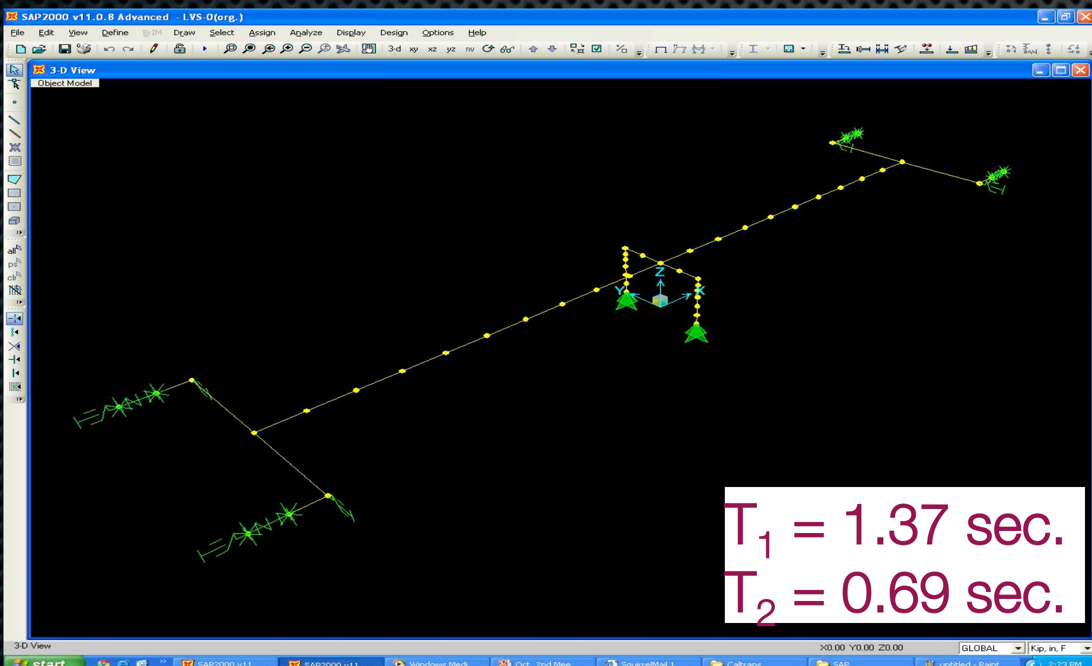
T_2 = 0.61 sec.

Bridge A: Two Span – Single-Column



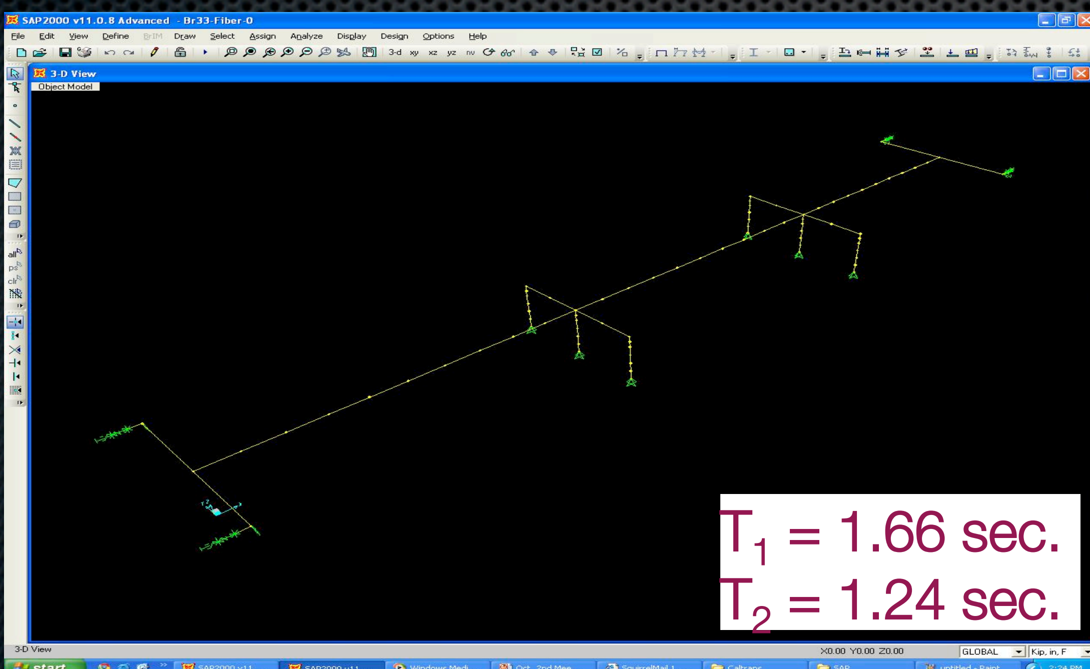


Bridge B: Two Span – Multi-Column



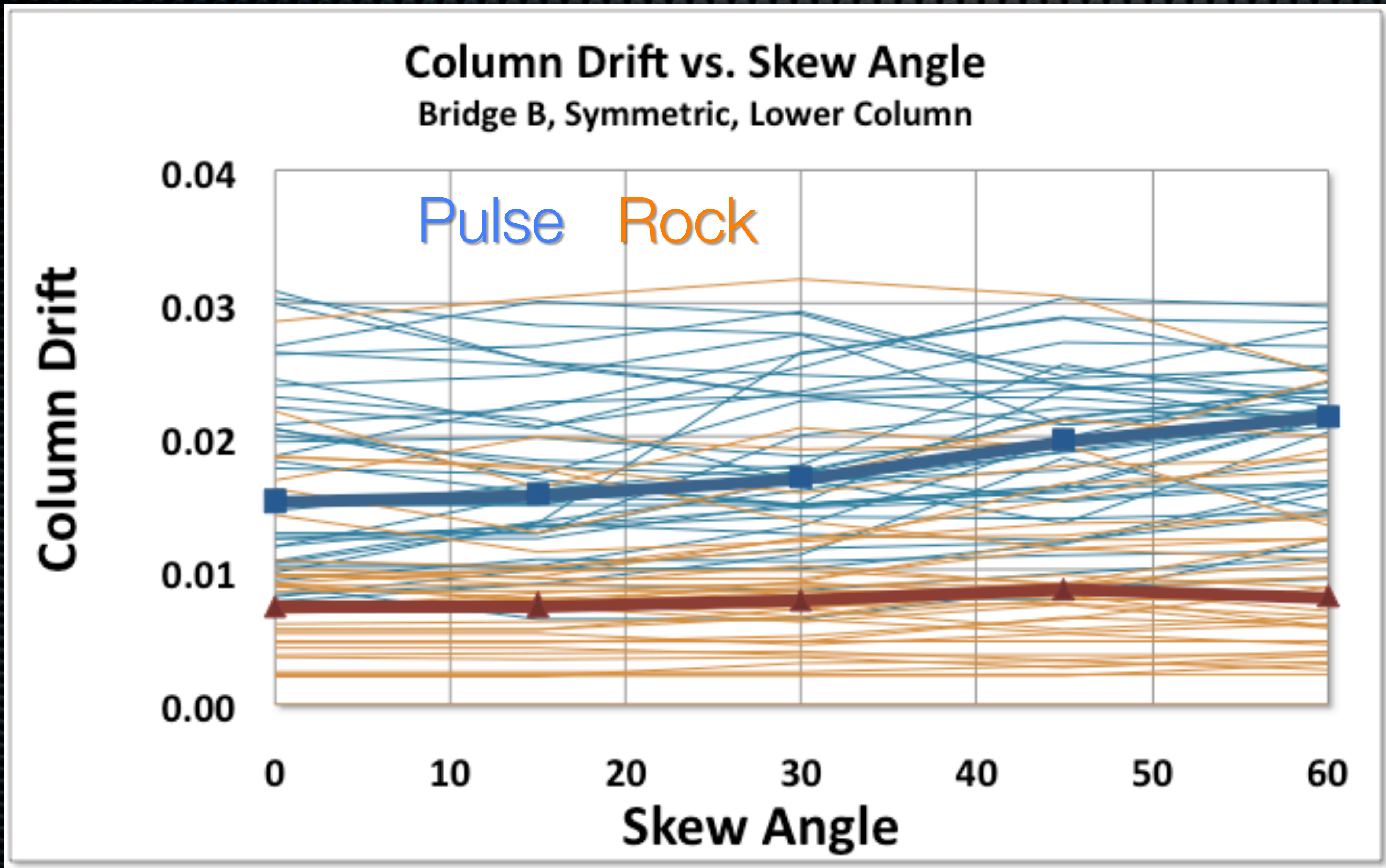
- Two spans: 47.2 m + 44.2 m
- Continuous cast in place prestressed concrete box girder. Cap beam integral with the deck
- Two RC circular columns with 1.7 m diameter supported on CIDH Piles
- Reinforced concrete seat type abutments
- Non-skewed abutment bridge
- Concrete piles

Bridge C: Three Span – Multi-Column

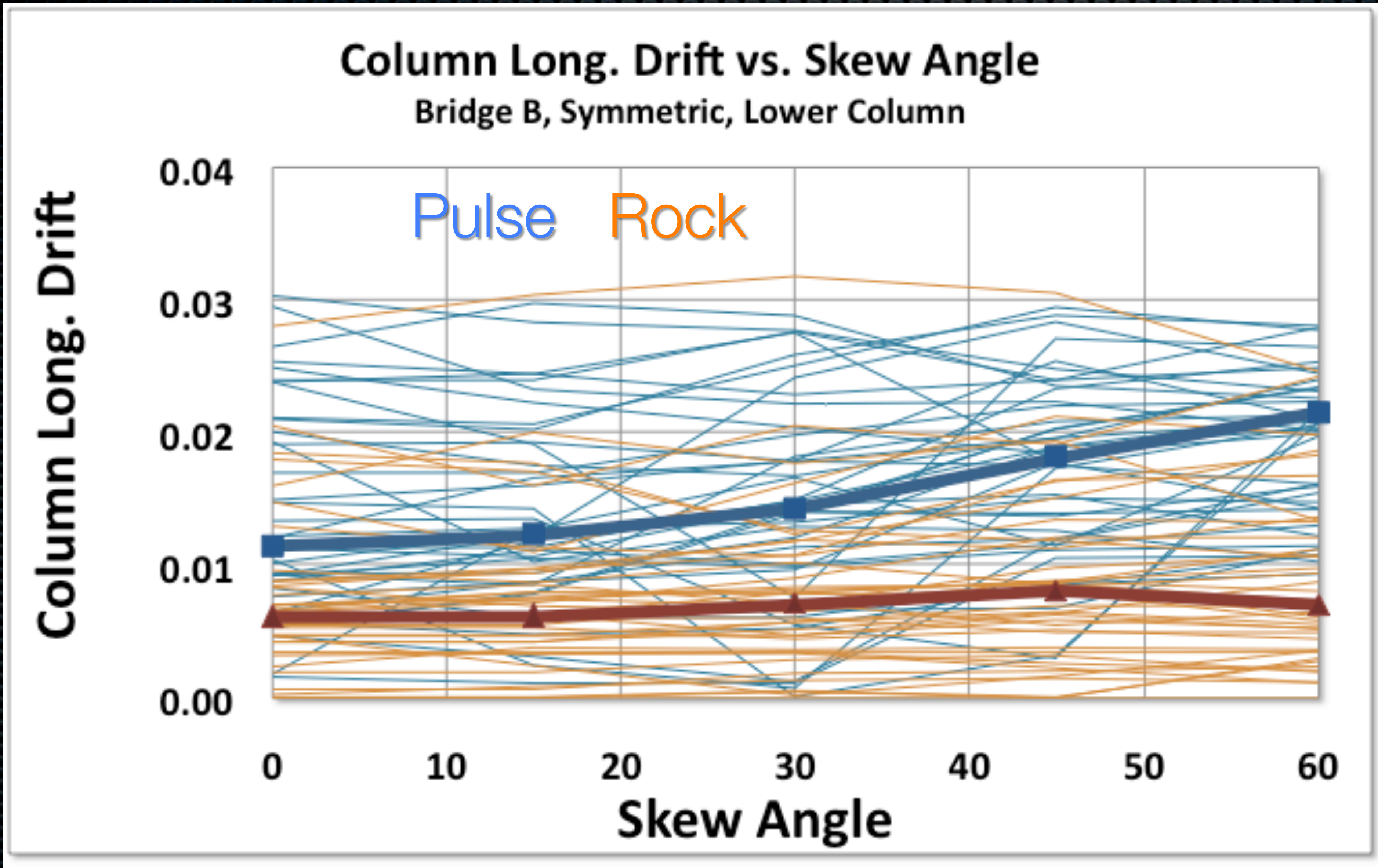


- Three Spans: 47.6 m + 43.9 m + 36.0 m
- Continuous cast in place prestressed concrete box girder. Cap beam integral with the deck .
- Three reinforced concrete columns per bent (1.68 m diameter)
- Reinforced concrete cantilever type abutments
- Skewed abutment bridge (36 degree skewness)
- Steel piles

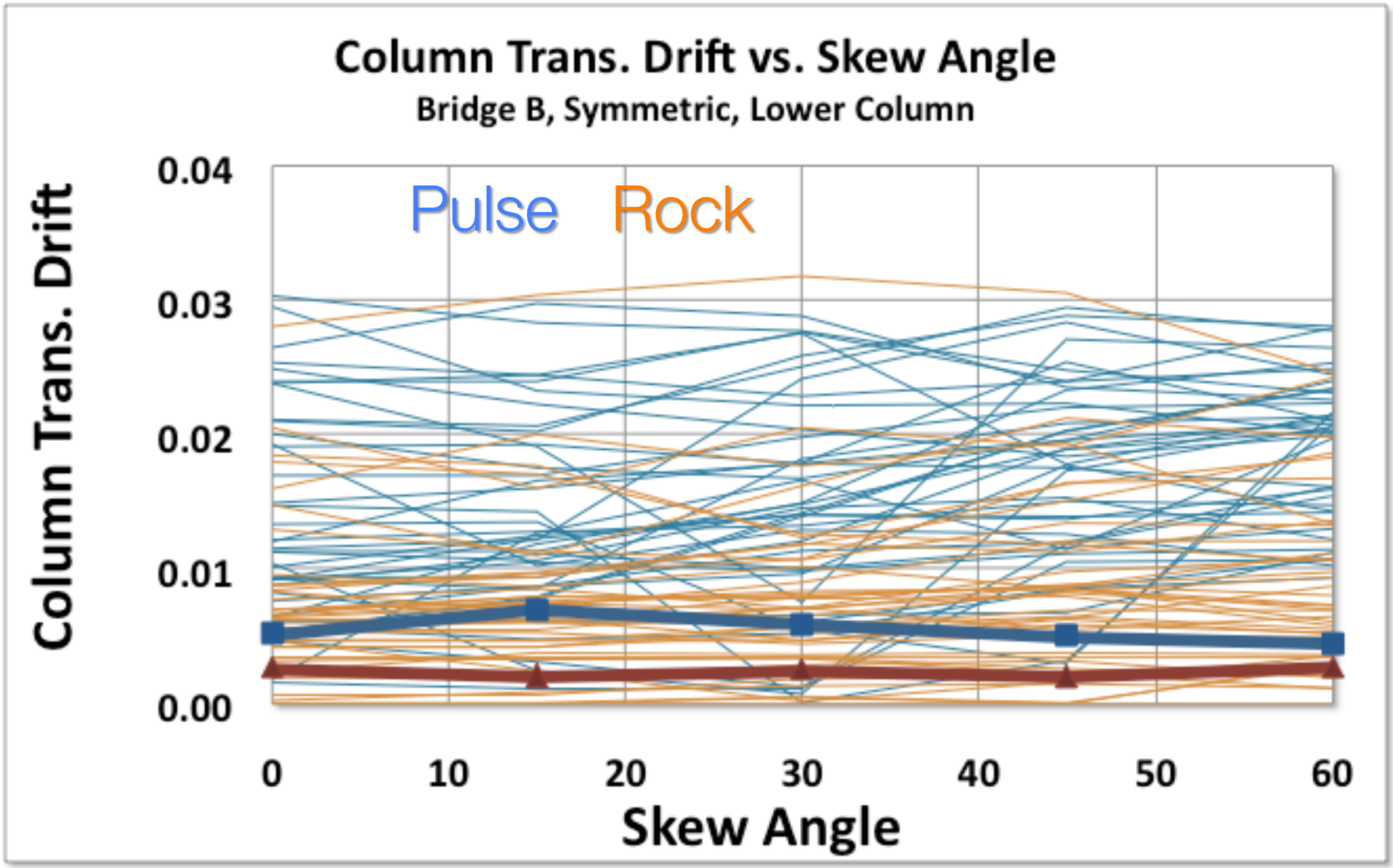
Bridge B: Column Drift vs. Skew Angle



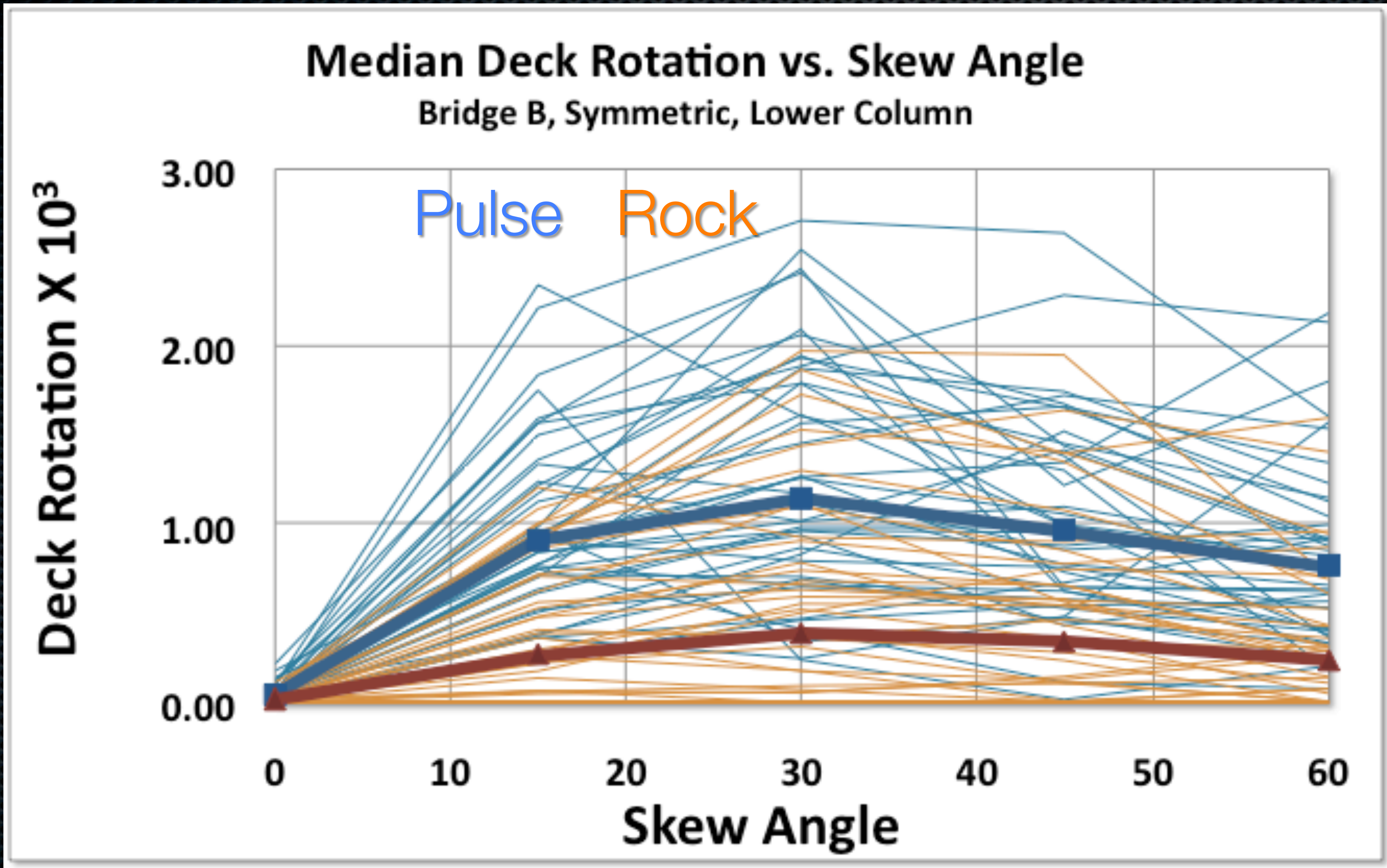
Bridge B: Column Long. Drift vs. Skew Angle



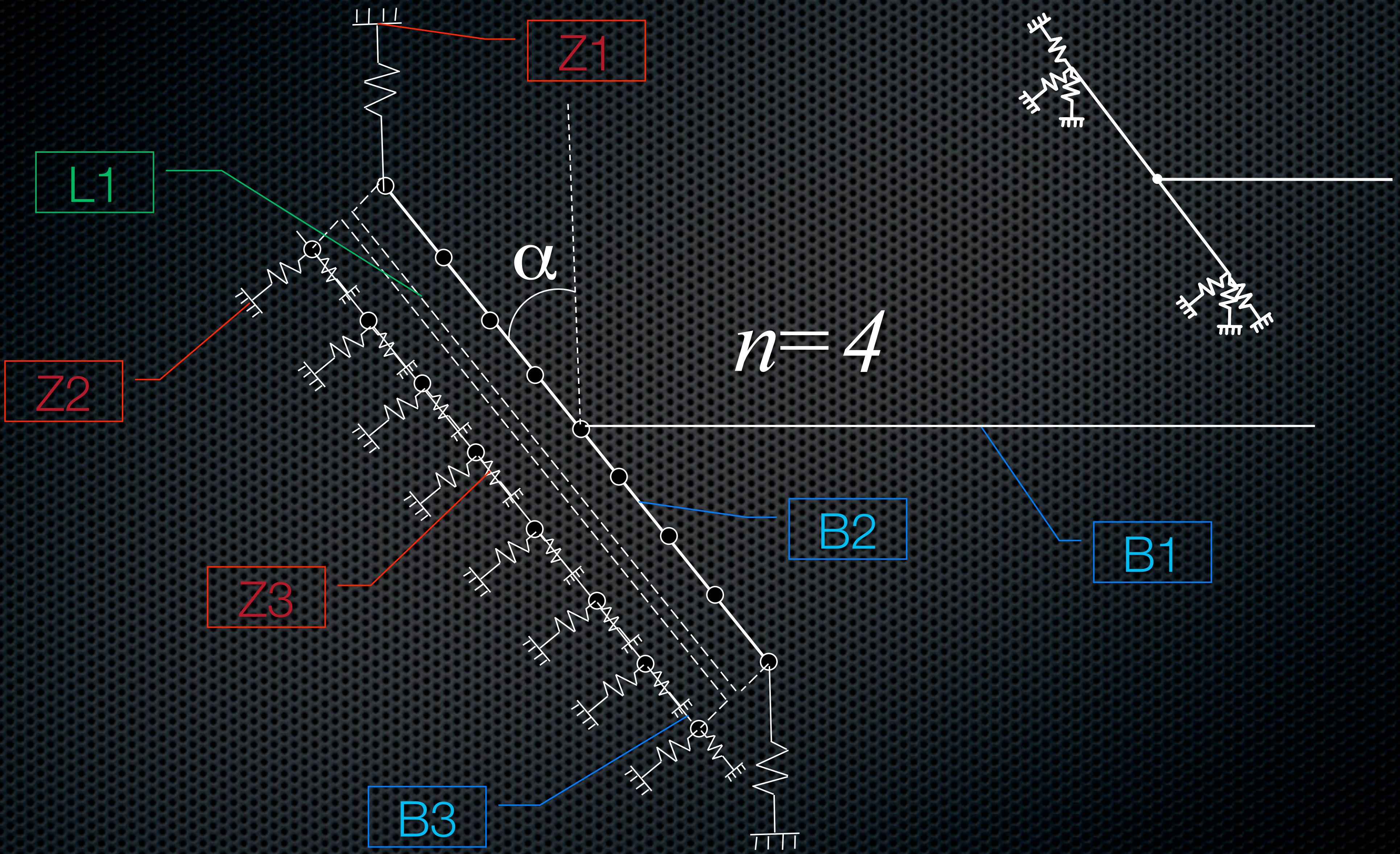
Bridge B: Column Trans. Drift vs. Skew Angle



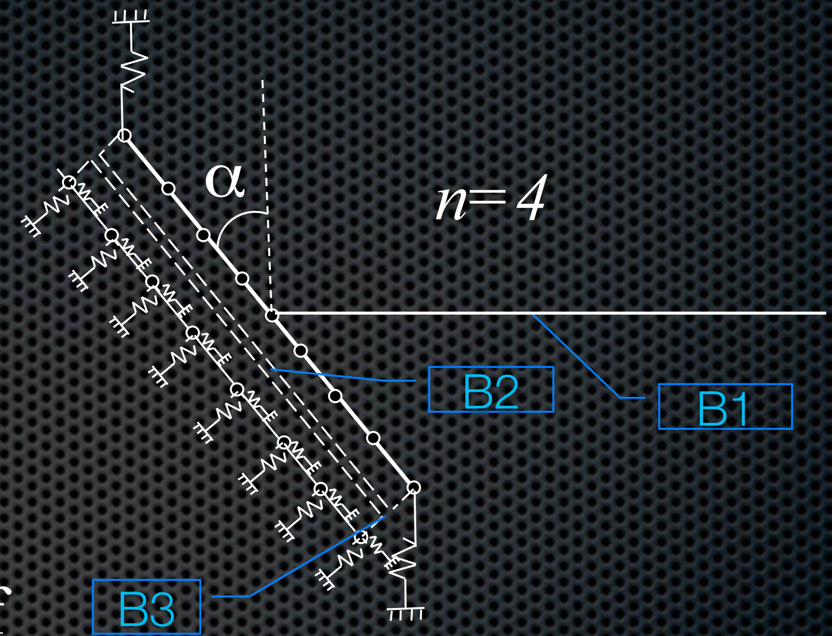
Bridge B: Deck Rotation vs. Skew Angle



Updated Abutment Model



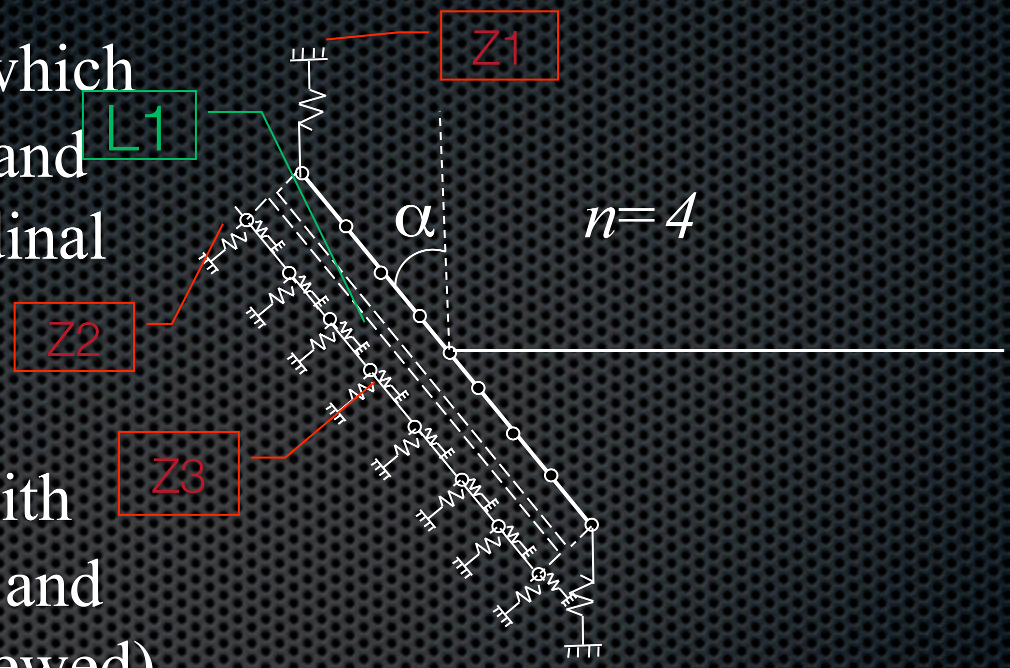
B1: Elastic Beam Column Element with Structural Superstructure Properties



B2: Rigid Element with Length of Superstructure Width

B3: Elastic Beam Column Element with Backwall Structural Properties

L1: twoNodeLink Element s which are released in all directions and only transfer force in longitudinal direction (Skewed)



Z1: zeroLength Element with Backbone Curve of Stiffness and Strength of Shear Key (Not Skewed)

Z2: zeroLength Element Located in Equal Distance from each others with SDC Backbone Curve (Skewed)

Z3: zeroLength Element with Shear Stiffness of Soil, behind of Backwall (Skewed)

Next Steps

1. Develop a three-DOF macro-element through numerical simulations with 3D continuum FE models and analytical considerations for torsionally flexible bridges.

2. Finalize the bridge models including the new abutment model.

3. Rotate Ground motions?

4. Quantify the Sensitivity of Skew Bridge Response and Damage Metrics to Key Input Parameters

5. Update Caltrans Seismic Design Criteria for Skew-Angled Bridges