Performance-Based Seismic Assessment of Skewed Bridges

An update

by

Ertugrul Taciroglu, Payman Khalili-Tehrani, UCLA

Farzin Zareian, Peyman Kaviani, UCI

PEER Transportation Systems Research Program

Coordination Meeting at UC-Berkeley, August 25, 2009

Performance-Based Seismic Assessment of Skewed Bridges

An update

collaborators

Anoosh Shamsabadi, PhD, PE
Senior Bridge Engineer
Office of Earthquake Engineering, Caltrans

Majid Sarraf, PhD, PE
Senior Project Manager/Seismic Specialist
PTG, Bridge and Tunnel Division, Parsons

PEER Transportation Systems Research Program

Coordination Meeting at UC-Berkeley, August 25, 2009

Outline

1. Project overview **FZ**
2. Matrix of skew bridges to be assessed **FZ**
3. Modeling skew abutment response **ET**
4. Discussion

Project Overview

1 **Lead, UCLA**

Develop Experimentally Validated Macro-element Models for Skew Abutments

2

Adapt Macroelement Models for Biaxial Pile/Foundation-Soil Interaction

3 **Lead, UCI**

Develop a Database of Simulation Models for Skew Bridges

4

Develop/Select Sets of Representative Ground Motions

5

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

6

Update Caltrans Seismic Design Criteria for Skew-Angled Bridges

Defining a bridge analysis matrix

- Need recently designed bridges
- Box-girder deck and seat-type abutment
- Located at a highly seismic region
- Availability of as-built structural drawings

Skewed Bridge Model Matrix

	Column Height	Symmetric					Non-symmetric				
		00°	15°	30°	45°	60°	00°	15°	30°	45°	60°
2 Span Single Column	Lower										
	Upper										
2 Span Multiple Column	Lower										
	Upper										
3 Span Single Column	Lower										
	Upper										
3 Span Multiple Column	Lower										
	Upper										
Single Span											

Bridge modeled and analysis has started

Bridge in modeling phase

No action yet

Existing Bridges as Seed Models

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
3 Span Single Column	29 0318	JACK TONE ROAD OH	127.5	23.5	2001
3 Span Multiple Column	55 0835H	E91-5 HOV CONNECTOR OH	141	23.6	2000

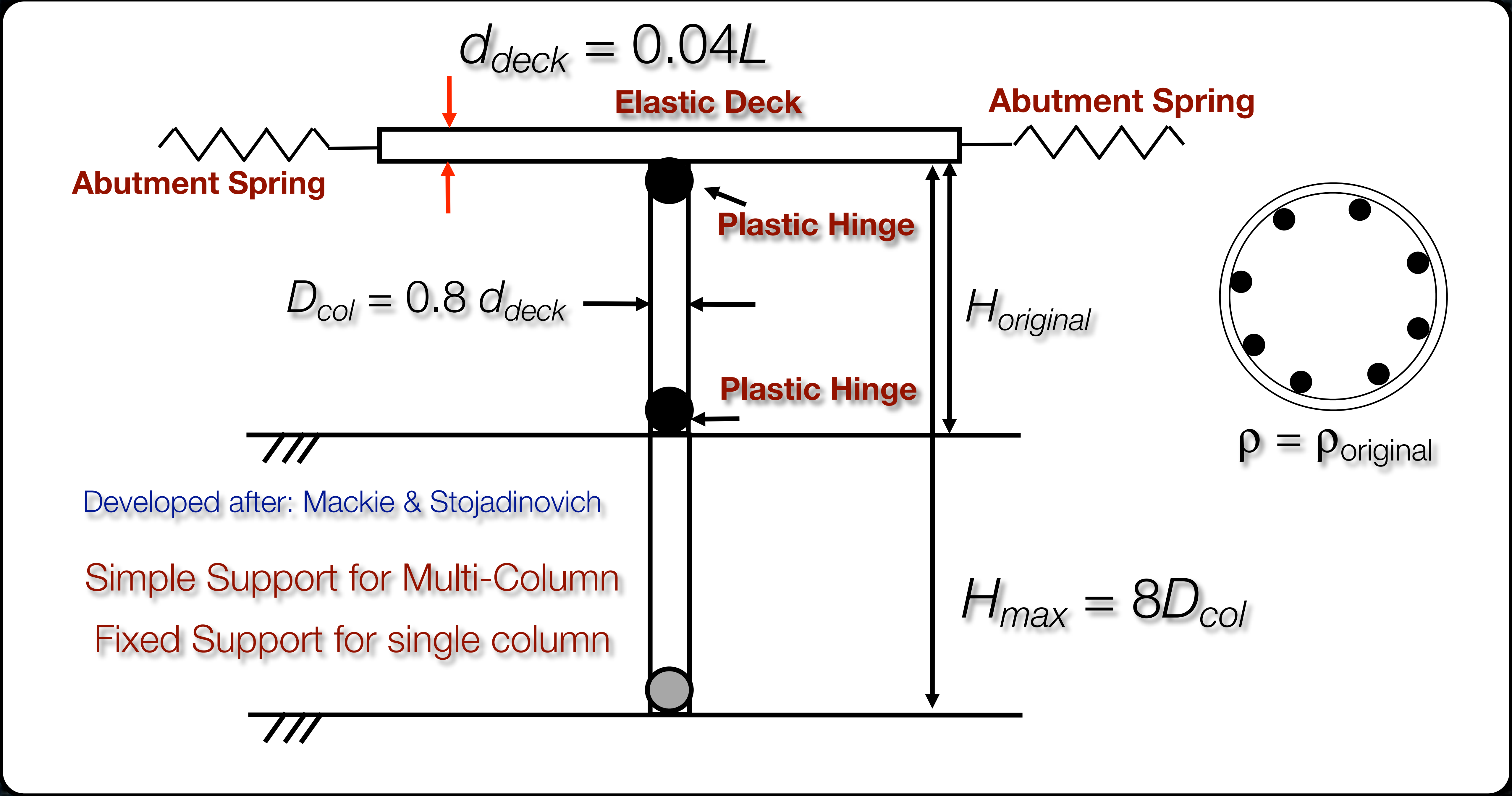
2 Span Single Column

Jacktone – SB 99

2 Span Multiple Column

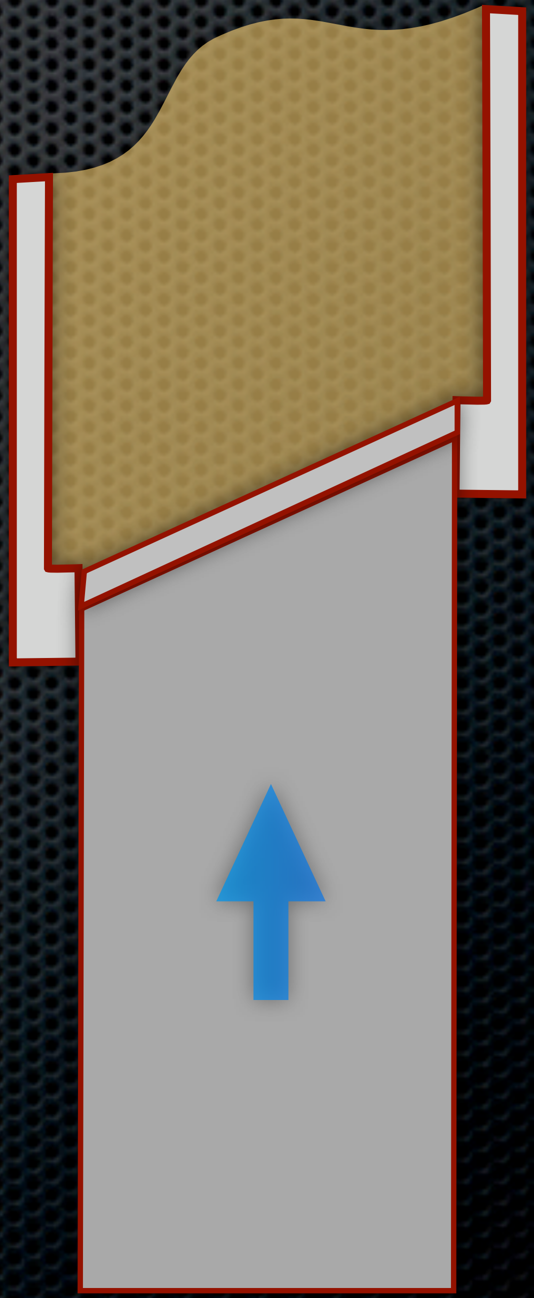
La Veta Ave. / CA-55

Rules for varying bridge structural parameters from seed models



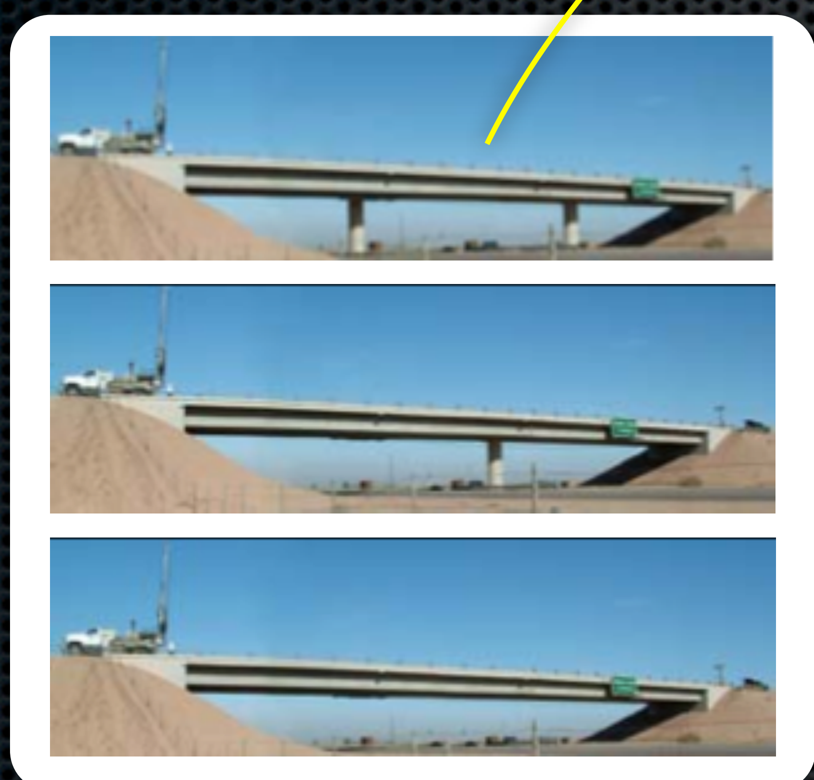
Development of Macroelements for Skew Abutments

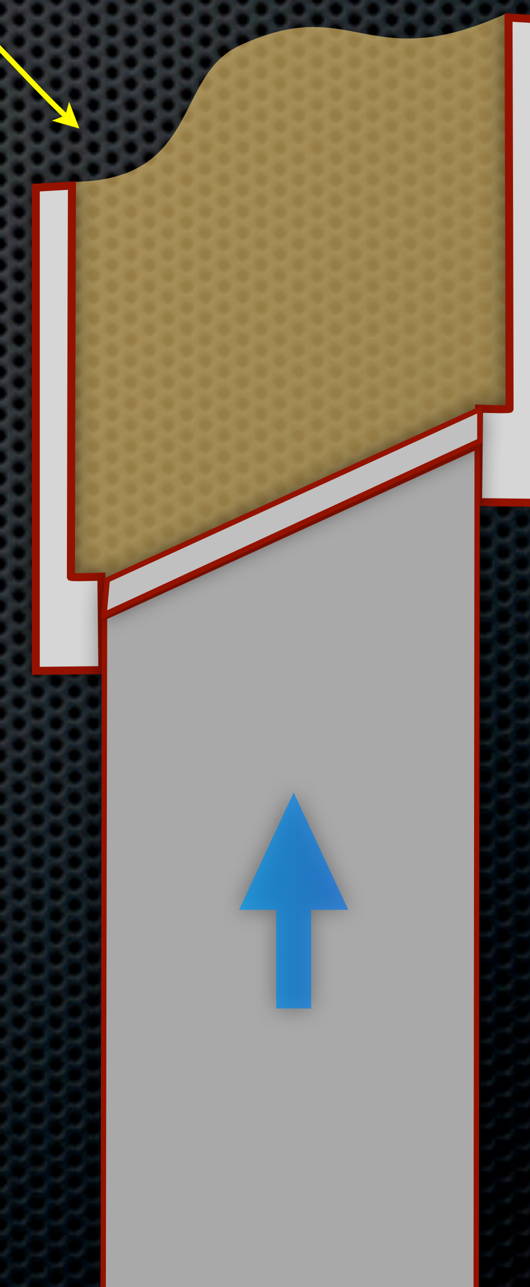
Skew-angled abutments



Skew-angled abutments

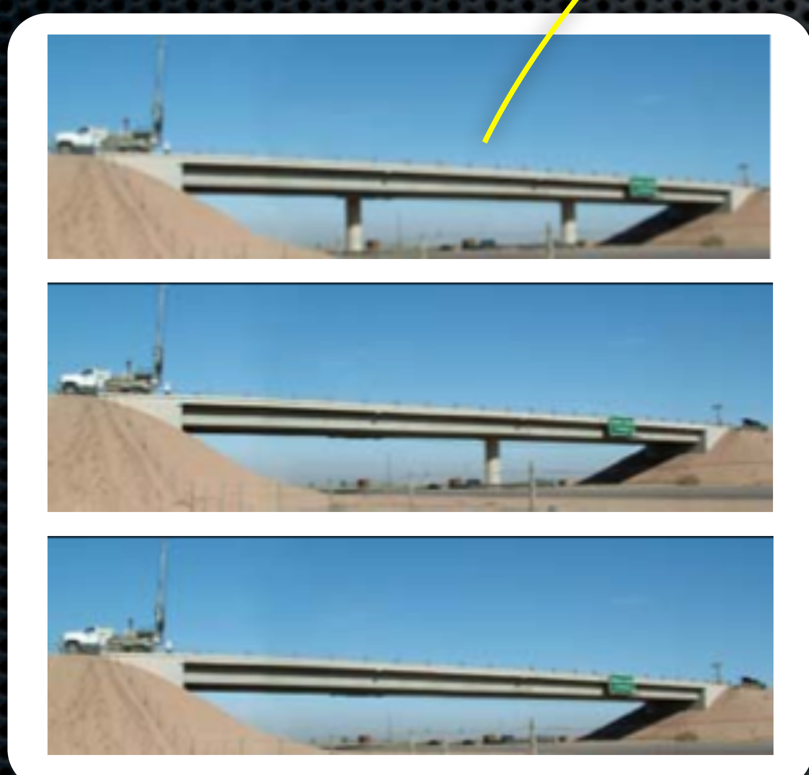
torsionally stiff

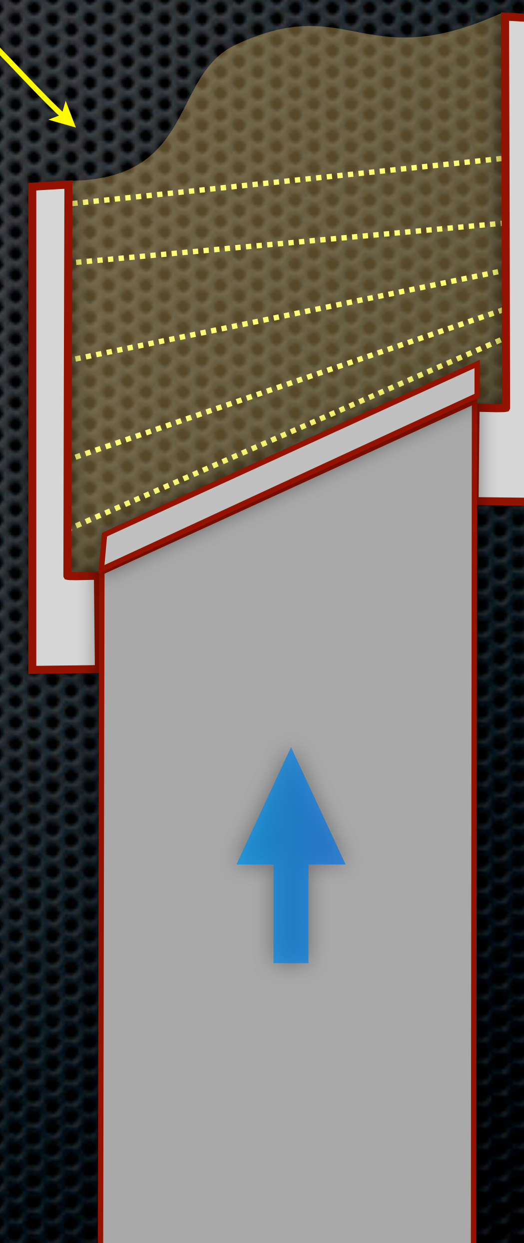




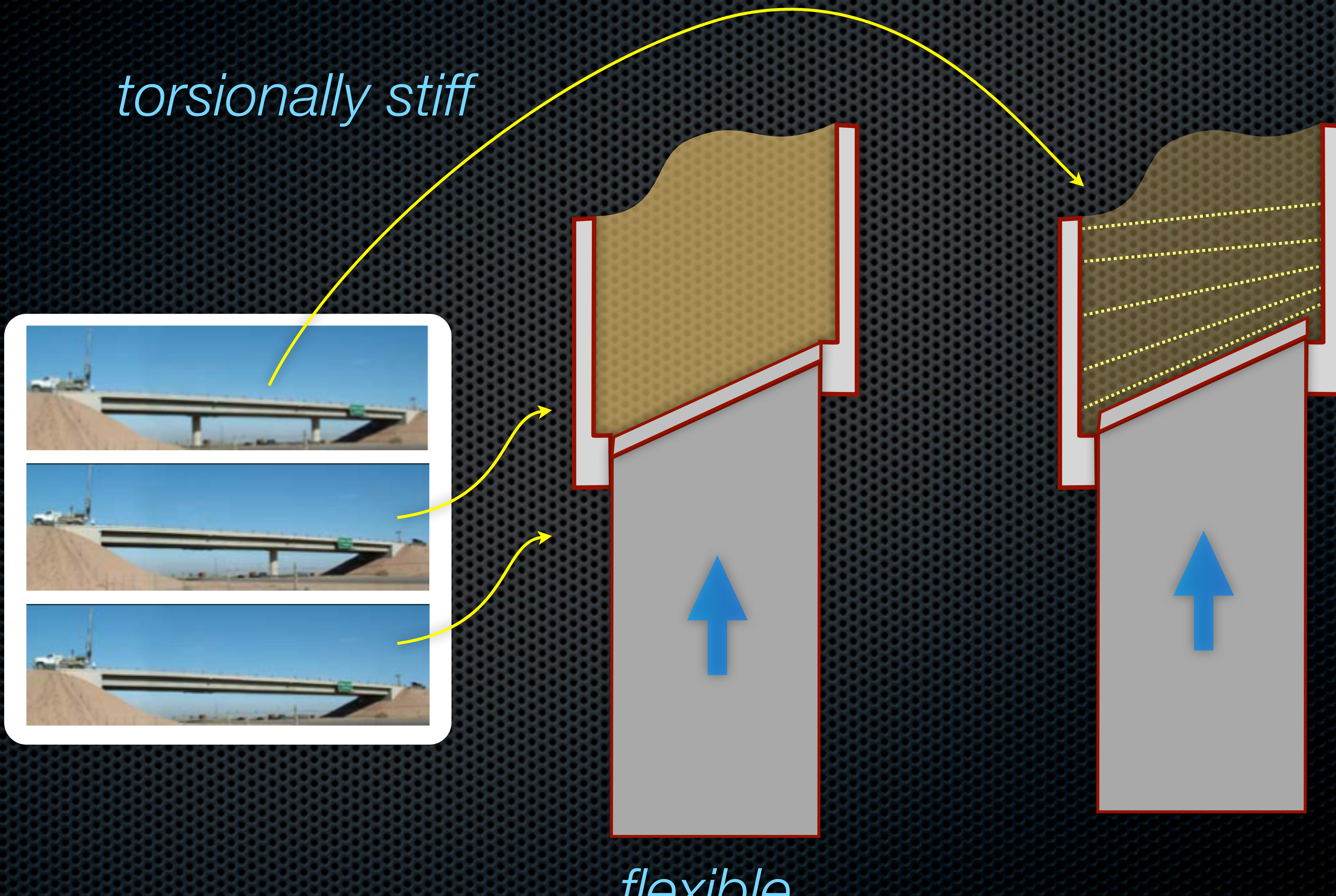
Skew-angled abutments

torsionally stiff

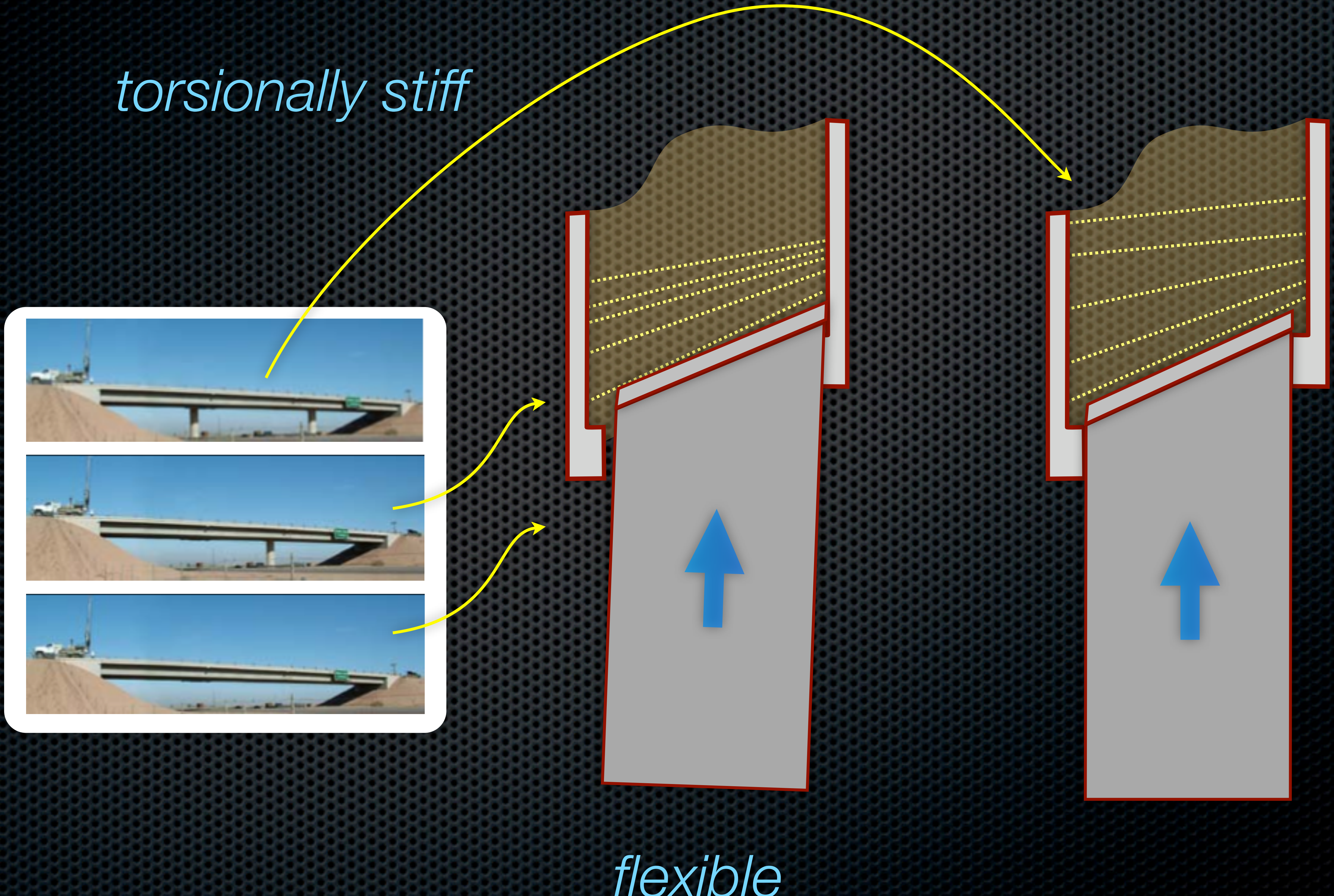




Skew-angled abutments



Skew-angled abutments

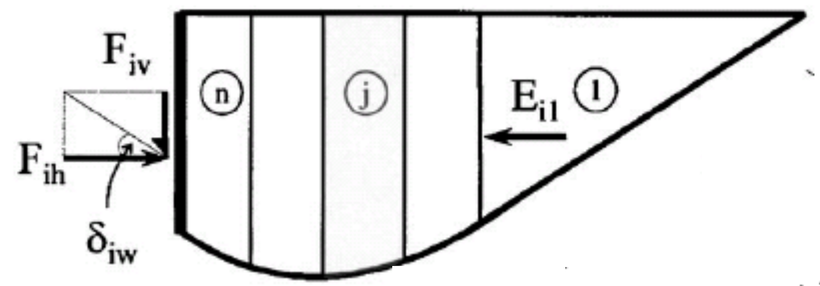


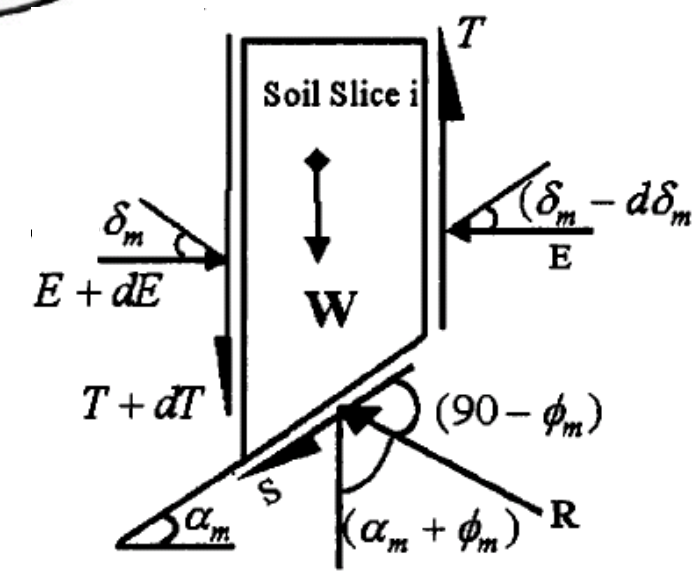
Past Work (Caltrans)

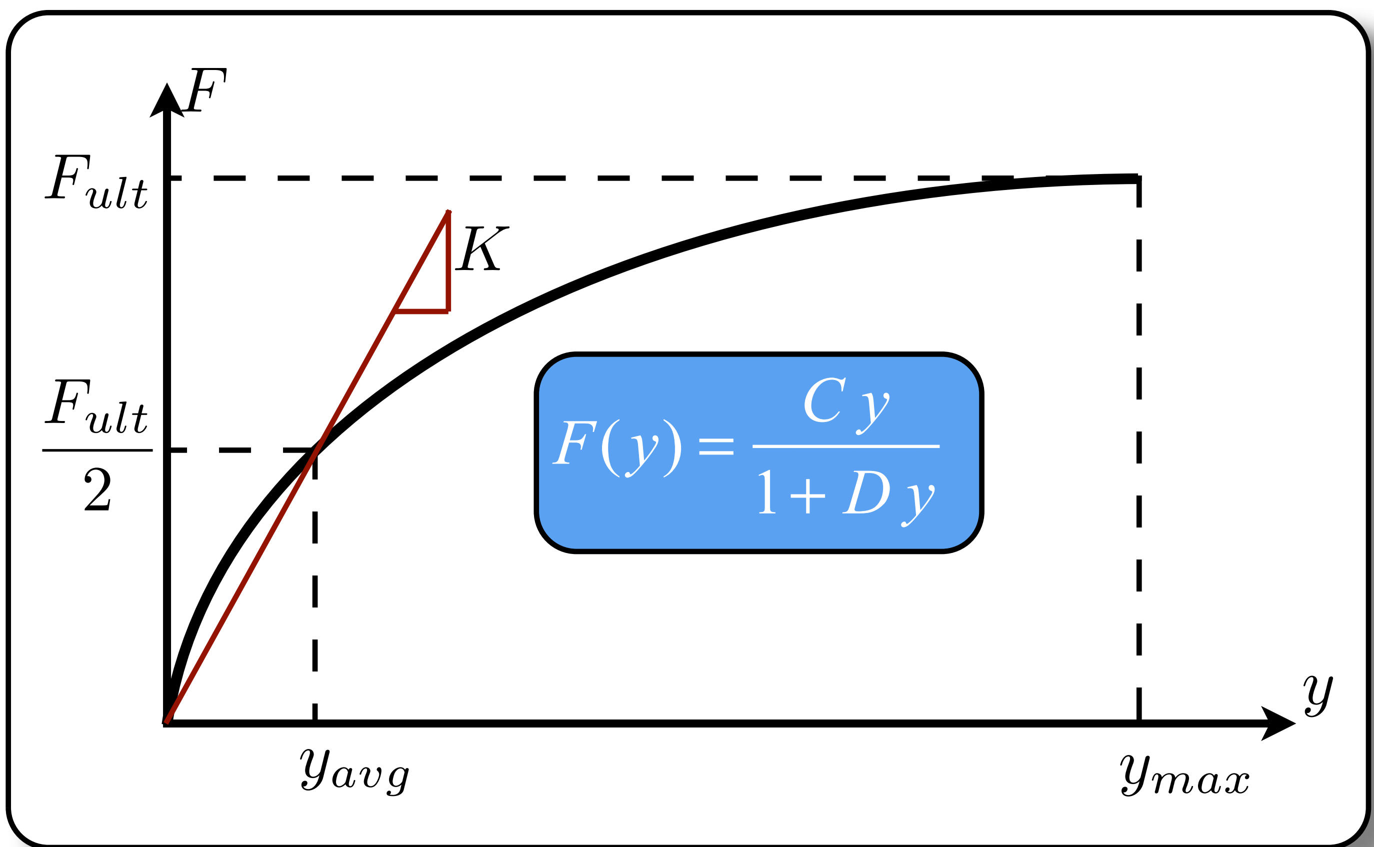
Model for Zero-Skew

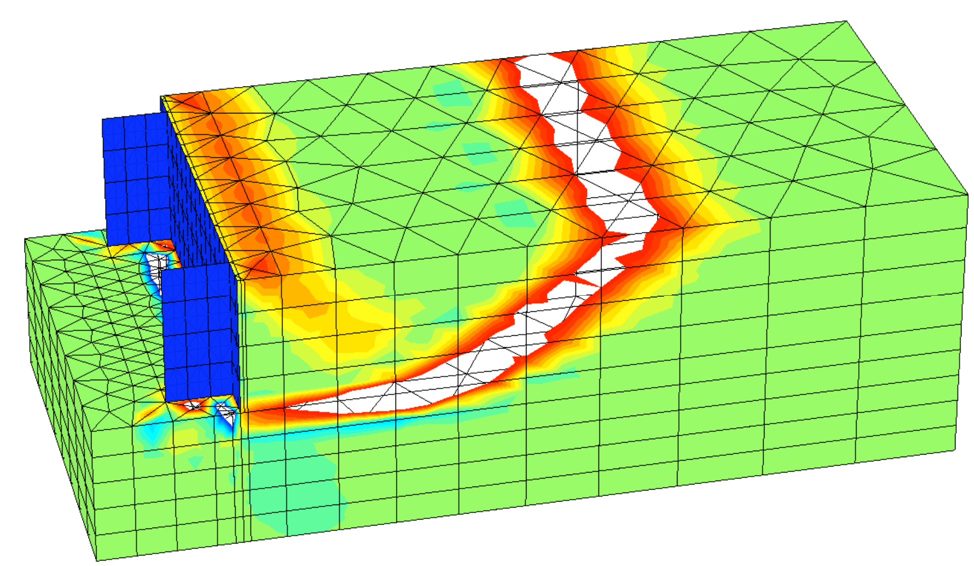
Modeling Approaches

1. Limit equilibrium (LSH) models
2. Finite element models
3. *Simplified (HFD) models*





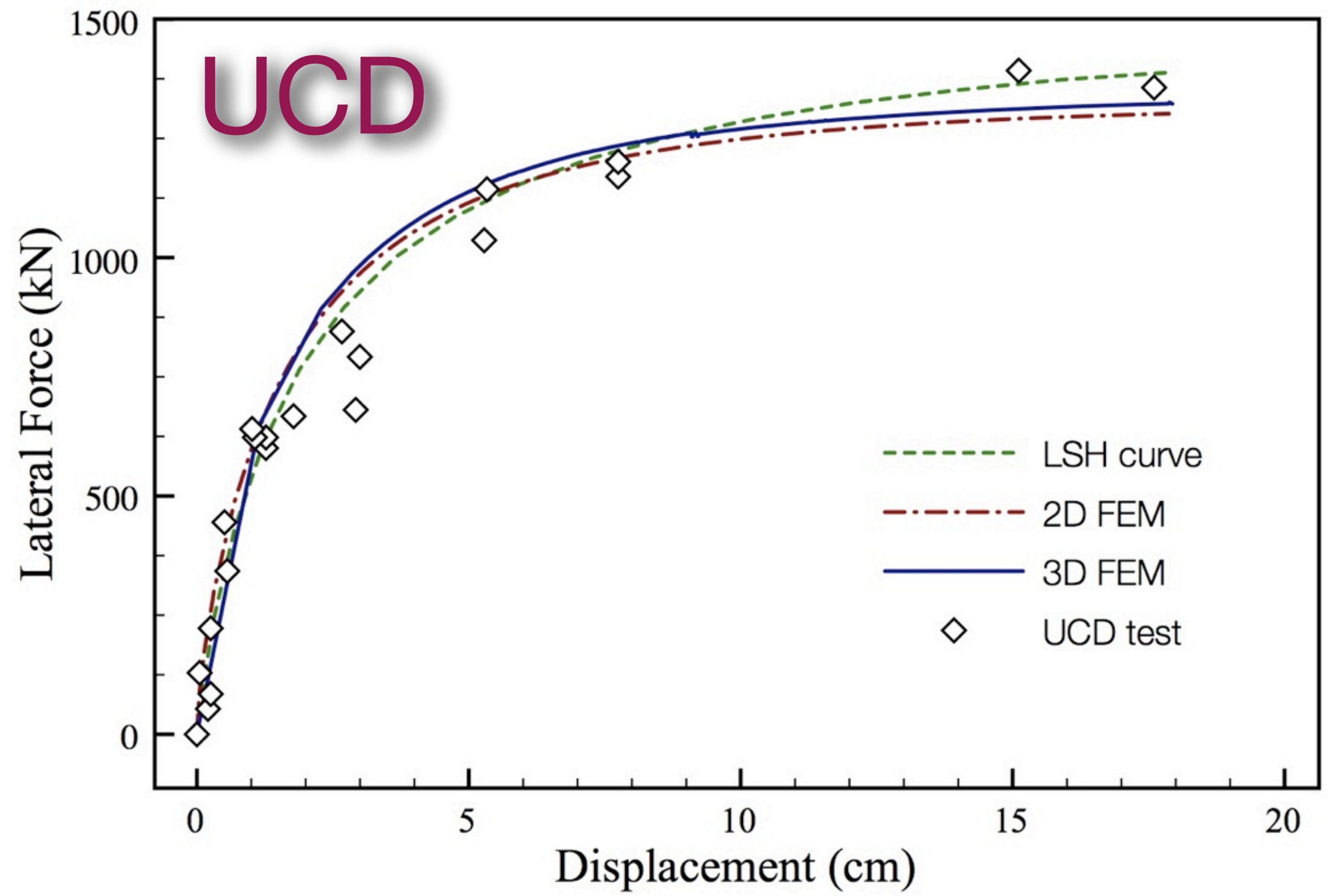




Validation

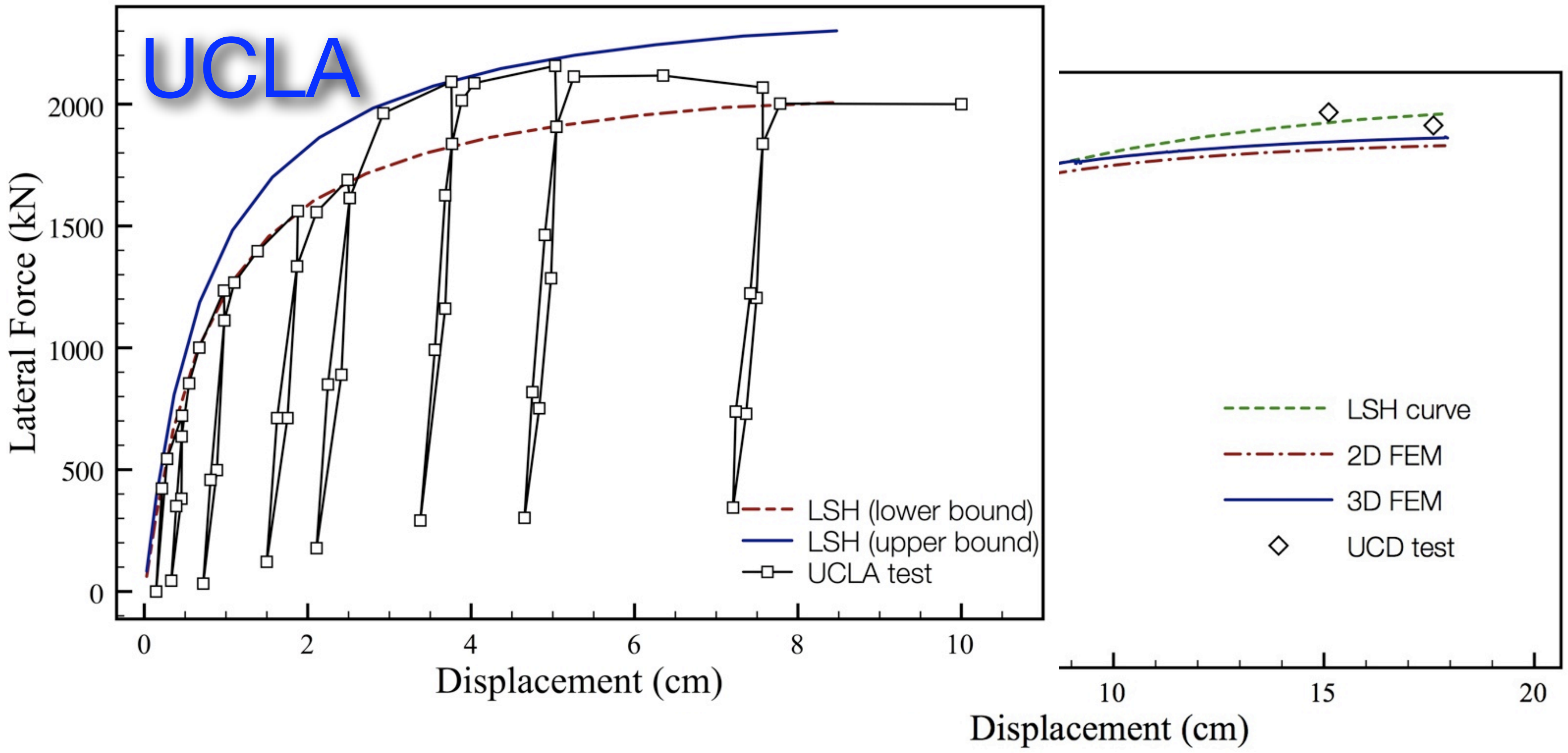
Validation

✦ UCD test by Romstad et al. (1995) (cohesive)



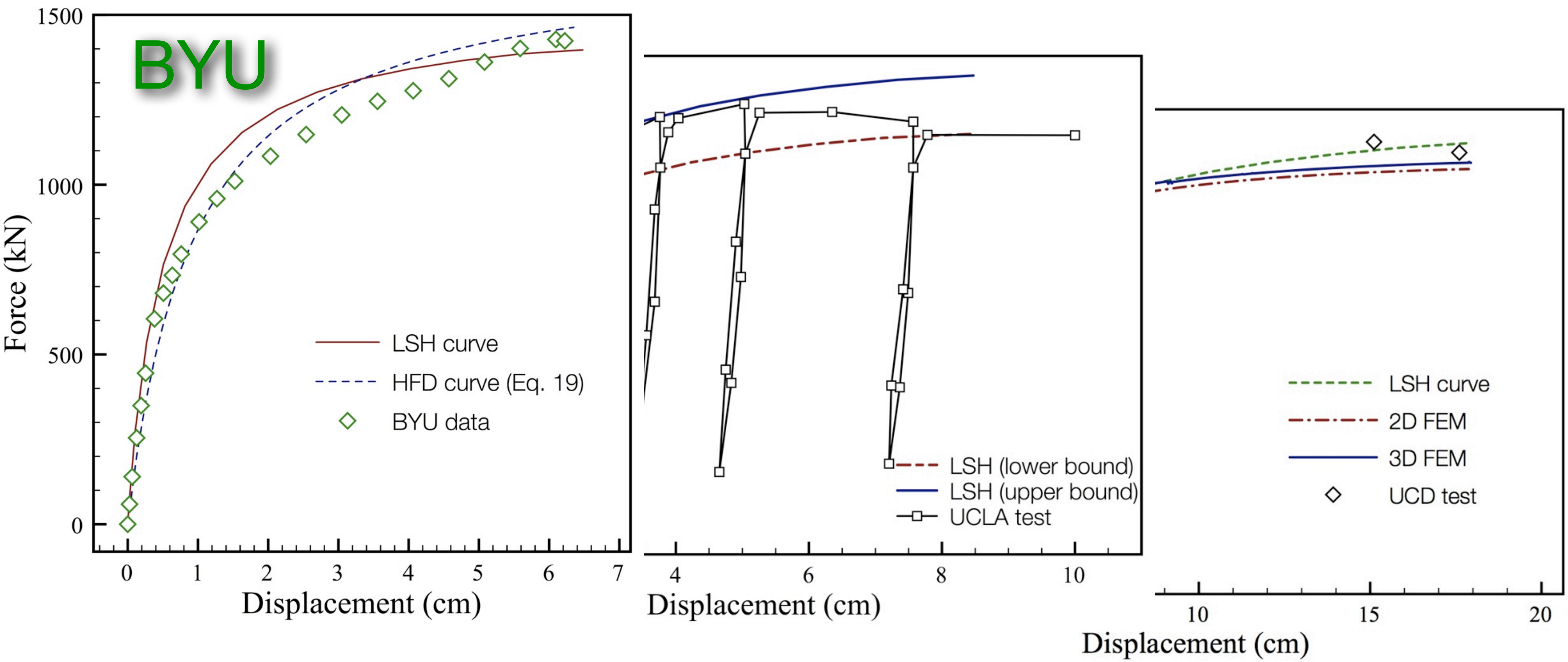
Validation

- UCD test by Romstad et al. (1995) (cohesive)
- UCLA test by Stewart et al. (2007) (silty sand)



Validation

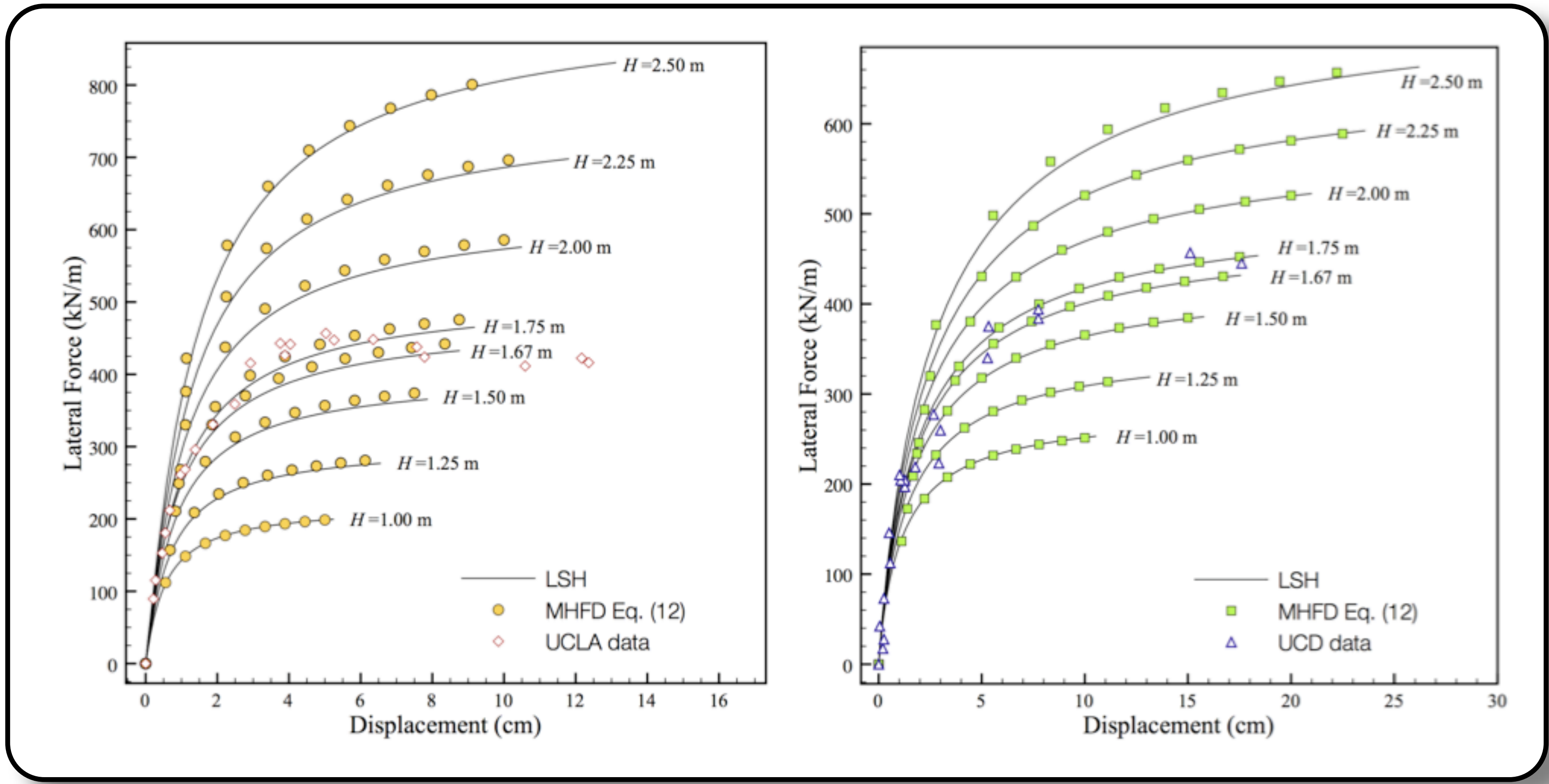
- UCD test by Romstad et al. (1995) (cohesive)
- UCLA test by Stewart et al. (2007) (silty sand)
- BYU tests by Rollins et al. (circa 2003) (clean & silty sands, gravel)



HFD Model

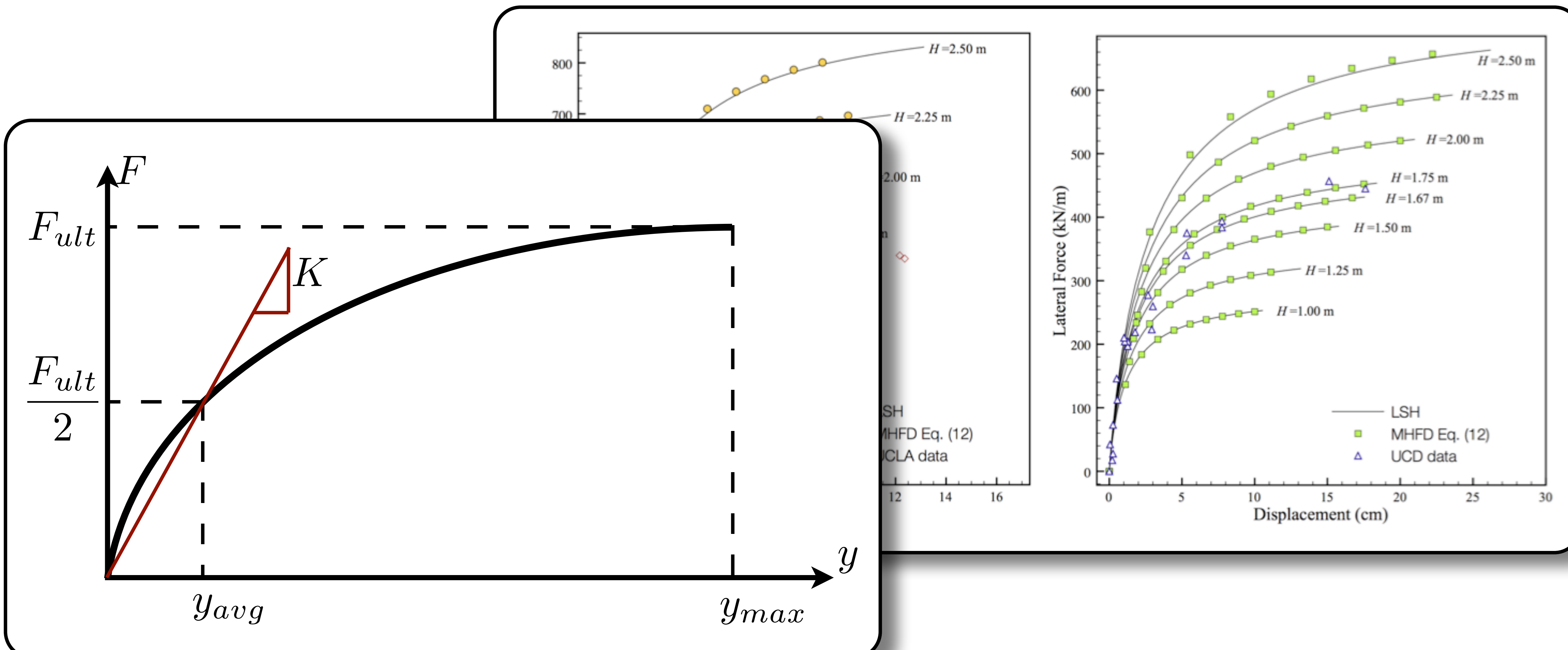
HFD Model

- Height-dependence is explicitly modeled



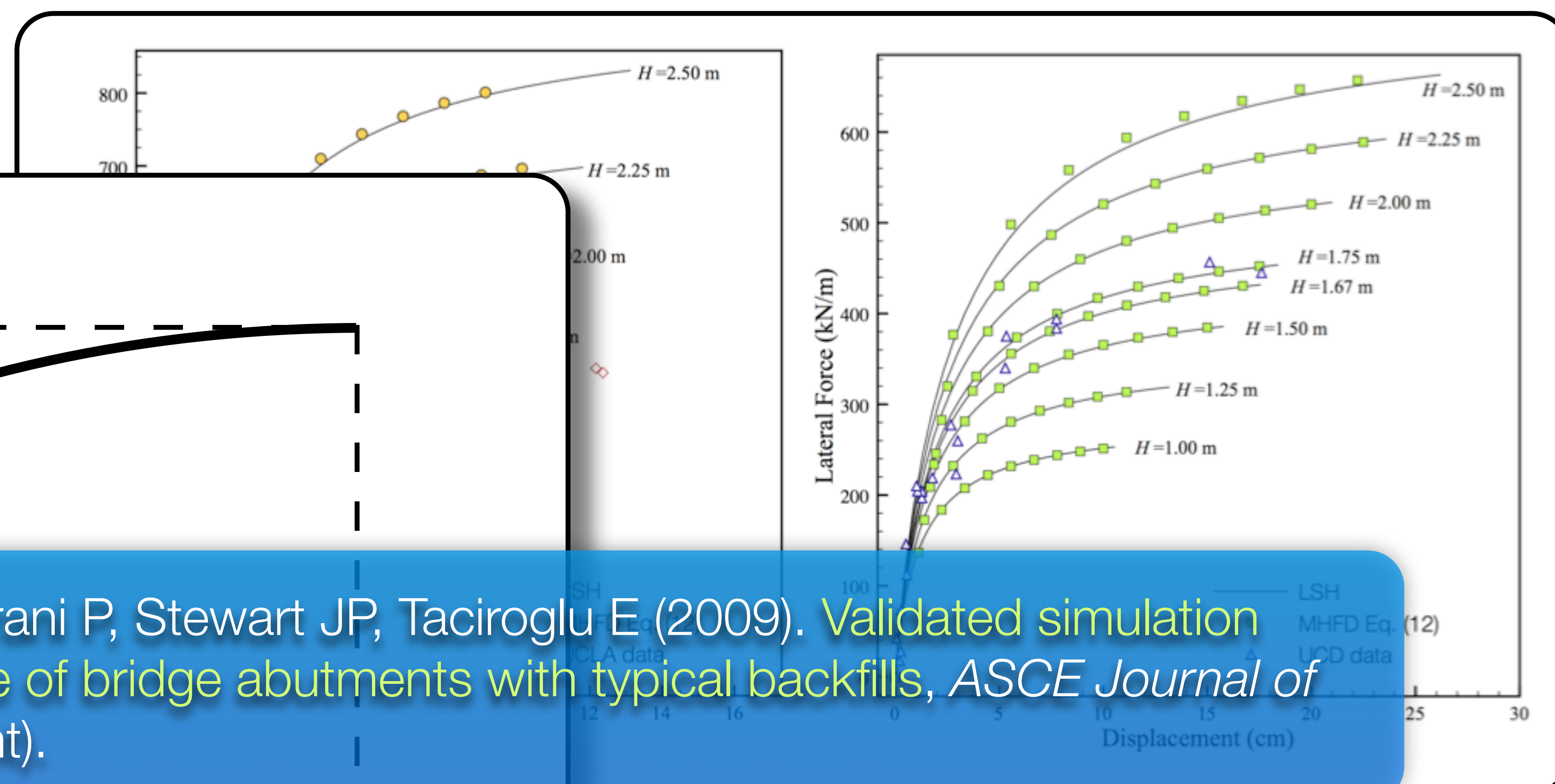
HFD Model

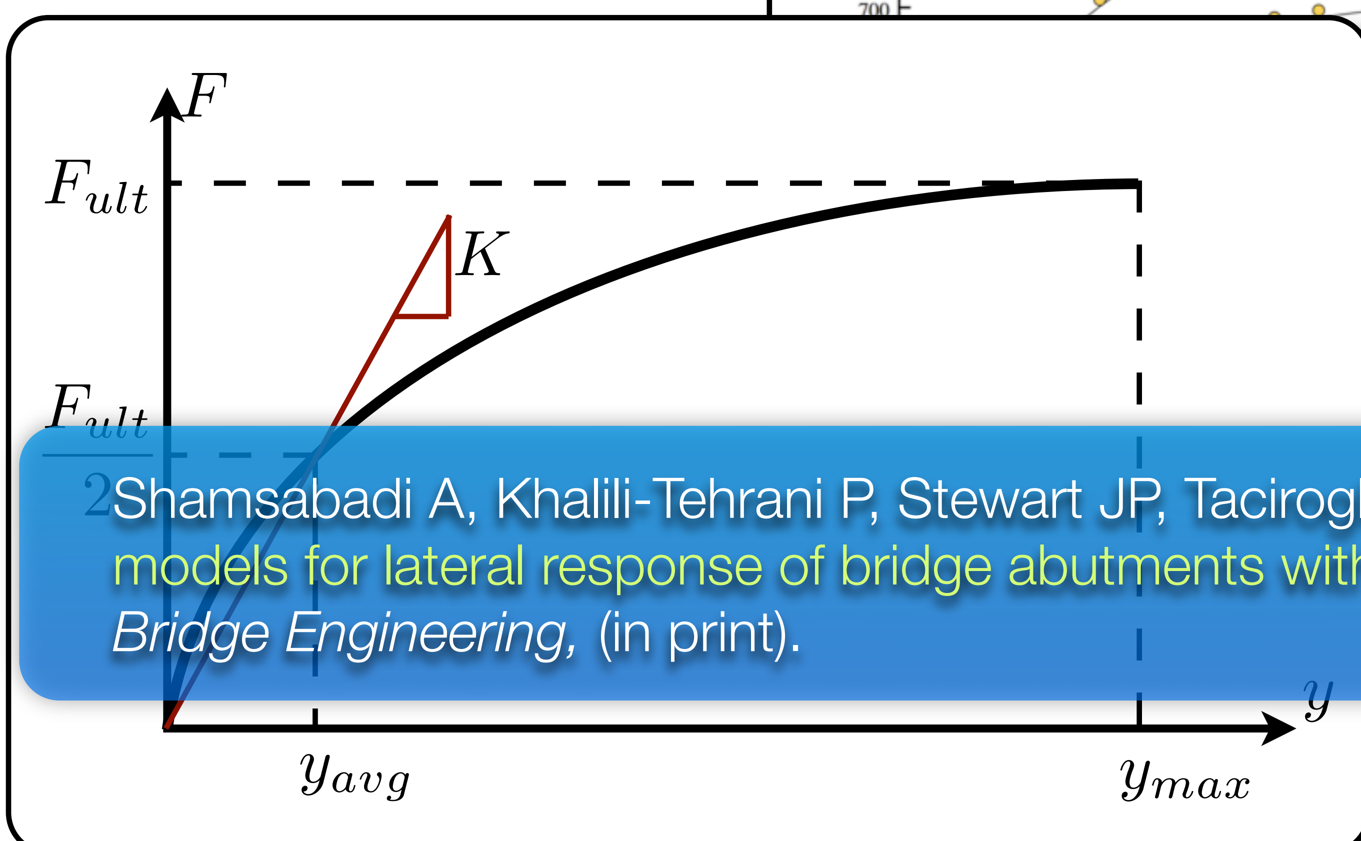
- Height-dependence is explicitly modeled
- Suitable for massive computation



HFD Model

- Height-dependence is explicitly modeled
- Suitable for massive computation
- Cited in upcoming Caltrans SDC



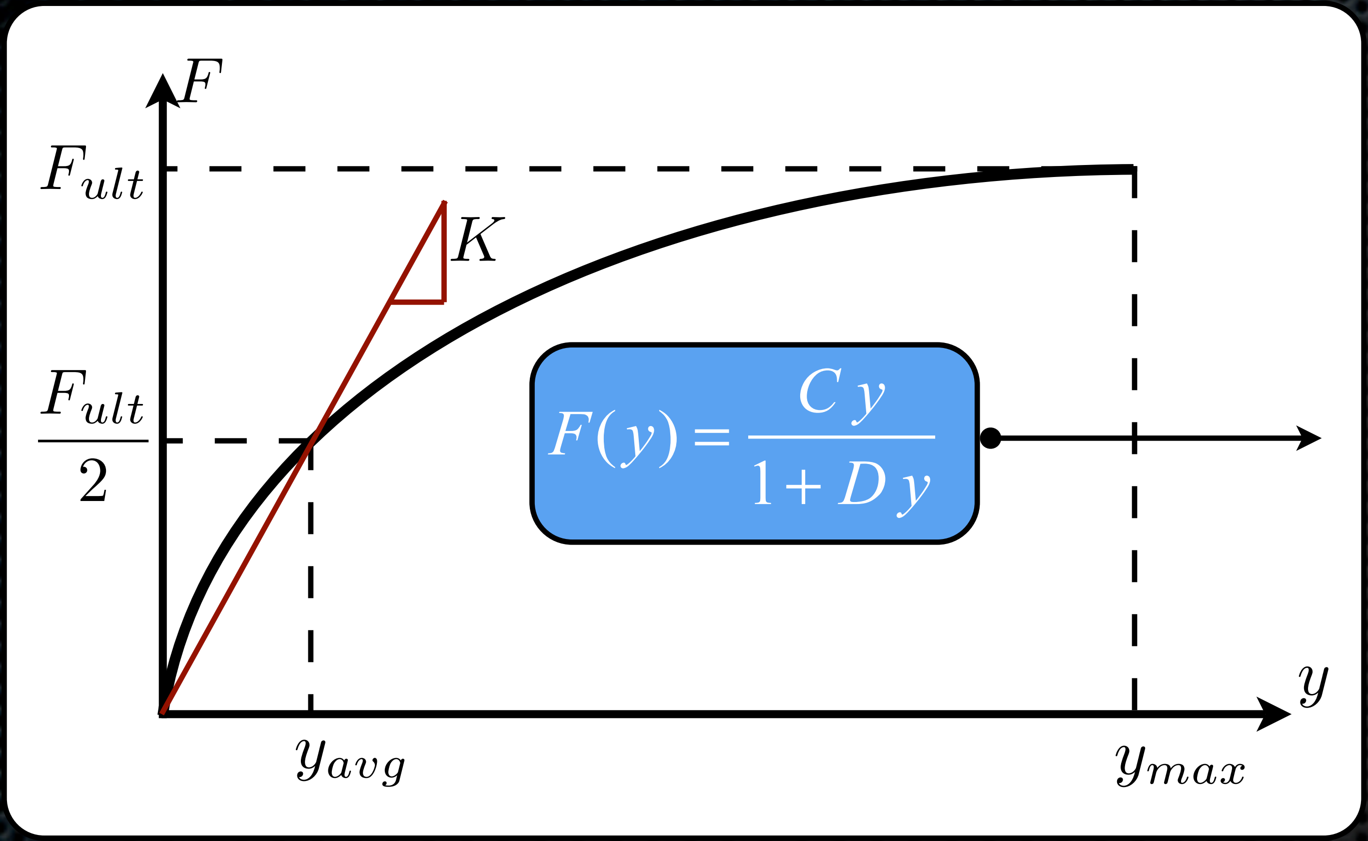


Shamsabadi A, Khalili-Tehrani P, Stewart JP, Taciroglu E (2009). Validated simulation models for lateral response of bridge abutments with typical backfills, *ASCE Journal of Bridge Engineering,* (in print).

Recent Work (Caltrans & PEER)

Physically parameterized HFD curves

EHFD Equation



$$F(y) = \frac{a_r\,y}{\hat{H} + b_r\,y}\hat{H}^n$$

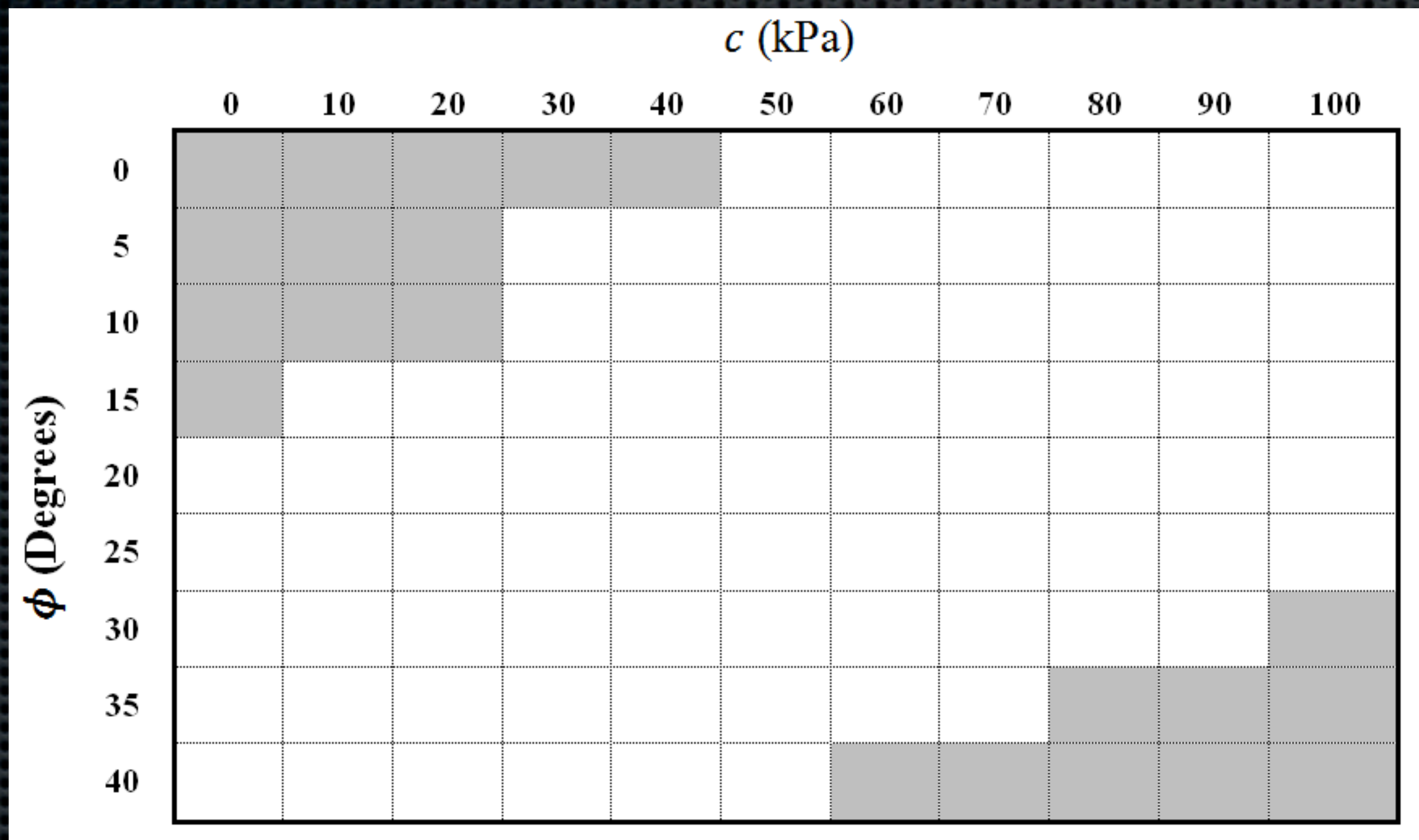
a_r , b_r had been shown to be height-independent parameters.

We decompose them further as in $a_r = \frac{1}{\beta}(\eta - 1)\alpha$ $b_r = \frac{1}{\beta}(\eta - 2)$

where $\alpha = \frac{F_{ult}}{\hat{H}^n}$ $\beta = \frac{y_{\max}}{\hat{H}}$ $\eta = \frac{y_{\max}}{y_{50}}$

Parametric Studies via LSH

Matrix of soil parameters considered in parametric studies



Soil unit weight: $\gamma \in \{14 \sim 24\}\mathrm{kPa}$

$\varepsilon_{50} \in \{0.0015 \sim 0.0075\}$

- Soil failure ratio: $R_f = 0.96$
- Interface Adhesion: $c_a = 0.65c$
- Interface friction: $\delta = 2/3\phi$

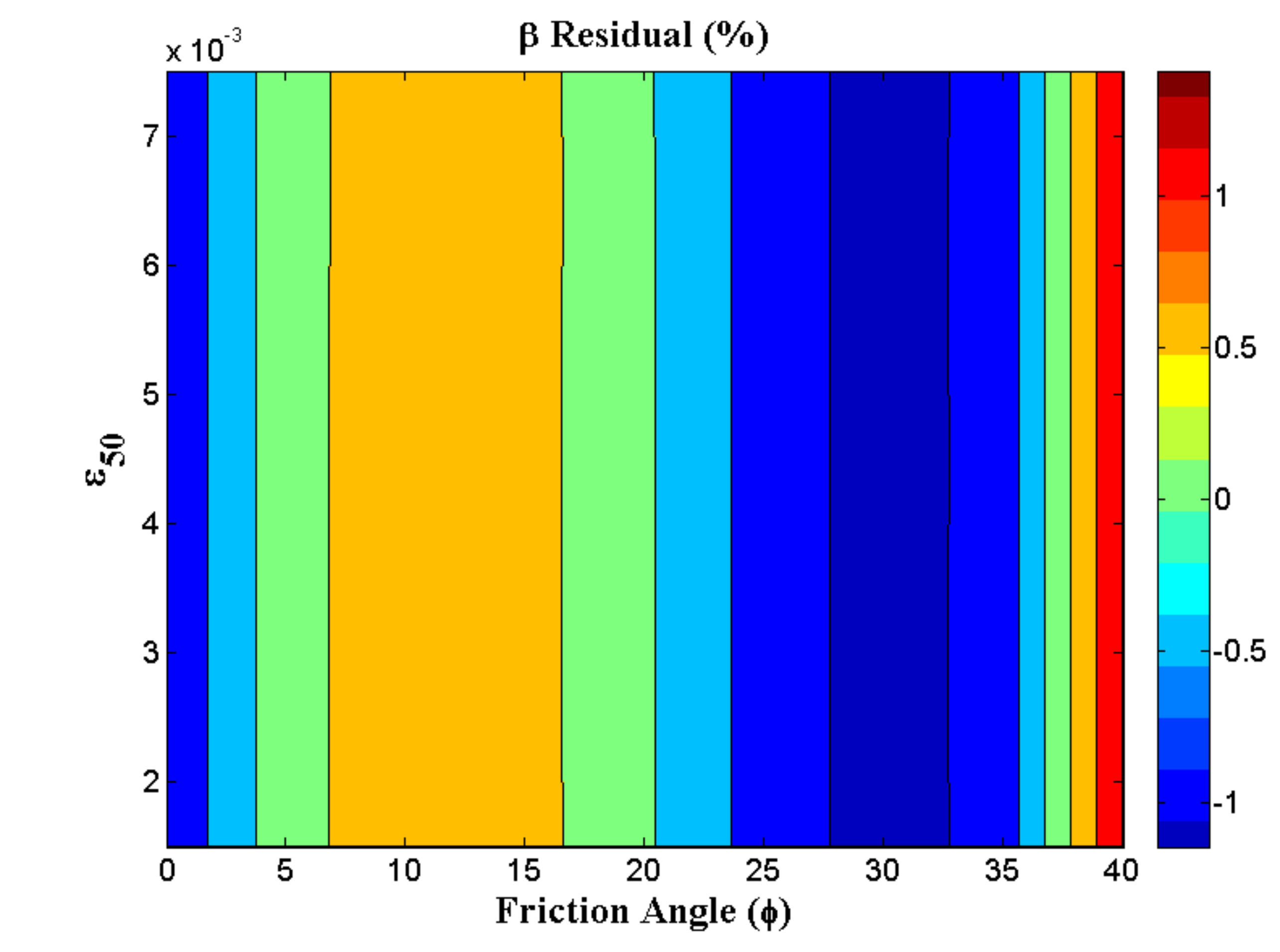
β-equation for Wall Deflection at Capacity

$\beta = \frac{y_{ult}}{\hat{H}} \equiv f\left(\phi, \varepsilon_{50}\right)$ Running LSH for $\phi - \varepsilon_{50}$ values and fitting $\beta = \beta_1 (\tan\phi)^{\beta_2} + \beta_3$

NLSM (Trust Region)

$$\beta = \left[1703 - 683.4(\tan\phi)^{1.23}\right]\varepsilon_{50}$$

$$\text{\# Residual} = \frac{(value)_{LSH} - (value)_{approximated}}{(value)_{LSH}} \times 100$$



α-equation for Wall Capacity

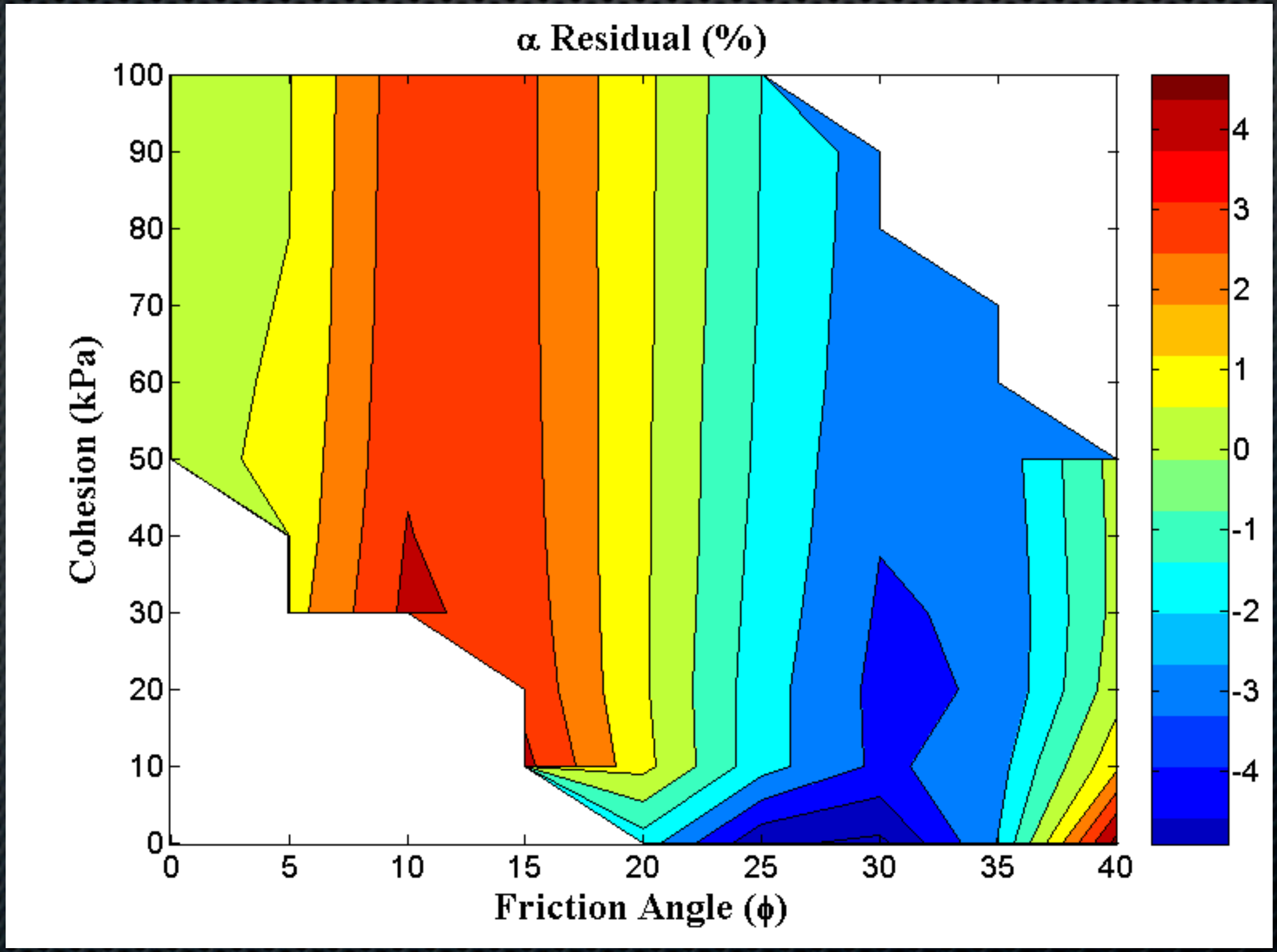
$$\alpha = \frac{F_u}{\hat{H}^n} \equiv f(\phi, c, \gamma)$$

Linear dependence on γ in agreement with Bell's equation.

$$\alpha = slope \times \gamma + imtercept$$

$$F_{ult} = \frac{1}{2}\gamma K_p H^2 + 2c\sqrt{K_p}H$$

$$\alpha = \begin{cases} 0.50\gamma + 2.63c & \text{if} \quad \phi = 0 \\ \left[5.62(\tan\phi)^2 + 0.53\right]\gamma + \left[10.58(\tan\phi)^{1.79} + 2.86\right]c & \text{otherwise} \end{cases}$$

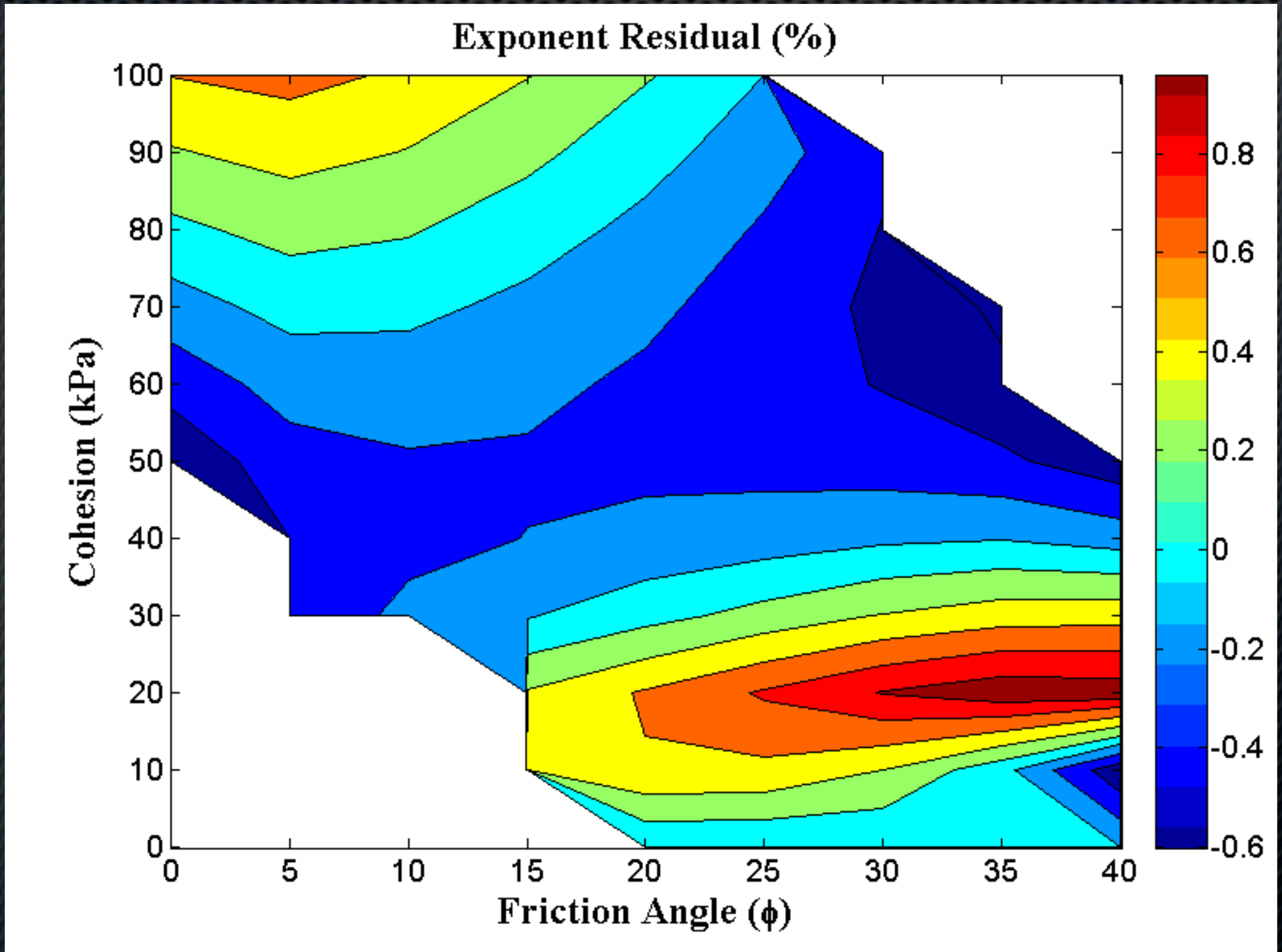


n-equation for Height Effect on Wall Capacity

$$F_{ult} = \frac{1}{2}\gamma K_p H^2 + 2c\sqrt{K_p}H \Rightarrow 1 < n \le 2$$

$$n \equiv f(c, \phi, \gamma)$$

$$n = \begin{cases} 2 & \text{if } c = 0 \\ \dfrac{0.91(\tan\phi)^{1.2} + 1.49}{\sqrt{c}} + 0.90 & \text{Otherwise} \end{cases}$$

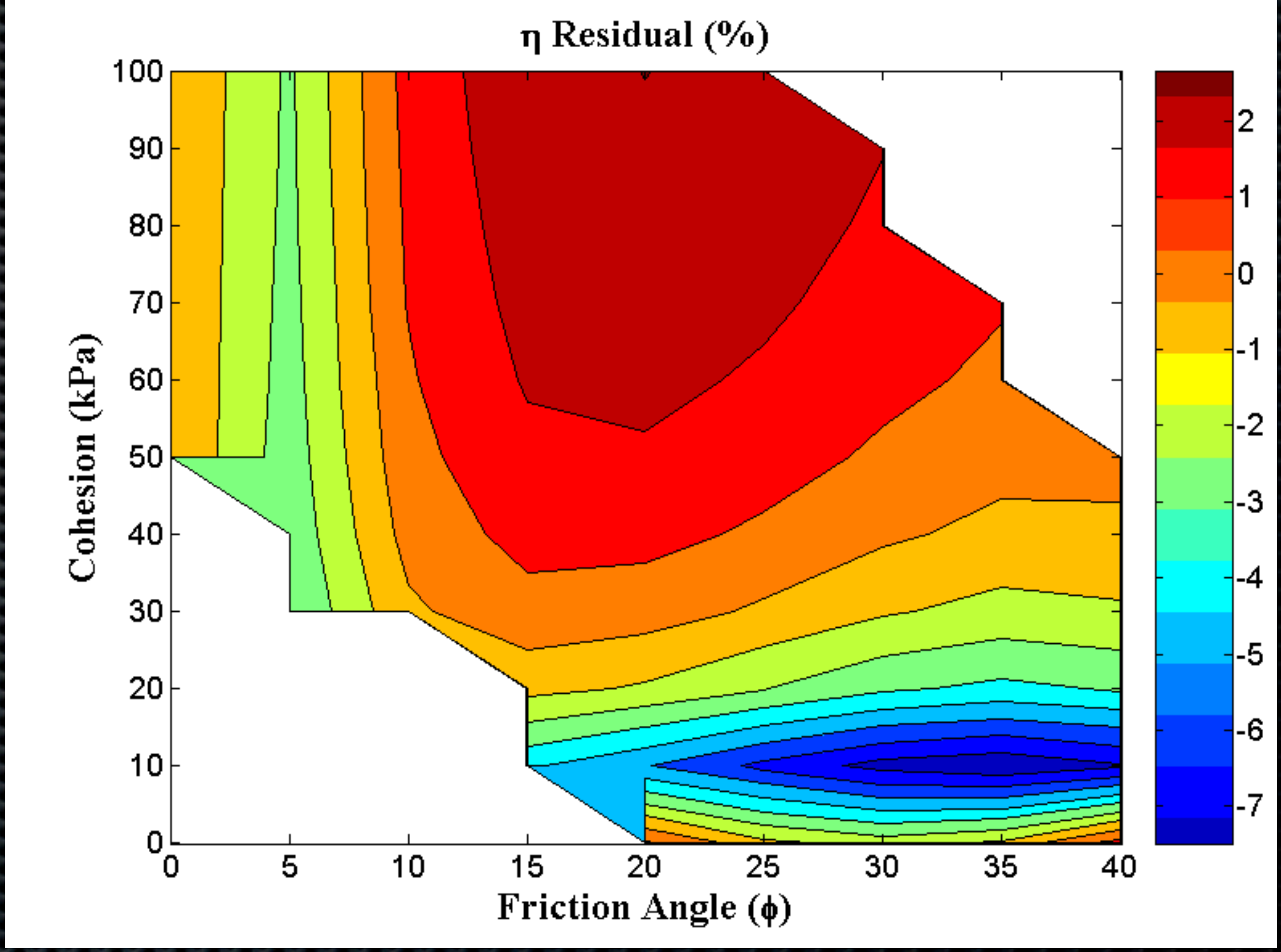


η -equation and its accuracy

$$\eta = \frac{y_{ult}}{y_{50}} \equiv f(\phi, c) \cong f(\phi)$$

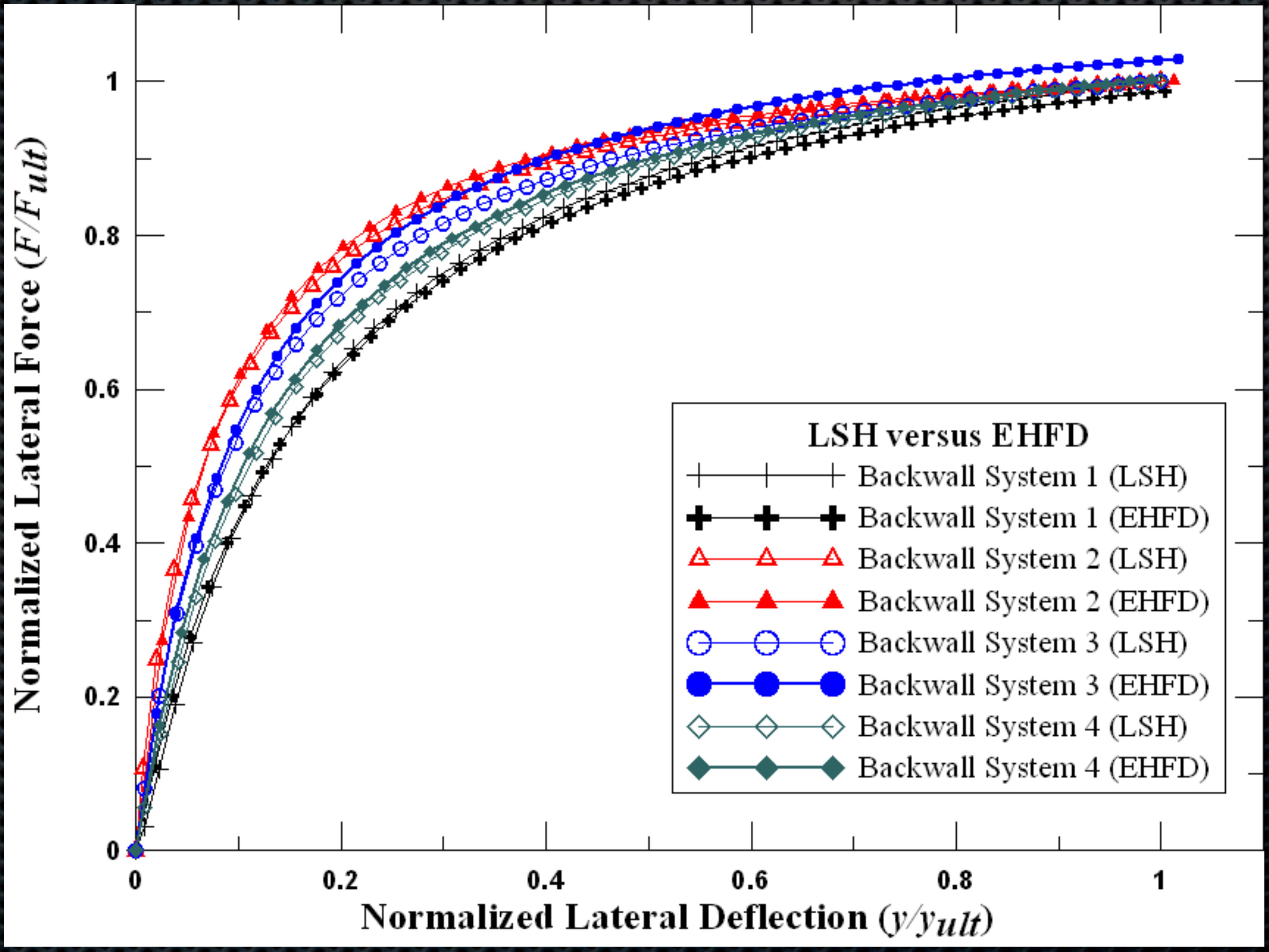
Affects backbone curve shape, especially at small displacements.

$$\eta = \begin{cases} 15.47 & \text{for } \phi < 5^{\circ} \,\&\, c \neq 0 \\ 18.10 - 9.38\sqrt{\tan(\phi)} & \text{for } \phi \geq 5^{\circ} \,\&\, c \neq 0 \\ 14.36 - 7.49\sqrt{\tan(\phi)} & \text{for all } \phi \,\&\, c = 0 \end{cases}$$



Verification of EHFD Equations

Backwall System	C (kPa)	$\phi°$	γ (kN/m³)	ε_{50}	H (m)	$(F_{ult})_{LSH}$ (kN/m)	$(y_{max})_{LSH}$ (cm)
(1)	0	38	22.0	0.0030	1.5	212.19	5.68
(2)	85	0	16.5	0.0065	1.8	432.18	19.74
(3)	55	25	18.0	0.0045	2.0	727.29	12.79
(4)	20	40	20.0	0.0035	1.1	343.98	4.54



Validation against Experimental Data

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

Validation against Experimental Data

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

wall friction factor

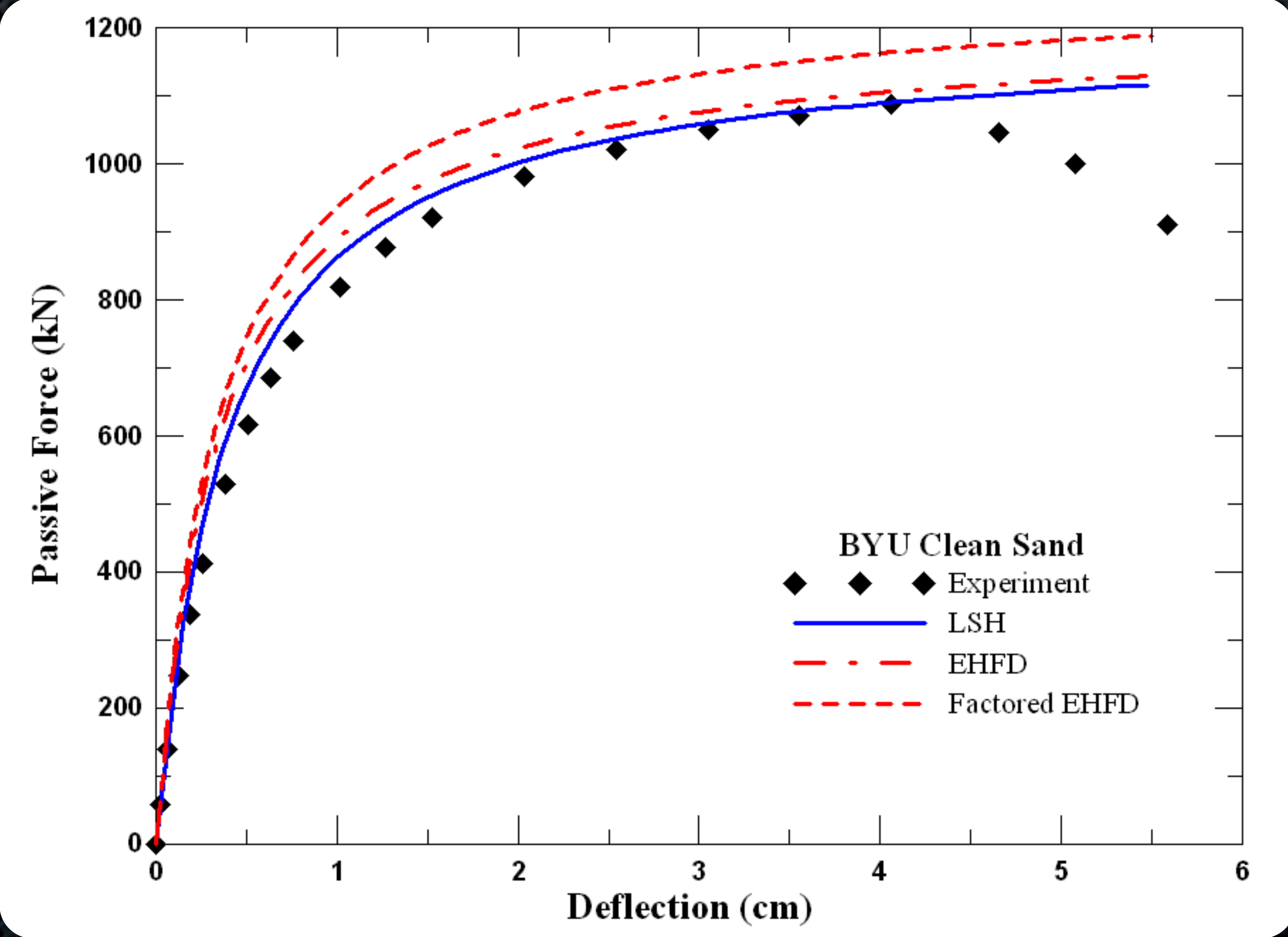
$$f = 0.64\,(\delta/\phi) + 0.56$$

Validation against Experimental Data

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

wall friction factor

$$f = 0.64\,(\delta/\phi) + 0.56$$

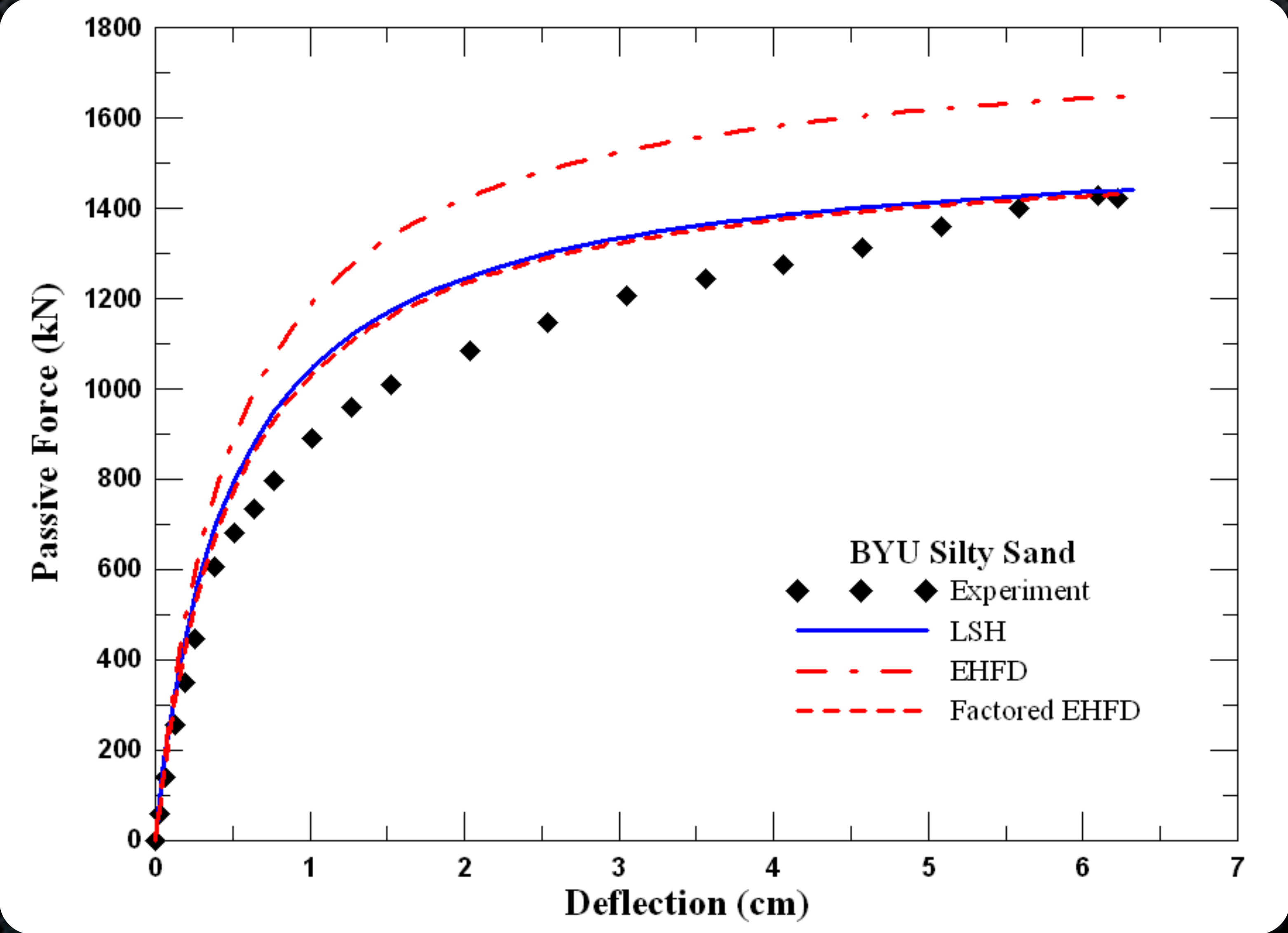


Validation against Experimental Data

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

wall friction factor

$$f = 0.64\,(\delta/\phi) + 0.56$$

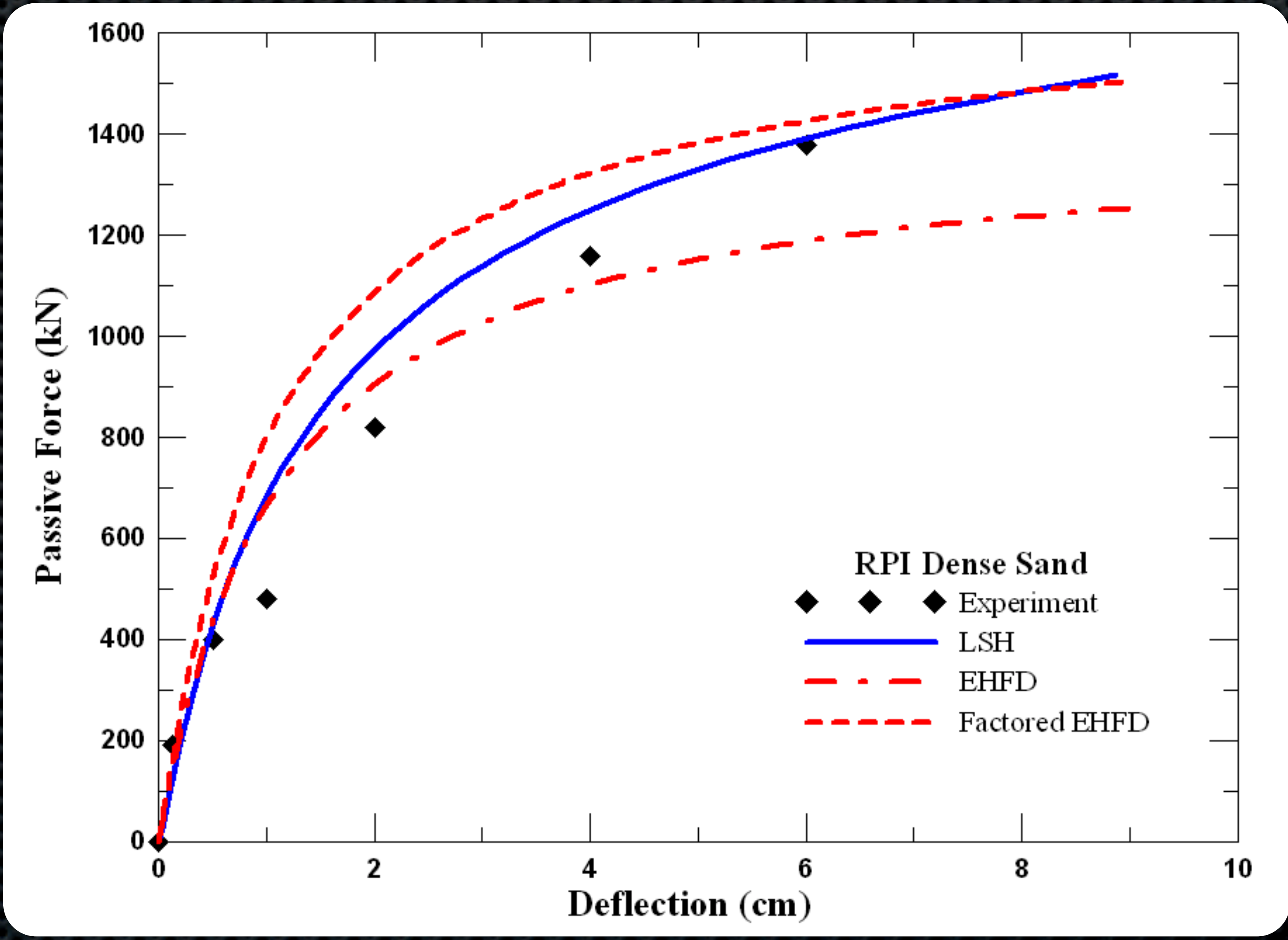


Validation against Experimental Data

Experiments	Parameters							
	Backfill Soil					LSH		
	c (kPa)	ϕ°	γ (kN/m^3)	ε_{50}	ν	δ°	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

wall friction factor

$$f = 0.64\,(\delta/\phi) + 0.56$$

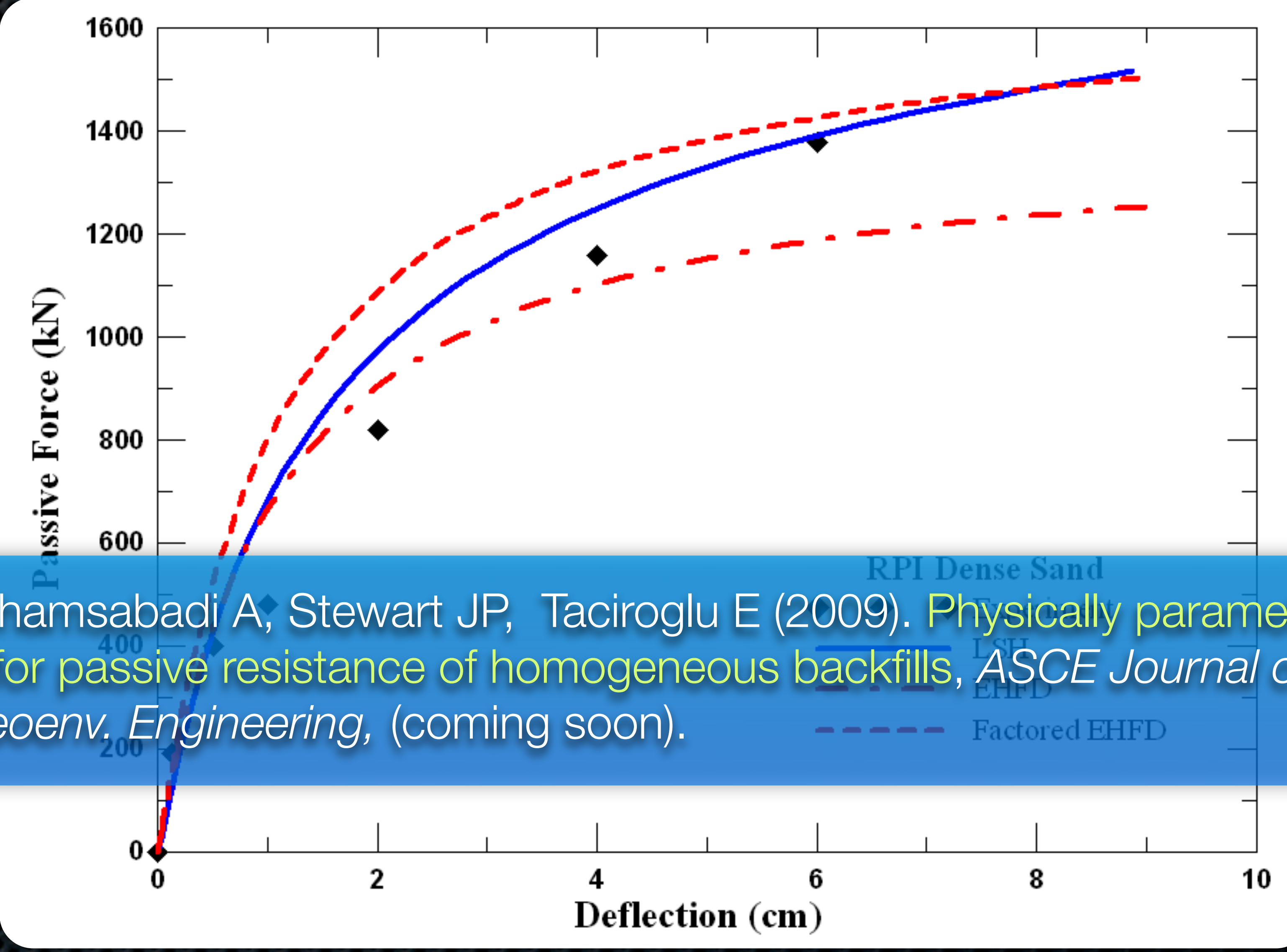


Validation against Experimental Data

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

wall friction factor

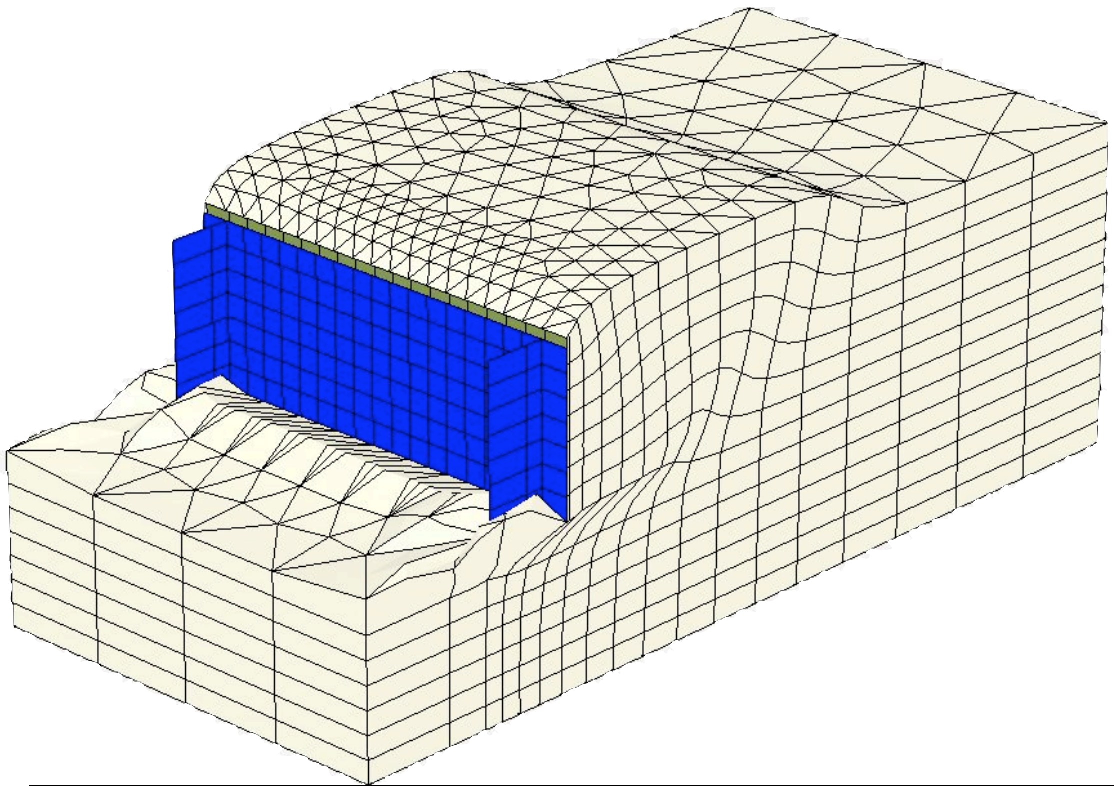
$$f = 0.64\,(\delta/\phi) + 0.56$$

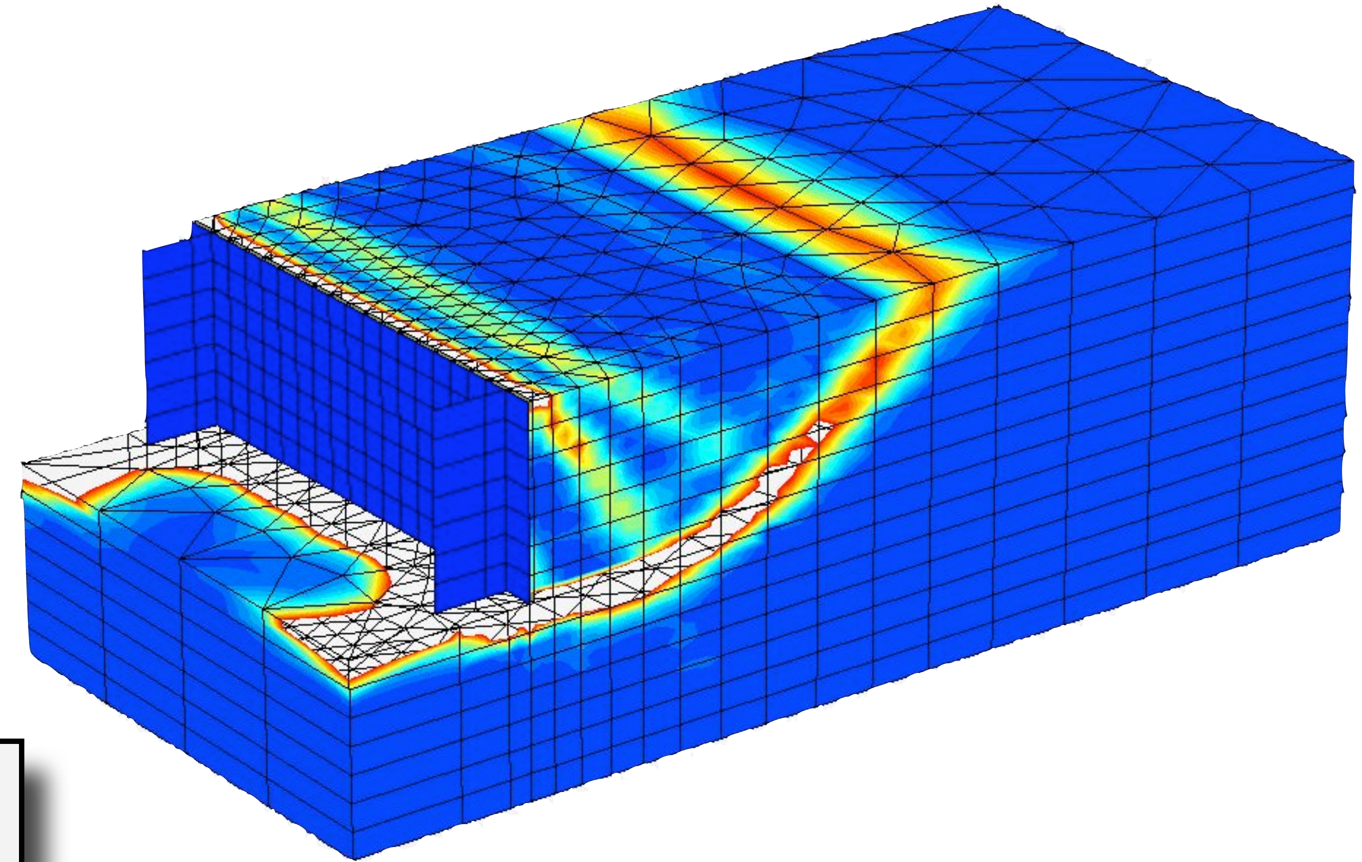


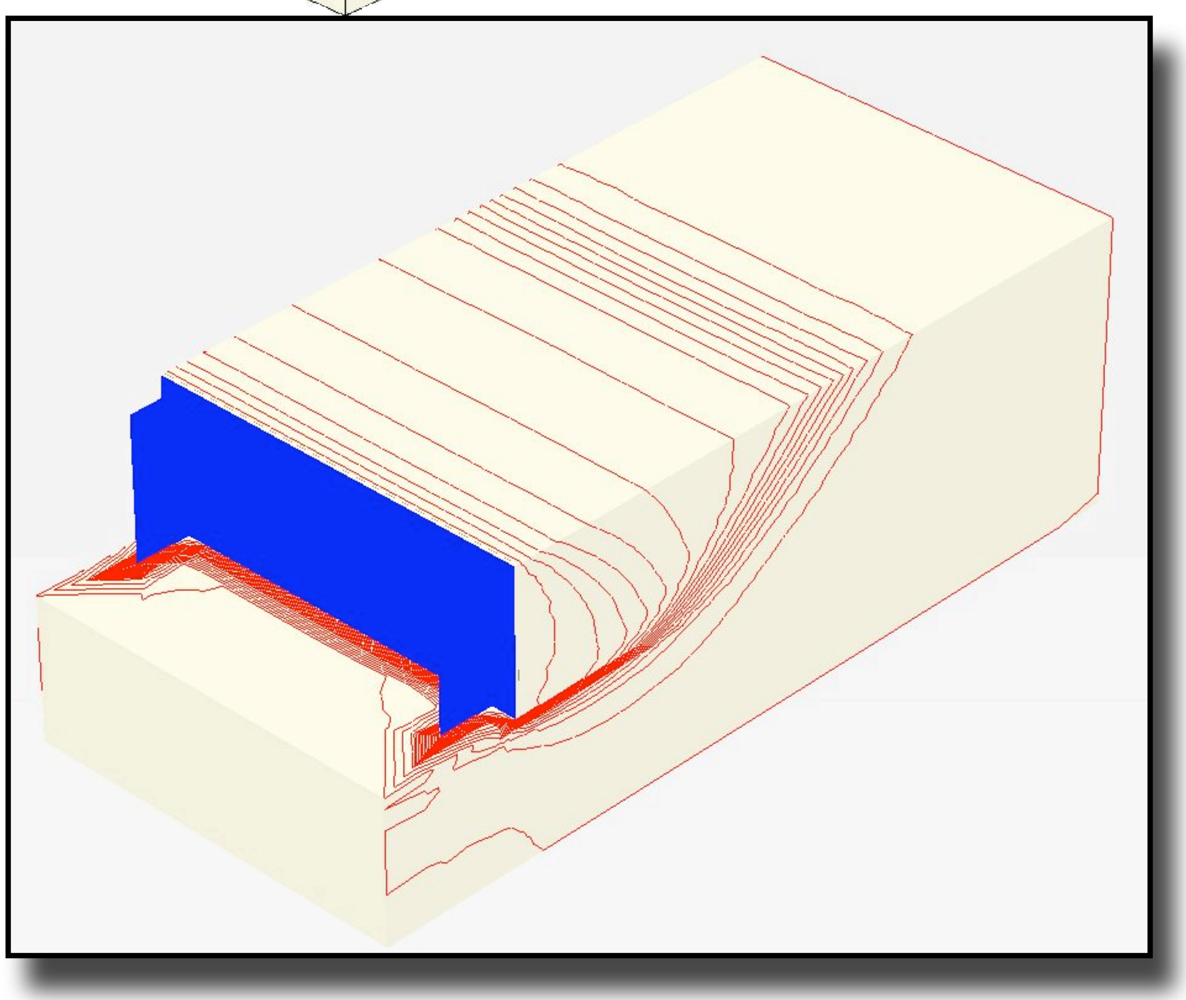
Khalili-Tehrani P, Shamsabadi A, Stewart JP, Taciroglu E (2009). Physically parameterized backbone curves for passive resistance of homogeneous backfills, *ASCE Journal of Geotechnical & Geoenv. Engineering,* (coming soon).

Extension to Skew Abutments

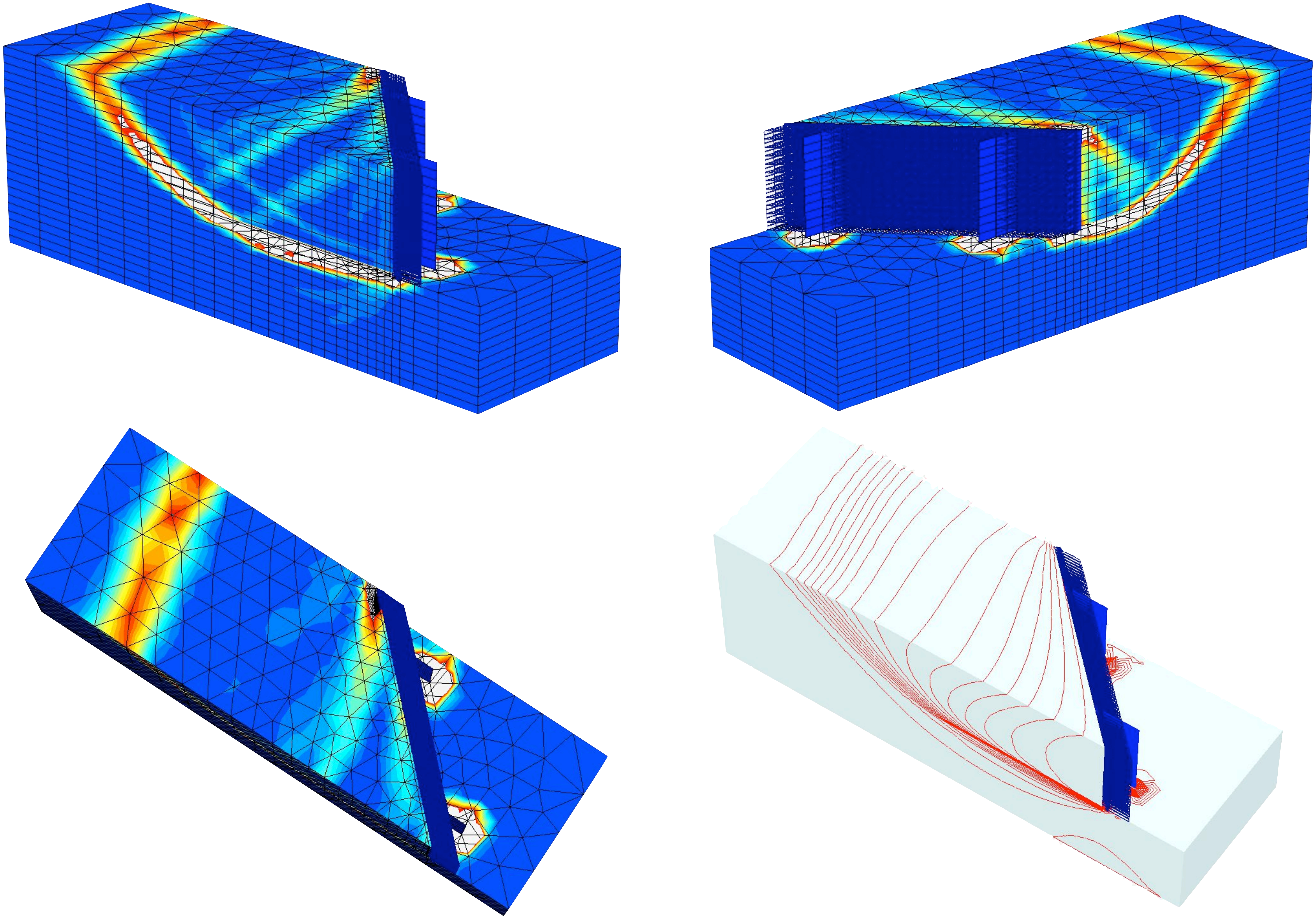
UCLA Straight Abutment as Tested



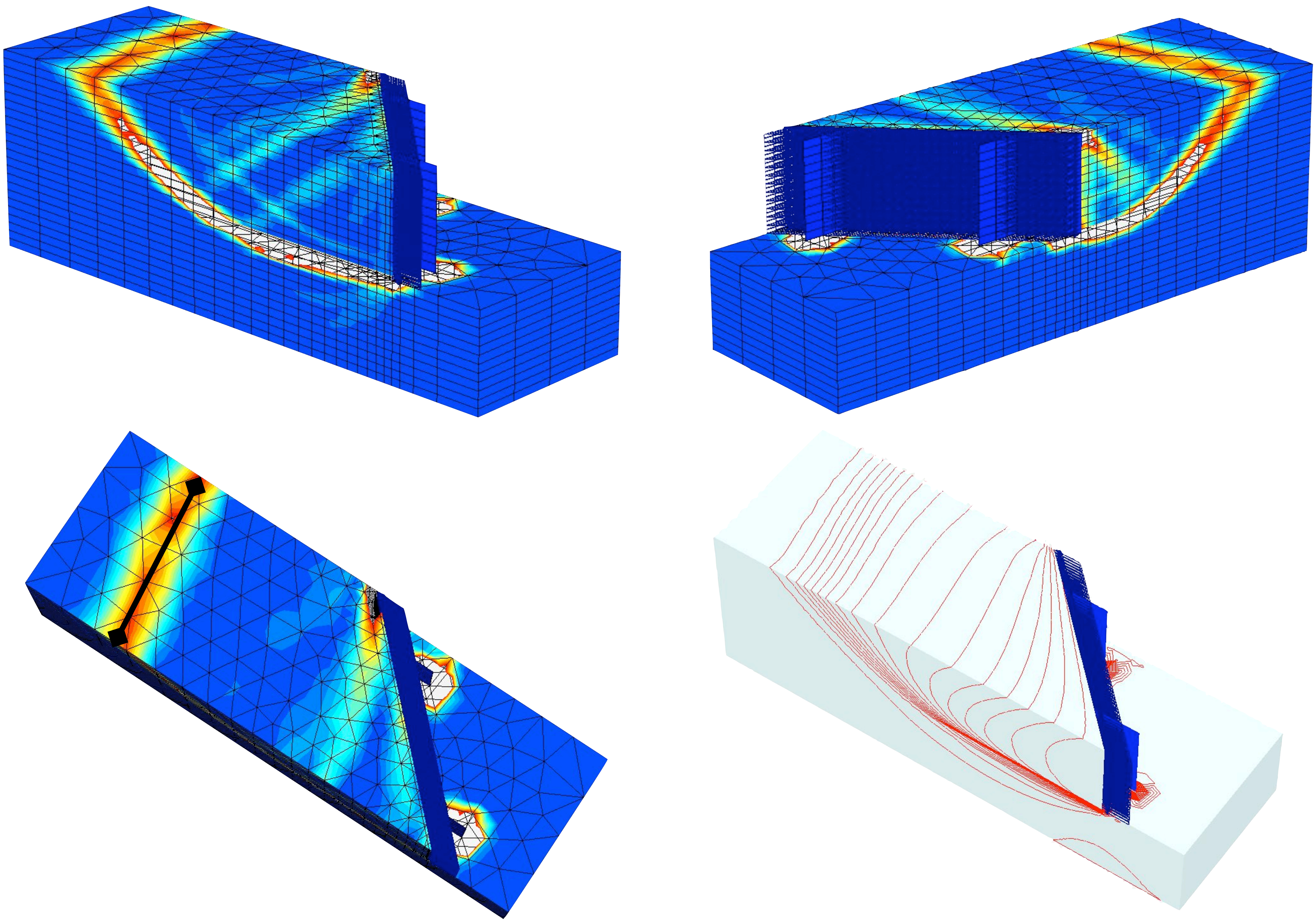




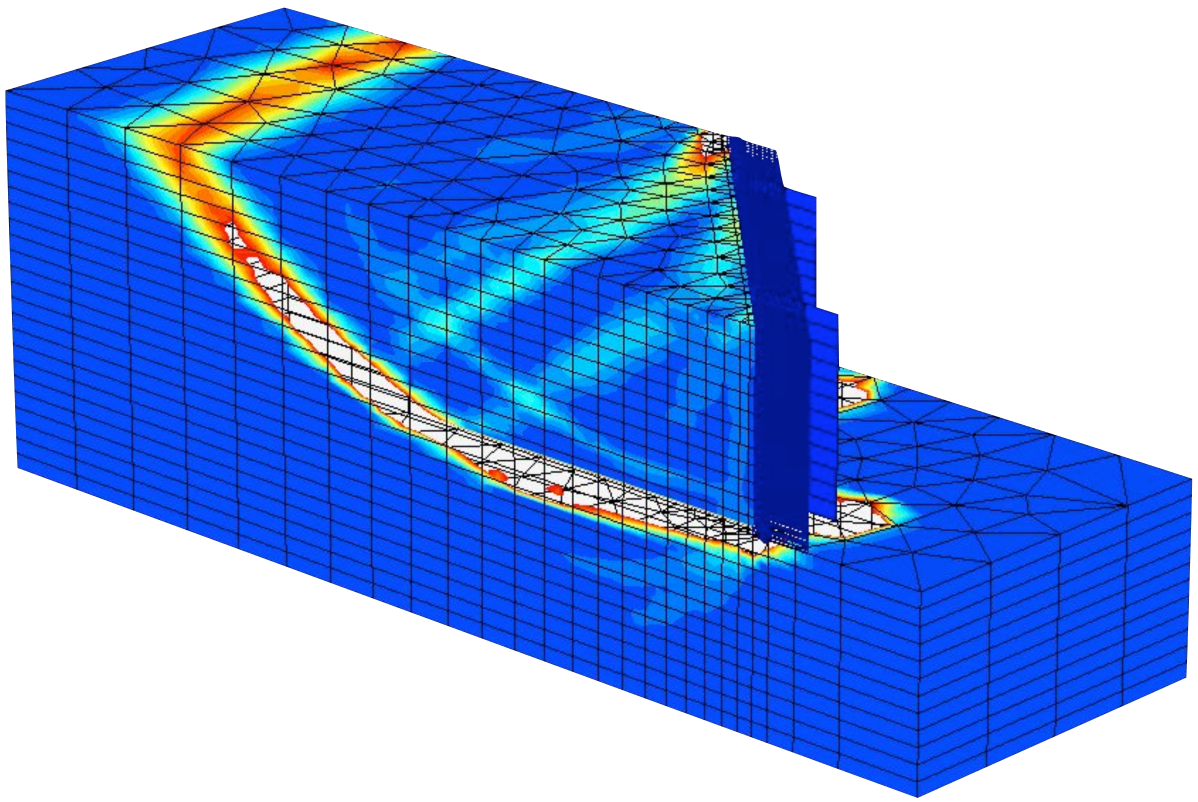
45^o skew Abutment with UCLA backfill

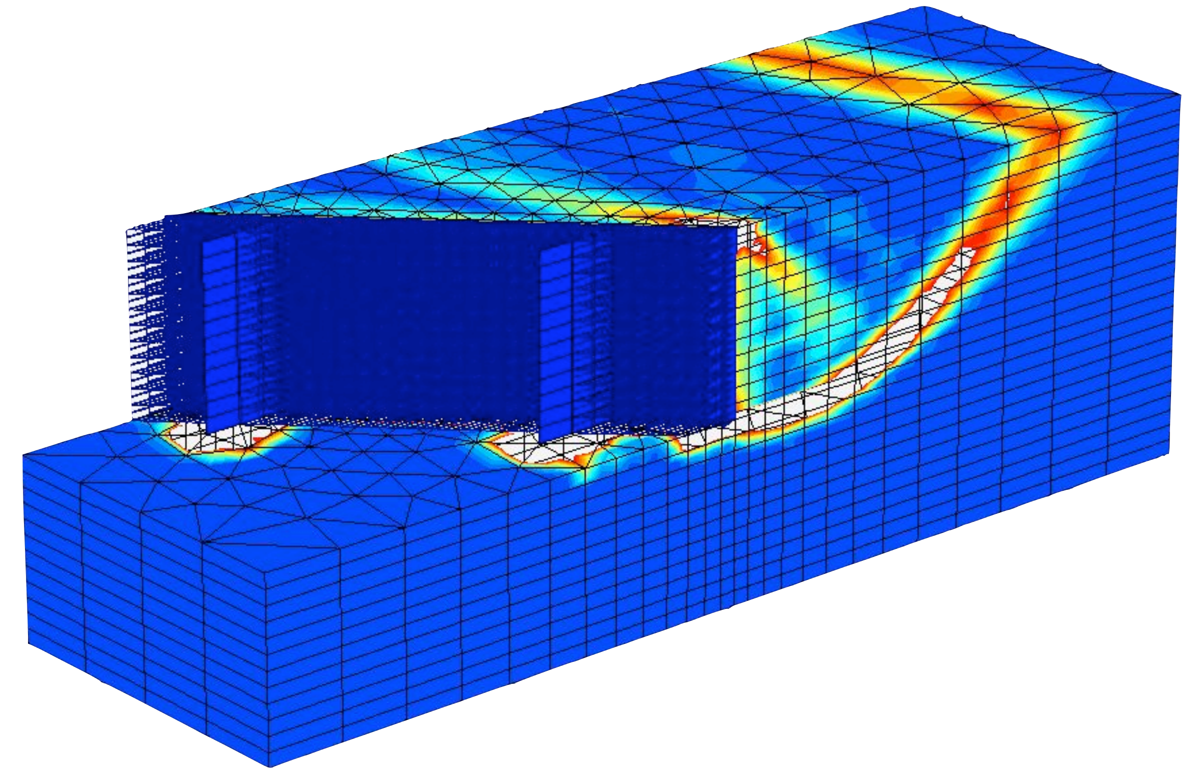


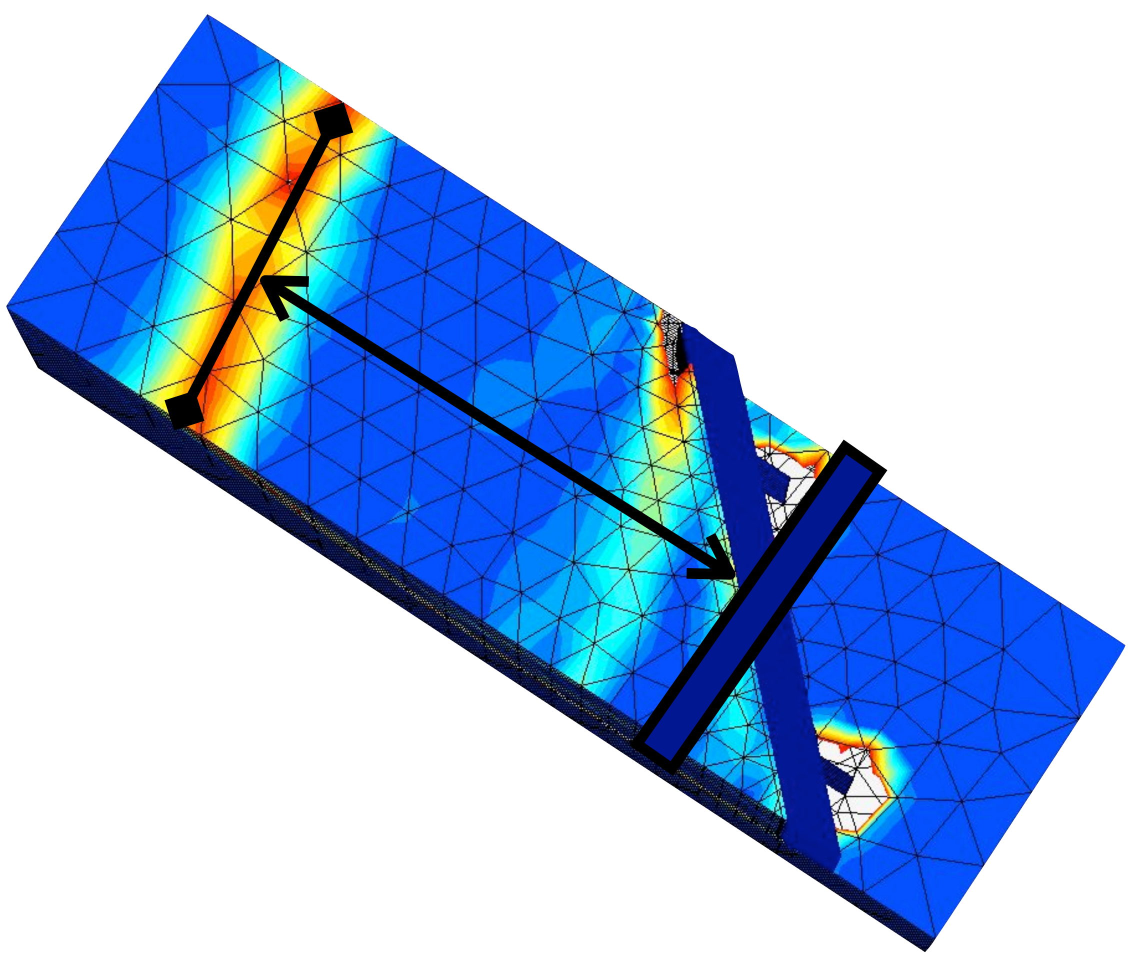
45^{o} skew Abutment with UCLA backfill

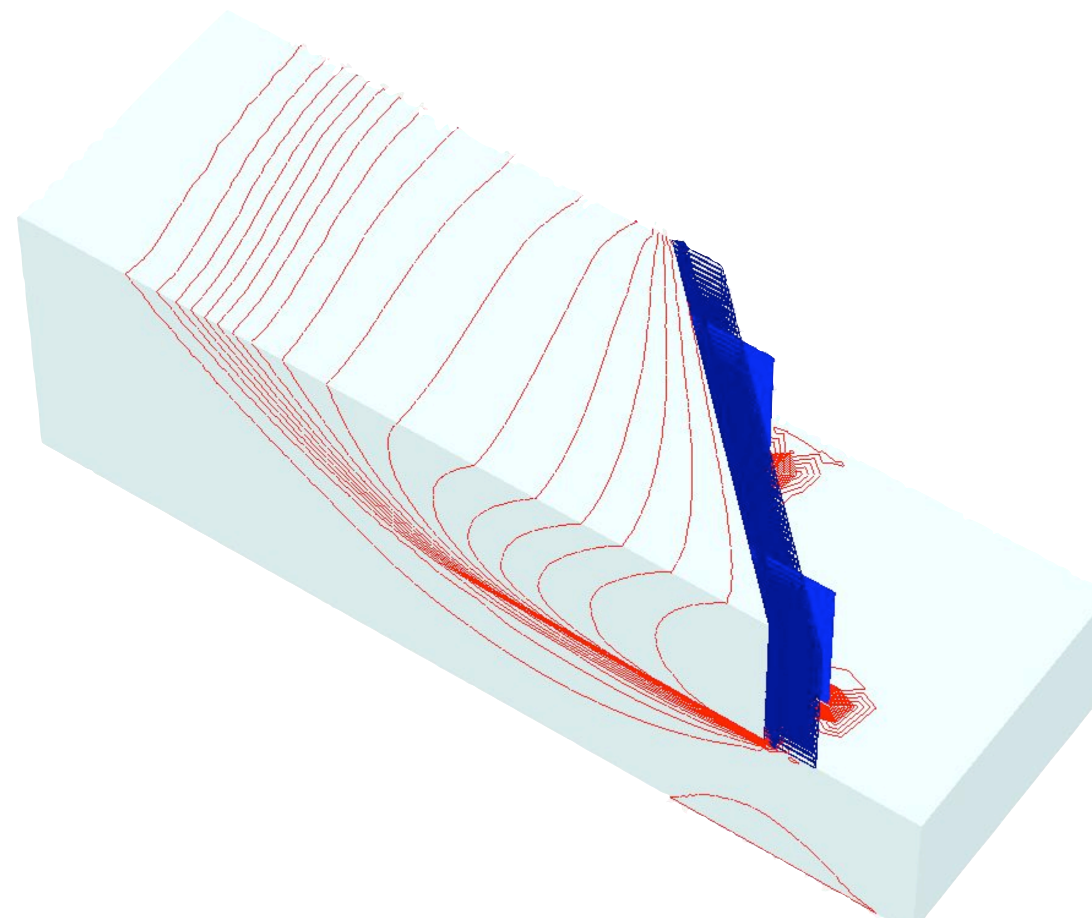


45^{o} skew Abutment with UCLA backfill

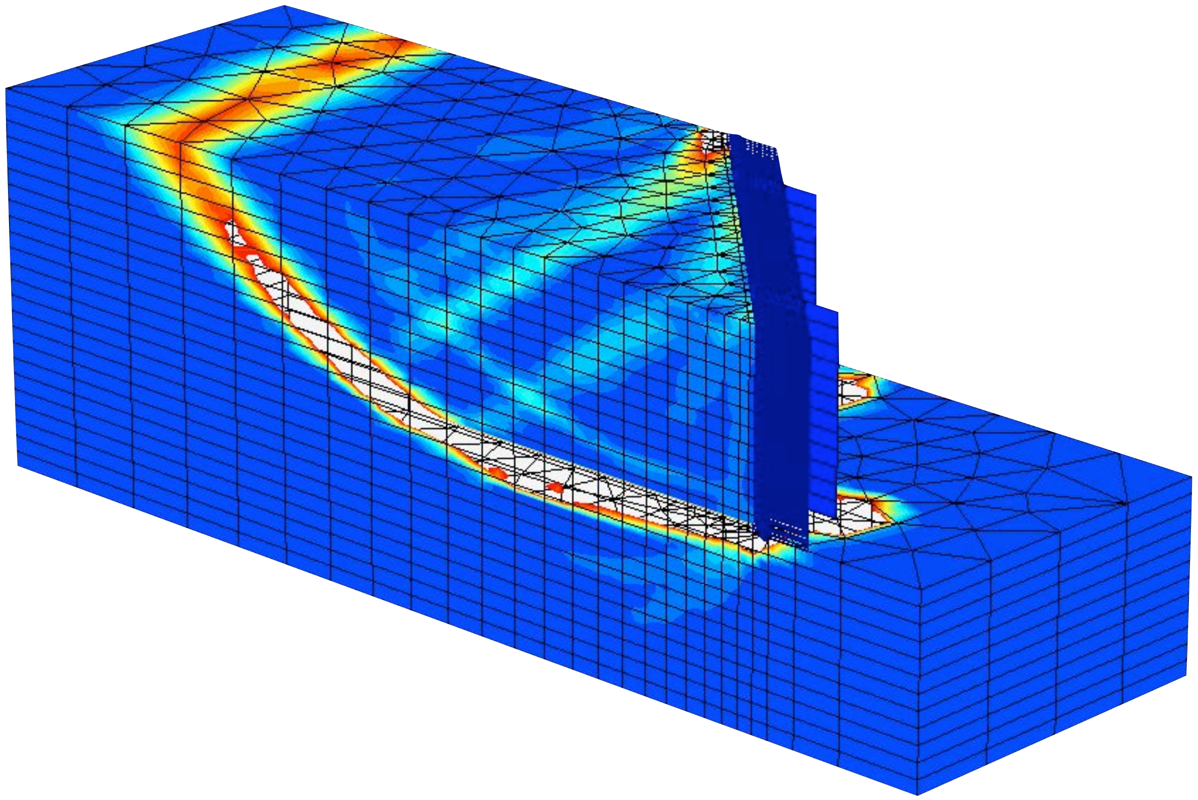


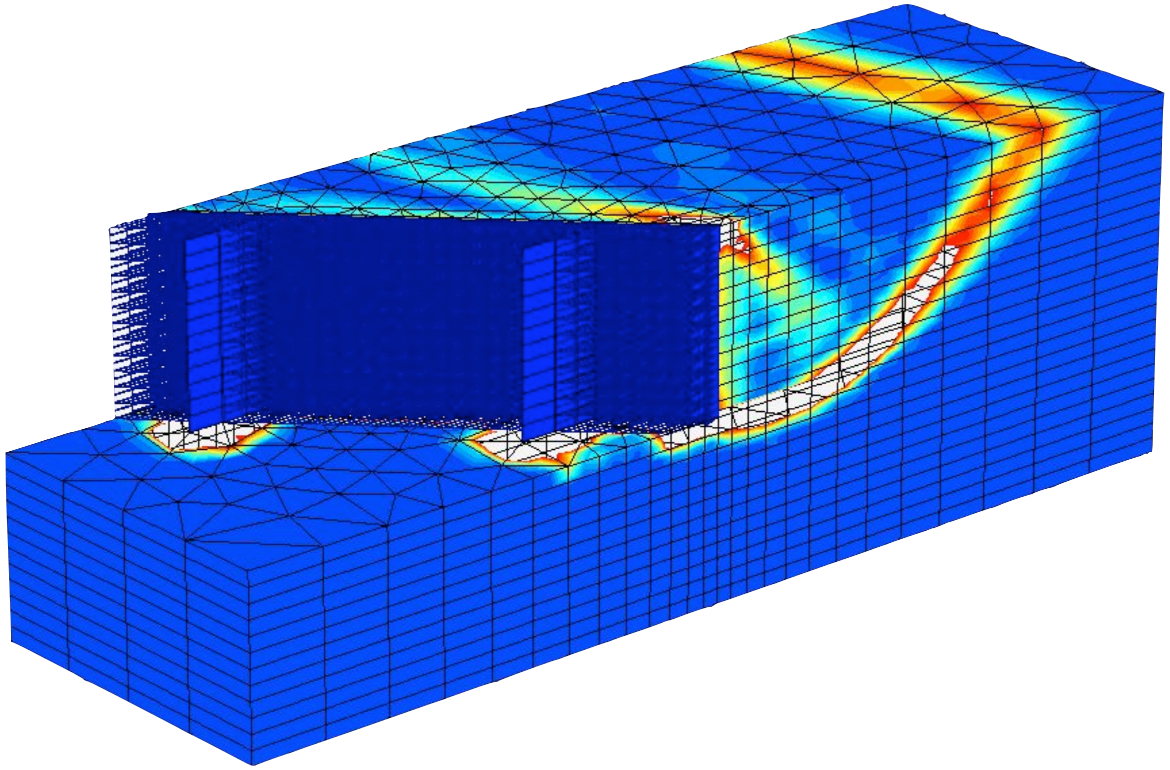


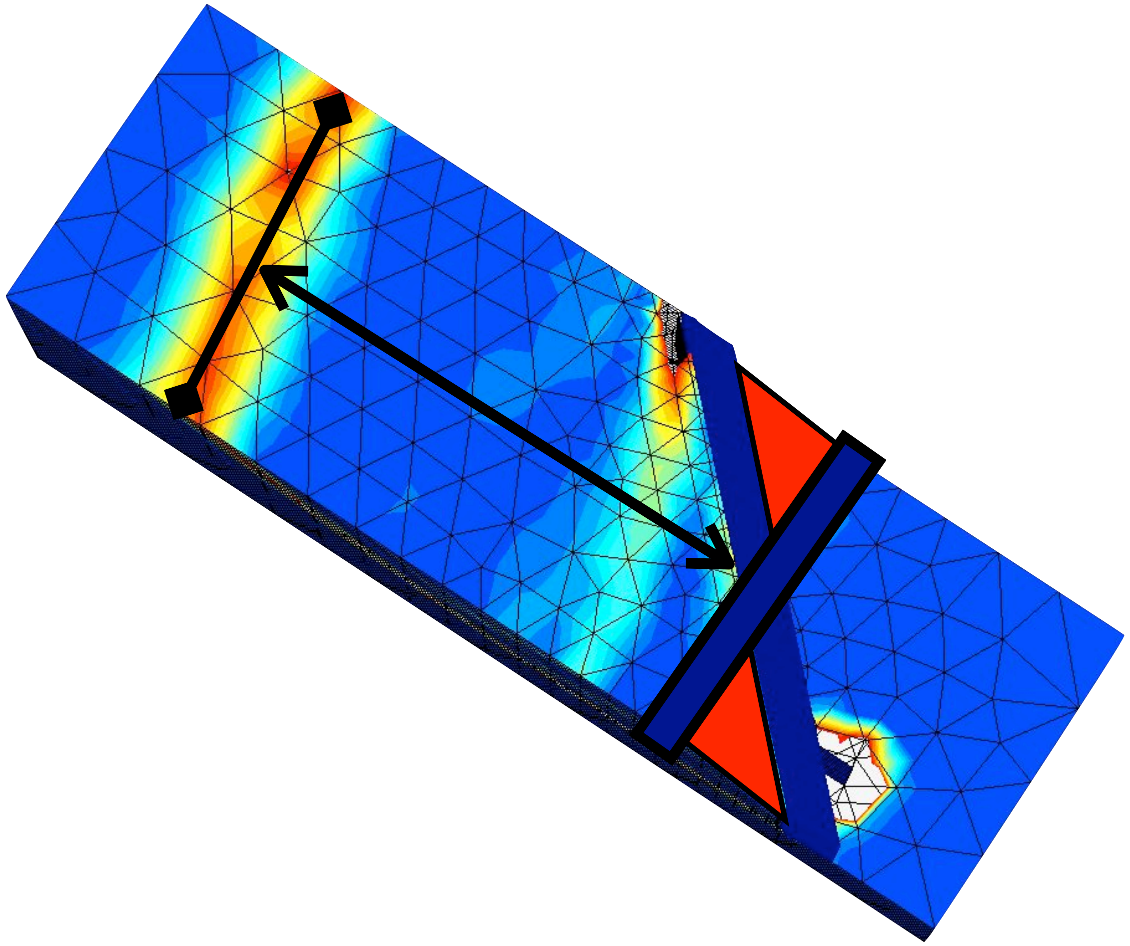


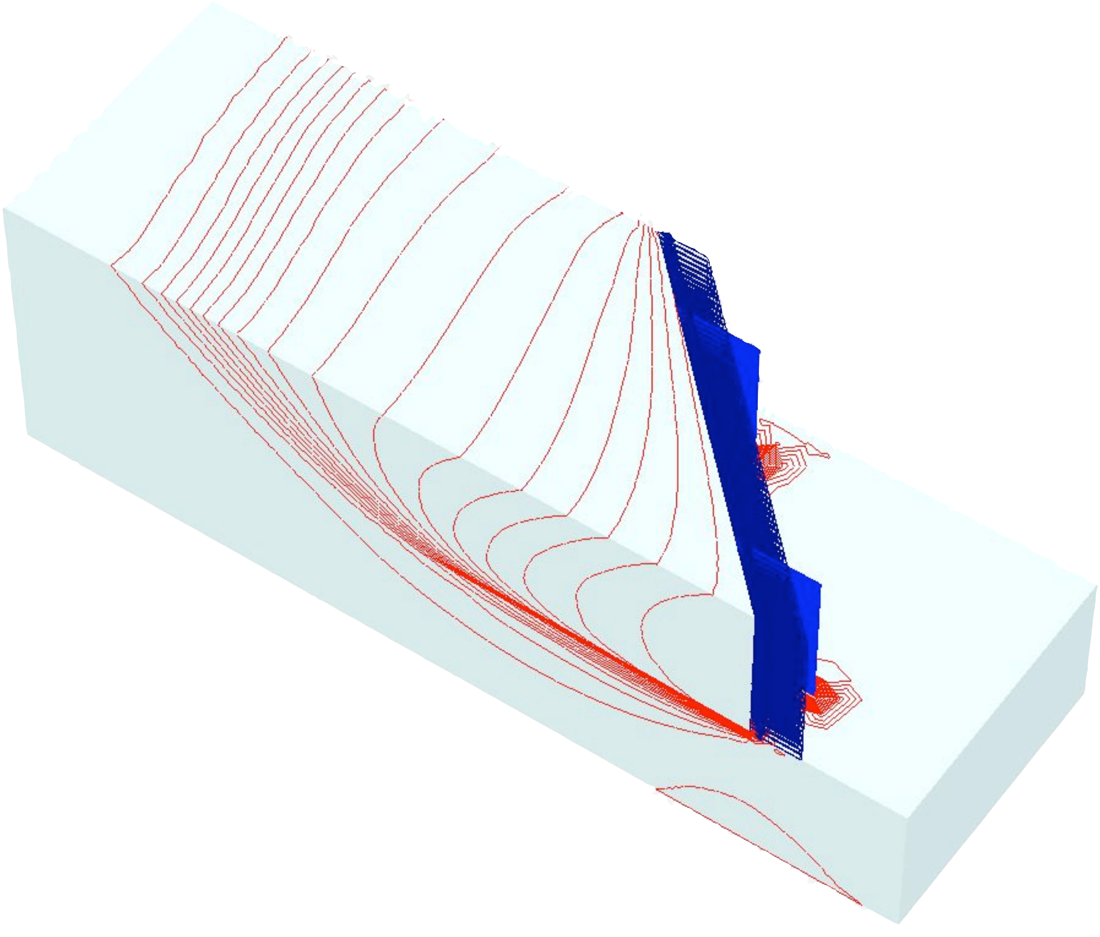


45^o skew Abutment with UCLA backfill

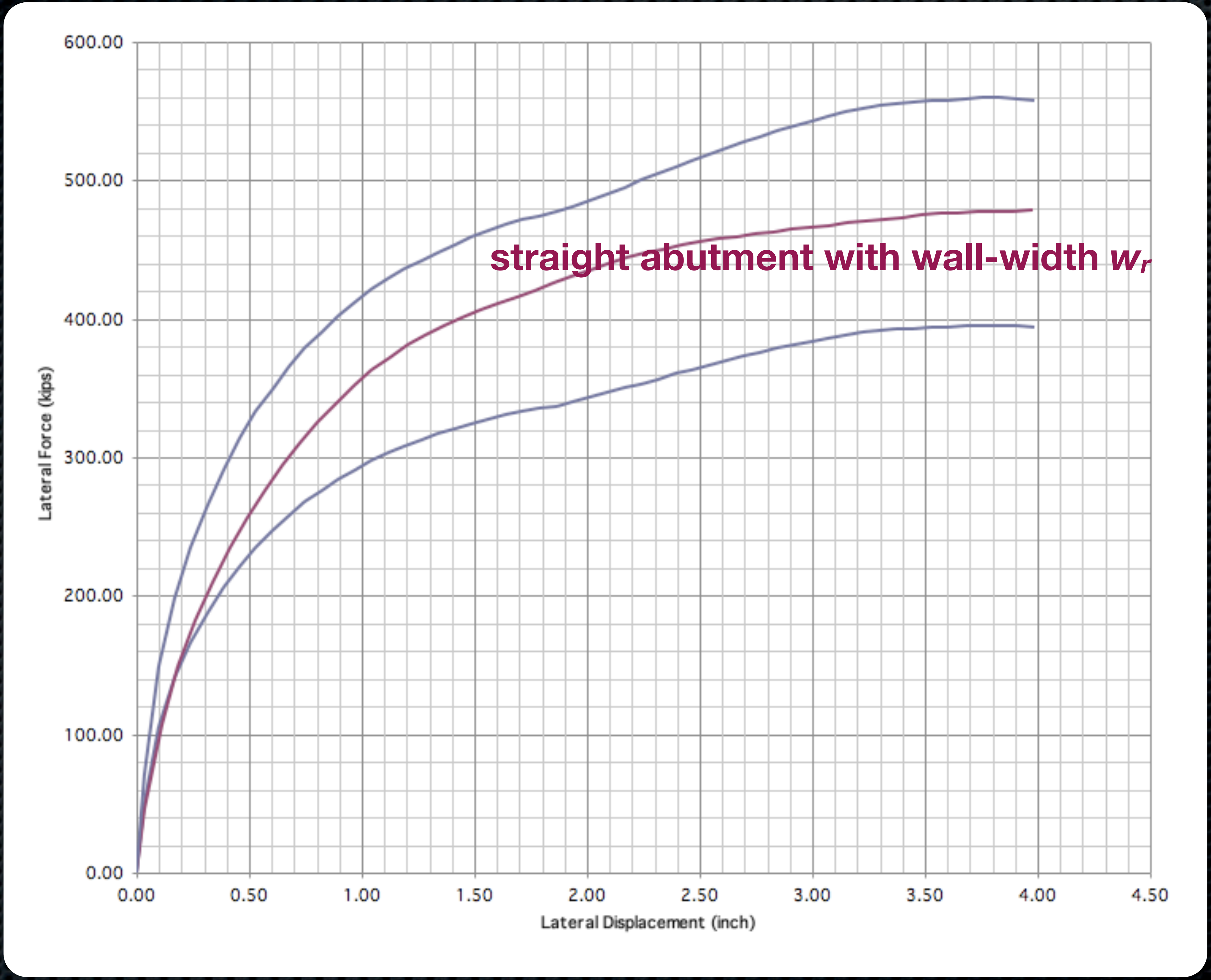




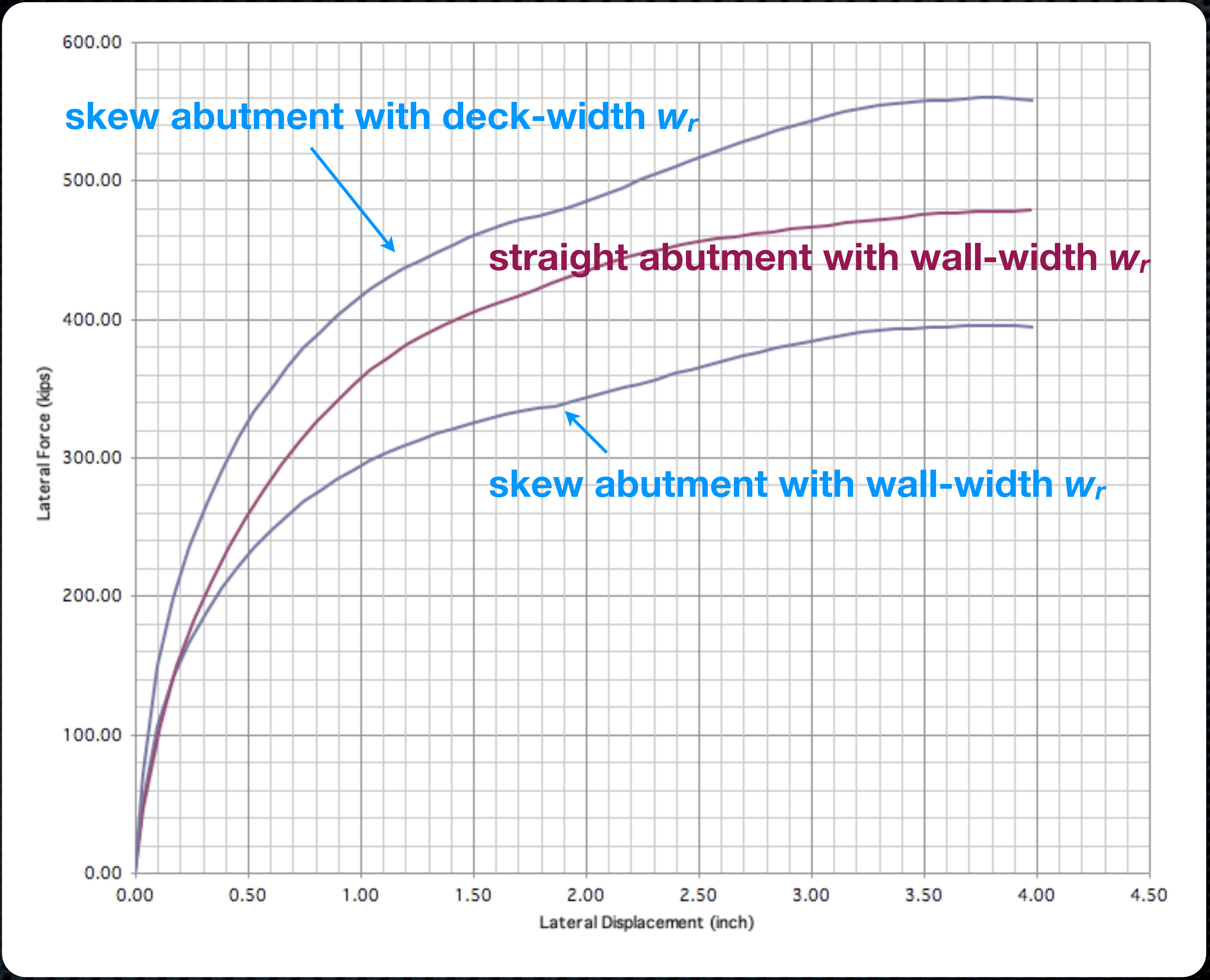




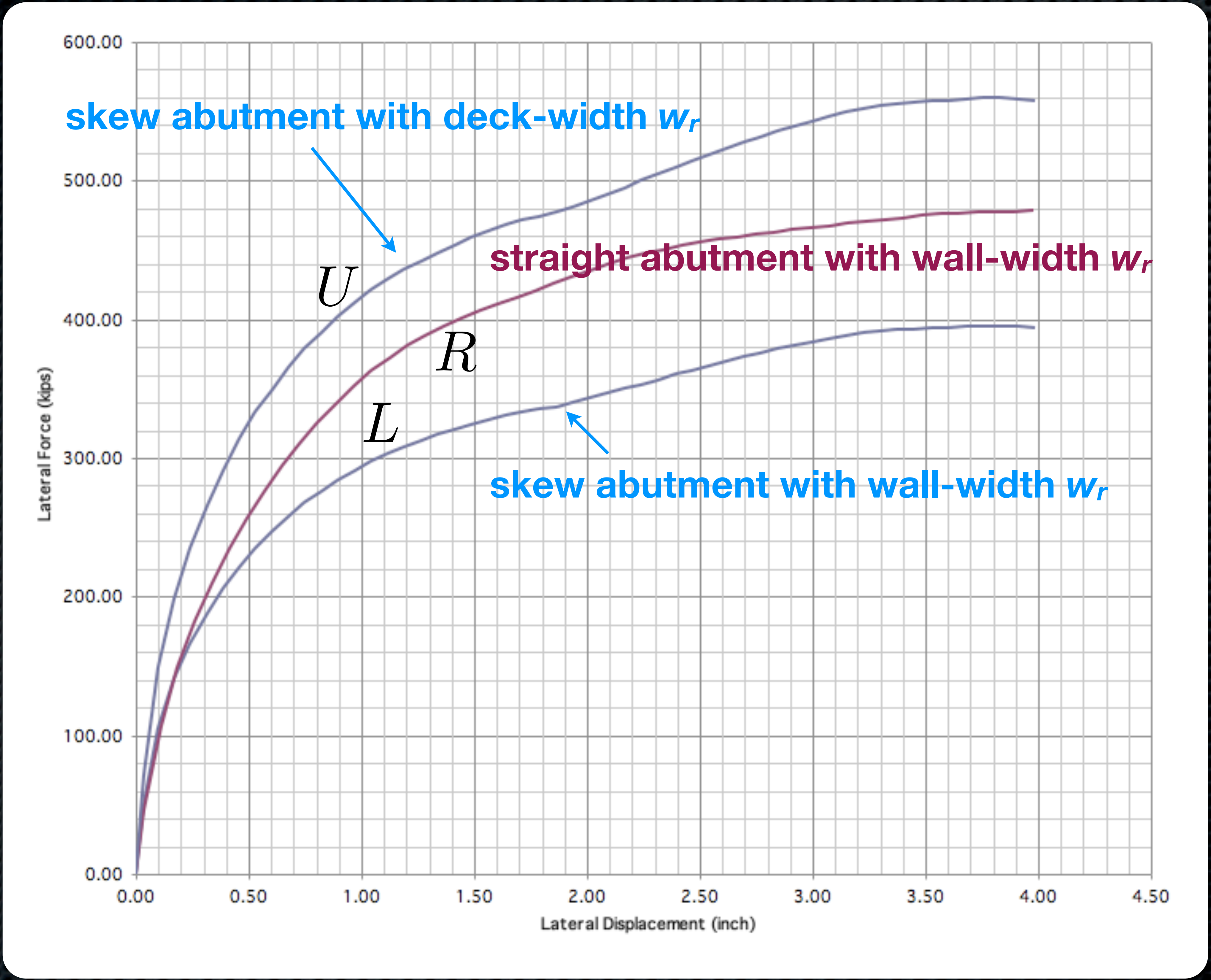
How to scale for skew?



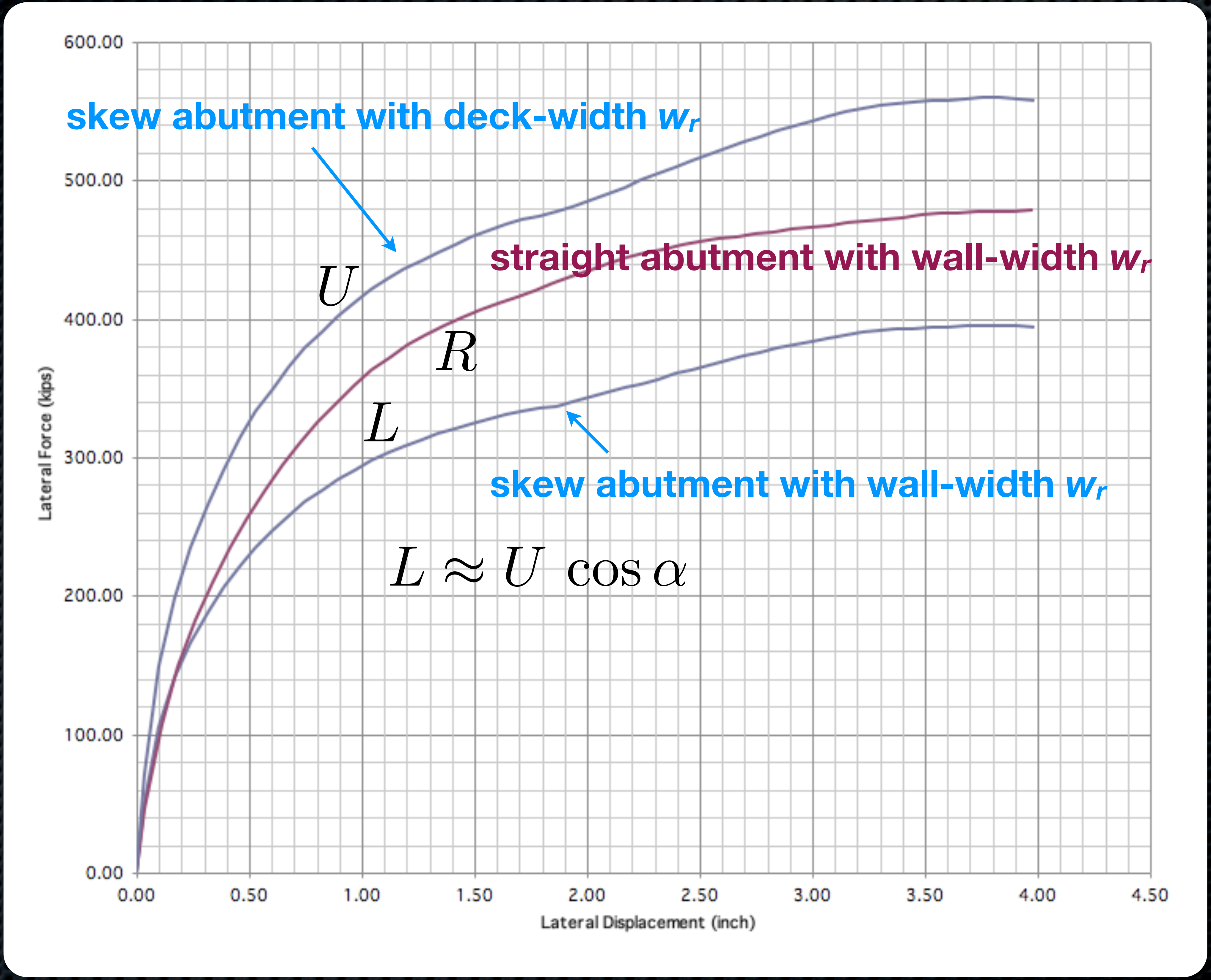
How to scale for skew?



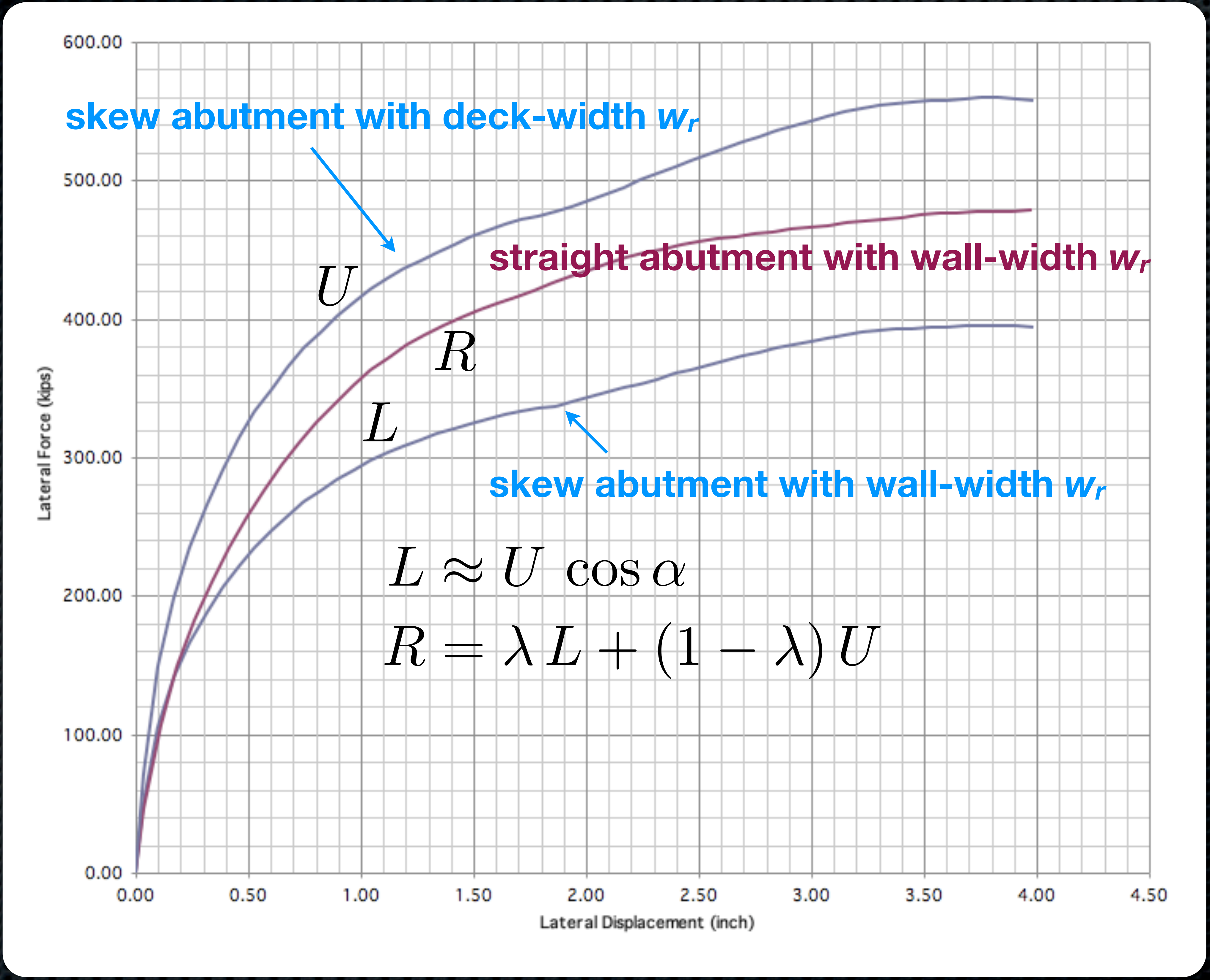
How to scale for skew?



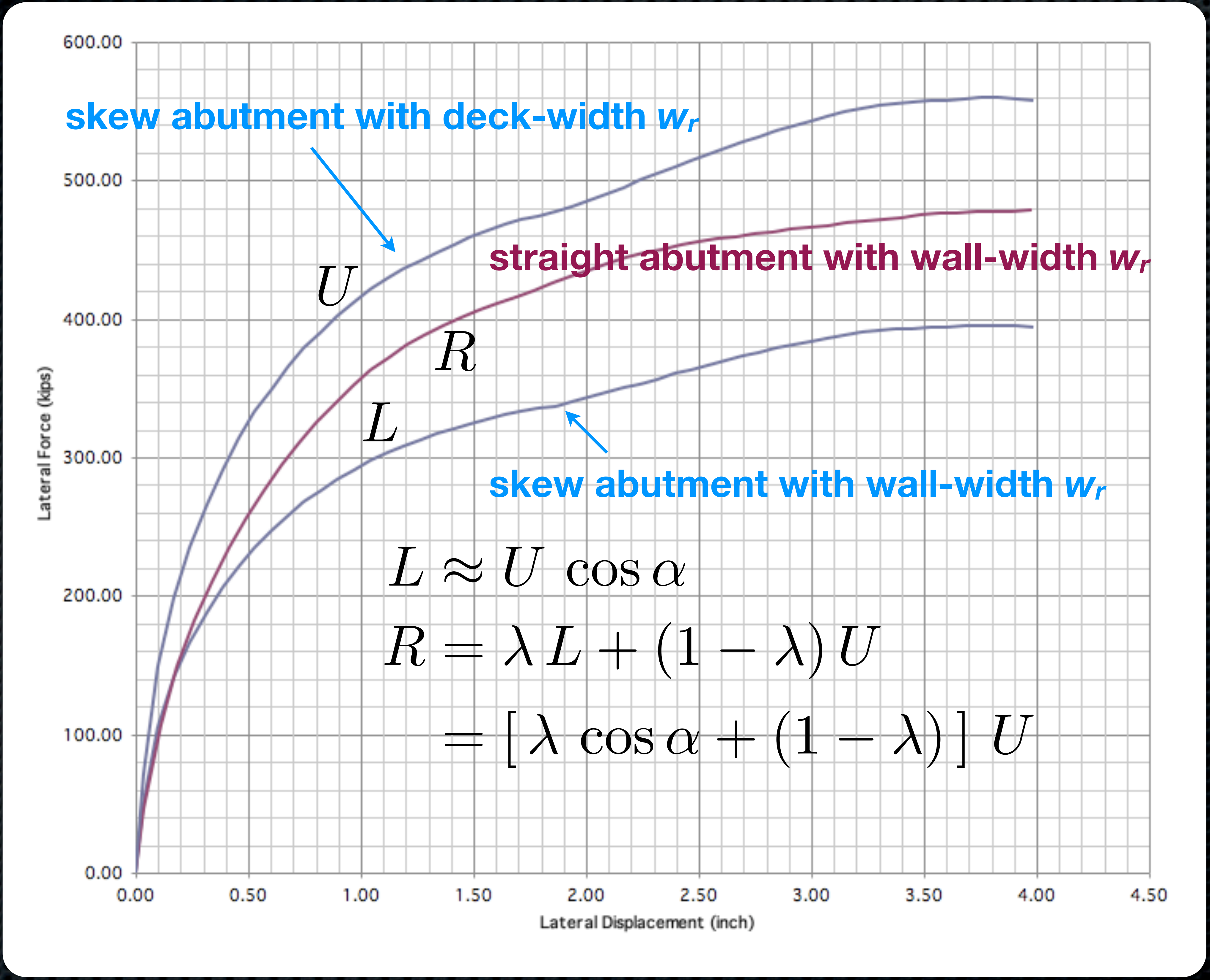
How to scale for skew?



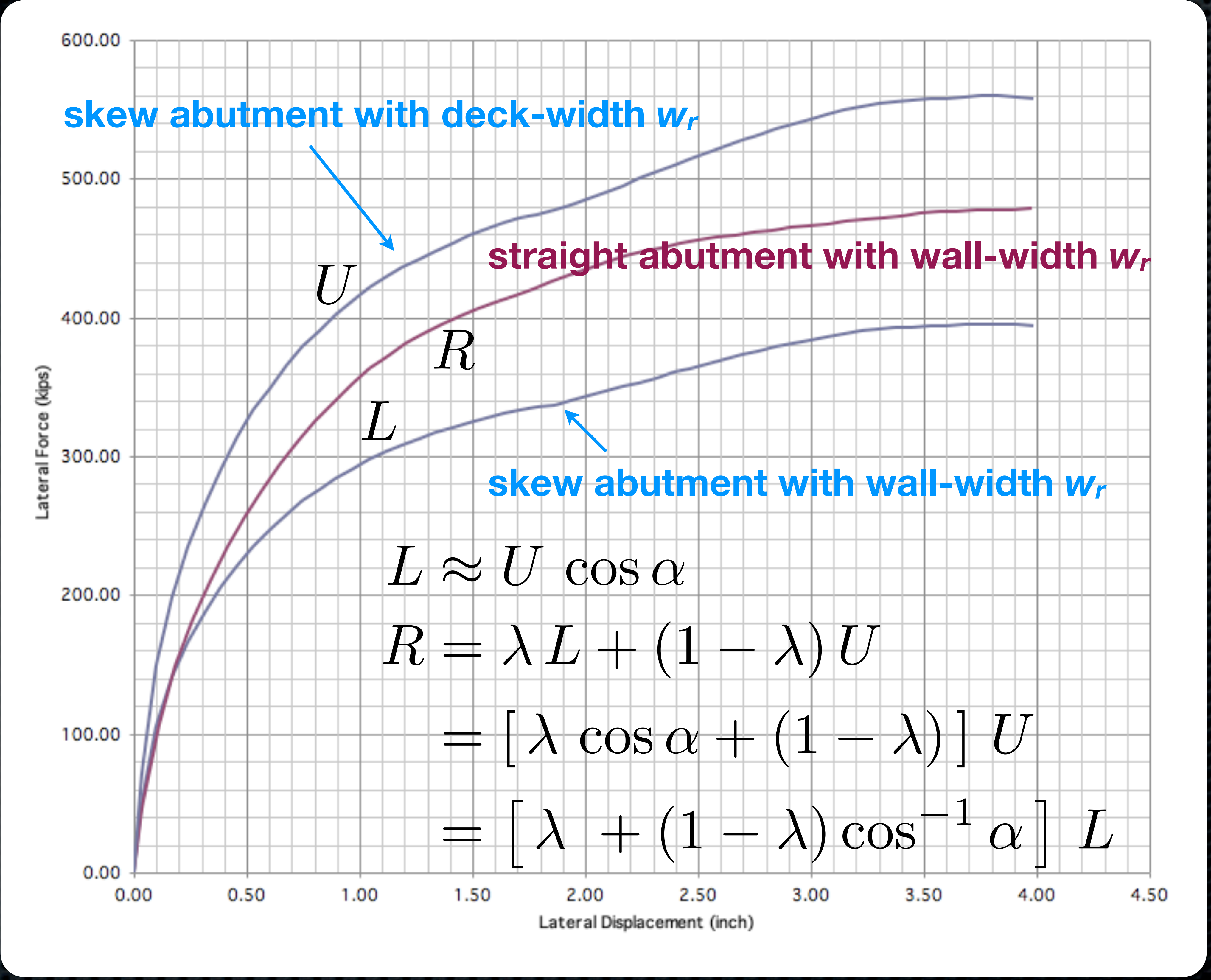
How to scale for skew?



How to scale for skew?



How to scale for skew?



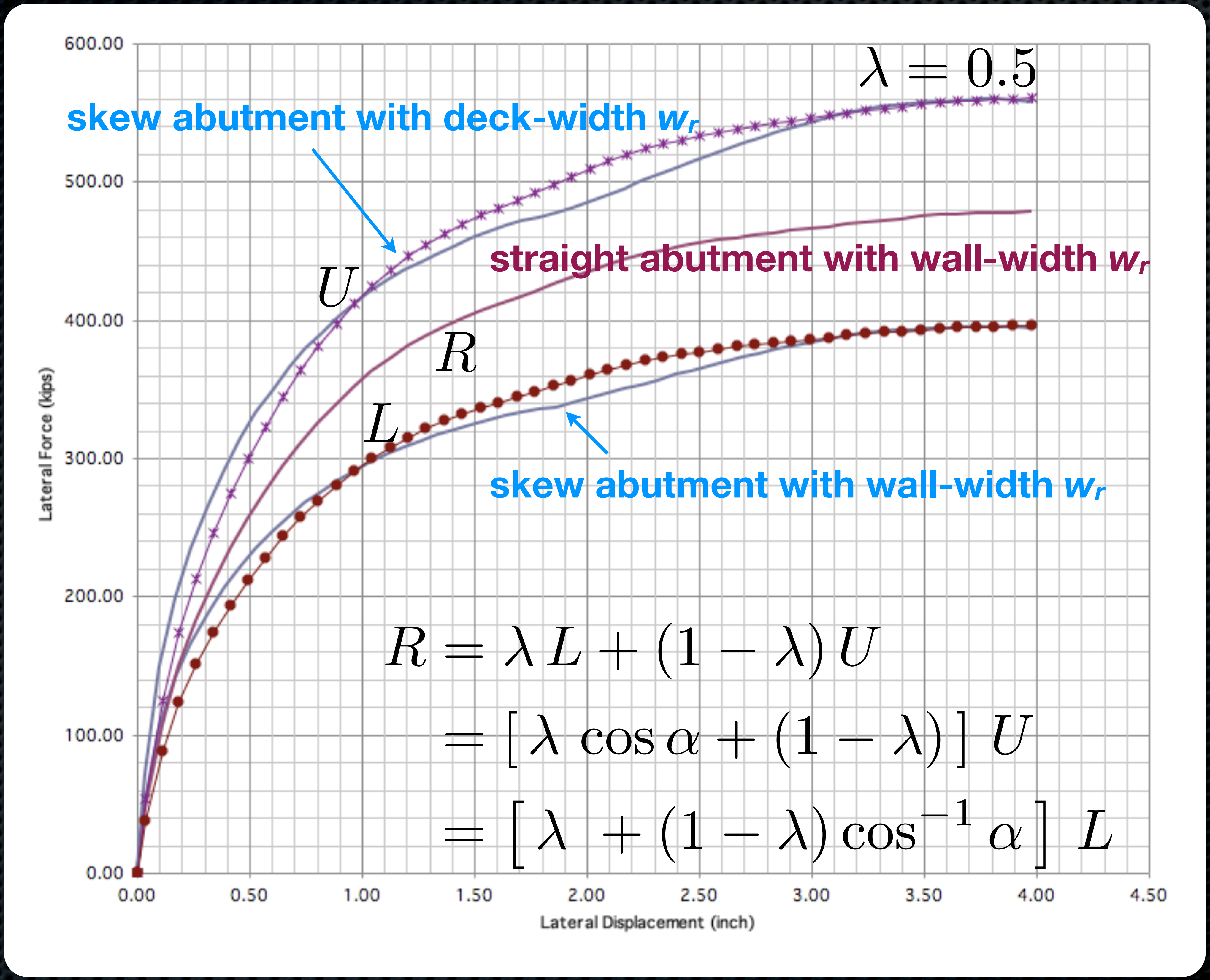
$$L \approx U \cos\alpha$$

$$R = \lambda L + (1-\lambda)\,U$$

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

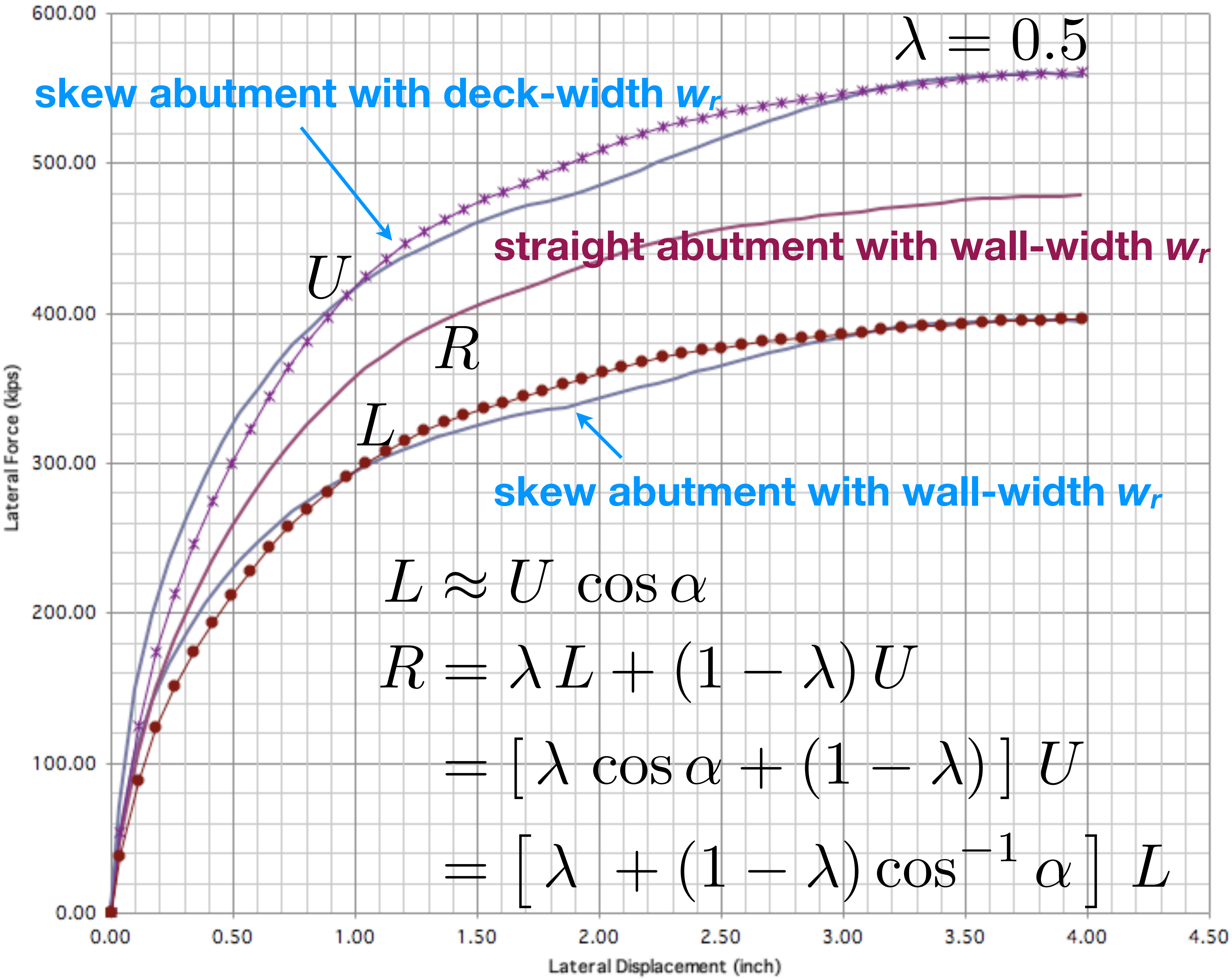
$$= [\lambda + (1-\lambda)\cos^{-1}\alpha]\,L$$

How to scale for skew?



$$
\begin{aligned}
R &= \lambda\, L + (1-\lambda)\, U \\
&= \left[\lambda \cos\alpha + (1-\lambda)\right] U \\
&= \left[\lambda\ + (1-\lambda)\cos^{-1}\alpha\right]\ L
\end{aligned}
$$

How to scale for skew?



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

$$R = \lambda L + (1-\lambda) U$$

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

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

quo vadis?

1. Complete the development of bridge models
2. Obtain the ground motion suite
3. Upcoming skew test at UCLA
4. Develop a macroelement for a rotating backwall
5. Incorporate new abutment macroelements into the bridge matrix
6. Plan the hybrid test for following year

discussion