PERFORMANCE LIMIT STATES OF RCFST DRILLED SHAFTS

Speaker:

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aci Fall 2017 | Anaheim
The Concrete Convention and Exposition

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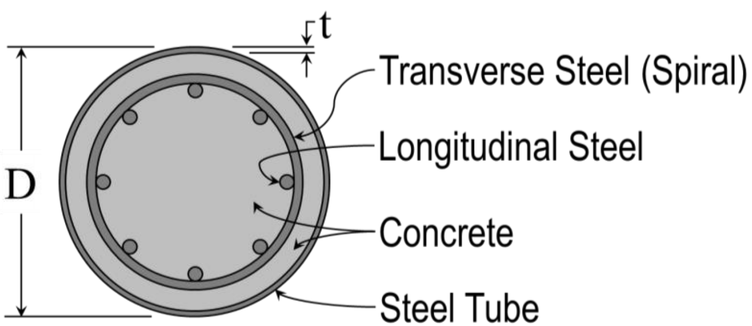
Outline

1. Introduction
2. Experimental Program
3. Analytical Studies
4. Performance Limit States
5. Conclusions

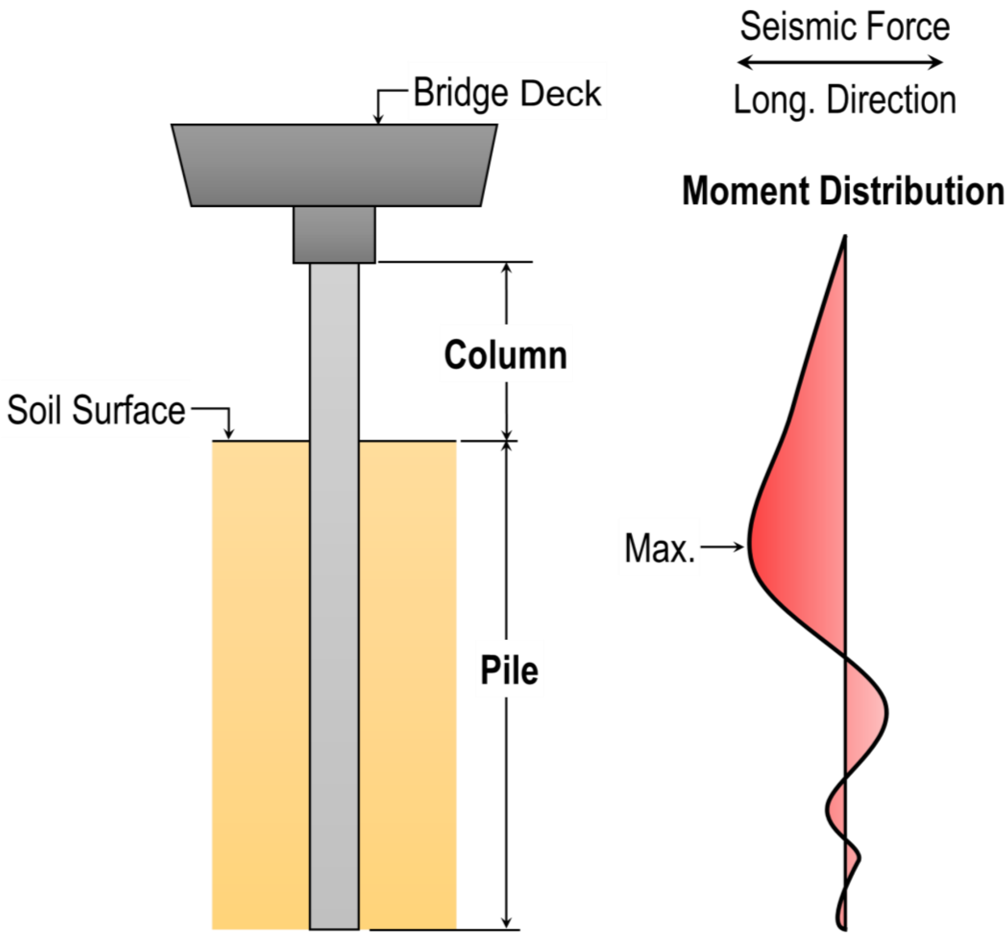
1. Introduction

Reinforced Concrete Filled Steel Tube (RCFST) Drilled Shafts

OMalley Bridge (Courtesy, AKDOT)



RCFST Cross Section



Pile-Column System Elevation

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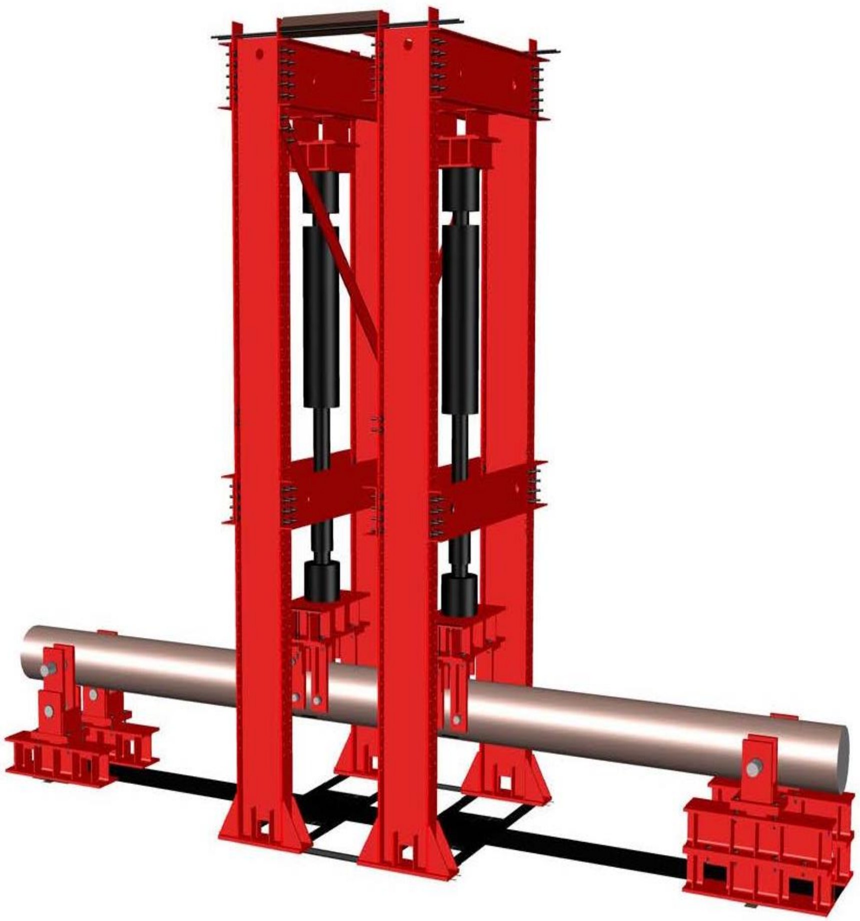
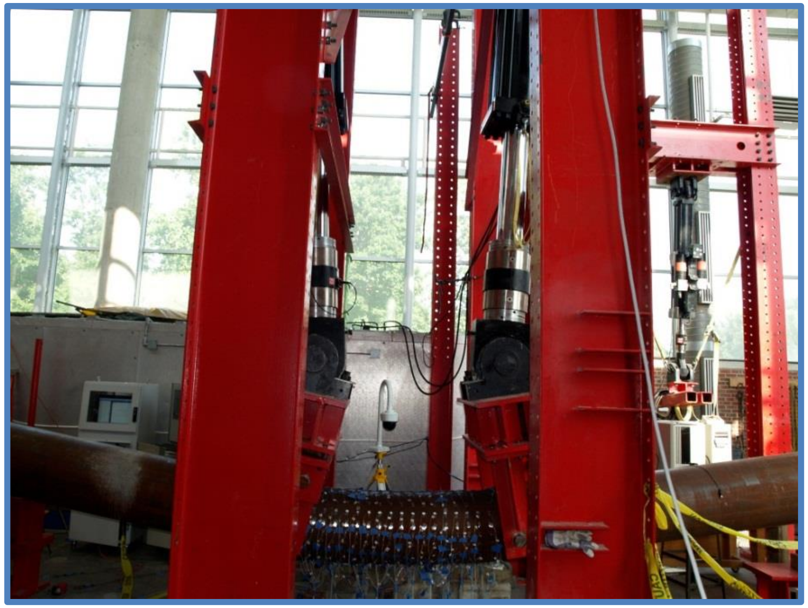
Past Research: Brown et al. (2015)



- 12 Large-scale tests
- D/t ratios of 33 to 160



- D/t ratio
- Equilibrium and strain compatibility

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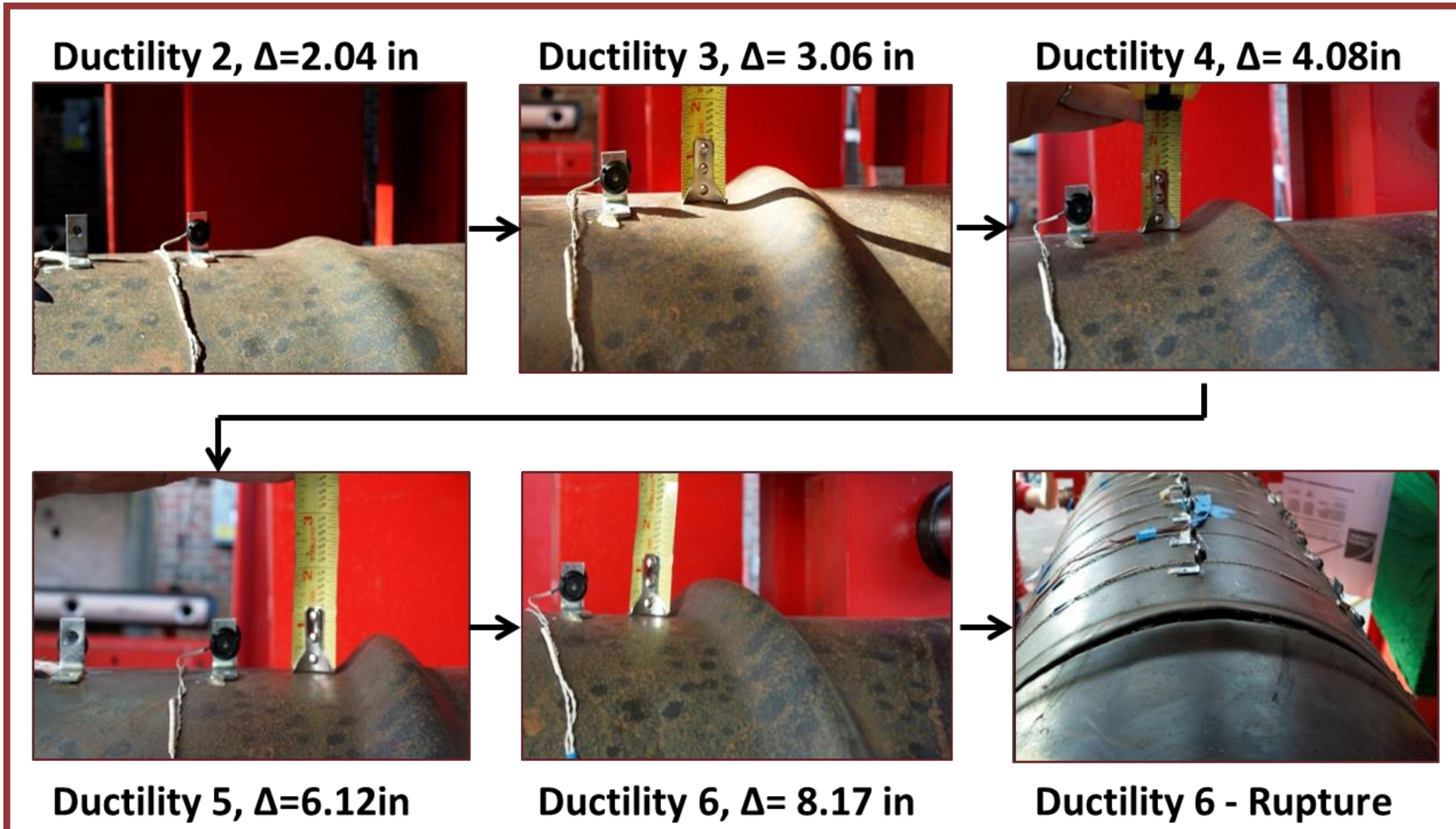
Past Research: Brown et al. (2015)



Progression of Buckling for "Thin Wall" Tubes

1. Introduction

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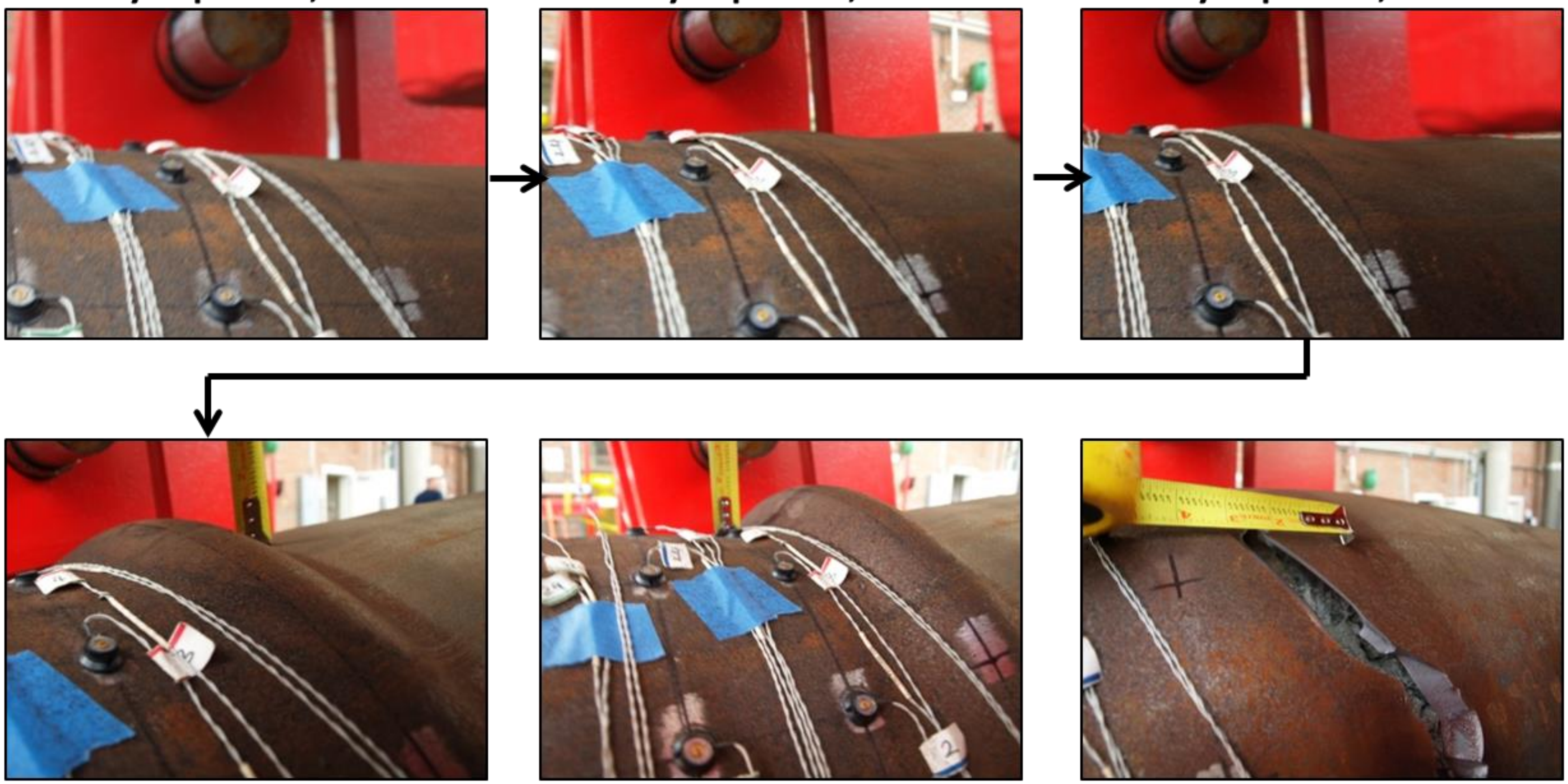
Past Research: Brown et al. (2015)



Ductility 5-push 1, Δ=13 in — Ductility 5-push 3, Δ= 13 in — Ductility 6-push 1, Δ= 15.6in

Ductility 6-push 3, Δ=15.6in — Ductility 7-push 1, Δ= 18.2in — Ductility 7-pull 1

Progression of Buckling for "Thick Wall" Tubes

Outline

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2. Experimental Program

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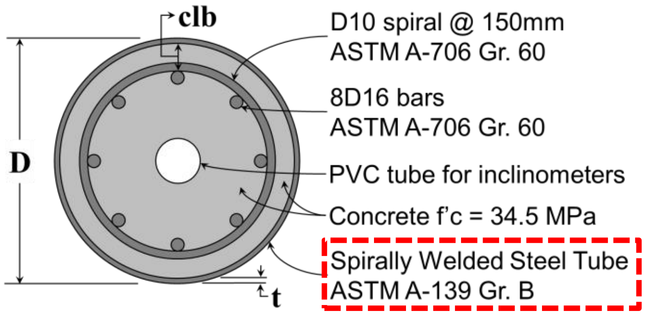
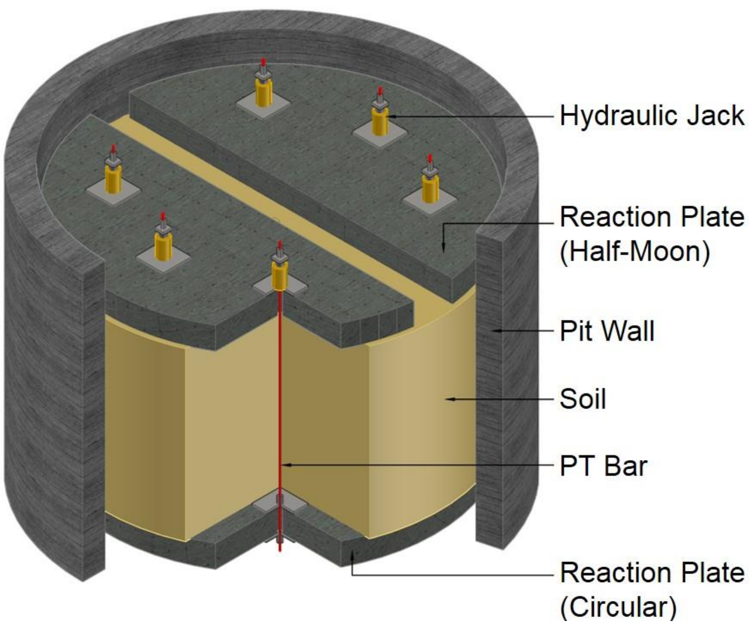
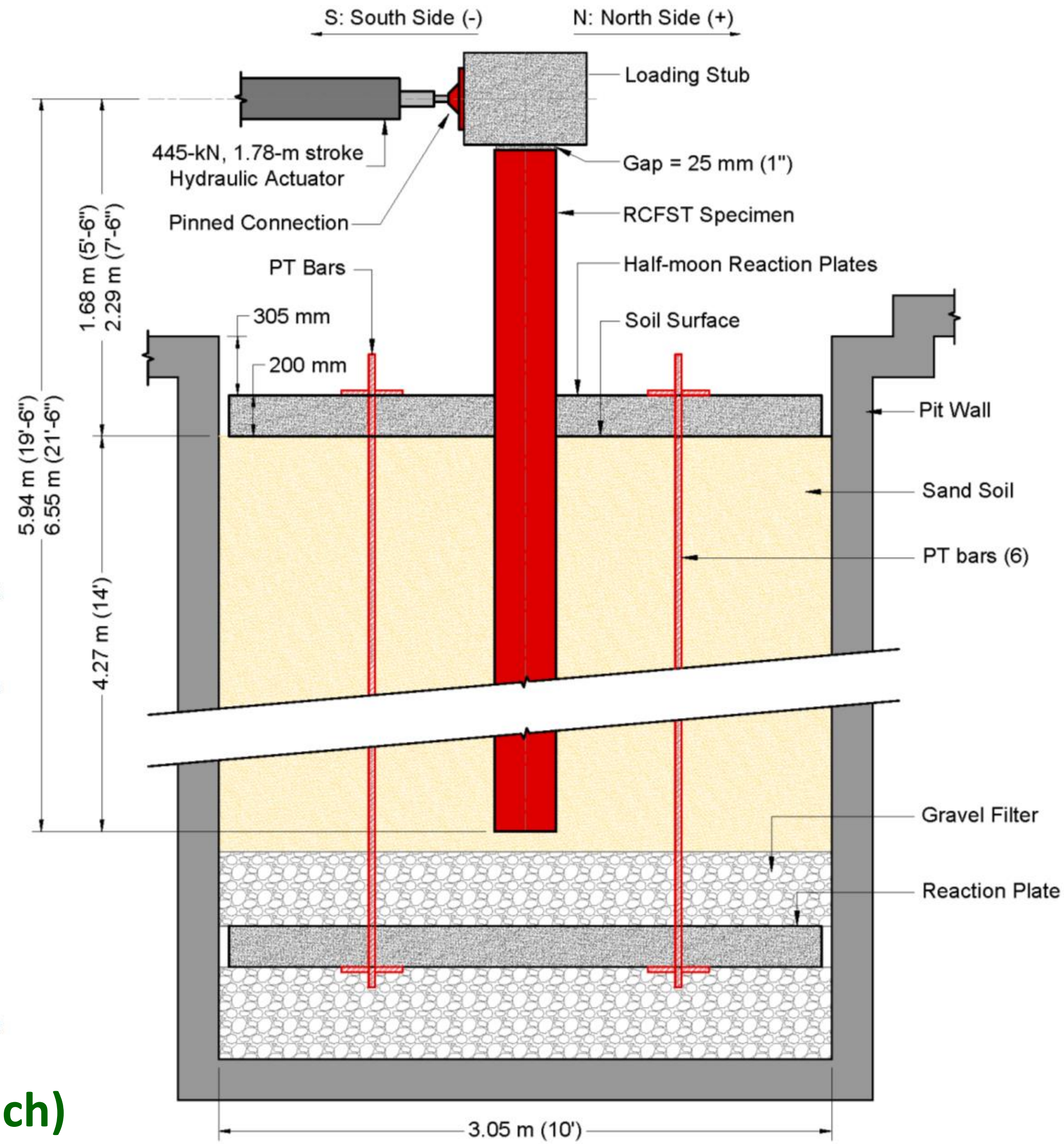
Test Setup



RCFST Specimen Cross Section



Soil Surcharge System (Soil Sandwich)



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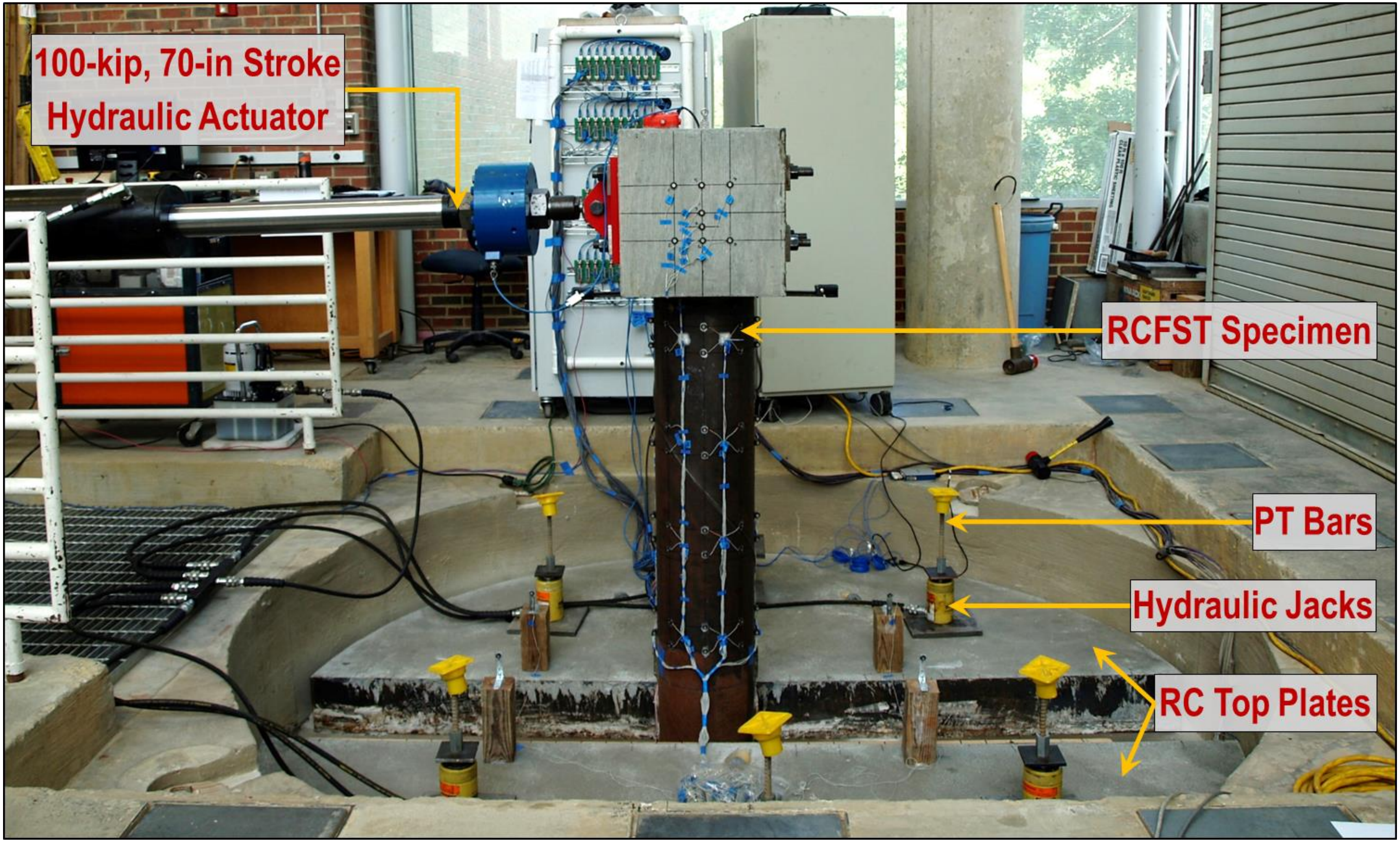
Test Setup



2. Experimental Program

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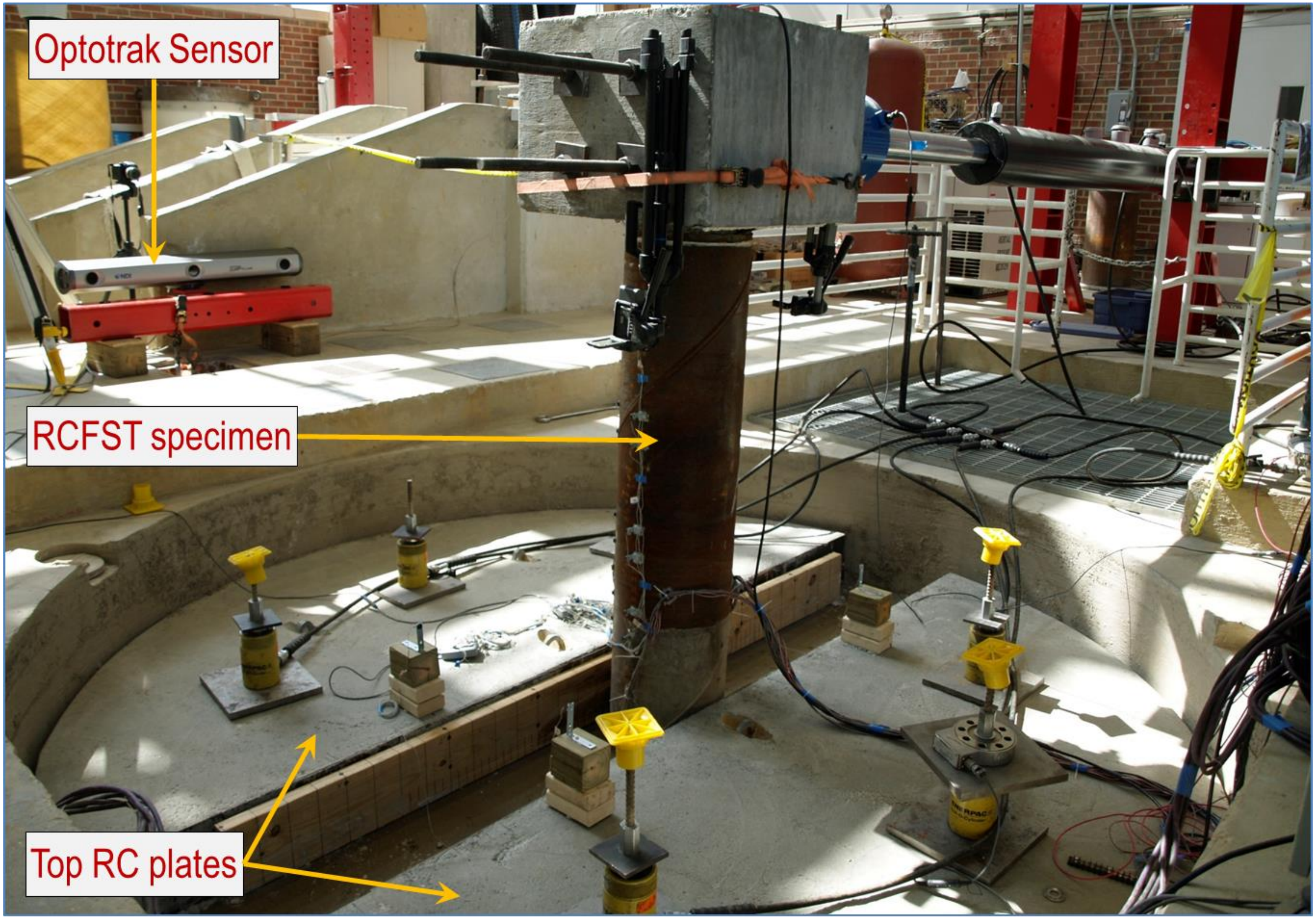
Test Setup



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Example: Test #11 – August 18, 2016

Test # 11

Reinforced Concrete Filled Steel Tube in Soil

Outer diameter	:	D	=	12.75 in
Tube Thickness	:	t	=	0.129 in
Nominal D/t ratio	:	D/t	=	95
Above ground height	:	L_1	=	7.24 D

Test Day : August 18, 2016

2. Experimental Program

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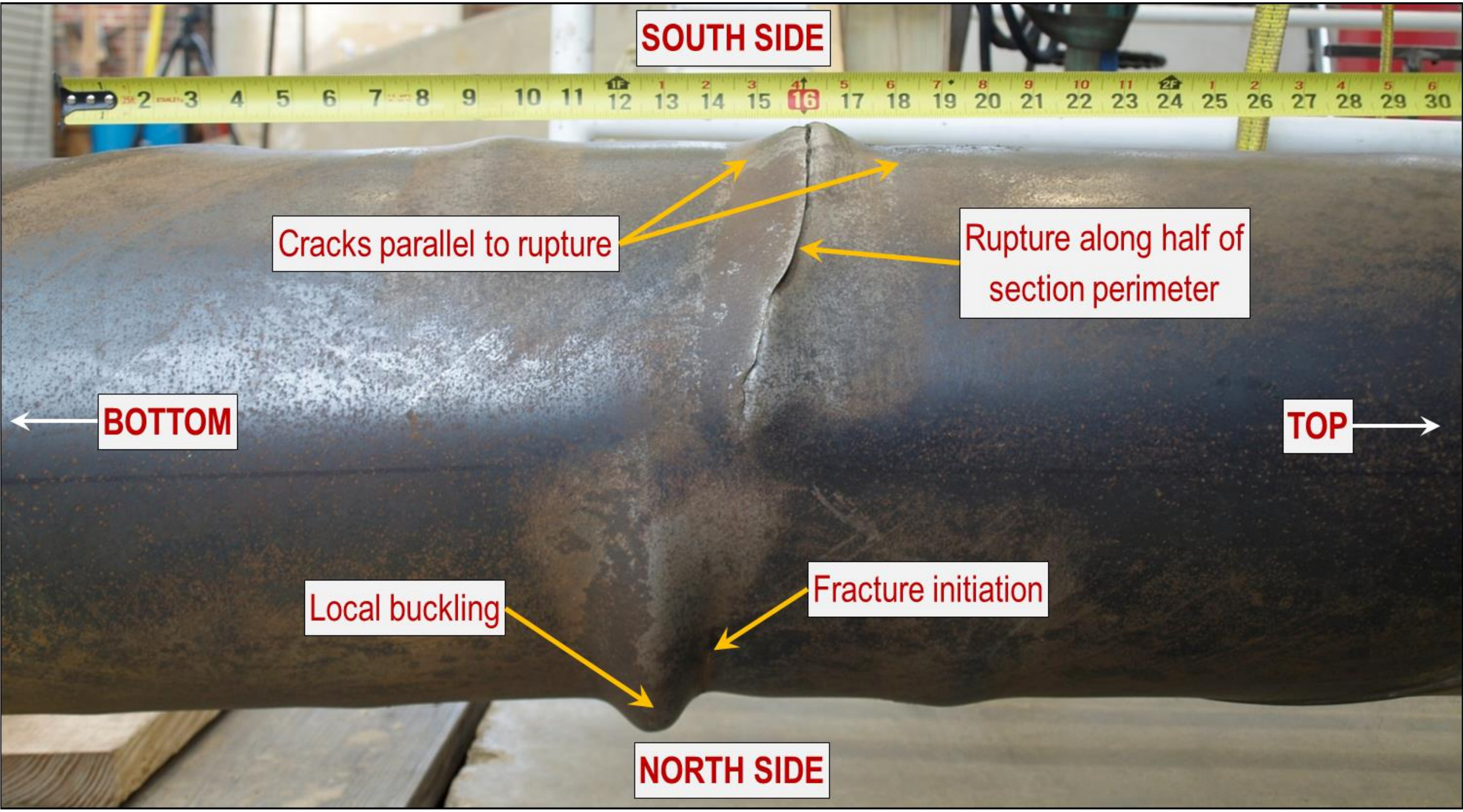
Failure Mechanism



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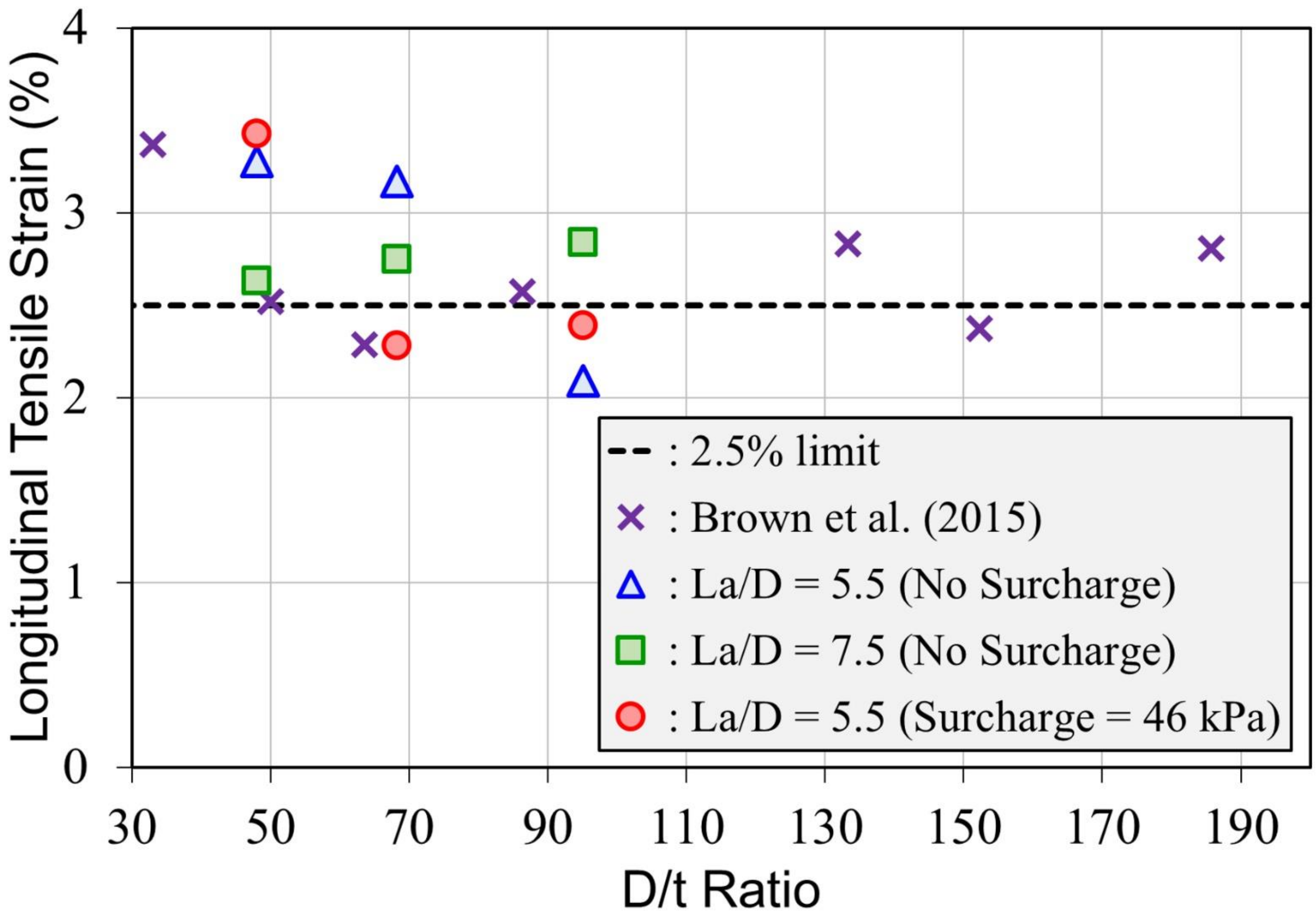
Tensile Strains Prior Fracture:



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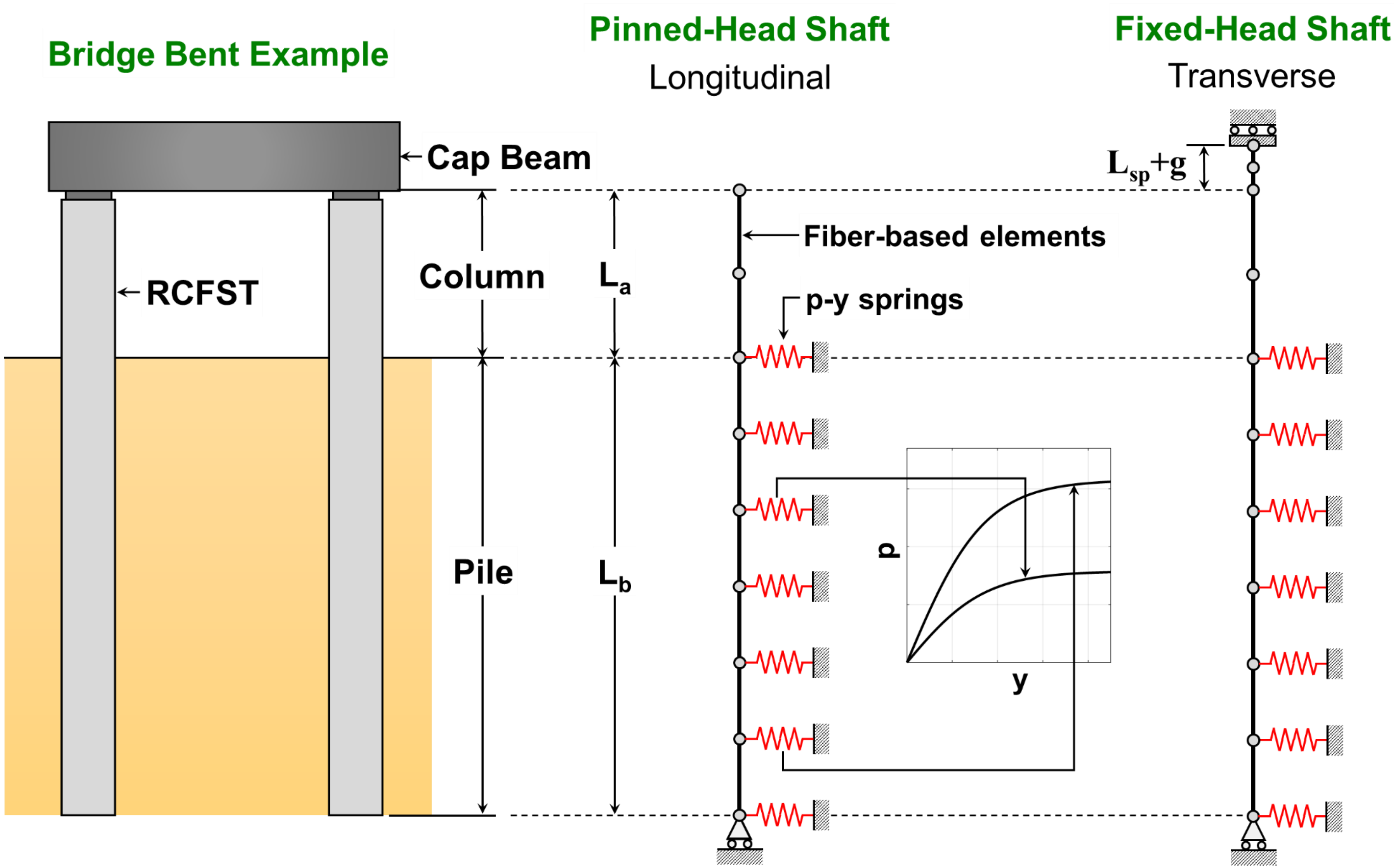
Analytical Model: finite element, fiber-based approach (OpenSees)



5. Analytical Studies

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Parametric Study: general considerations

- Simulations on **single RCFST specimens**
- Internal reinforcement: ρ = 2% and ρ_v = 1%
- Material properties:
  - Concrete: f_{ce}' = 36.4 MPa (5.2 ksi)
  - Steel tube: APIx52L f_{yte} = 396 Mpa (57.2 ksi)
  - Reinforcement: A706-Gr.60 f_{yre} = 462 Mpa (66 ksi)

Basic parameters:

Head Fixity	Diameter (mm)	ALR (%)	D/t Ratio	La/D Ratio
Pinned	610	5	48	4
Fixed	1,220	10	64	8
		15	95	12

3. Analytical Studies

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Parametric Study: soil considerations

- Uniform soil layer
- Deep enough to achieve zero rotation at shaft tip
- Undrained conditions for clay – **Matlock**
- Dry or moist conditions for sand – **API + Reese and Van Impe**

Soil parameters:

			Soil Strength and Stiffness			
			Sand		Clay	
Soil Type	Soil Profile	γ (kN/m³)	Ø (°)	n_h (kN/m³)	C_u (kPa)	ε_{50}
Sand	Flexible	15.7	30	9500	12	0.020
Clay	Medium	17.3	35	27200	36	0.010
	Stiff	18.9	40	61100	72	0.005

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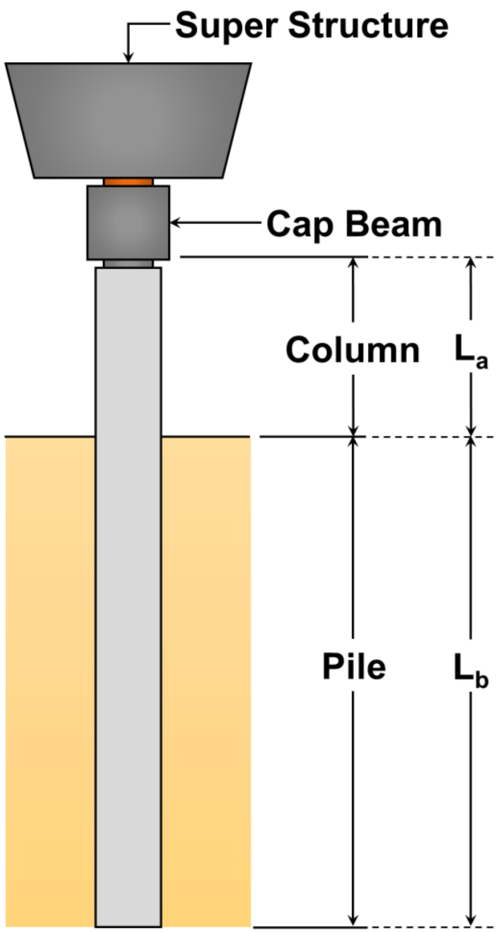
System Behavior

Eklutna River Bridge (echoak.com)



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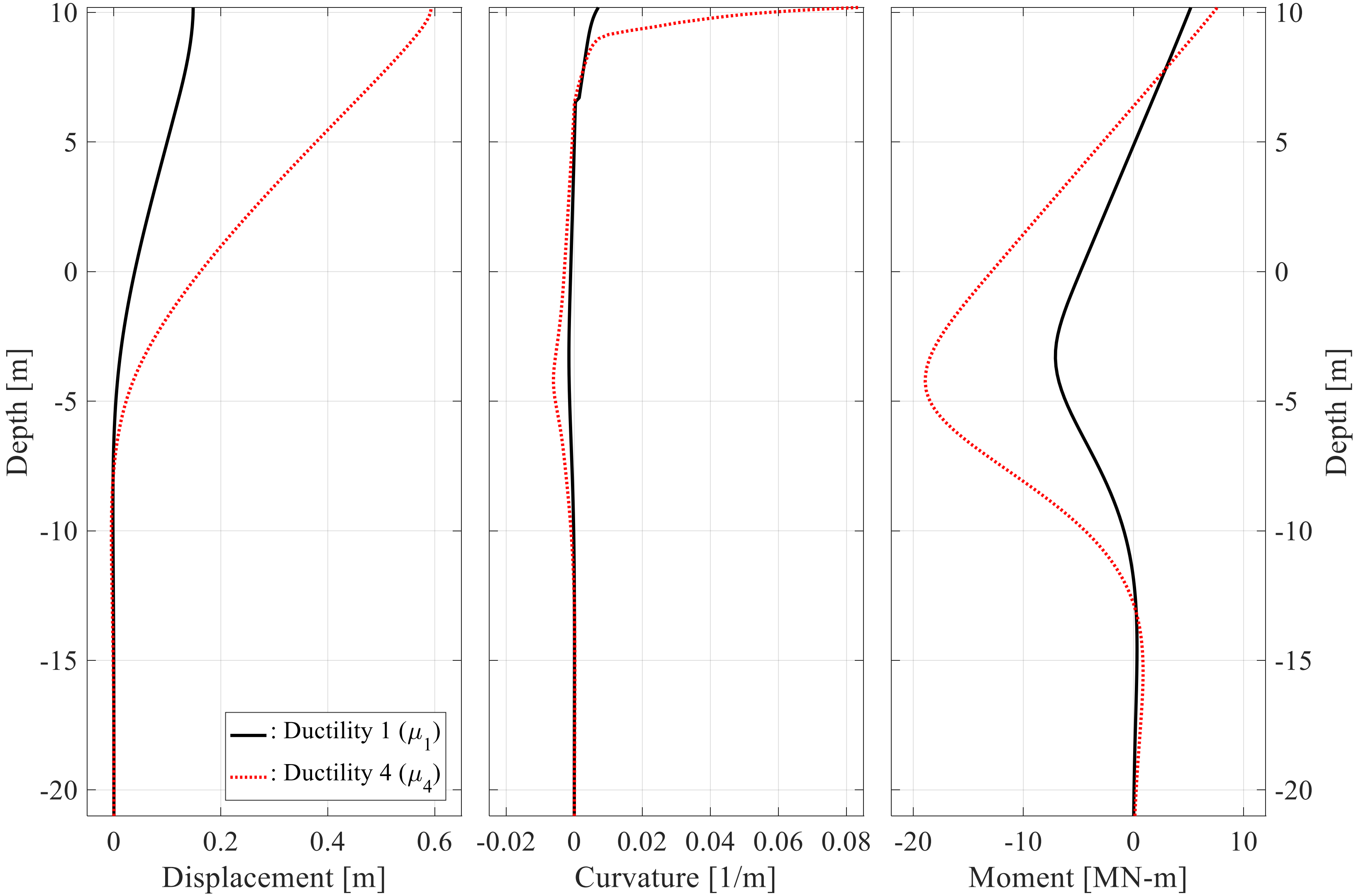
System Behavior: fixed-head RCFST



3. Analytical Studies

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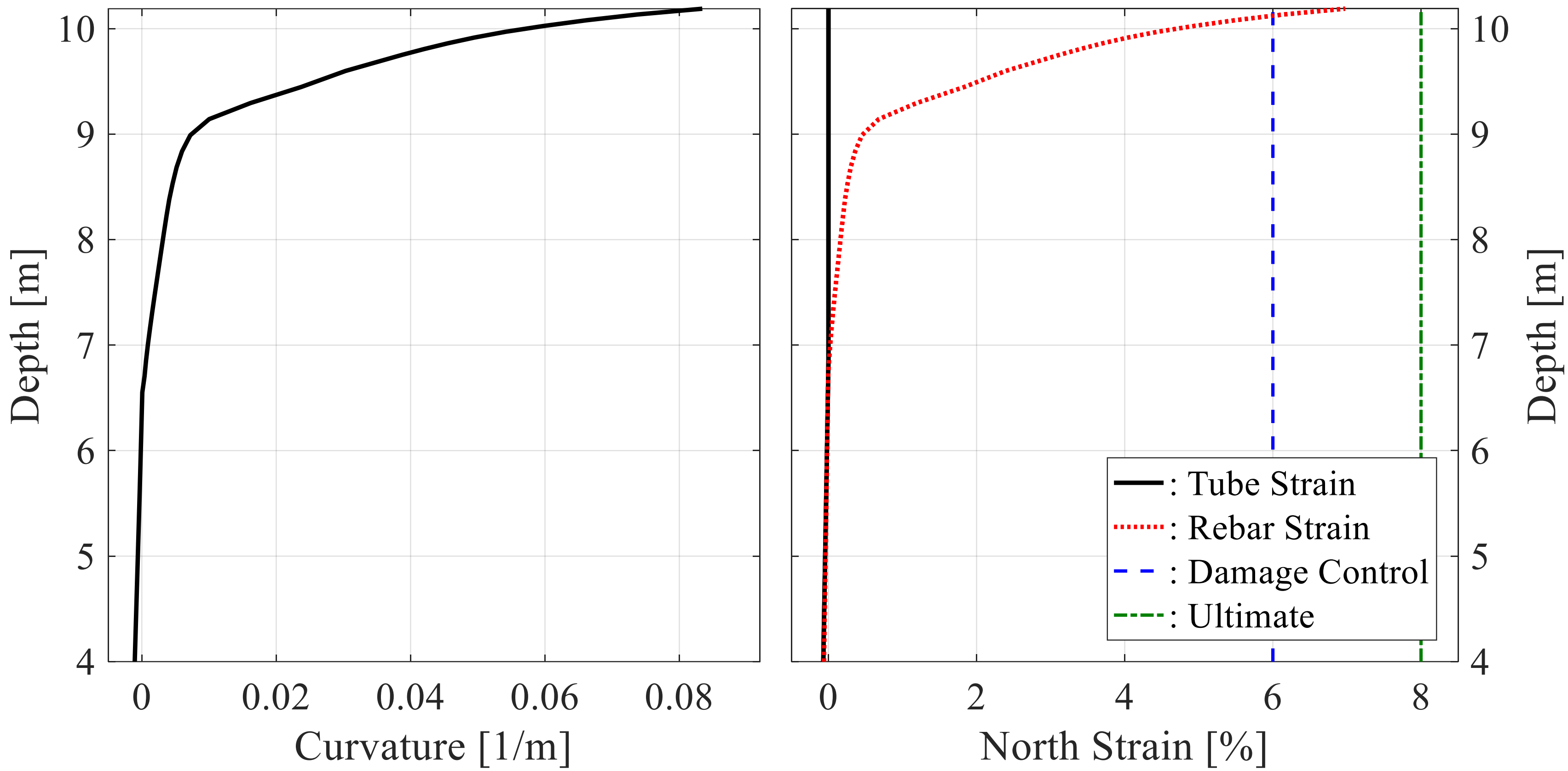
System Behavior: fixed-head RCFSTs

➢ Top plastic hinge



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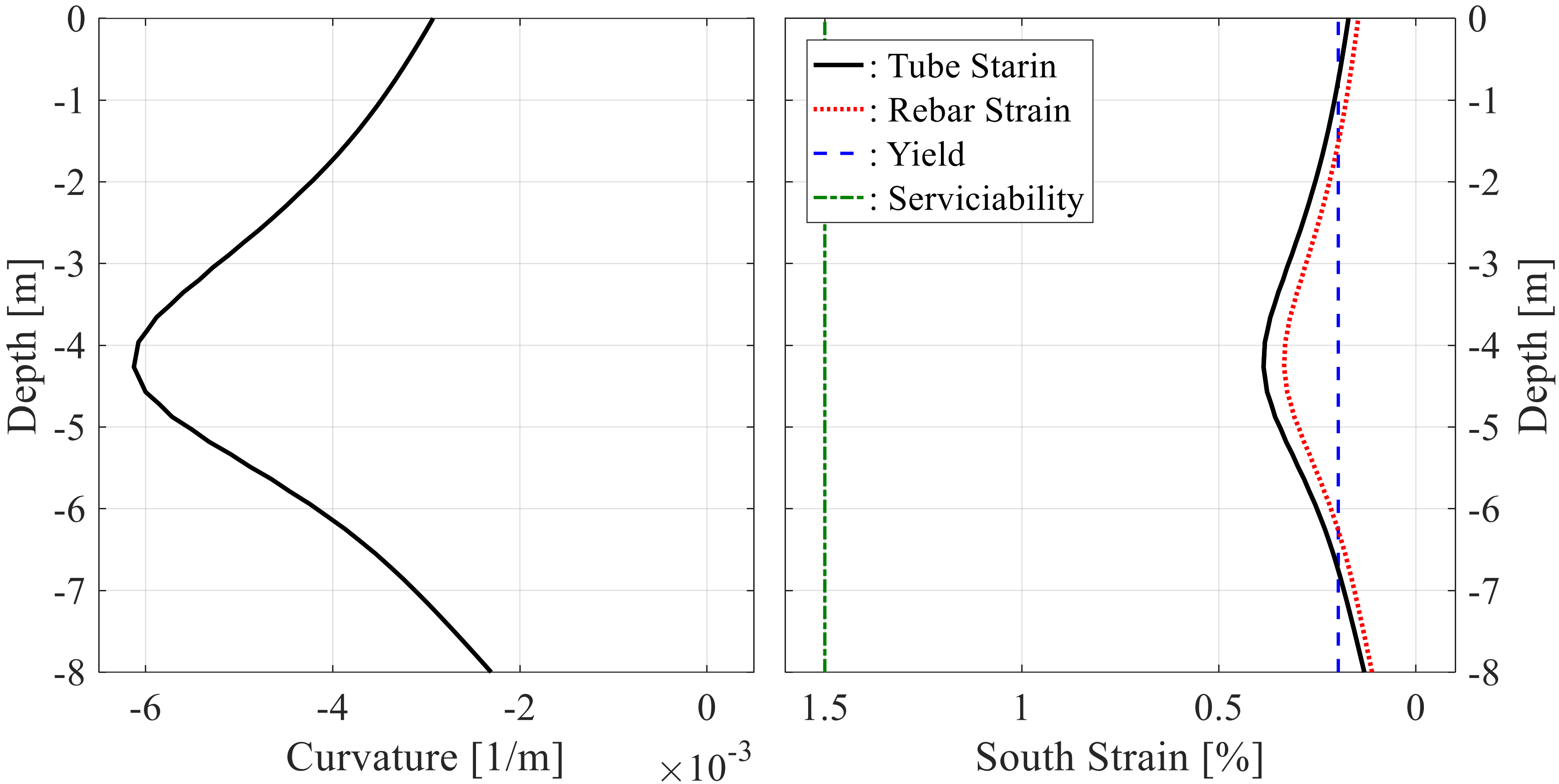
System Behavior: fixed-head RCFSTs

- Inground plastic hinge



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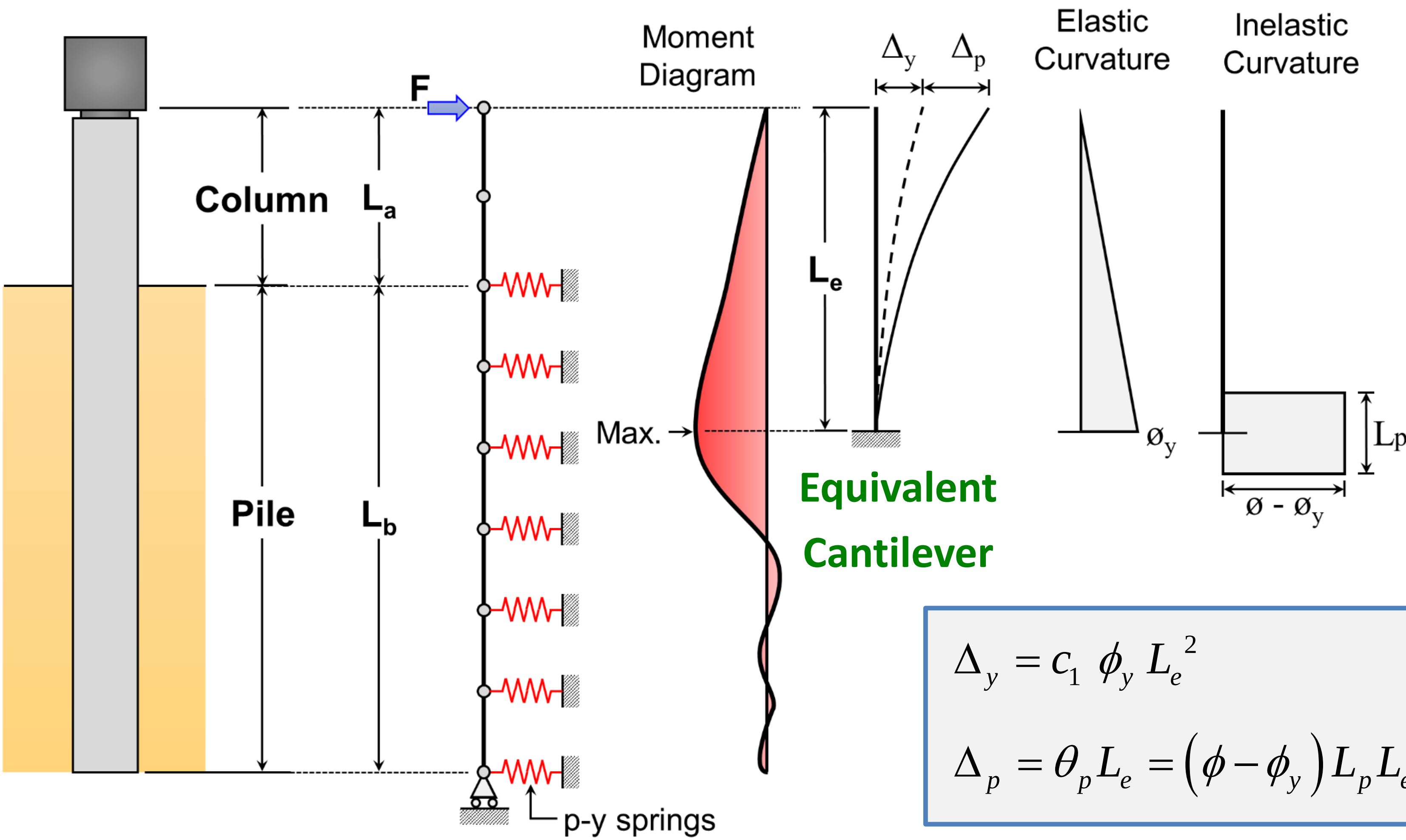
Equivalent Cantilever Plastic Hinge Model

Pinned-Head RCFSTs: Aguirre et al. 2017



$$\Delta_y = c_1 \, \phi_y \, L_e^{\,2}$$

$$\Delta_p = \theta_p L_e = \left(\phi - \phi_y\right) L_p L_e$$

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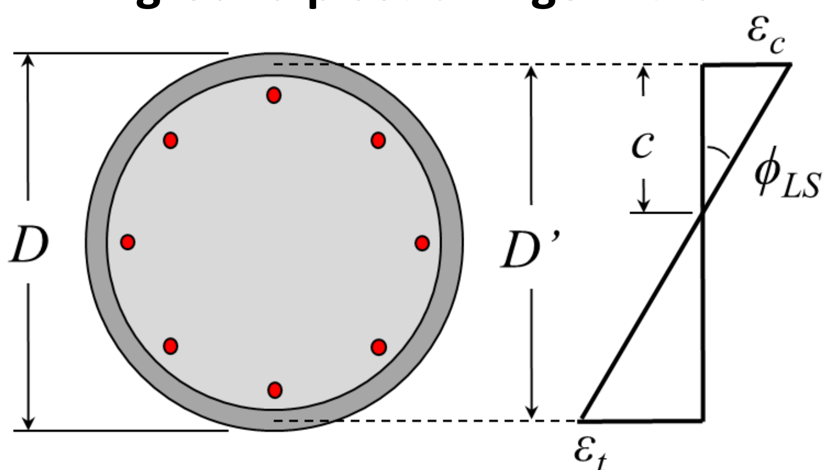
Performance Limit States: pinned-head shafts

In-ground plastic hinge: RCFST



Note: steel tube provides confinement and flexural strength

Limit state curvature:

$$\phi_{LS,t} = \frac{\varepsilon_t}{D' - c}$$

$$D' = D - t$$

Inground plastic hinge strain limits

Strain	Performance Level		
	Serviceability	Damage Control	Ultimate
Tension	0.015	$\varepsilon_t = 0.021 - \dfrac{D}{9100t} \geq \varepsilon_{y(tube)}$	0.025

4. Performance Limit States

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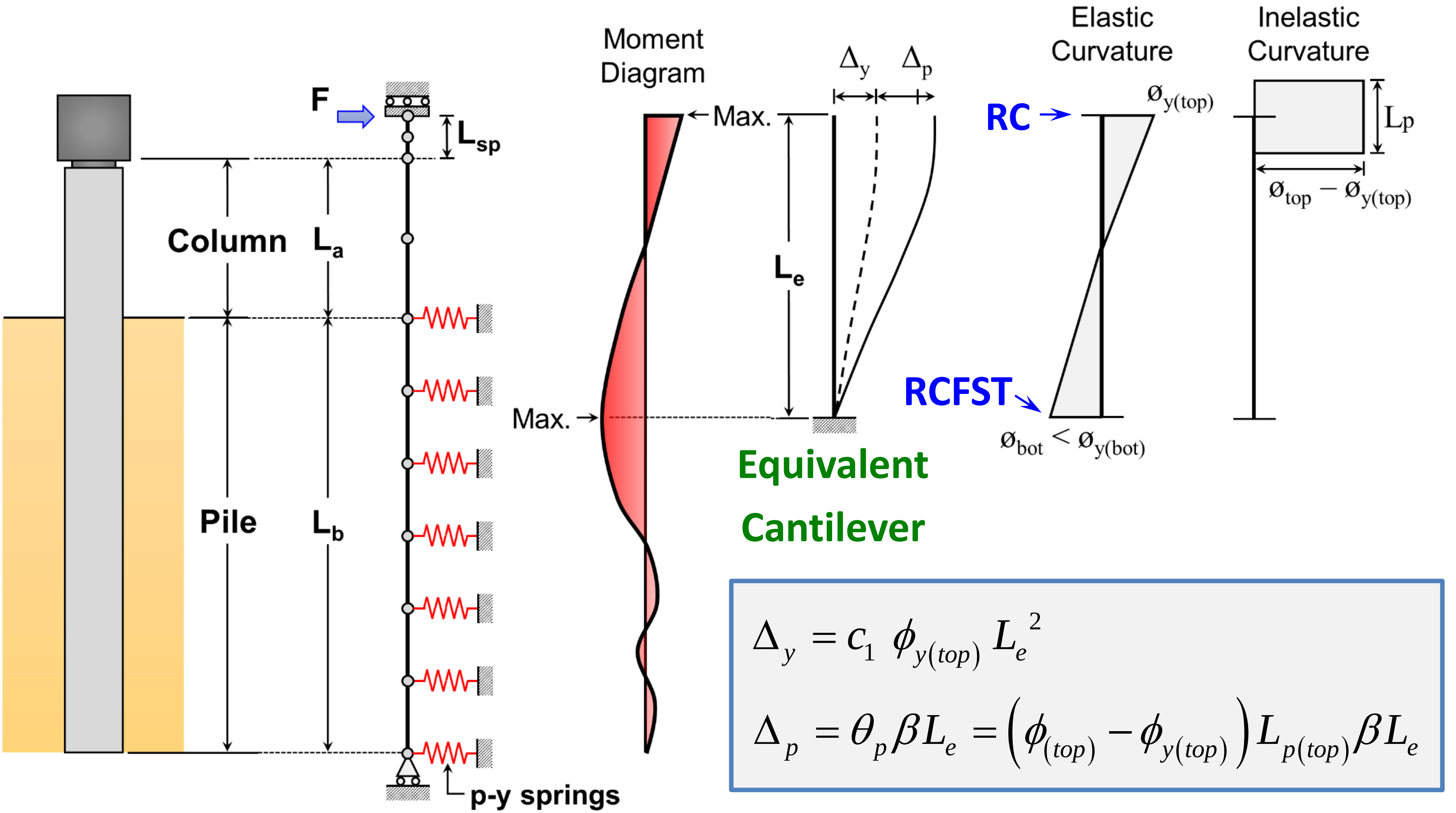
Equivalent Cantilever Plastic Hinge Model

Fixed-Head RCFSTs: Aguirre et al. 2017



$$\Delta_y = c_1 \, \phi_{y(top)} \, L_e^{\,2}$$

$$\Delta_p = \theta_p \beta L_e = \left(\phi_{(top)} - \phi_{y(top)}\right) L_{p(top)} \beta L_e$$

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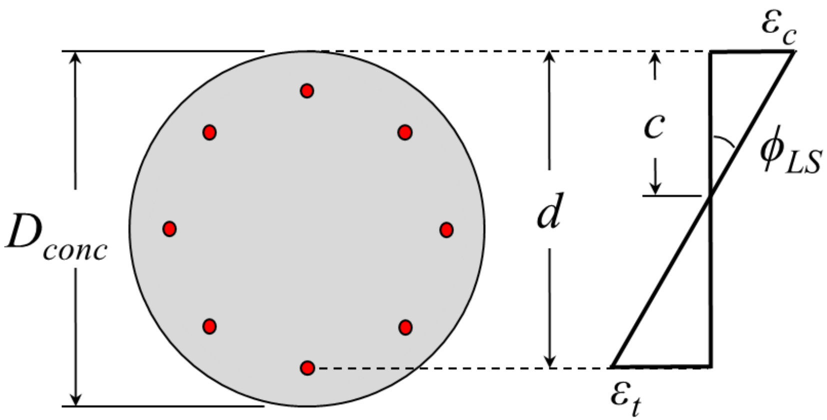
Performance Limit States: fixed-head shafts

Top plastic hinge: RC



Limit state curvature:

$$\phi_{LS,t} = \frac{\varepsilon_t}{d - c}$$

$$d = D_{conc} - c_{bl} - \frac{d_{bl}}{2}$$

Note: steel tube provides confinement only

Top plastic hinge strain limits (POLA, 2010)

Strain	Performance Level		
	Serviceability	Damage Control	Ultimate
Tension	0.015	$0.6\varepsilon_{sm} \leq 0.06$	$0.8\varepsilon_{sm} \leq 0.08$

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5. Conclusions

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Pinned-Head Shafts:

- Displacement capacity up to **μ_3** (even for D/t = 95)
- Controlling LS: **tube tensile strain of 2.5%**
- **PJP** spiral welds **negatively influence performance**

5. Conclusions

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Fixed-Head Shafts:

- Displacement capacity up to **μ_4**
- Controlled by **top plastic hinge only**
- Controlling LS: **bar tensile strain of 8%** (POLA, 2010)
- In-ground hinge has reserved capacity

Questions?

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Thank you!

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Acknowledgements:

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