Predicting the Complete Non-Linear Response of Two-Column Steel Bridge Piers with Socket Connections

Arjun Jayaprakash, James Nau, Mervyn Kowalsky, and Mohammad Pour-Ghaz

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NC STATE UNIVERSITY

Steel piles/columns supported structures

Bridges in Alaska

Source: Alaska Department of Transportation and Public Facilities

Steel piles/columns supported structures

Piers in Australia

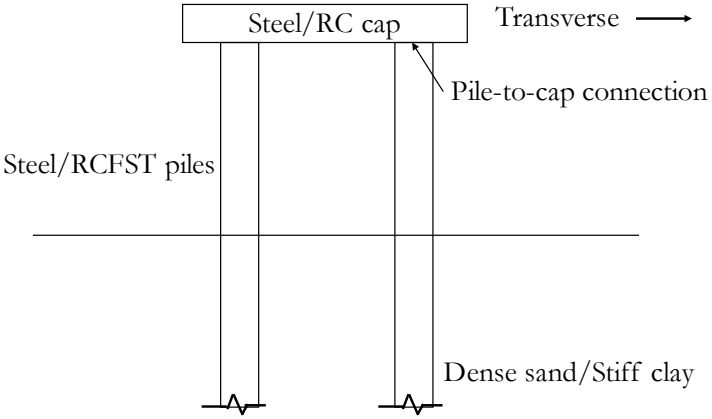
Source: chuaneu.com

Steel piles/columns supported structures

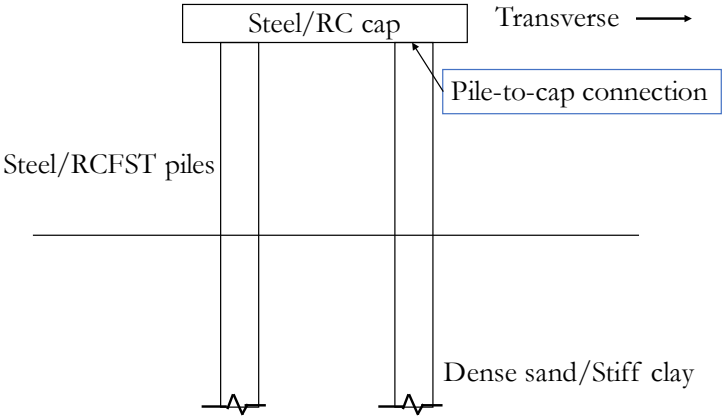
School building in Alaska

Source: arcticfoundation.com

A typical bridge pier



A typical bridge pier



A typical bridge pier

Grouted Shear Stud Connection

The Grouted Shear Stud (GSS) Connection

The Grouted Shear Stud (GSS) Connection

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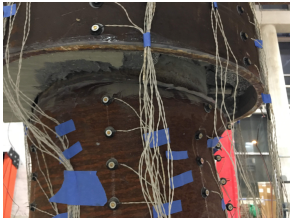
Large-scale Experiments and Identifying Damage States

Large-scale Experiments and Identifying Damage States

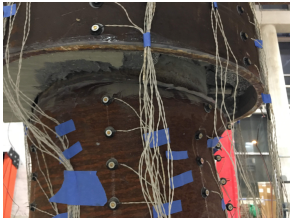
- Serviceability - Easily Repaired

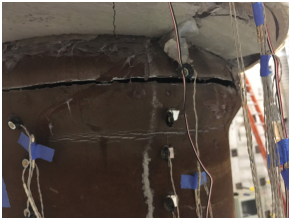
Large-scale Experiments and Identifying Damage States



- Serviceability - Easily Repaired
- Local Buckling - Expensive Repair

Large-scale Experiments and Identifying Damage States

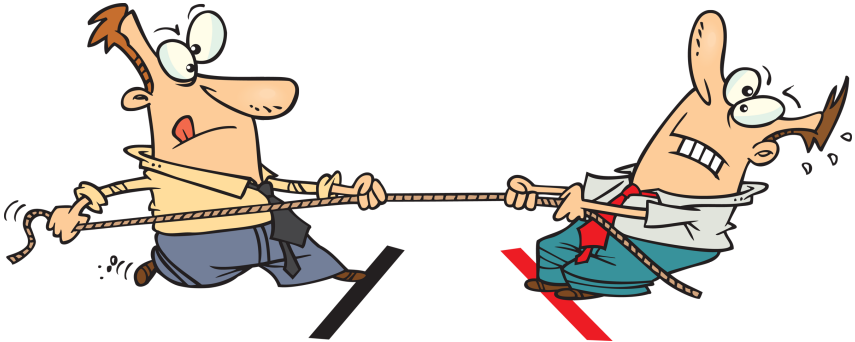




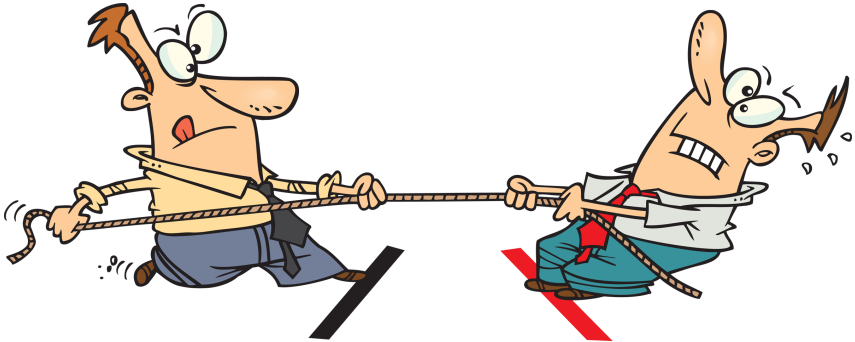
- Serviceability - Easily Repaired
- Local Buckling - Expensive Repair
- Ultimate - Replace

Capacity

Demand



Capacity Demand

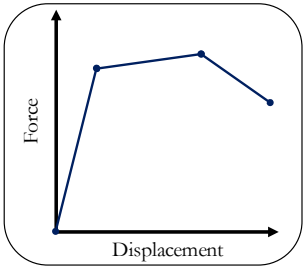


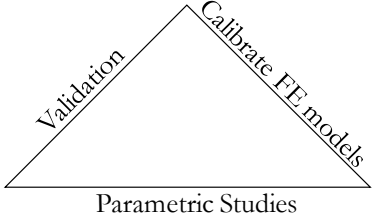
For seismic design,

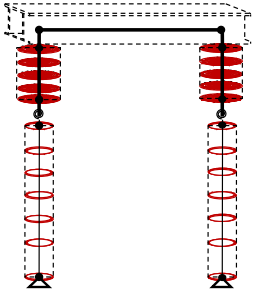
$$\text{Displacement Capacity} > \text{Displacement Demand}$$

Objective: To develop a simple model to estimate the capacity of steel pile systems with GSS connections.

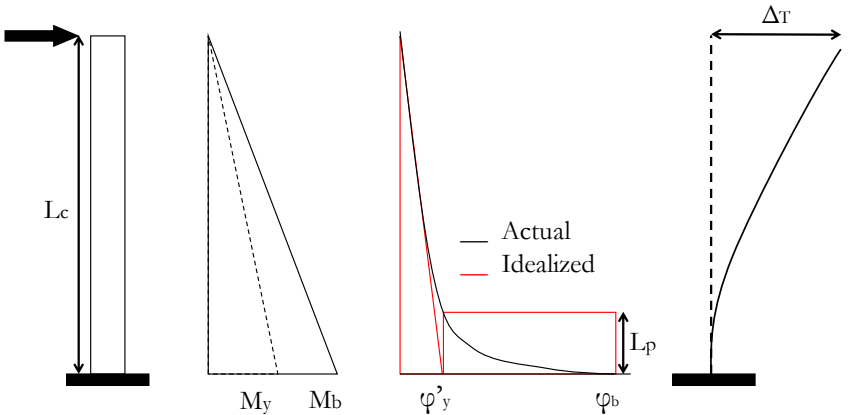
How did we approach this problem?



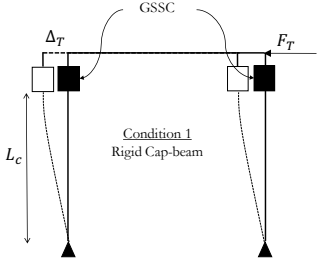




What's wrong with a moment-curvature analysis?



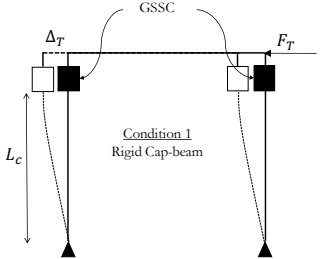
Condition 1



Rigid Cap-beam

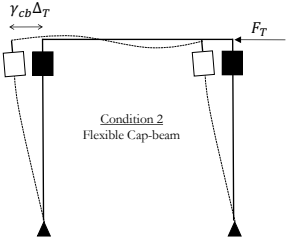
Flexibility Conditions

Condition 1



Rigid Cap-beam

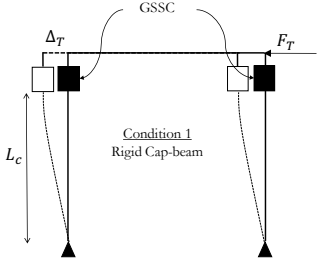
Condition 2



Flexible Cap-beam

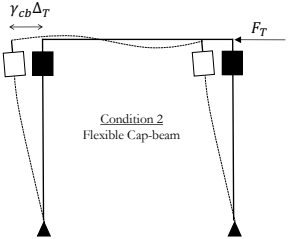
Flexibility Conditions

Condition 1



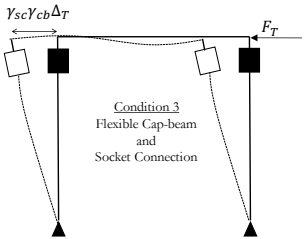
Rigid Cap-beam

Condition 2



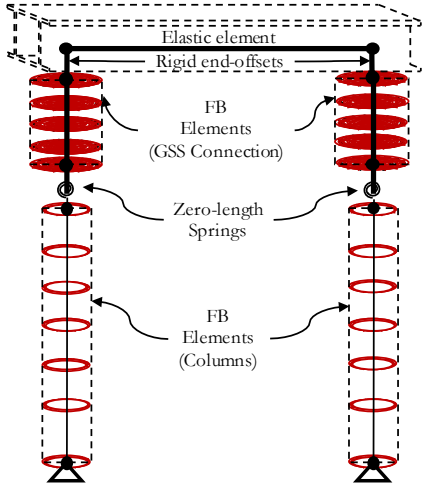
Flexible Cap-beam

Condition 3

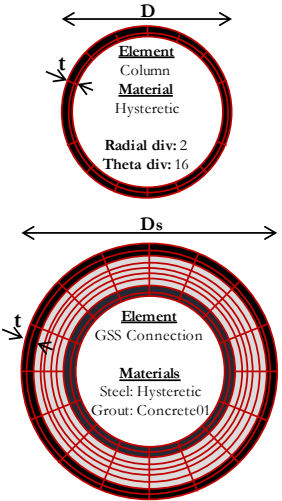


Add Socket Action

Numerical Model Development

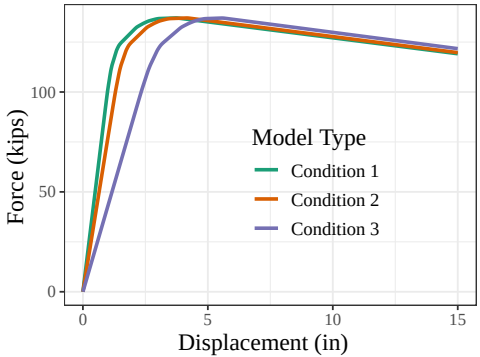


2-D Global model

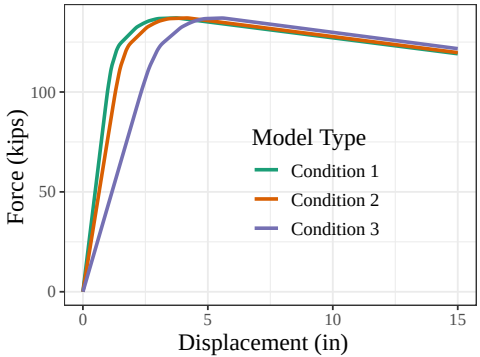


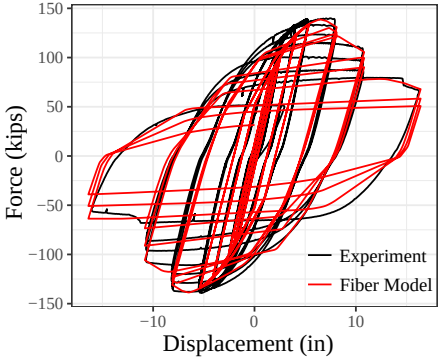
Fiber Sections

Model Calibration and Benchmarking

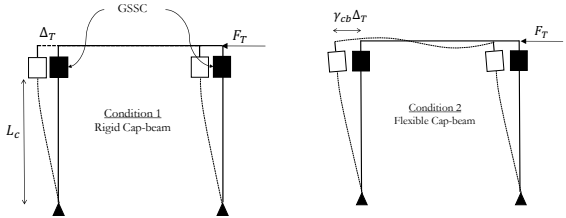


Model Calibration and Benchmarking

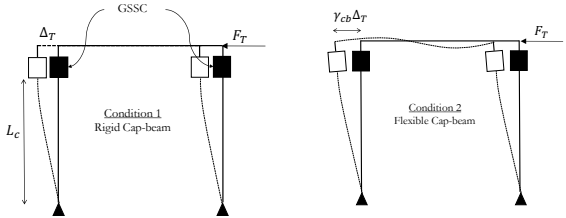




Condition 1 v Condition 2

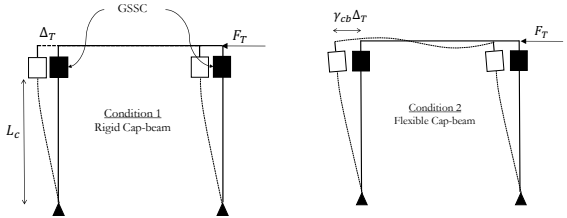


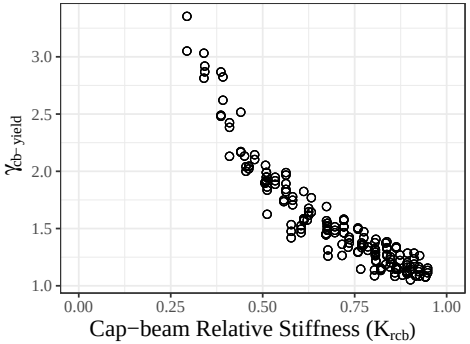
Condition 1 v Condition 2



Relative stiffness of the cap-beam in each joint is a **significant** variable to estimate system displacement.

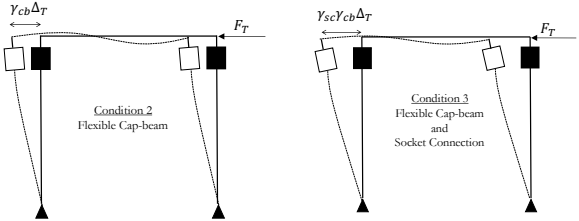
Condition 1 v Condition 2



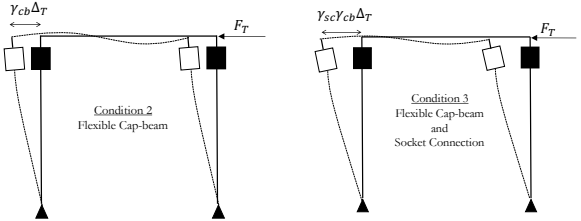


Relative stiffness of the cap-beam in each joint is a **significant** variable to estimate system displacement.

Condition 2 v Condition 3

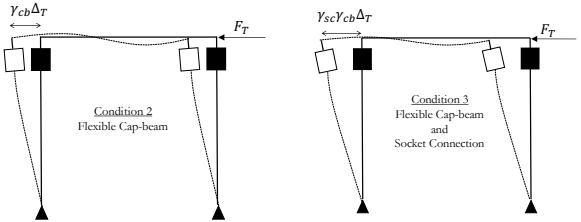


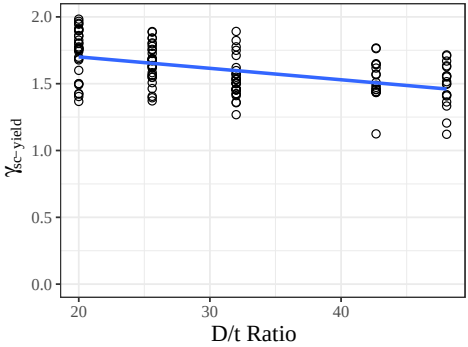
Condition 2 v Condition 3



Everything else remaining the same, smaller D/t ratio means larger force.

Condition 2 v Condition 3





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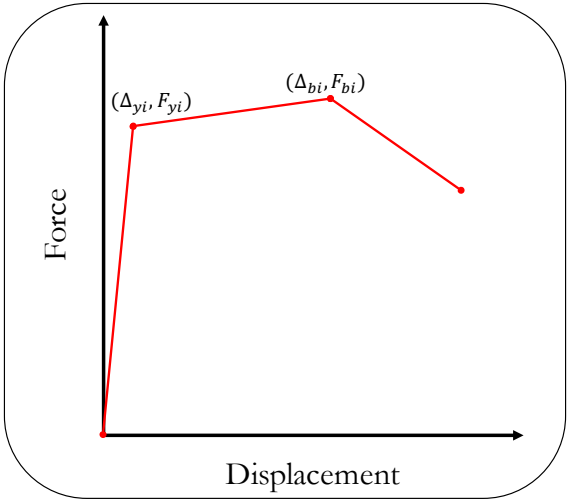
Outcome: Theoretical Capacity Curve



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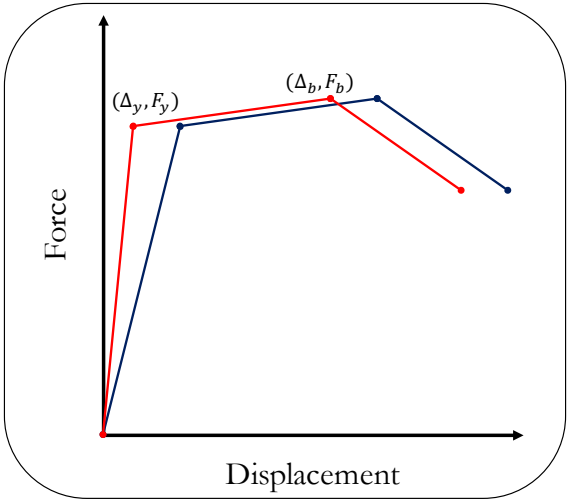

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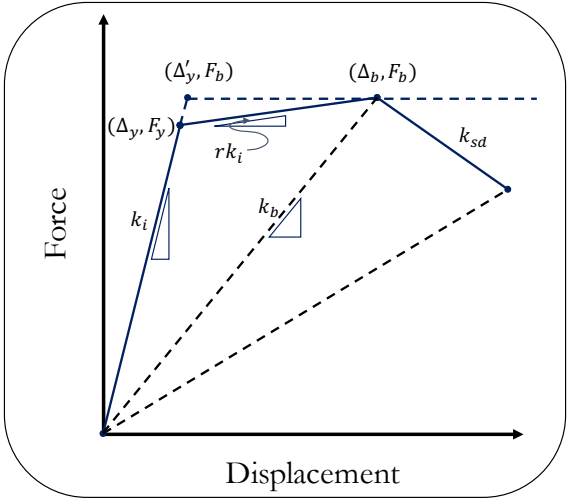
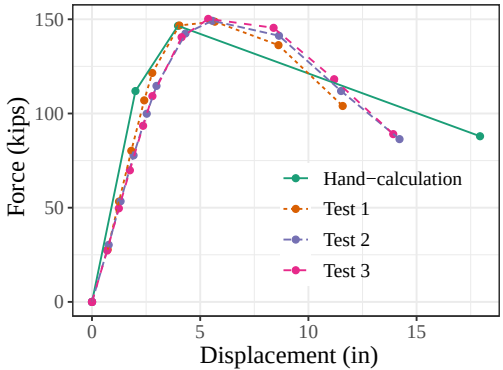
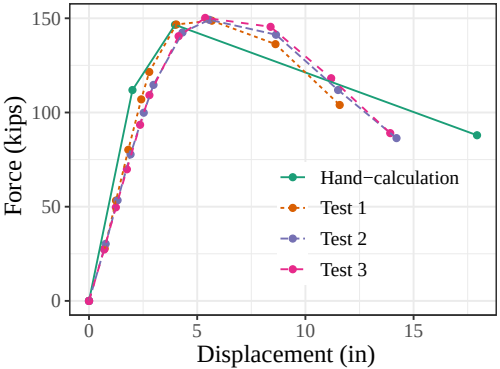
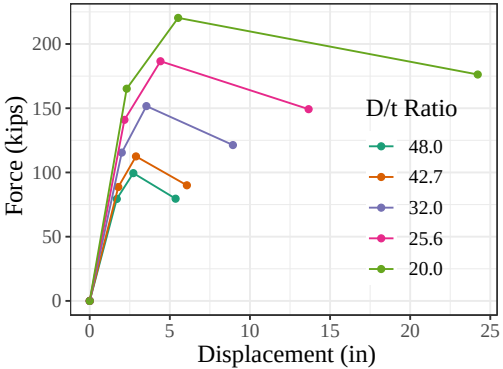


Model in Action



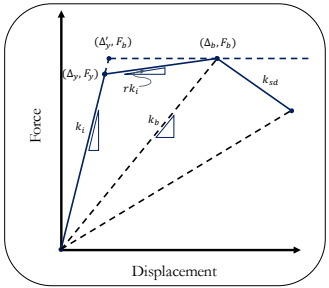
Model in Action





Contributions

- **A set of equations** that can **predict** the **force and displacement** of these types of systems at various **key performance limit-states**.
- This model is a **crucial component** in **displacement-based seismic design and assessment** of **steel bridge piers** with **socket connections**.



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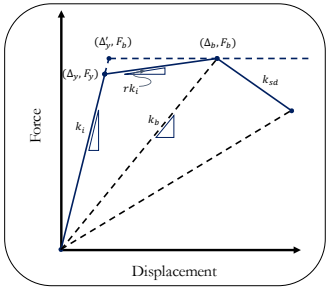
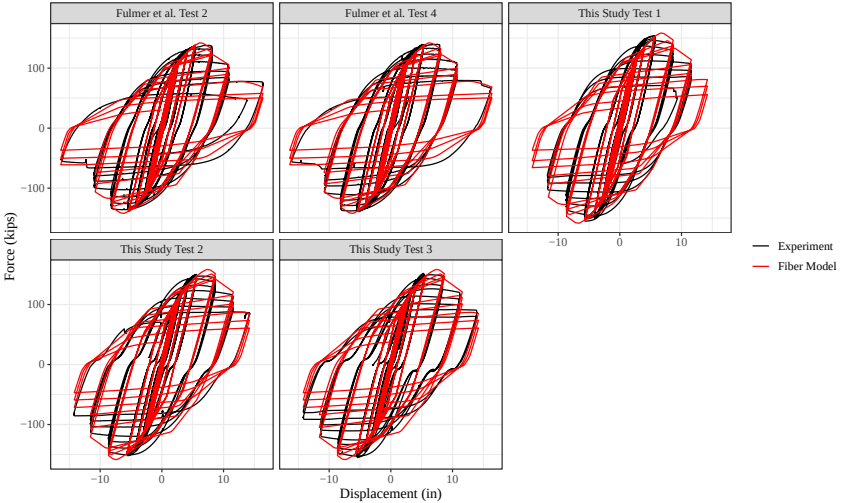
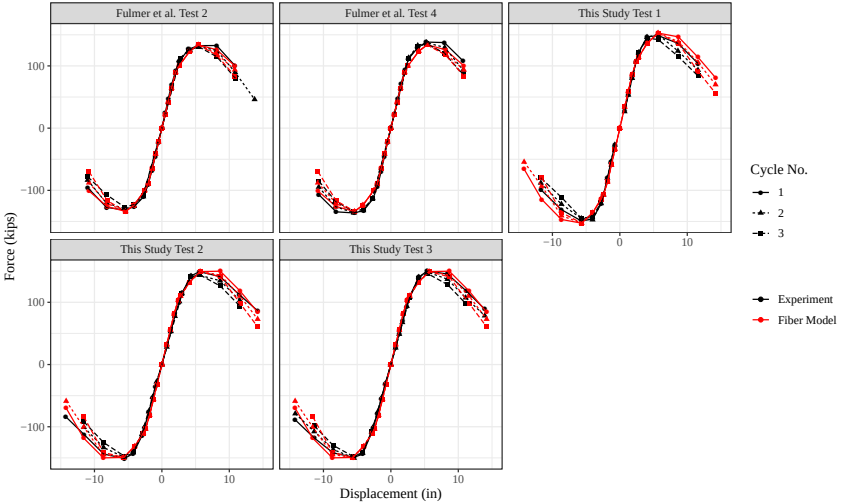
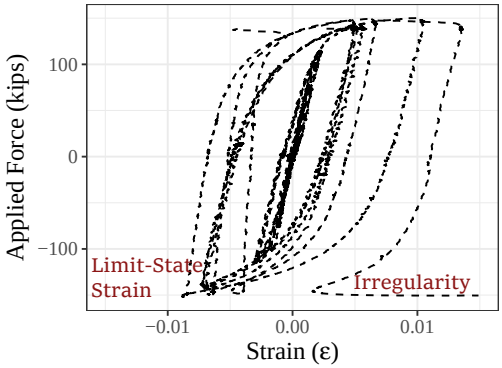


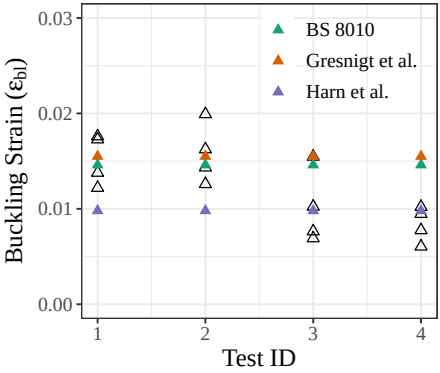
Questions?

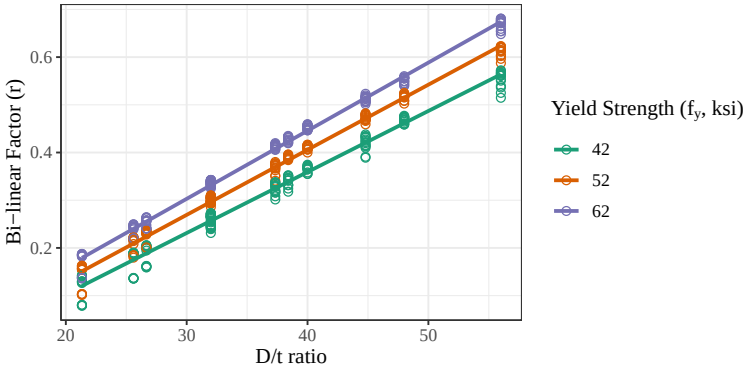
Backup Slides

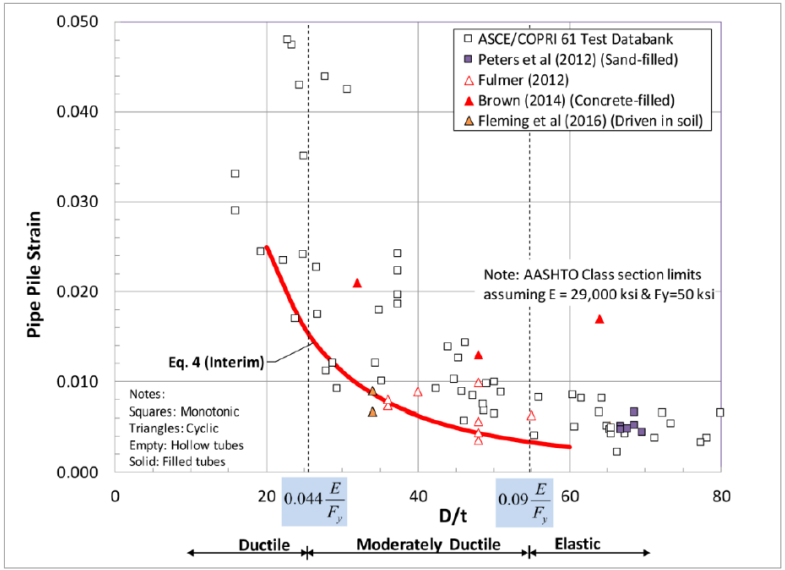

Fulmer et al. Test 2
Fulmer et al. Test 4
This Study Test 1
This Study Test 2
This Study Test 3
Force (kips)
100
0
−100
−10
0
10
Displacement (in)
Experiment
Fiber Model


Fulmer et al. Test 2
Fulmer et al. Test 4
This Study Test 1
This Study Test 2
This Study Test 3
Force (kips)
Displacement (in)
100
0
−100
−10
0
10
Cycle No.
1
2
3
Experiment
Fiber Model

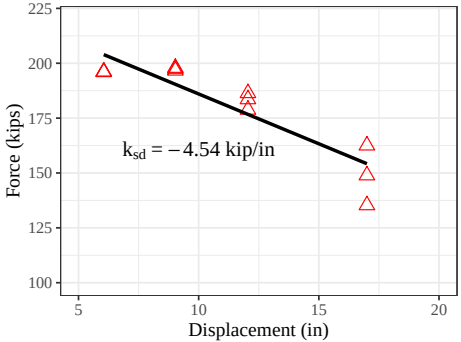

Applied Force (kips)
100
0
−100
−0.01
0.00
0.01
Strain (ε)
Limit-State
Strain
Irregularity


Buckling Strain (εbl)
0.03
0.02
0.01
0.00
1
2
3
4
Test ID
BS 8010
Gresnigt et al.
Harn et al.

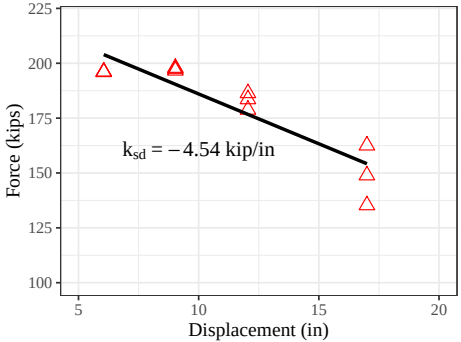

Bi−linear Factor (r)
0.6
0.4
0.2
20
30
40
50
D/t ratio
Yield Strength (f_y, ksi)
42
52
62

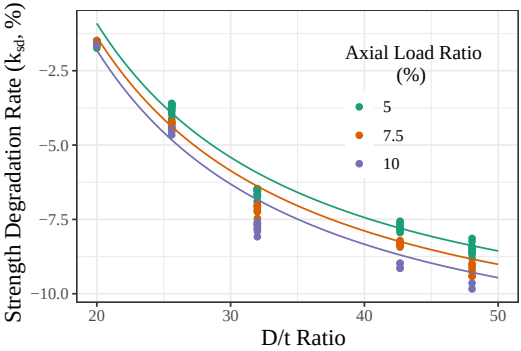

ASCE/COPRI 61 Test Databank
Peters et al (2012) (Sand-filled)
Fulmer (2012)
Brown (2014) (Concrete-filled)
Fleming et al (2016) (Driven in soil)
Note: AASHTO Class section limits assuming E = 29,000 ksi & Fy=50 ksi
Eq. 4 (Interim)
Notes:
Squares: Monotonic
Triangles: Cyclic
Empty: Hollow tubes
Solid: Filled tubes
Pipe Pile Strain
0.050
0.040
0.030
0.020
0.010
0.000
0
20
40
60
80
$0.044\frac{E}{F_y}$
$0.09\frac{E}{F_y}$
D/t
Ductile
Moderately Ductile
Elastic

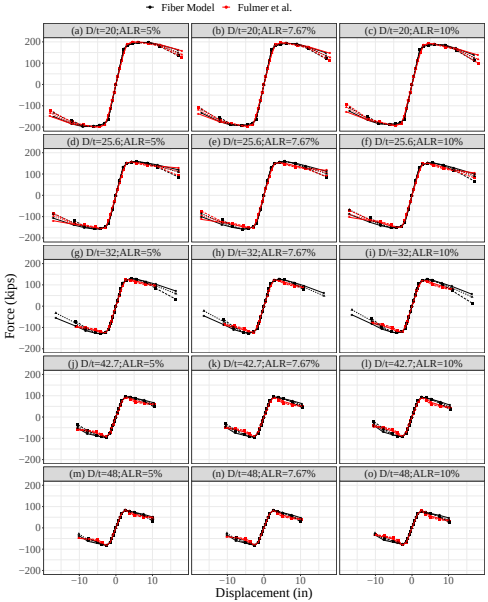
Strength Degradation Rate, k_{sd}

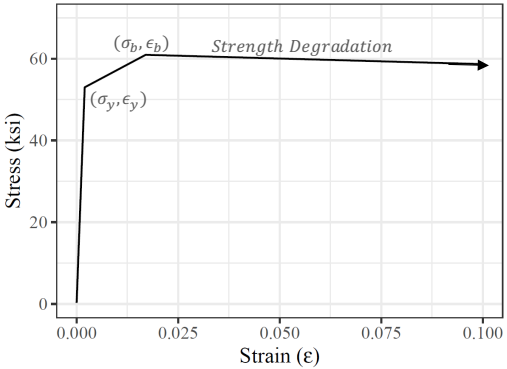


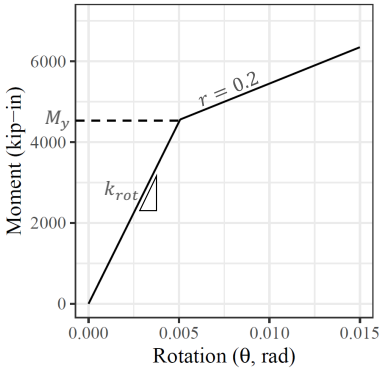
Strength Degradation Rate, k_{sd}






Fiber Model
Fulmer et al.
(a) D/t=20;ALR=5%
(b) D/t=20;ALR=7.67%
(c) D/t=20;ALR=10%
(d) D/t=25.6;ALR=5%
(e) D/t=25.6;ALR=7.67%
(f) D/t=25.6;ALR=10%
(g) D/t=32;ALR=5%
(h) D/t=32;ALR=7.67%
(i) D/t=32;ALR=10%
(j) D/t=42.7;ALR=5%
(k) D/t=42.7;ALR=7.67%
(l) D/t=42.7;ALR=10%
(m) D/t=48;ALR=5%
(n) D/t=48;ALR=7.67%
(o) D/t=48;ALR=10%
Force (kips)
200
100
0
−100
−200
−10
0
10
Displacement (in)


(σ_b, ϵ_b)
Strength Degradation
(σ_y, ϵ_y)
Stress (ksi)
60
40
20
0
0.000
0.025
0.050
0.075
0.100
Strain (ε)


$r = 0.2$
M_y
k_{rot}
Moment (kip−in)
6000
4000
2000
0
0.000
0.005
0.010
0.015
Rotation (θ, rad)