Lateral Resistance of Abutment Piles near MSE Walls

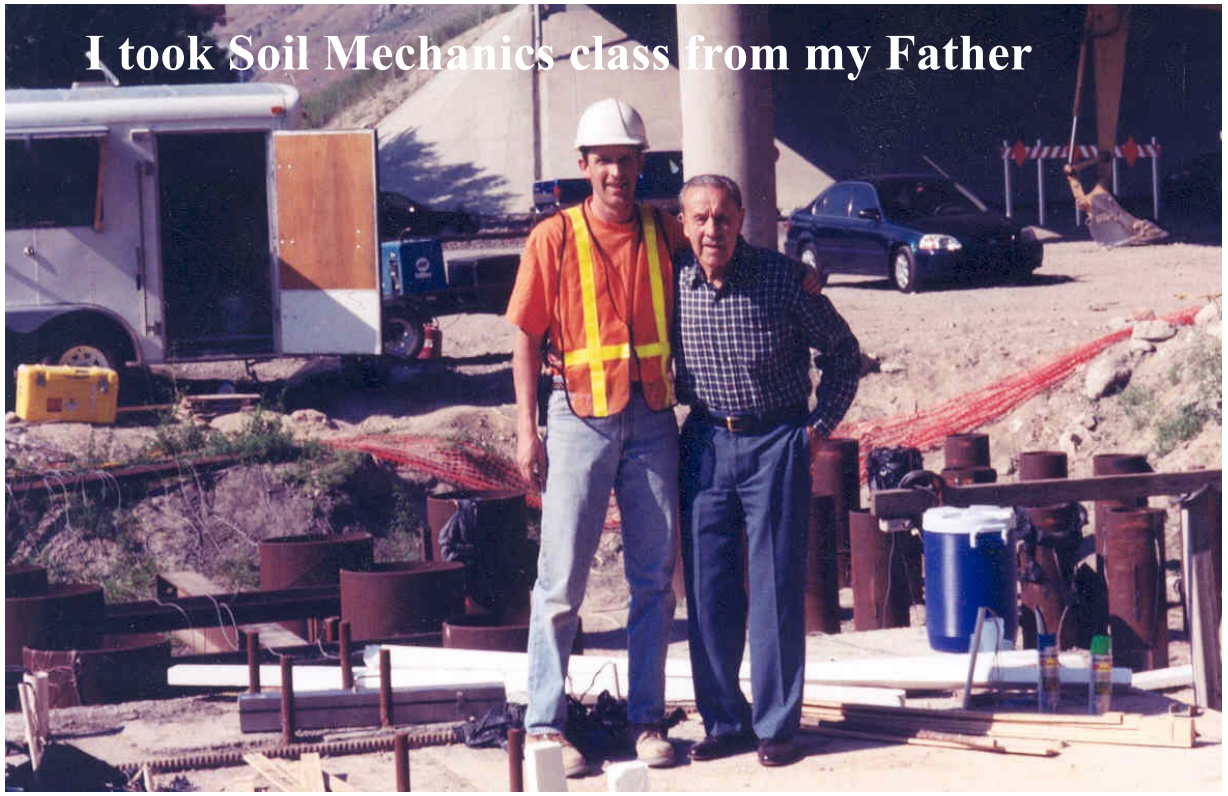
Kyle Rollins, Ph.D., Prof.
Civil & Construction Engineering
Brigham Young University
Provo, Utah





GeoVirginia 2025
March 18, 2025

Ralph Rollins, performed geotechnical investigations for over 5000 structures



Rachel Rollins was a Civil Engineering student



Granddaughter, Ella, shows early interest in soil behavior…



Lateral Resistance of Abutment Piles near MSE Walls

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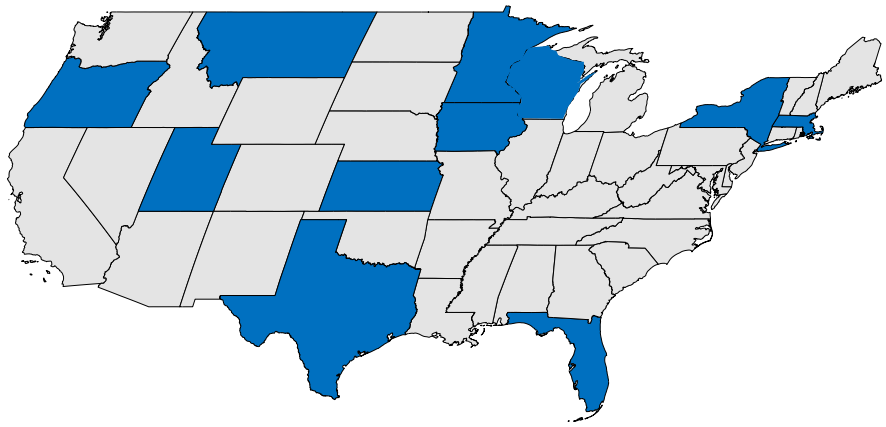




GeoVirginia 2025
March 18, 2025

FHWA Pooled Fund Sponsors

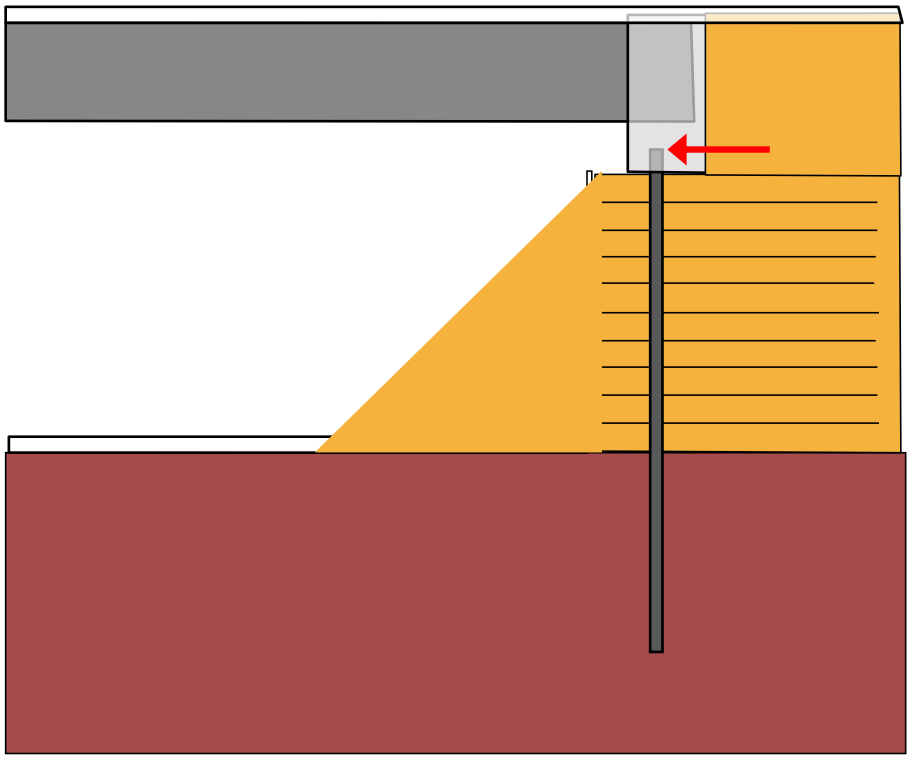
- Utah DOT – Lead Agency
- Florida DOT
- Iowa DOT
- Kansas DOT
- MassDOT
- Minnesota DOT
- Montana DOT
- New York DOT
- Oregon DOT
- Texas DOT
- Wisconsin DOT



In-Kind Donations

- Reinforced Earth Company – Ribbed Strip
- SSL, Inc. – Welded Wire Reinforcements
- Atlas Tube and Spartan Steel – Pile Foundations
- Desert Deep Foundations – Pile Driving

Abutment Piles near MSE Walls

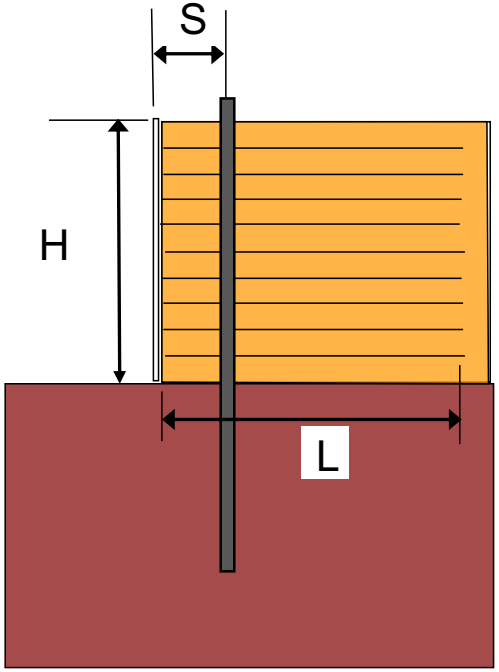


Abutment Piles Near MSE Walls

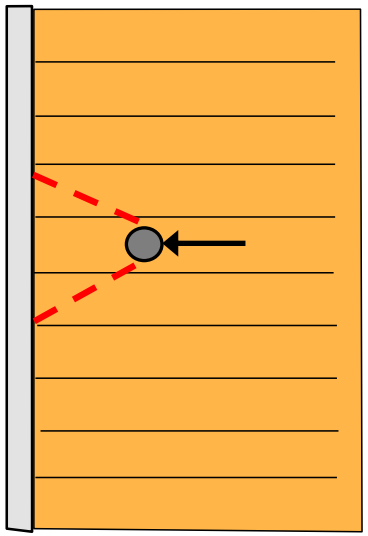




MSE Wall Geometry



Elevation View

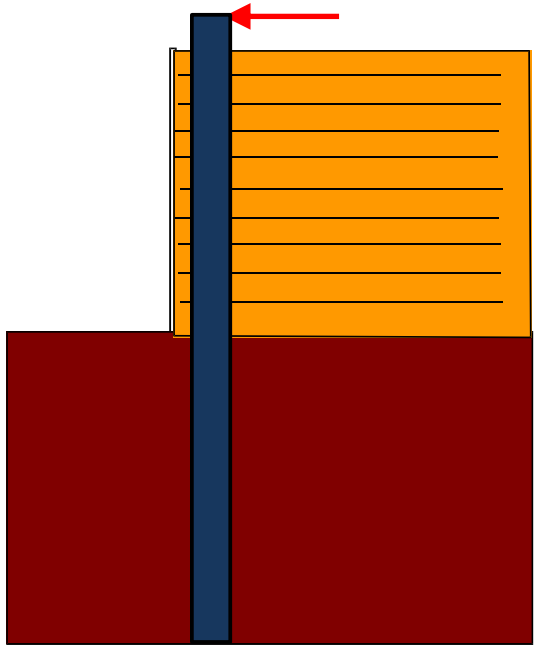


Plan View

- Wall decreases lateral pile resistance
- Pile load increases force on reinforcement

Approaches to the Problem

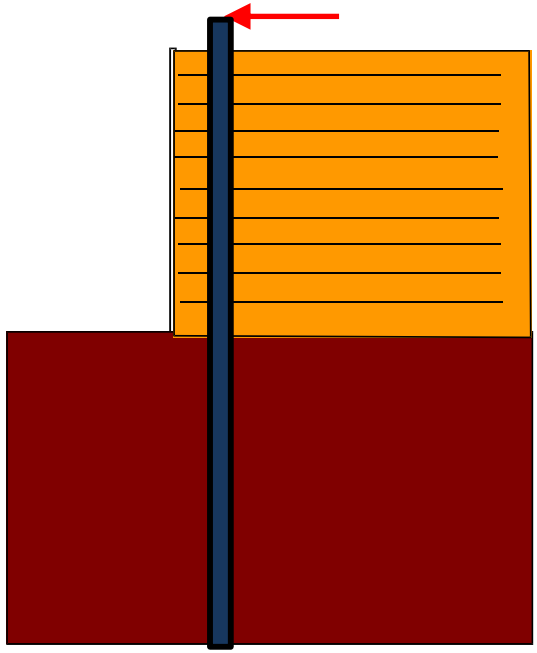
Ignore Soil Resistance



Increased Cost from Larger Pile Diameter or More Piles

Approaches to the Problem

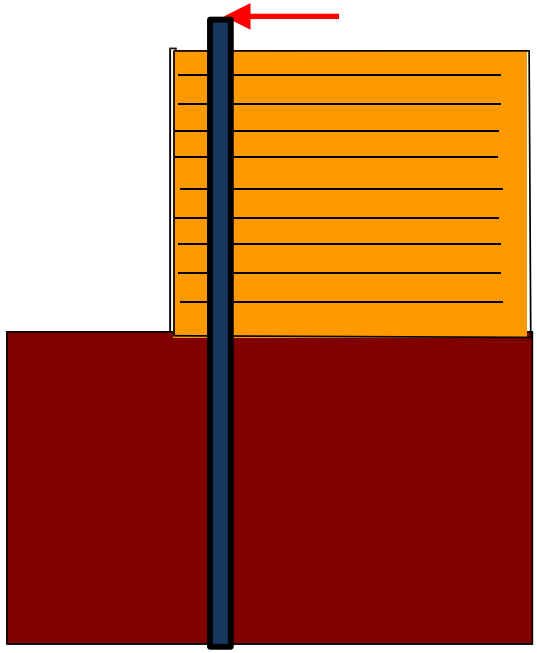
Increase Spacing to Eliminate Interaction



Increased Cost from Larger Bridge Span

Approaches to the Problem

Estimate a Reduction Factor



What should the reduction be?

Objectives of Research

1. Measure effect of pile shape and pile sleeves on lateral resistance.
2. Measure lateral pile resistance vs. displacement curves for piles at different distances behind the wall
   - Circular, Square and H piles
   - Ribbed strip & Welded wire reinforcement
3. Measure the increase and distribution of tensile force in the MSE reinforcement induced by lateral pile loading.
4. Develop design rules (e.g. p-multipliers) to account for reduced pile resistance as a function of spacing and reinforcement.
5. Develop design approach to predict reinforcement force induced by pile loading.

"One good test is worth a thousand expert opinions."





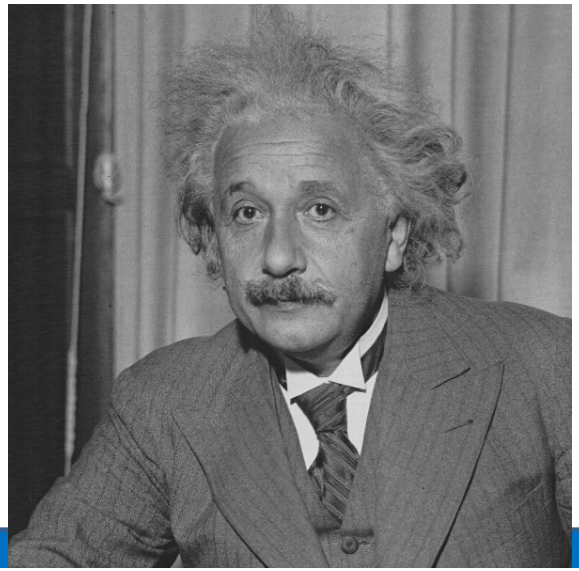
Werner Von Braun

Designer of Saturn V Moon Rocket

Healthy Skepticism for Tests

- **A theory is something nobody believes, except the person who proposed it**
- **An experiment (test) is something everybody believes, except the person who performed it**

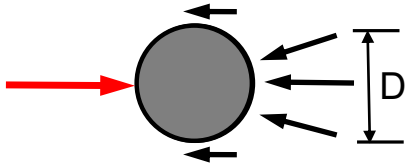
--Albert Einstein



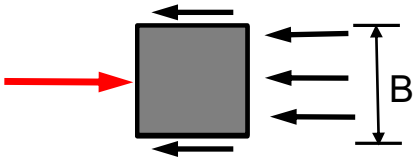
Effect of Pile Sleeves on Lateral Pile Resistance

Effect of Pile Shape

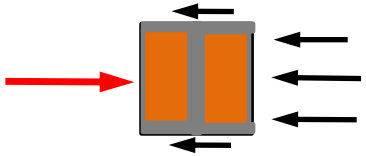
Round Pile



Square Pile

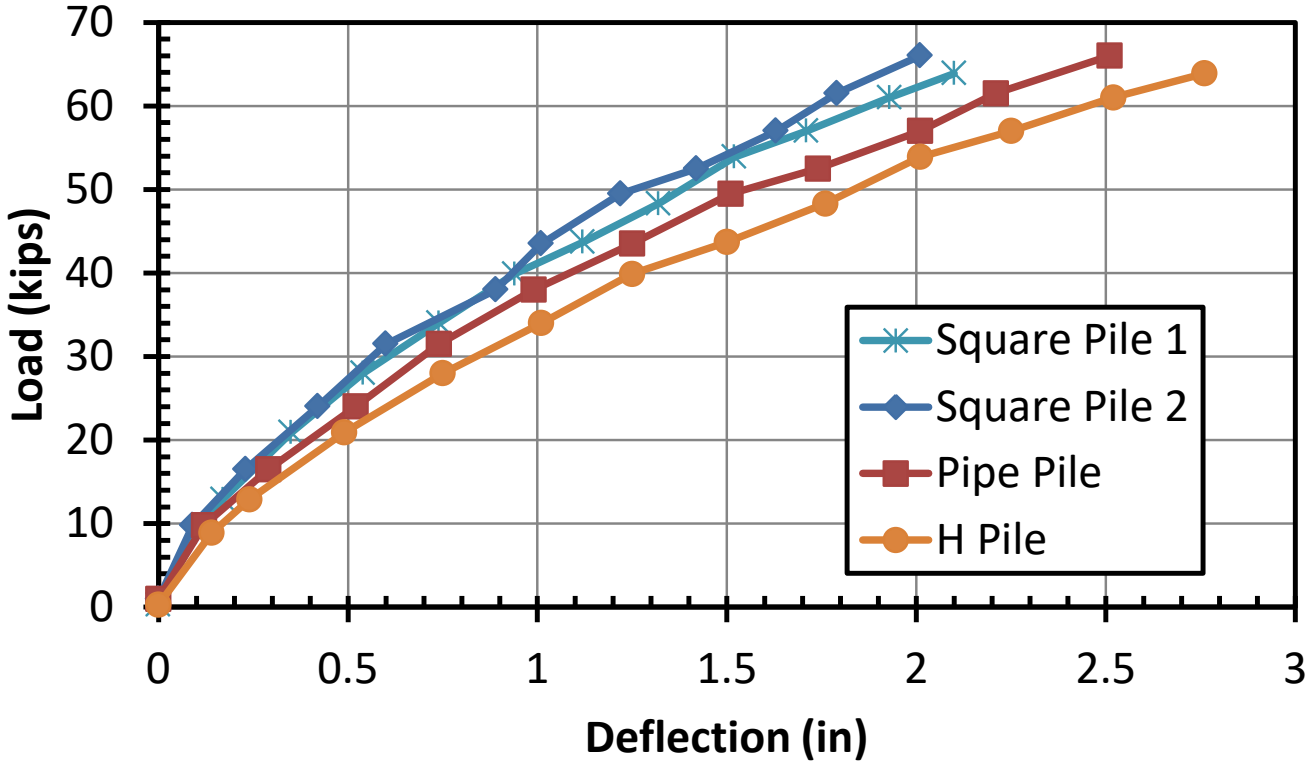


H Pile

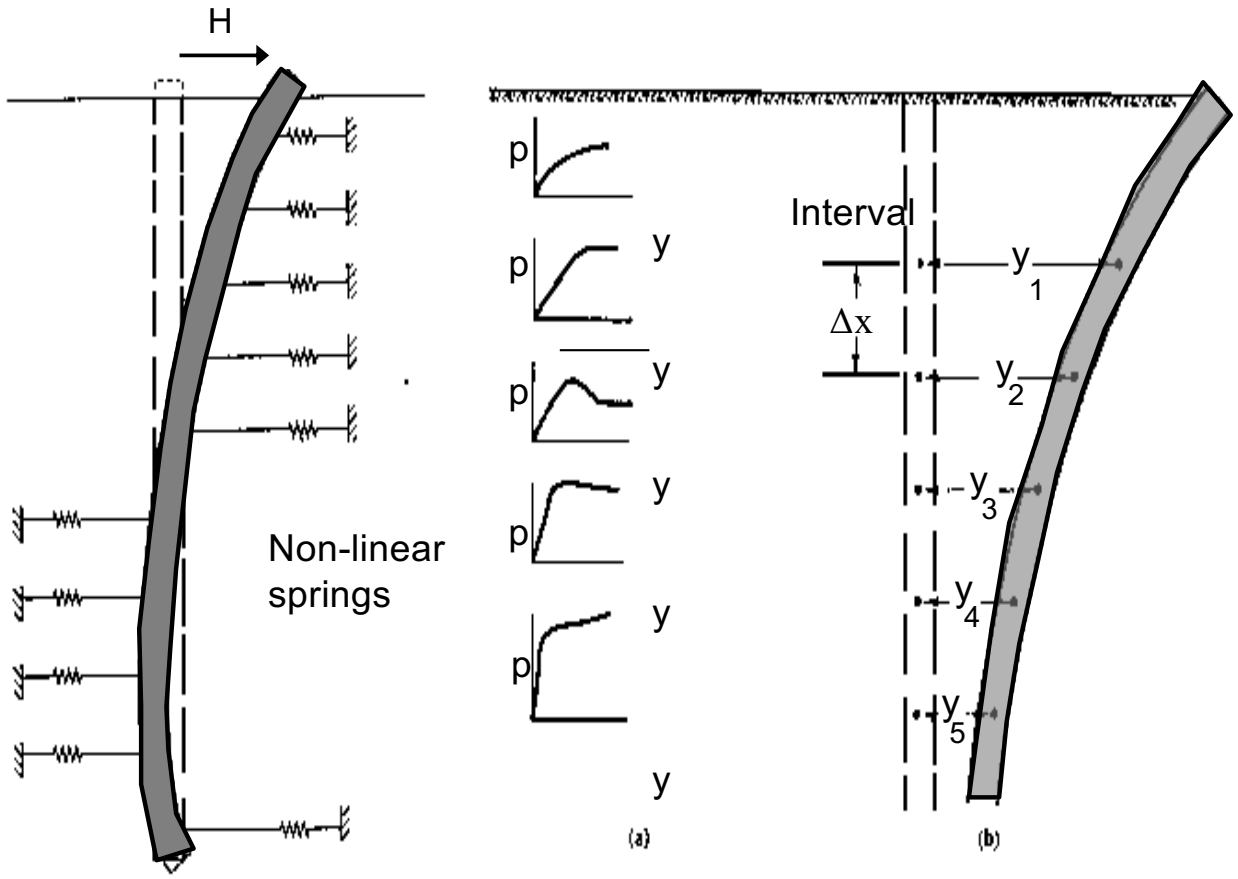


Different contributions of normal & shear stress

Single Pile Tests on Square, Round, and H piles

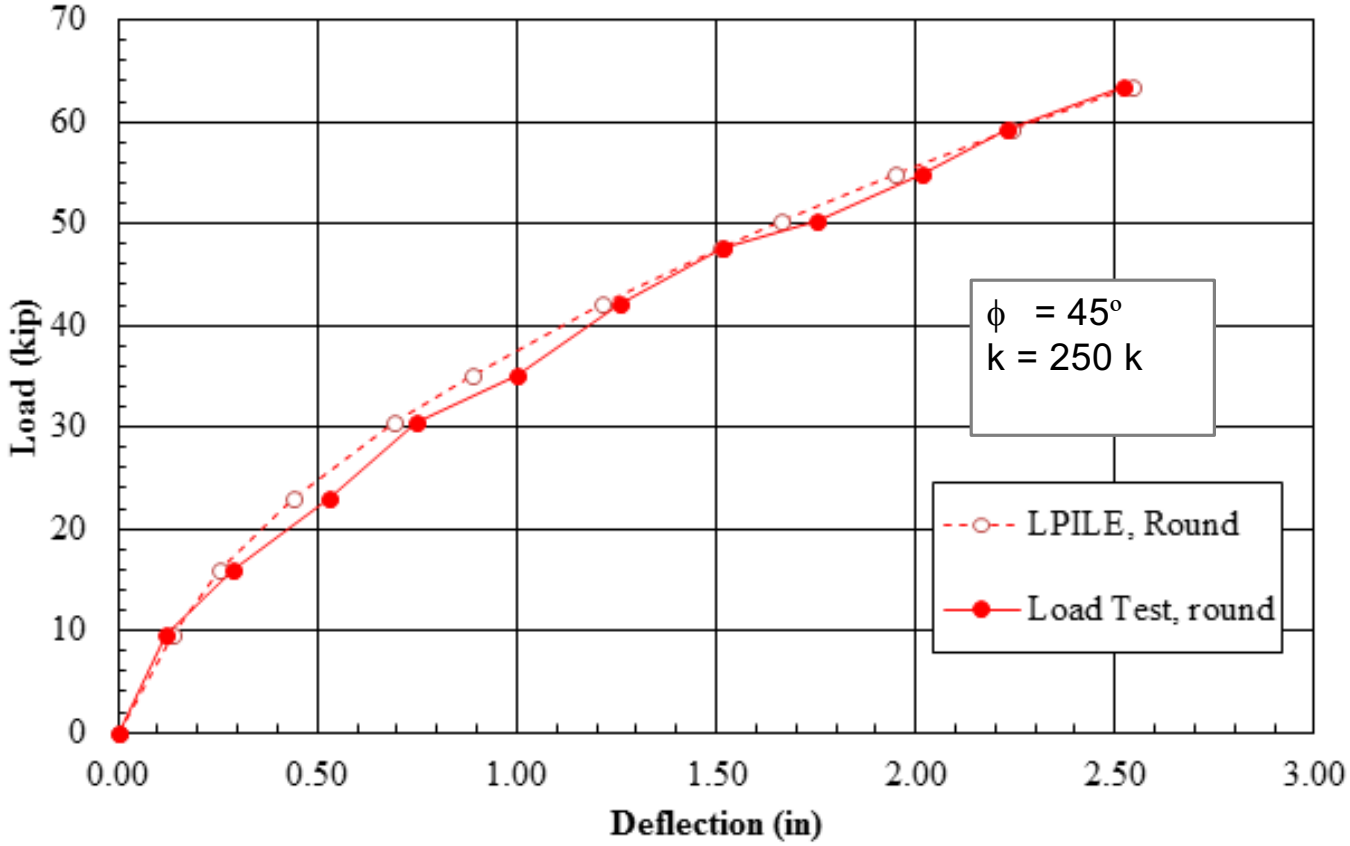


Lateral Load Analysis for Piles with *p-y* Curves



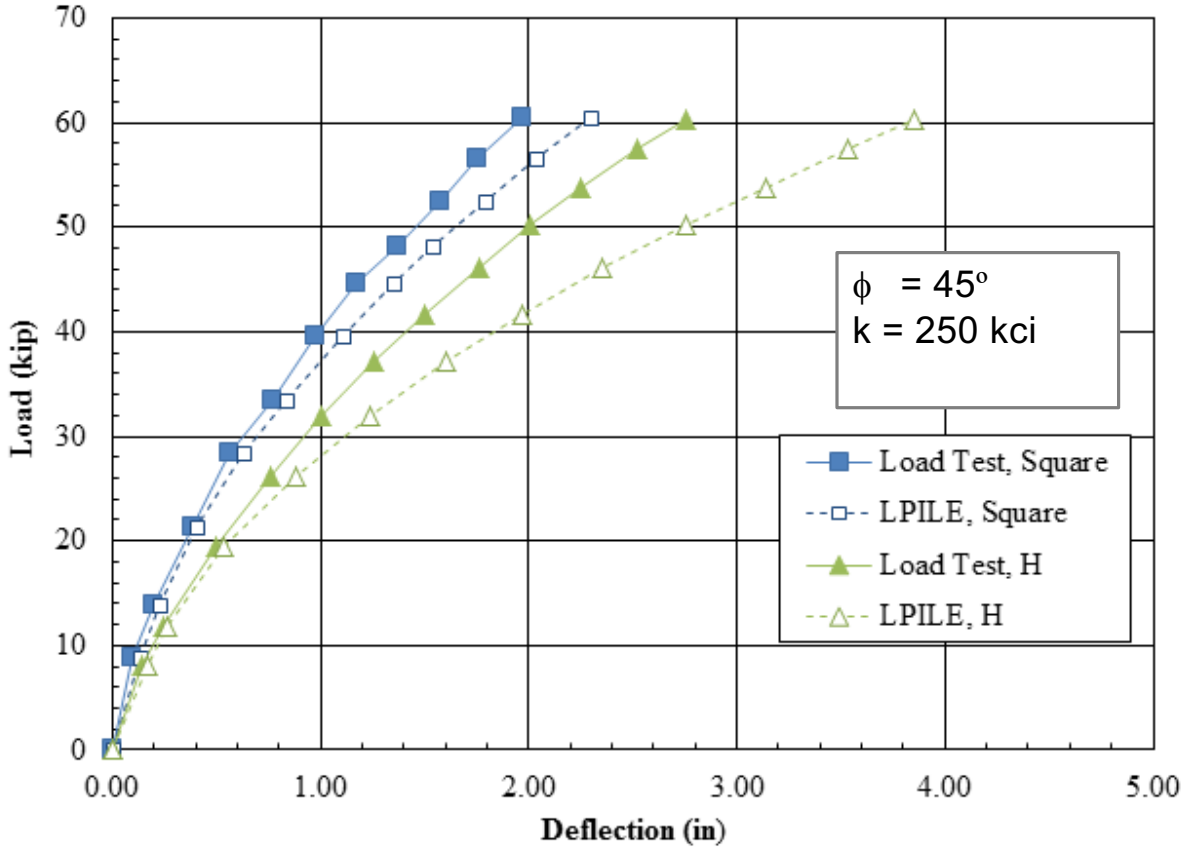
Measured vs Computed Load-Displacement

Round Pile

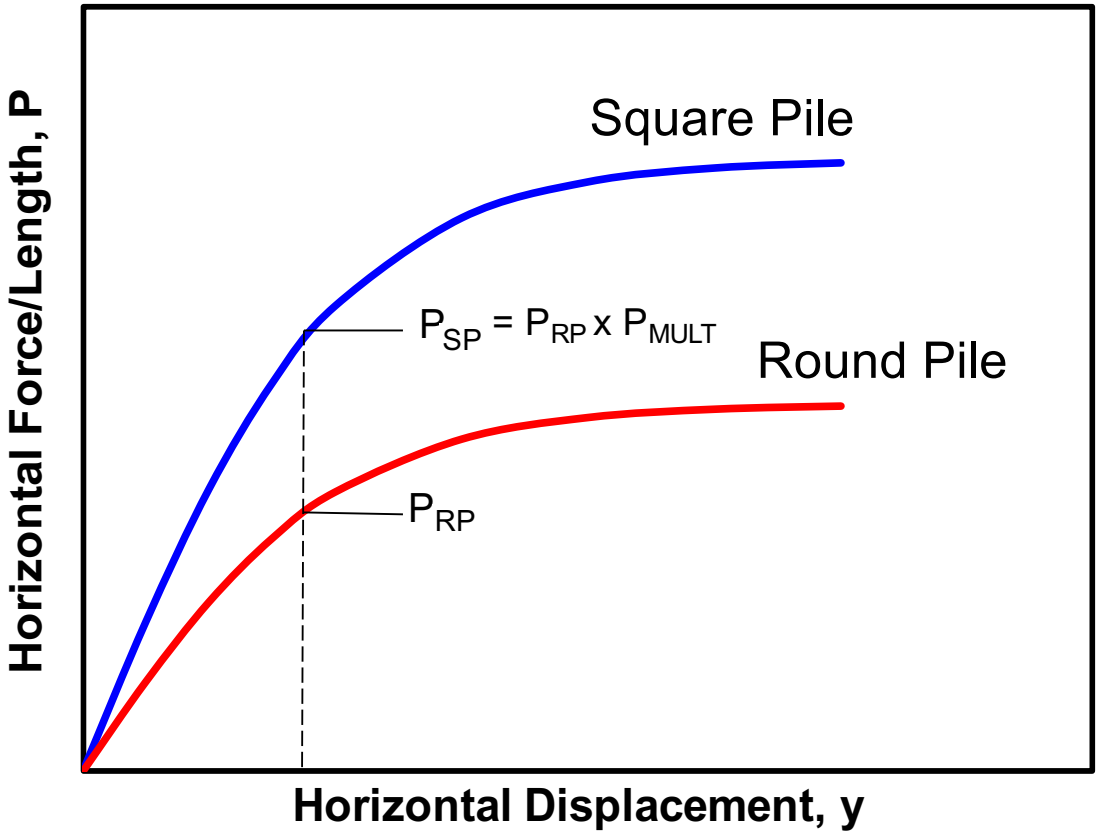


Measured vs Computed Load-Displacement

Square and H Piles

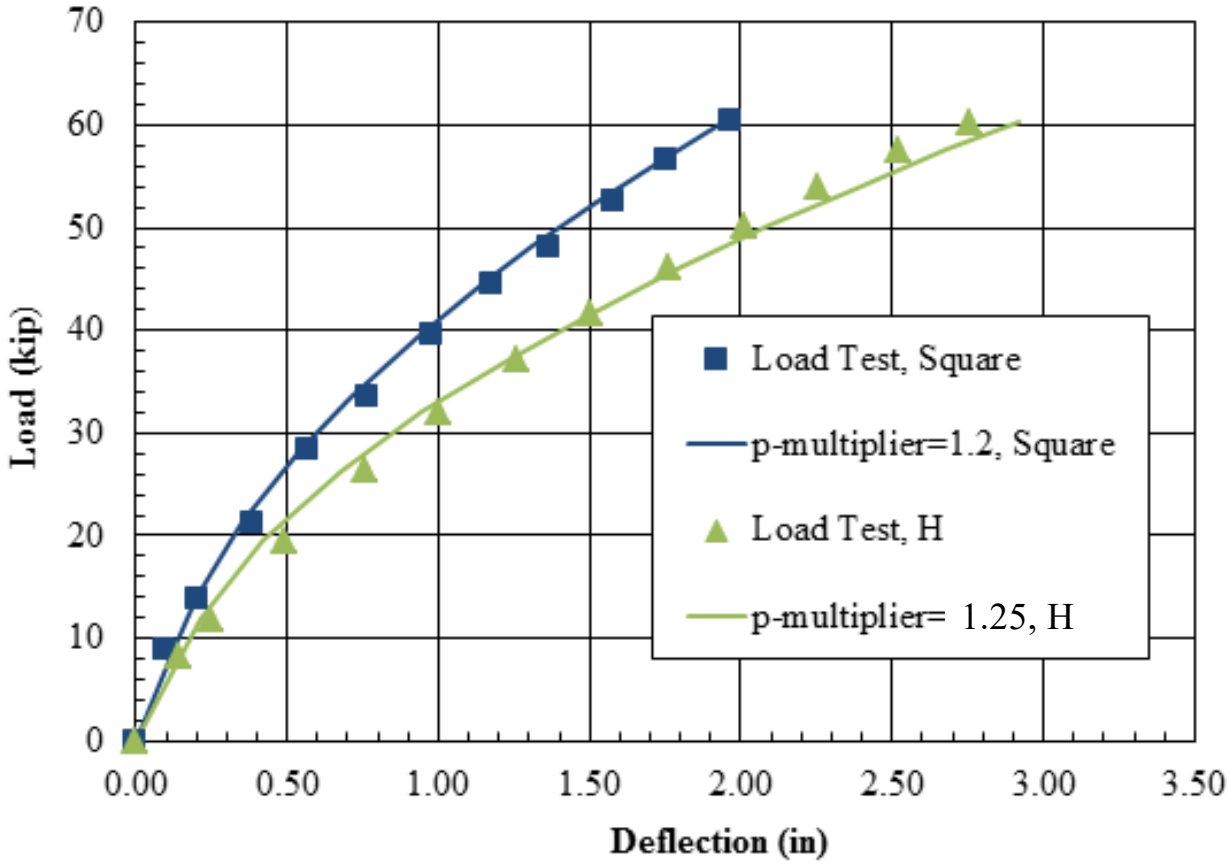


P-multiplier Concept for Pile Shape

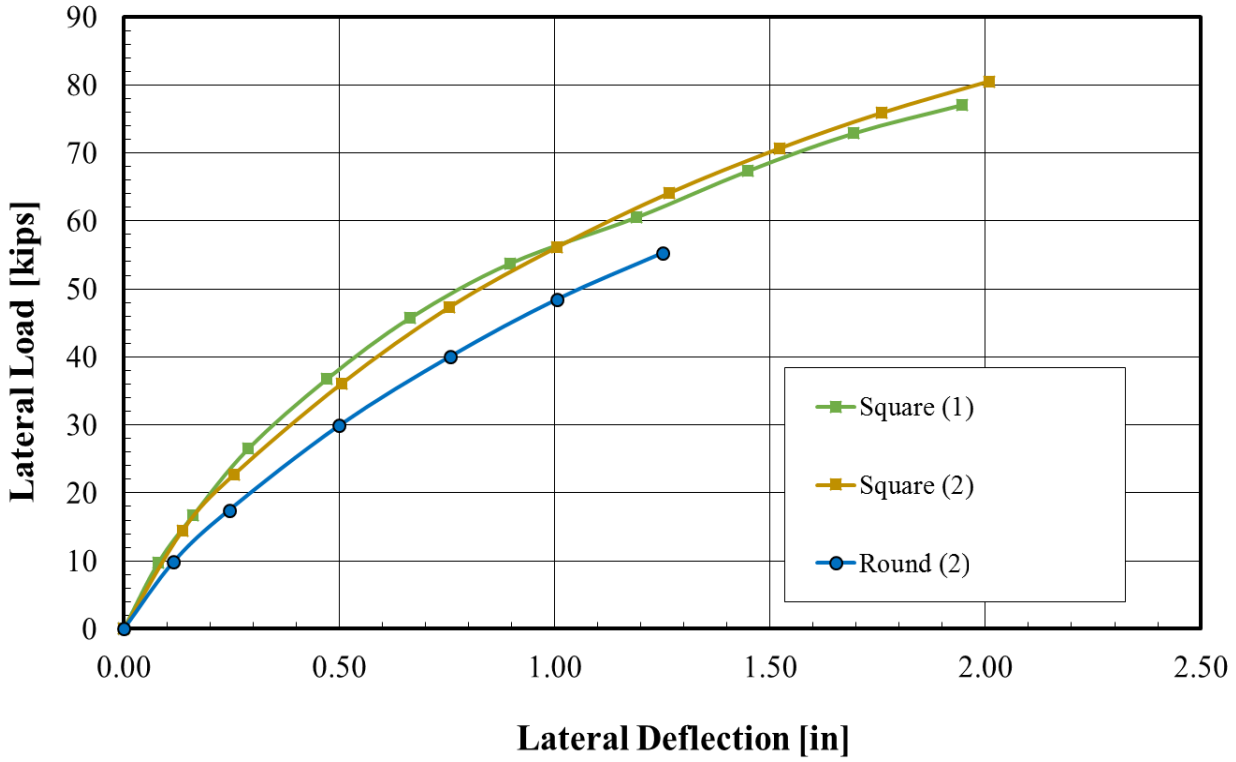


Measured vs Computed Load-Displacement

Square and H Piles

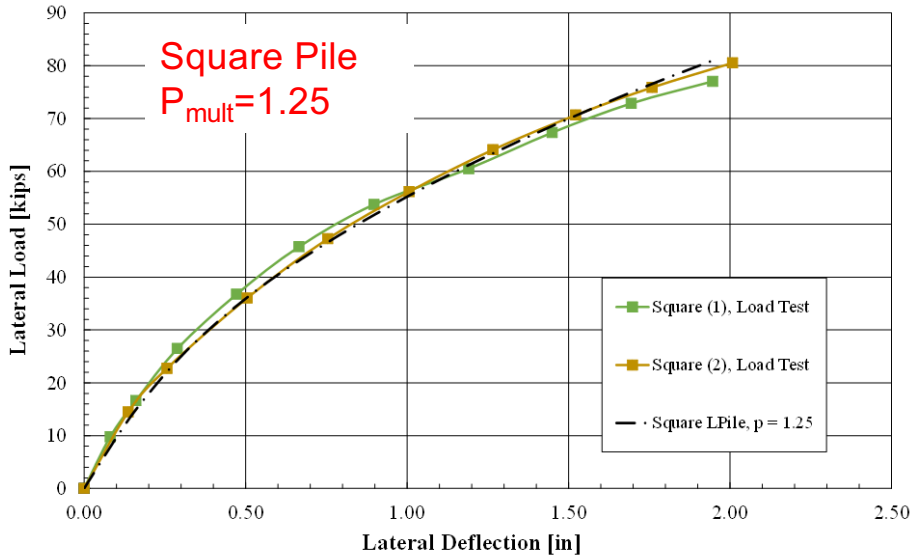


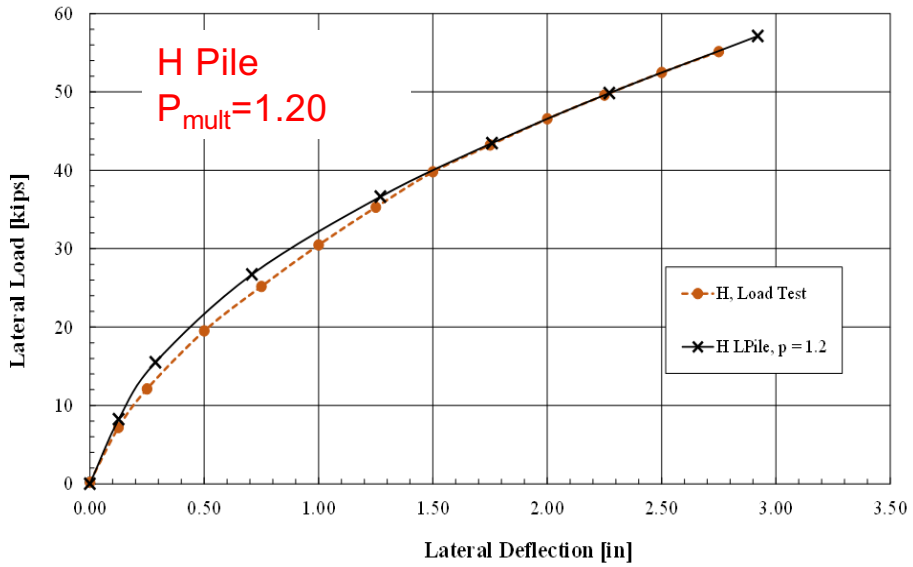
Load Deflection Curves – Additional Tests



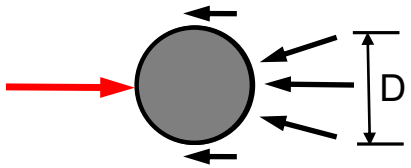
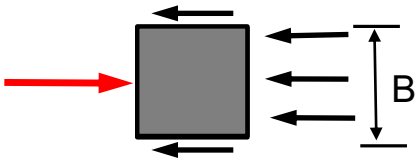
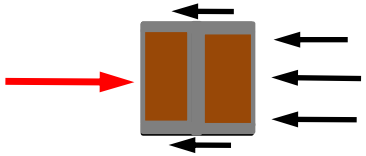
P-multiplier Approach for Square & H Piles

Square	H
1.25	1.2



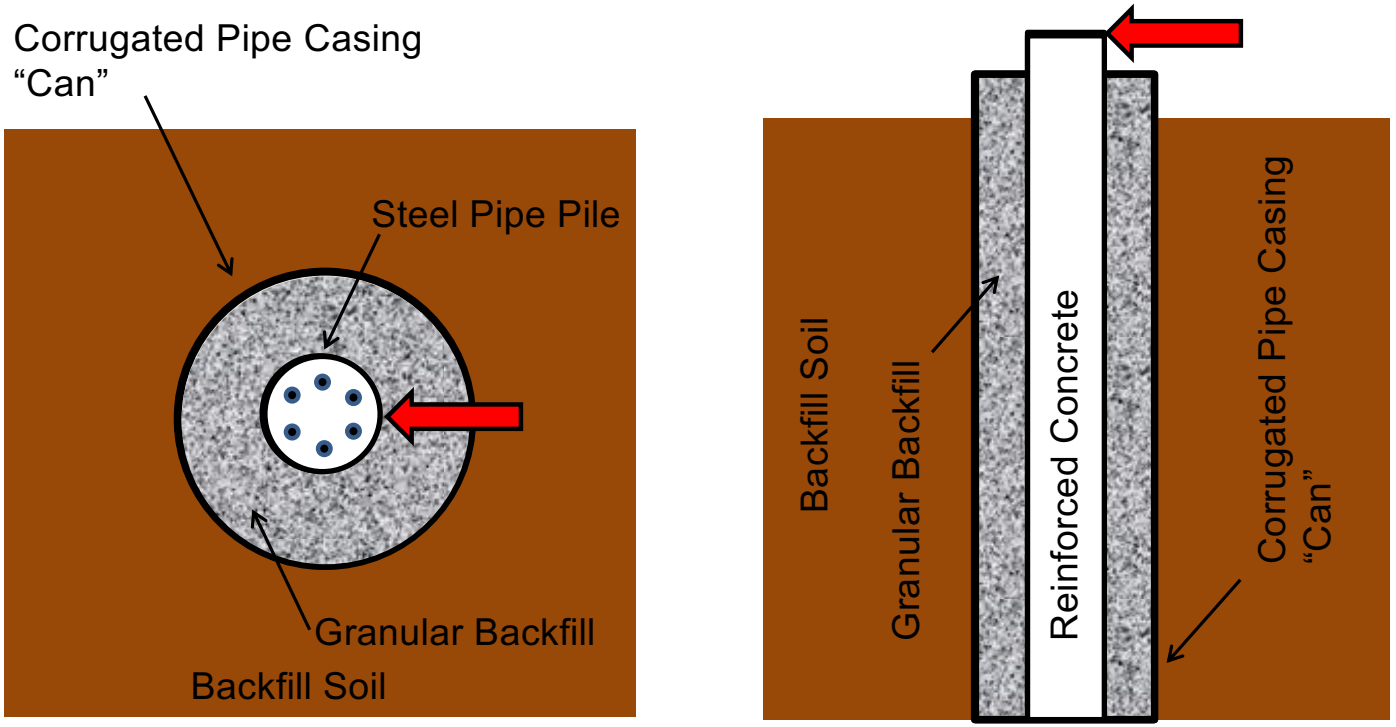


Effect of Pile Shape on Lateral Soil Resistance

Round Pile	Square Pile	H Pile
		
2 Tests	4 Tests	2 Tests
P_{mult}= 1.0	P_{mult}= 1.2-1.25	P_{mult}= 1.2-1.25

Effect of Sleeves on Lateral Pile Resistance

Schematic of Piles in “Cans”



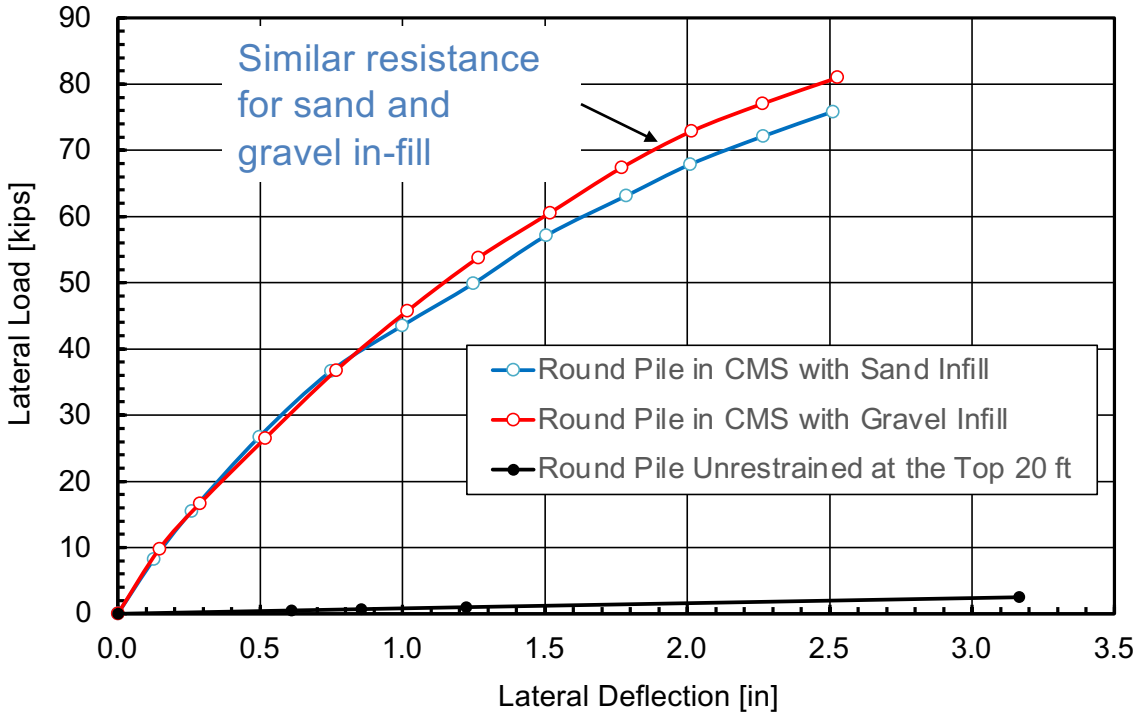
How much lateral resistance do we really have?

Piles in “Cans” on Mountainview Corridor



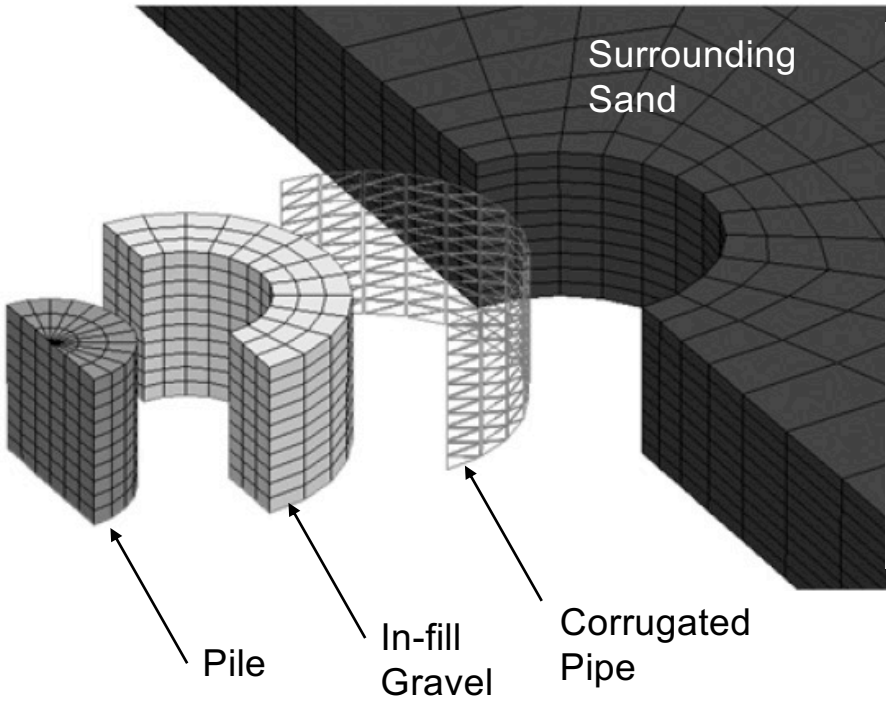


Round Pile with Corrugated Metal Sleeve (CMS)

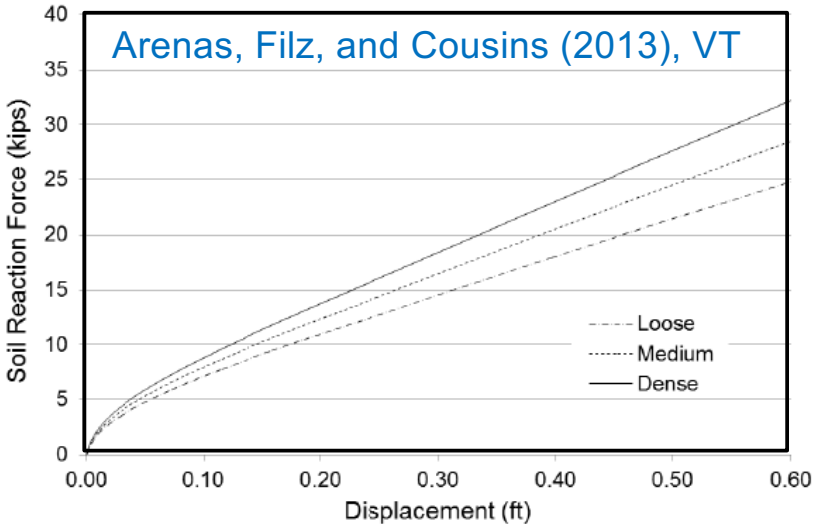


Round Pile with Corrugated Metal Sleeve (CMS)

Exploded View of Finite Element Model



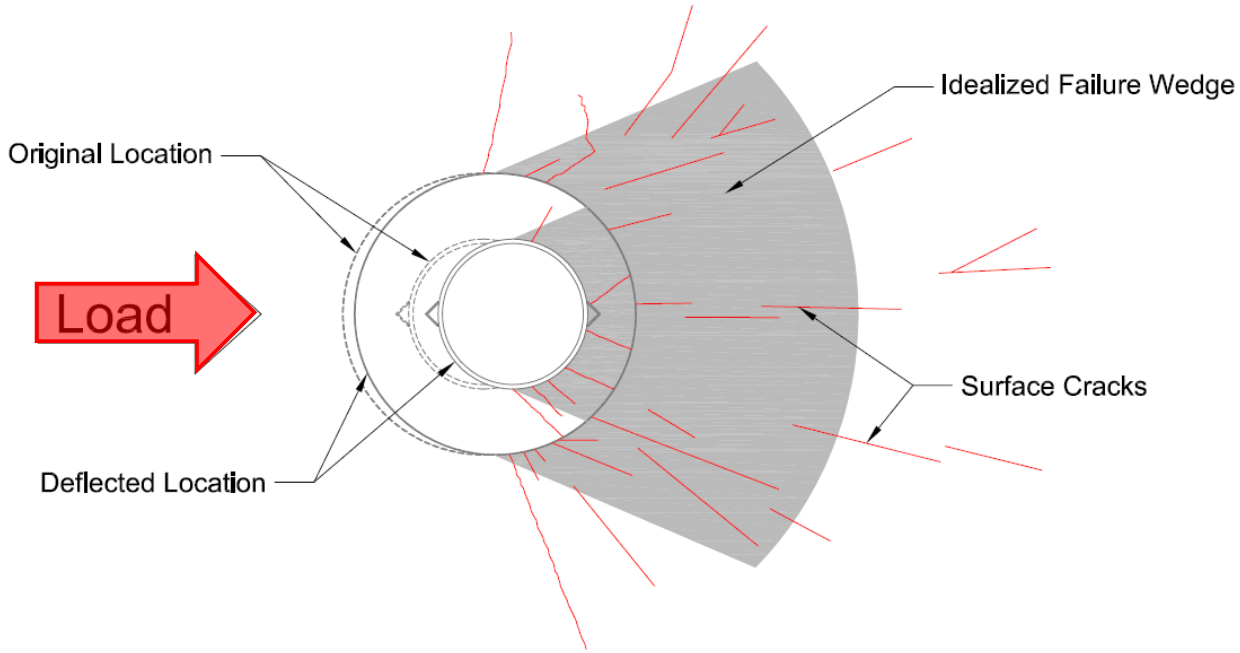
Computed Pile Force-Deflection Curves



Failure Planes for Sleeved Pile

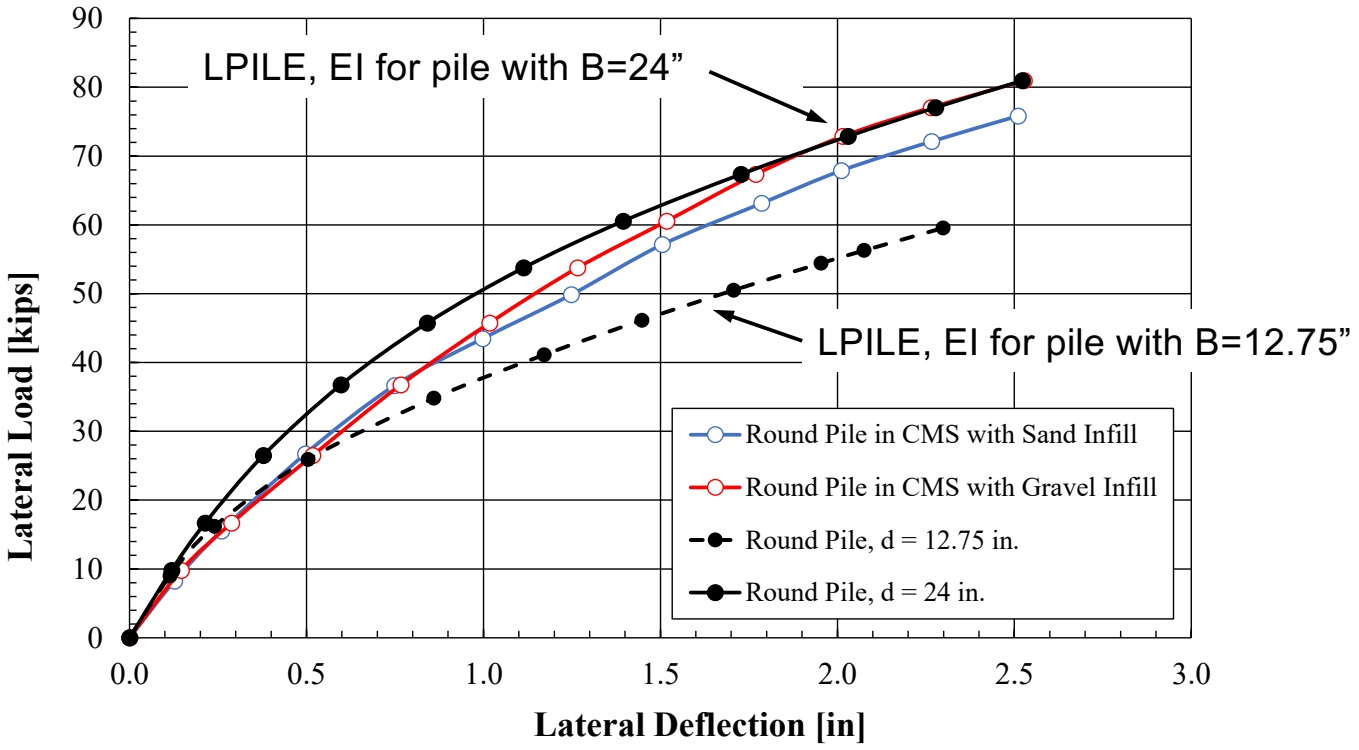


Failure Mechanism for Sleeved Piles

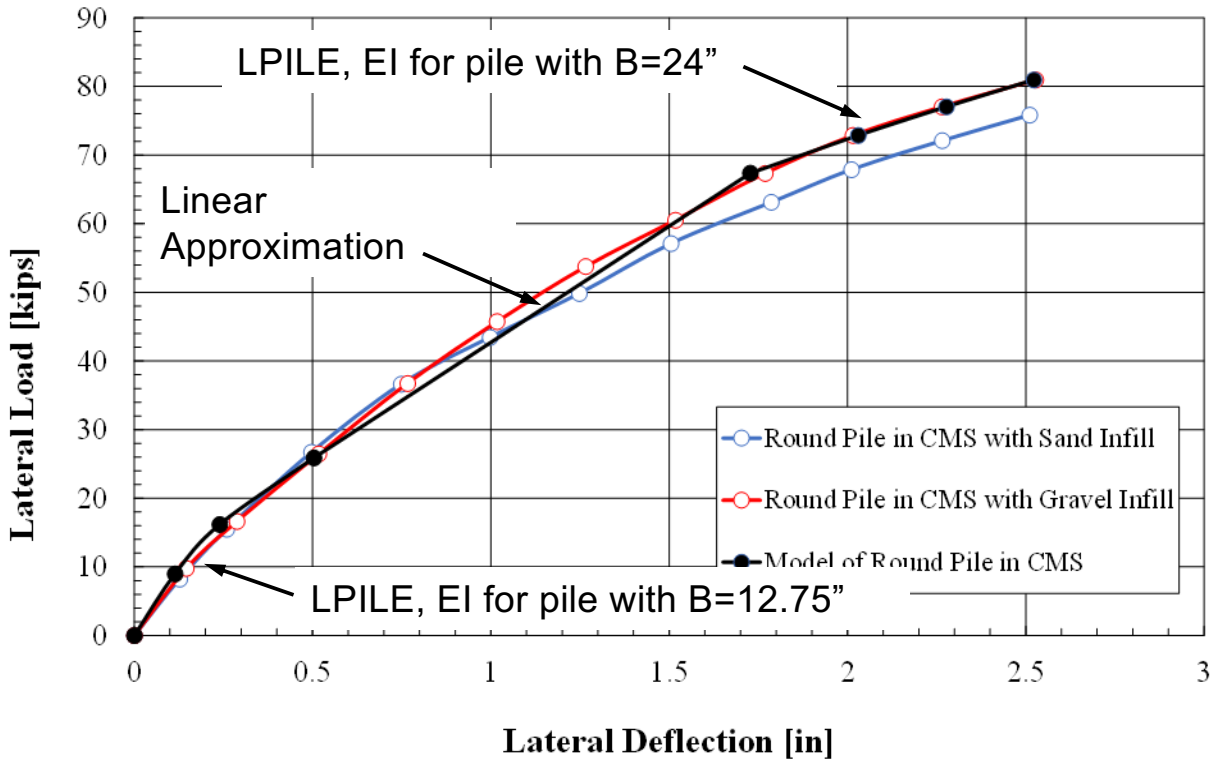


12.75 inch pipe pile inside 24 inch corrugated metal pipe

Lateral Resistance for Sleeved Piles



Lateral Resistance for Sleeved Piles

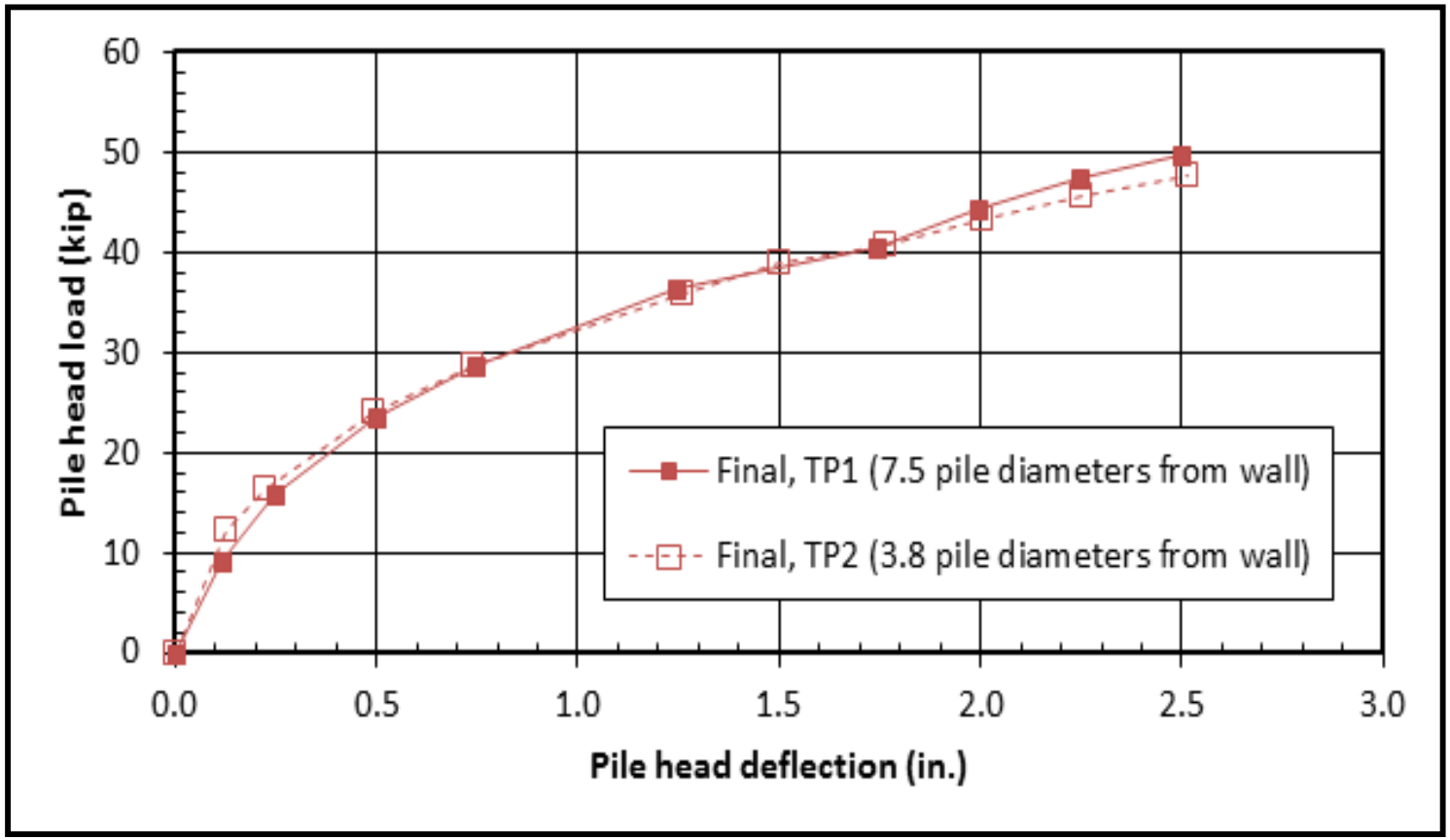


Conclusions Regarding Pile Shape & Sleeves

- Other factors being equal, lateral soil resistance for square piles and H piles is about 25% higher than that for a round pile with similar diameter
- Simple p-multiplier approach can account for increase in lateral resistance
  - P_{mult} = 1.25 for squares & H piles
- Sleeved piles with loose infill are likely to provide substantial lateral resistance owing to composite action
- Lateral resistance can be approximated in LPILE using EI for pile
  - With diameter of the pile for small deflection (<0.5 inch)
  - With diameter of sleeve for larger deflections (>1.5 inch)
  - Linear interpolation between these two limits

Testing with Piles Behind MSE Walls

U.S. Hwy 89 Lateral Load vs. Deflection

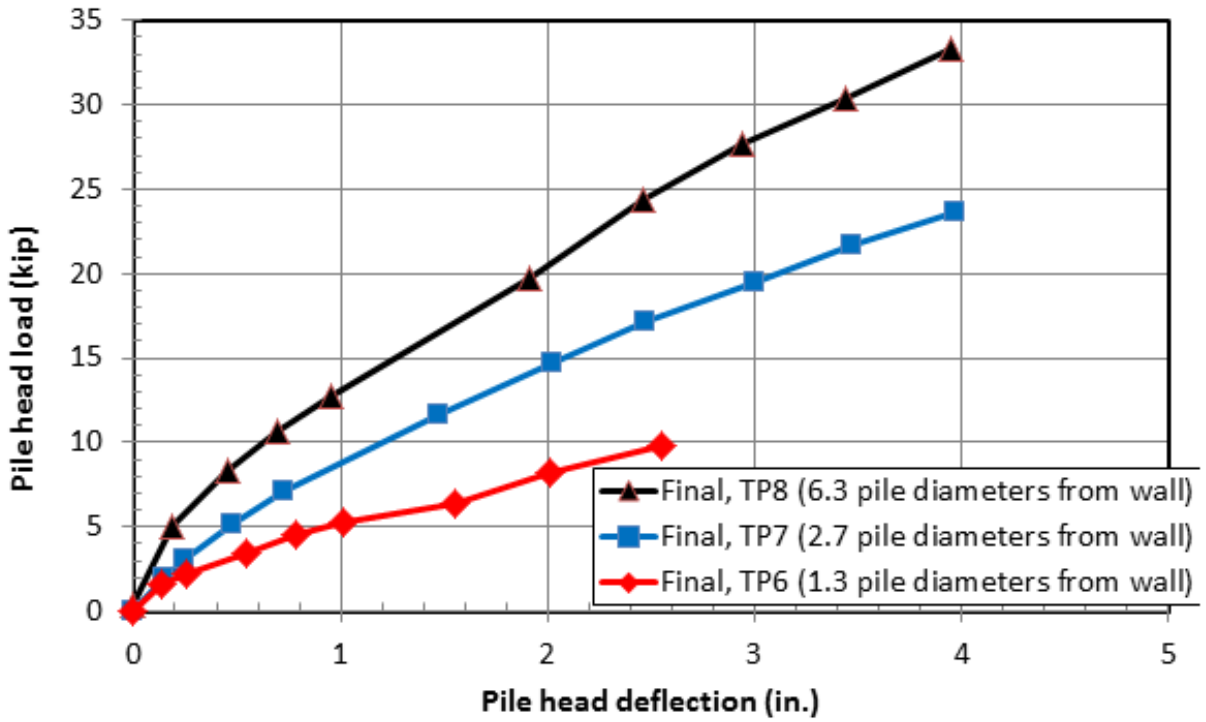


Provo Center Street



22 ft Two-Stage Wall
L/H=1.2

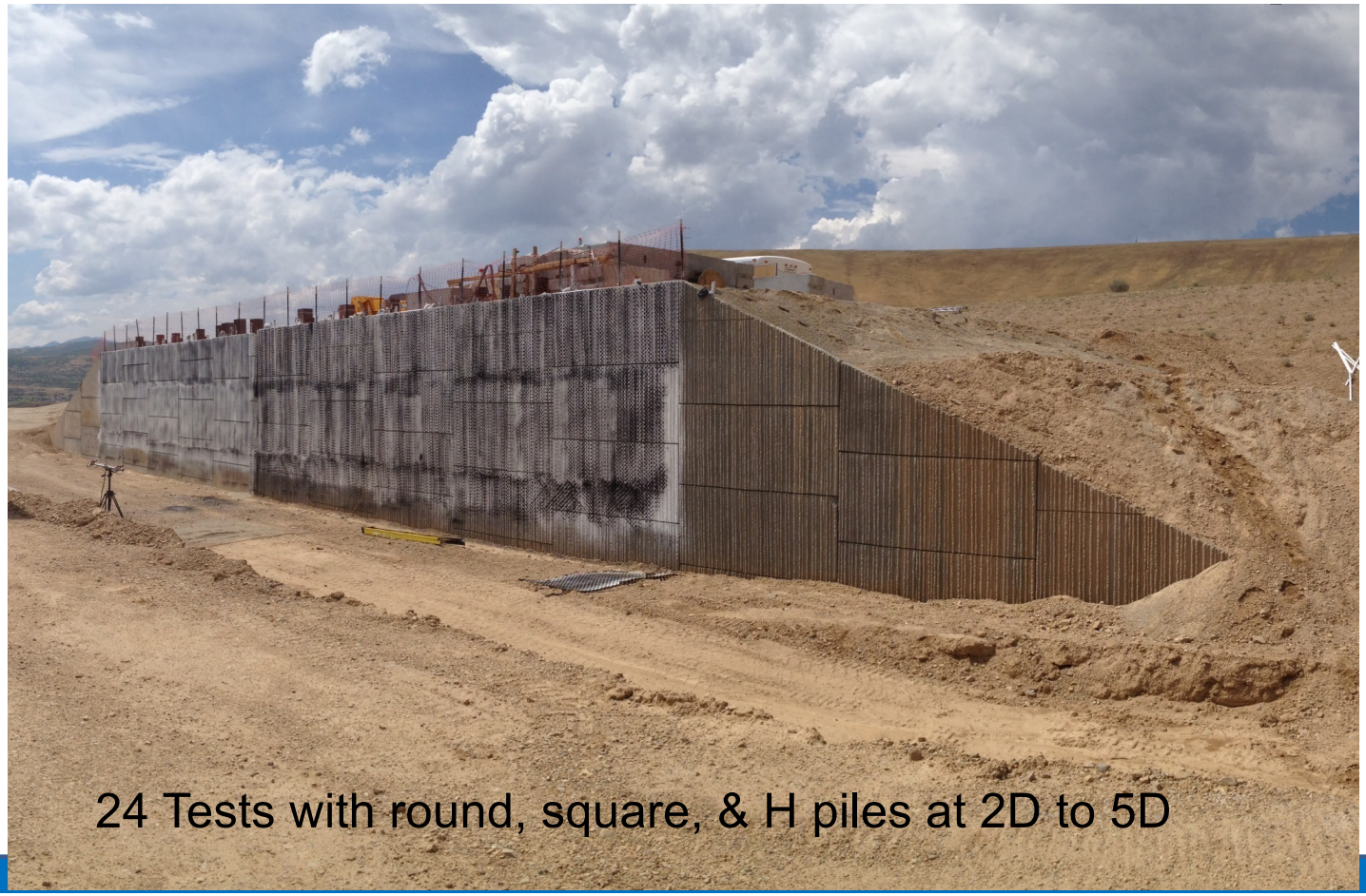
Provo Center St. Lateral Load vs. Deflection



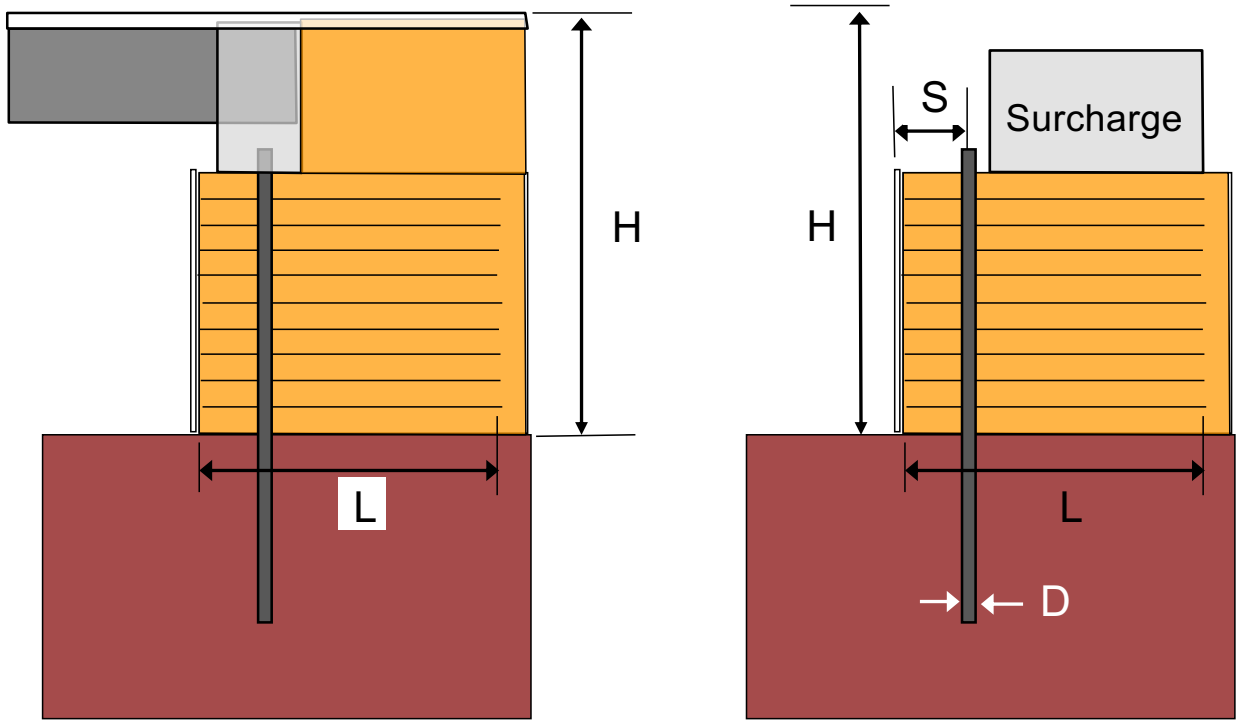
Mechanically Stabilized Earth Abutment Wall



MSE Test Wall (20 ft high & 100 ft long)



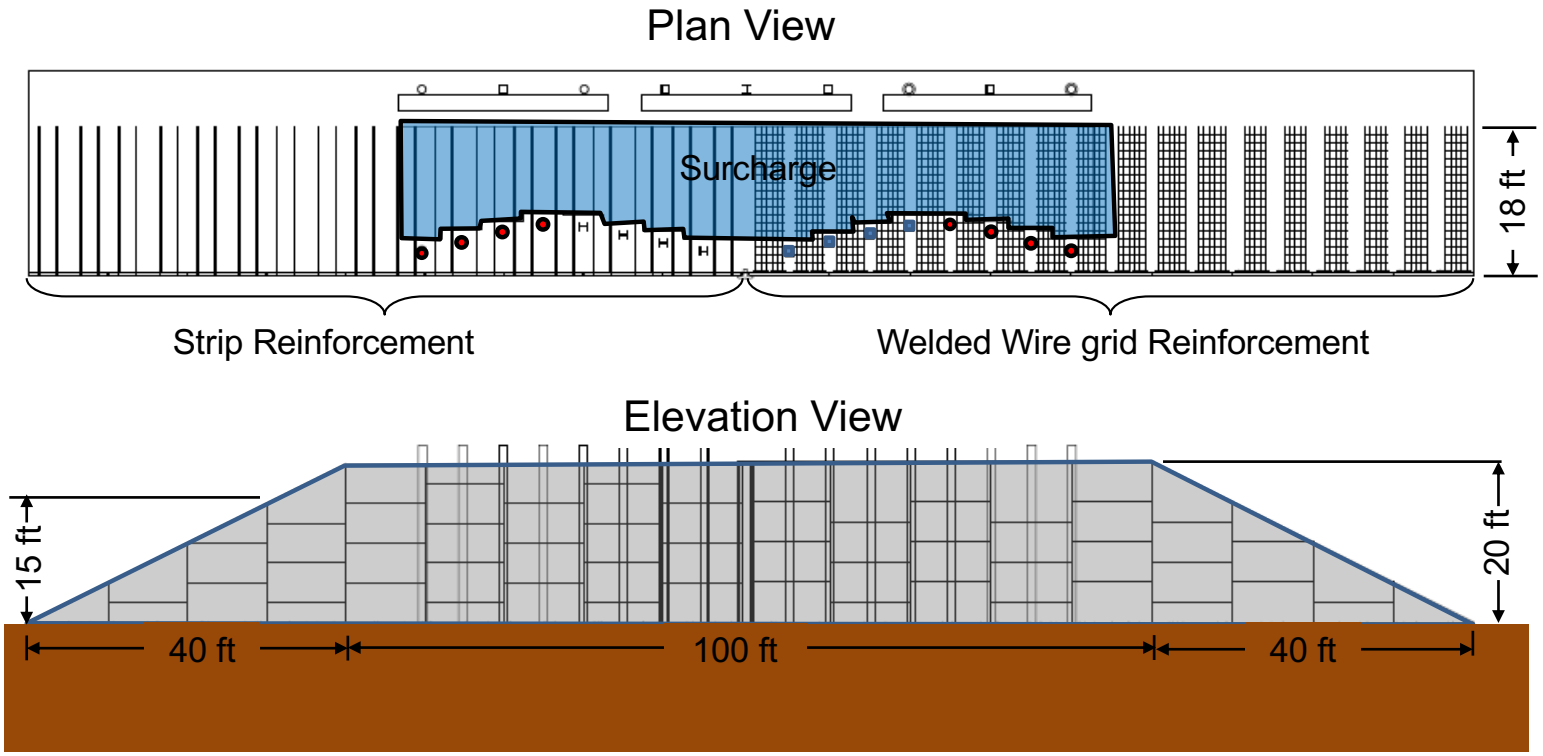
Profile View of Test Layout



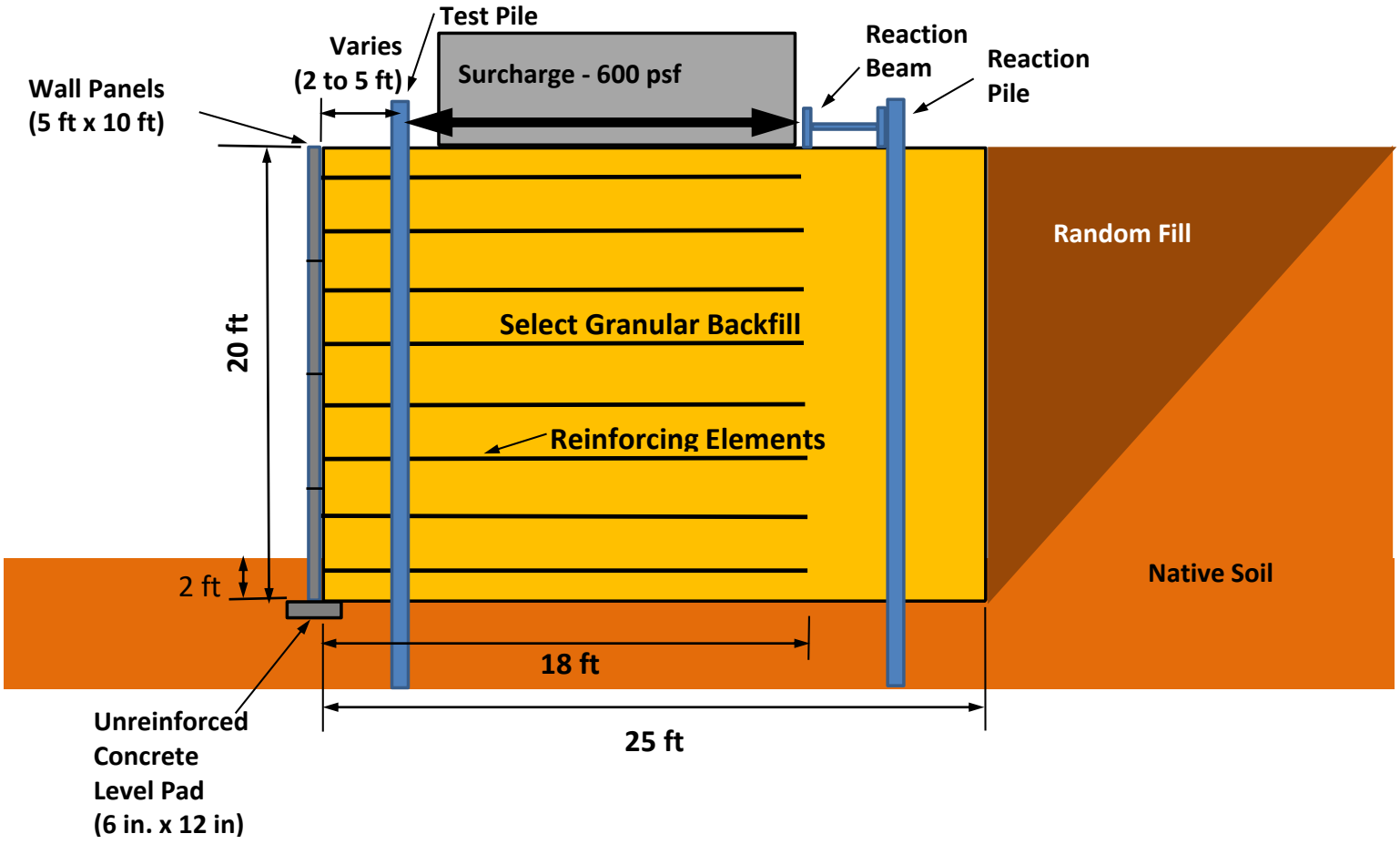
Ultimate Design

Layout During Tests

Plan and Elevation View of Test Abutment

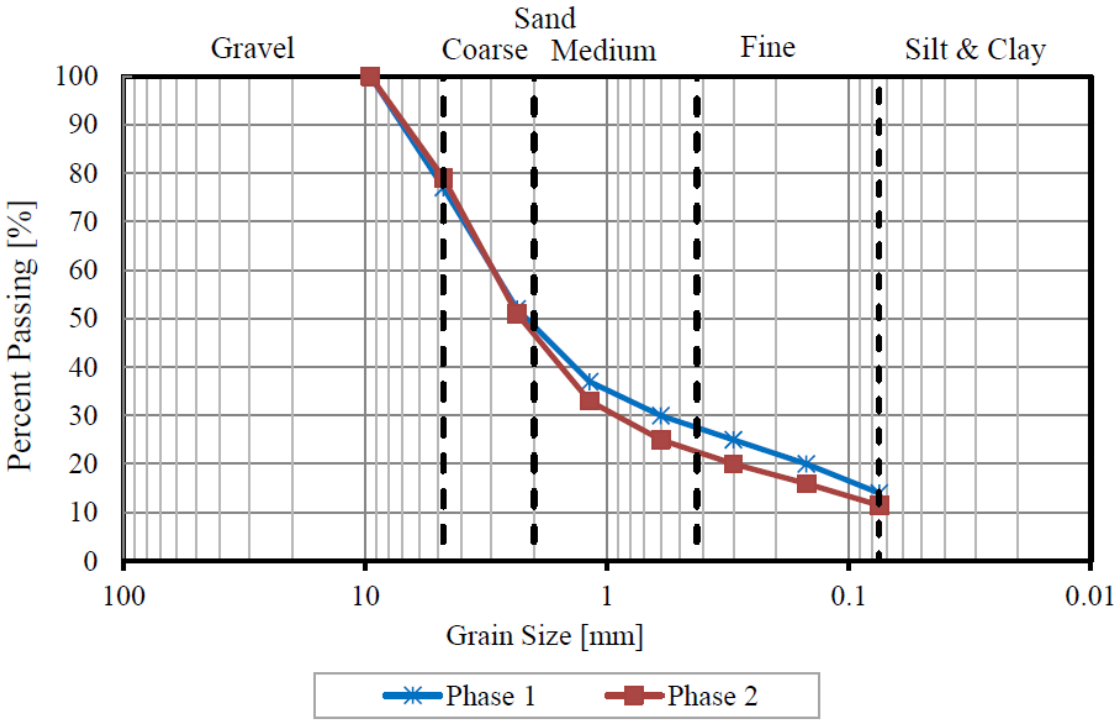


Cross-Section Through MSE Wall

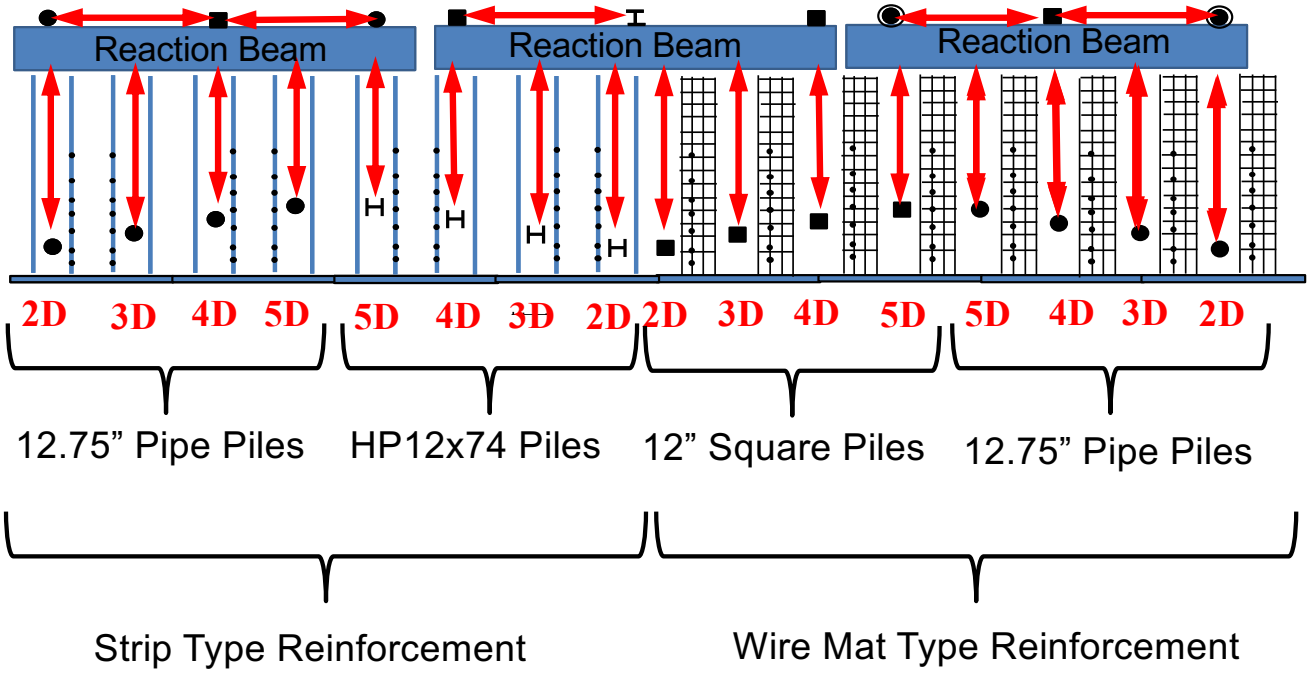


Backfill Properties

Property	Value
Std. Proctor Max. Density	128 pcf
Optimum Moisture	7.8%
Moist Unit Weight @ 95%	128.9
USCS Symbol	SP-SM, SM
AASHTO Symbol	A-1-a



Pile Testing Sequence



29 ft Wall Total of 34 Tests

Installation of Ribbed Strip Reinforcements



Installation of Welded Wire Mat



Compaction Away from the Wall



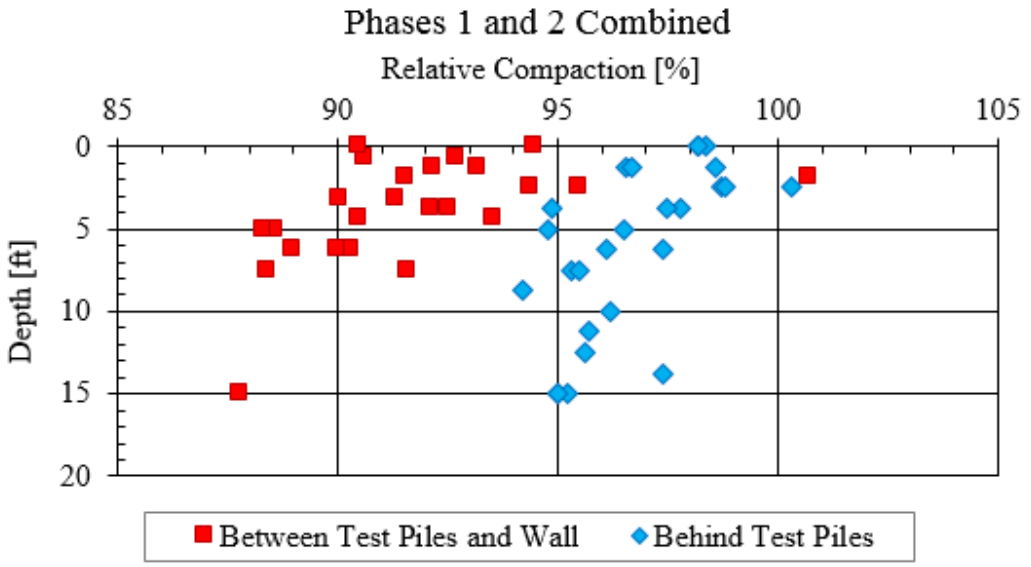


Compaction with Plate Compactor Near Test Piles

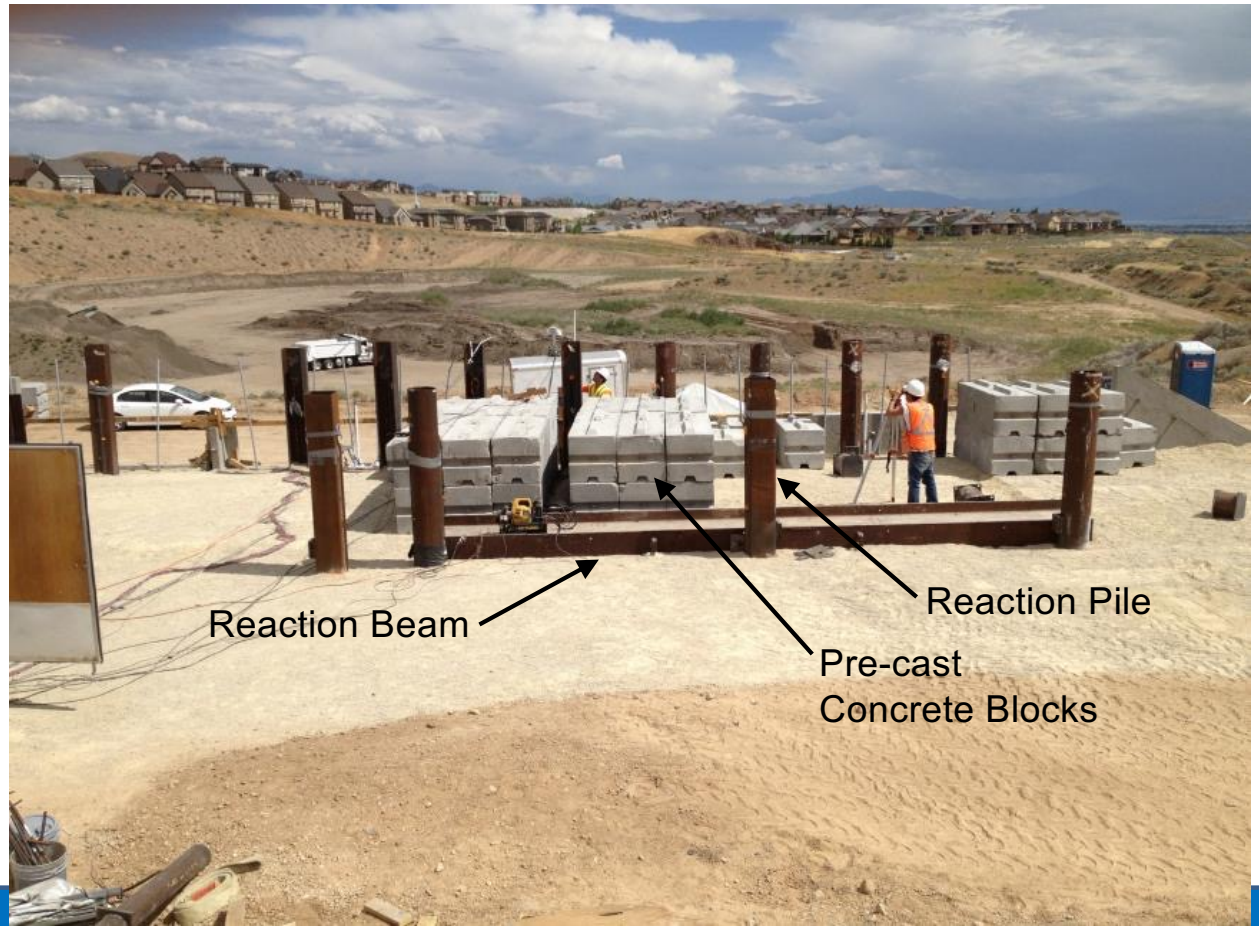


Nuclear Density Gauge Tests

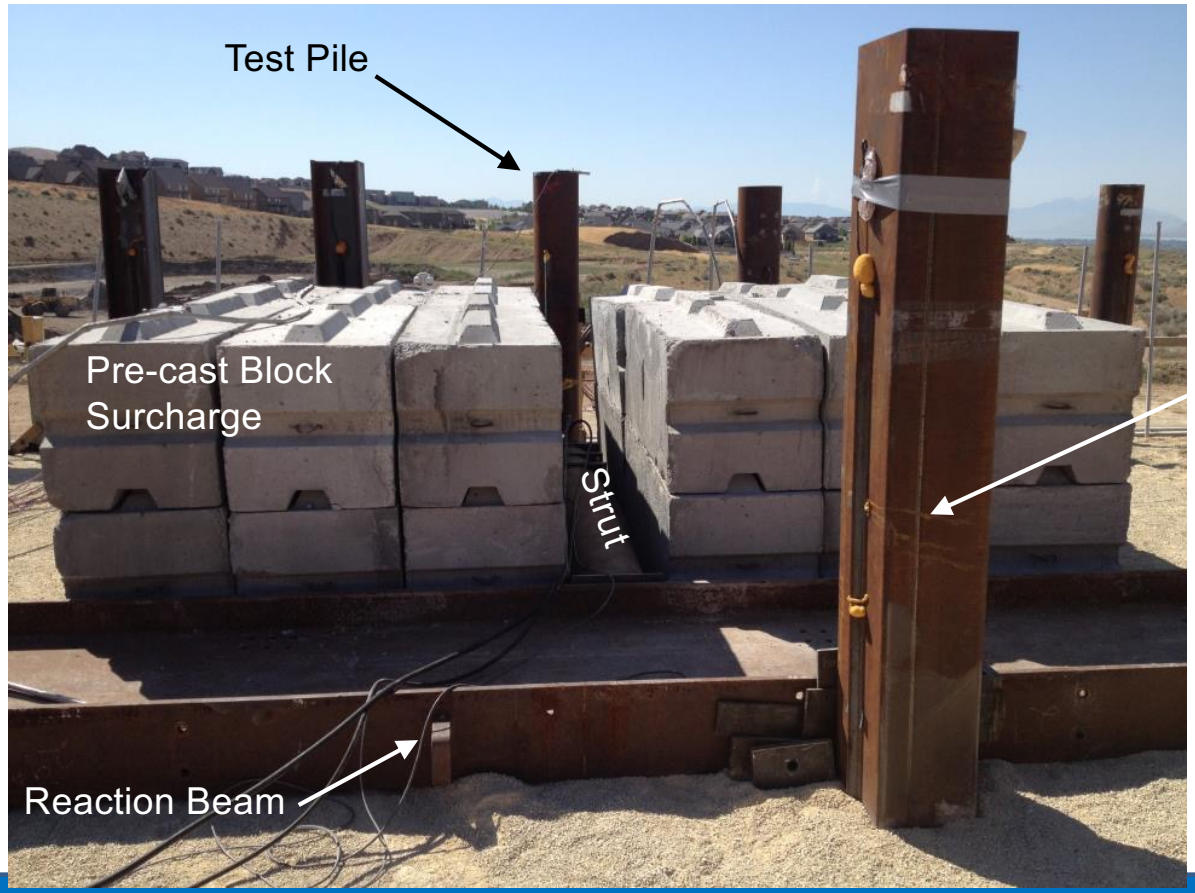




Typical Test Set-up

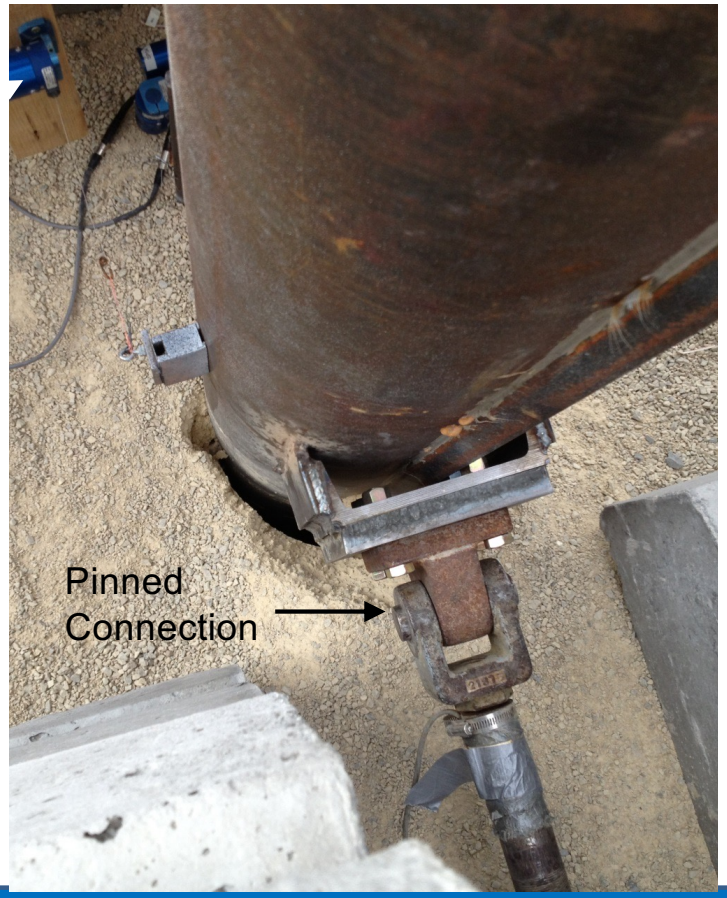


Typical Test Set-up

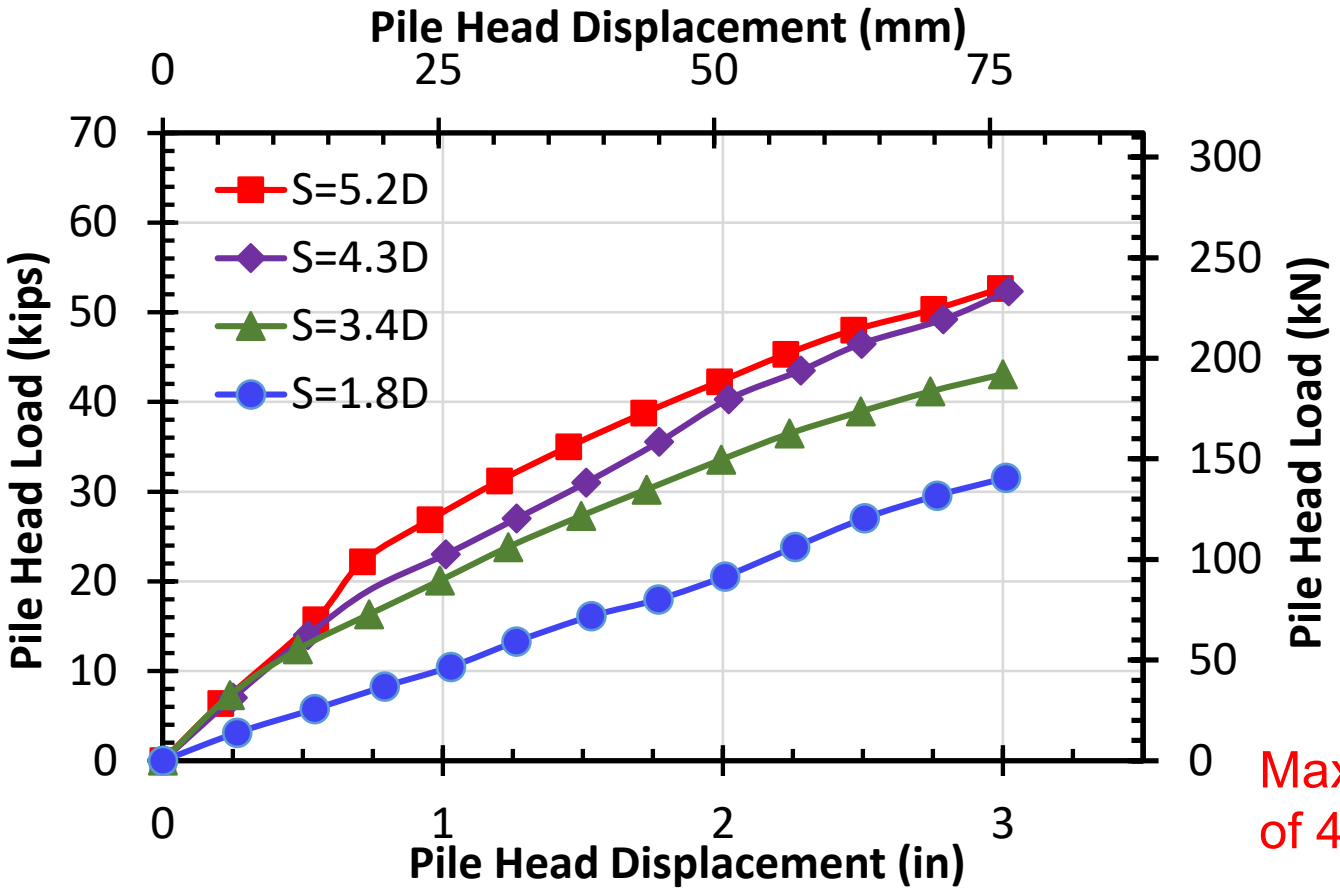


Load Test Photos





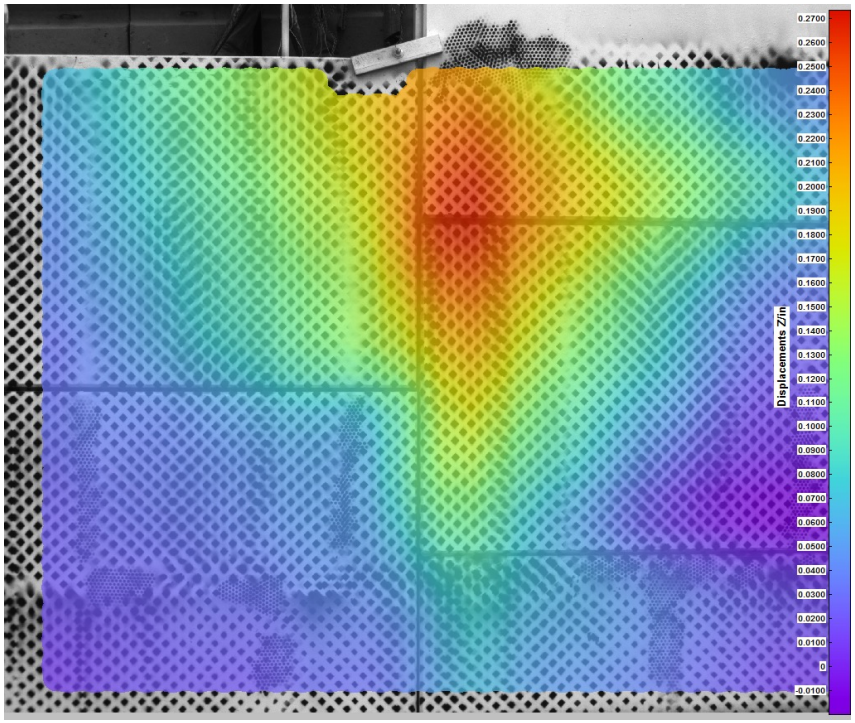
Measured Load-Deflection Curves



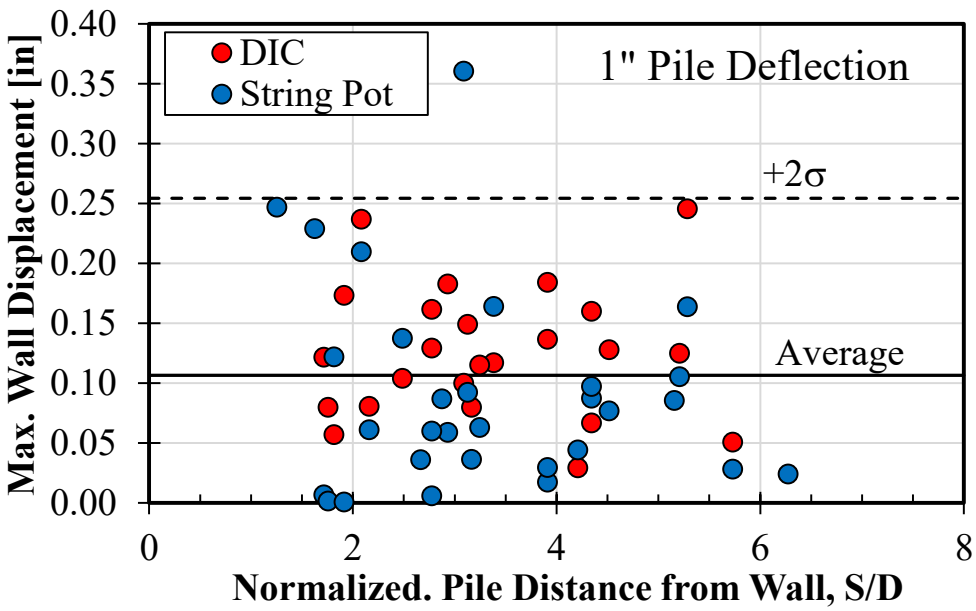
Maximum Loads of 40 to 60 kips

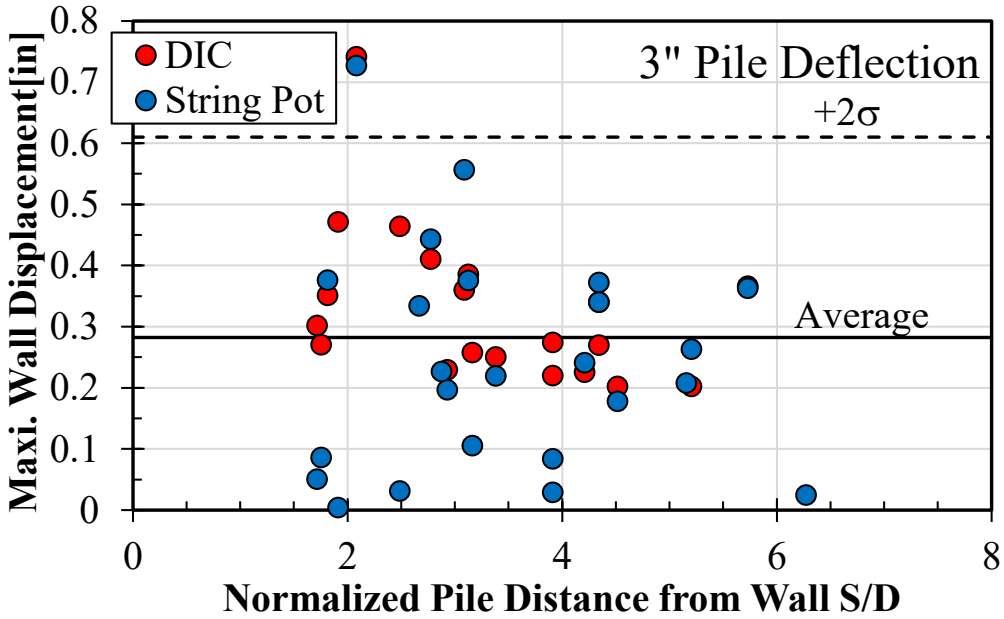
Digital Image Correlation System for Wall Displacement





Maximum Wall Movements

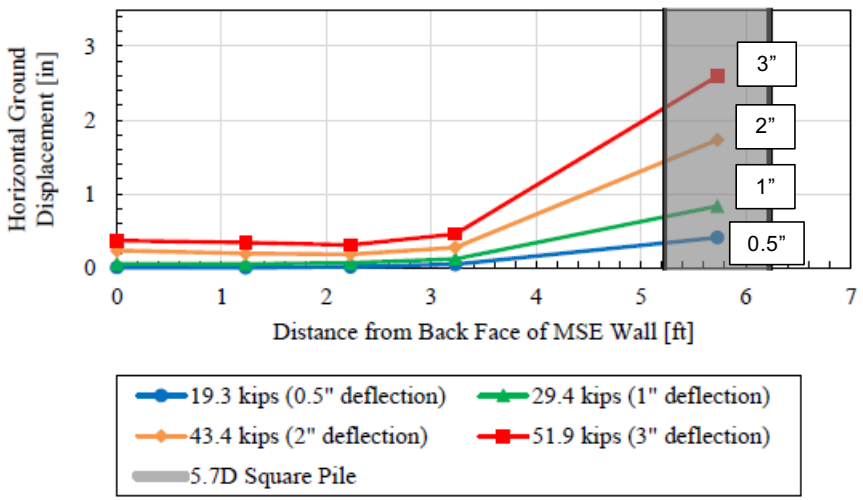




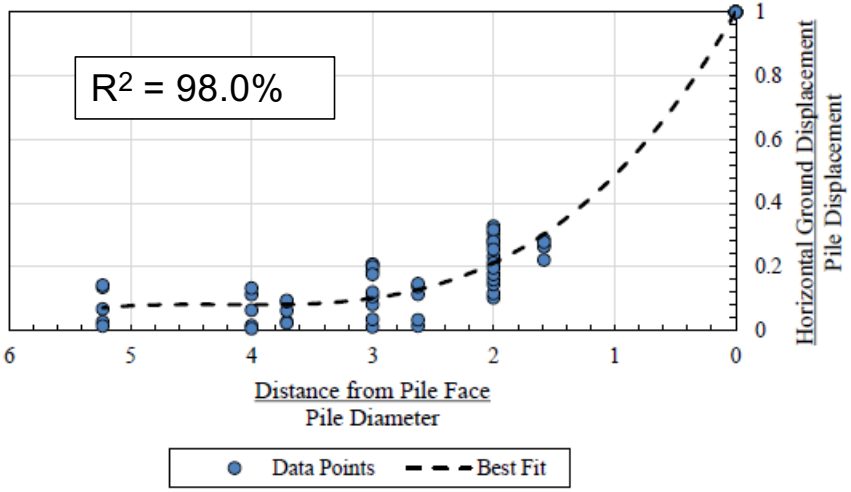
Maximum Loads of 40 to 60 kips

Horizontal Ground Displacement - Square Piles

5.7D Square Pile

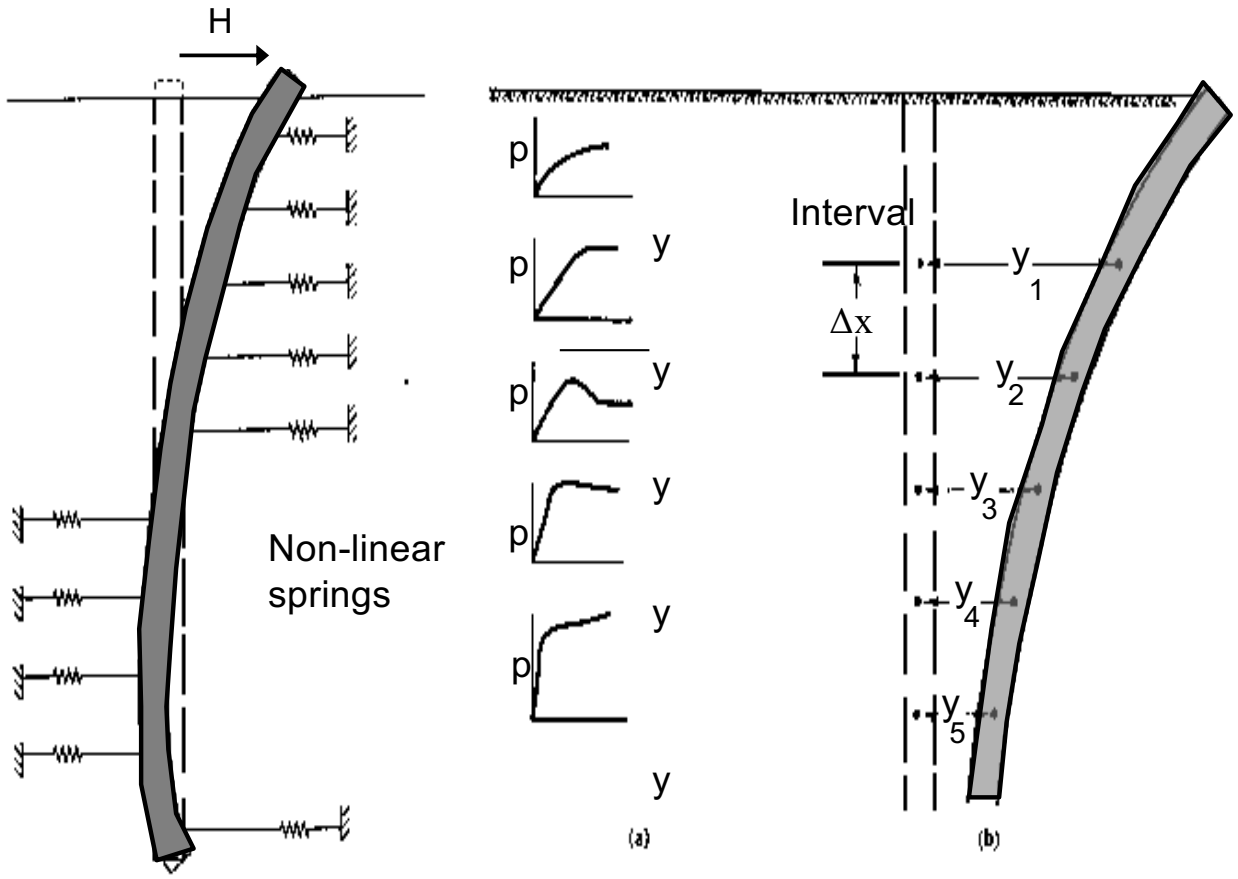


Normalized by displacement at pile face extrapolated to ground (δ_p)

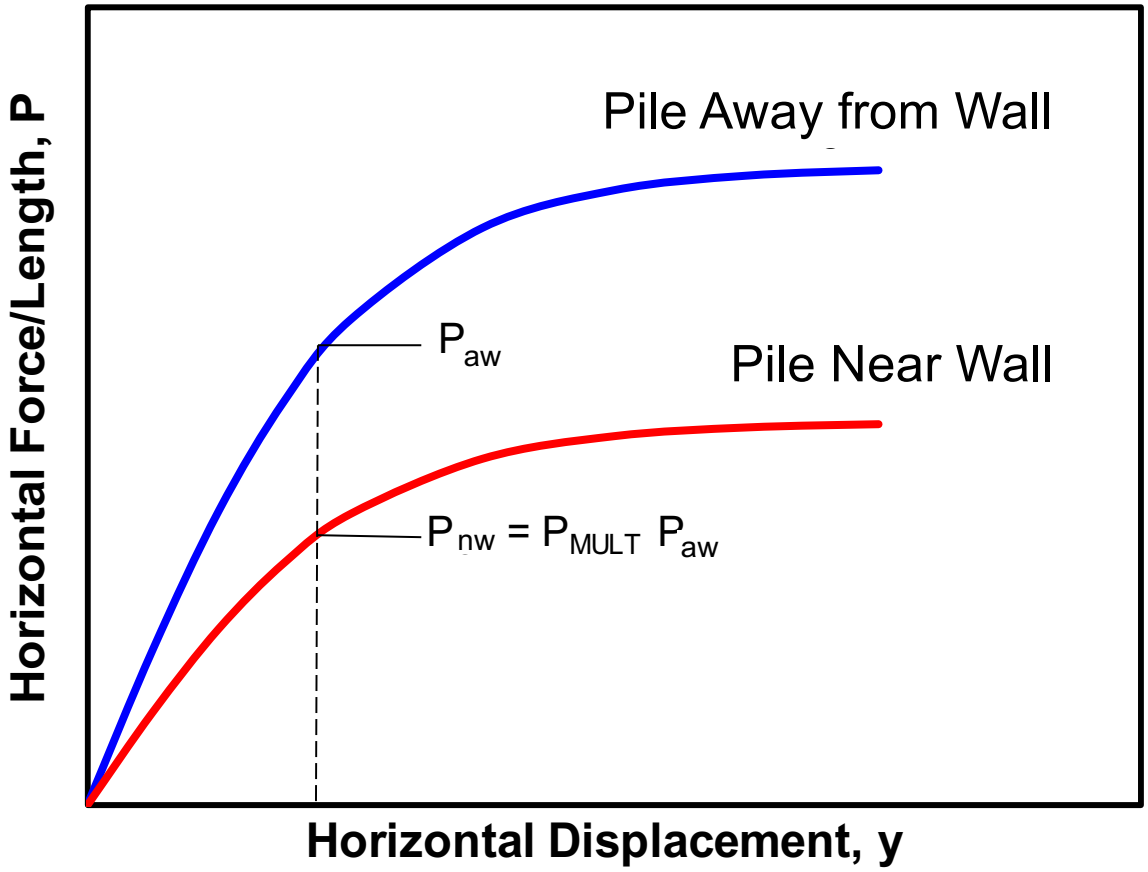


Reduction Factors (p-multipliers) for Wall Interaction

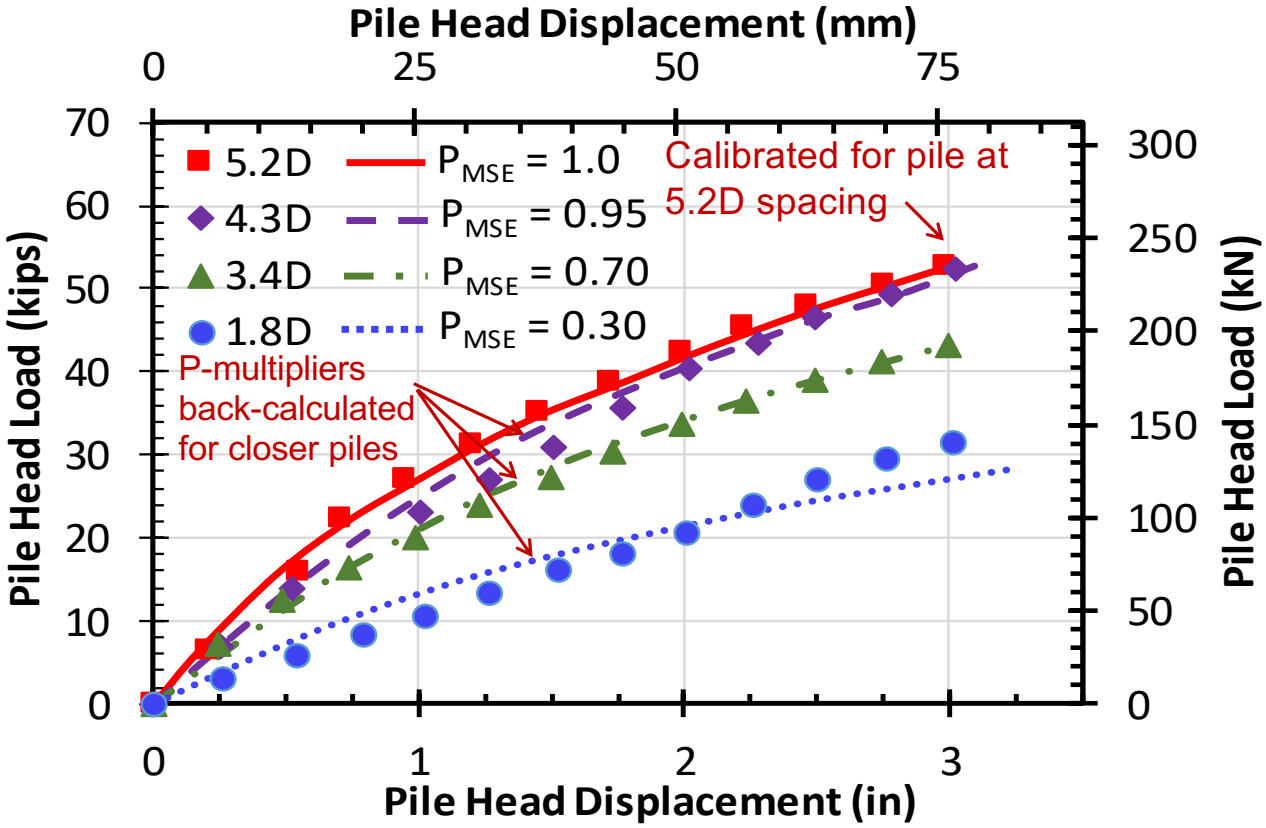
Lateral Load Analysis for Piles with *p-y* Curves



P-multiplier Concept For Proximity of the Wall



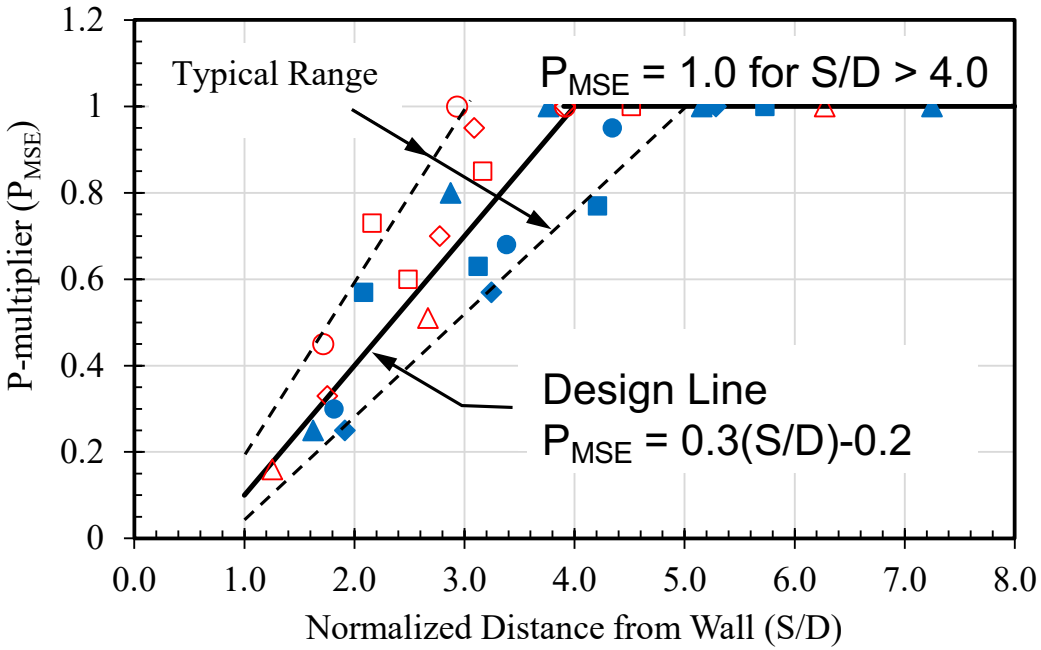
Measured and Computed Load-Deflection Curves



Back-Calculated LPILE Friction Angle

Student	Pile Type	Reinforcement Type	Friction Angle
Hatch (2014)	Pipe	Welded Wire	39°
Han (2014)	Pipe	Ribbed Strip	39°
Besendorfer (2015)	Pipe	Ribbed Strip	39°
Budd (2016)	Pipe	Welded Wire	38°
Luna (2016)	HP	Ribbed Strip	38°
Luna (2016)	Square	Welded Wire	39.5°

P-multipliers from All Tests - 12 inch Piles



▲ Welded-Wire, Pipe, L/H=1.0-1.3 △ Strip, Pipe, L/H=1.0-1.2

◆ Welded-Wire, Pipe, L/H=0.9 ◇ Strip, Pipe, L/H=0.9

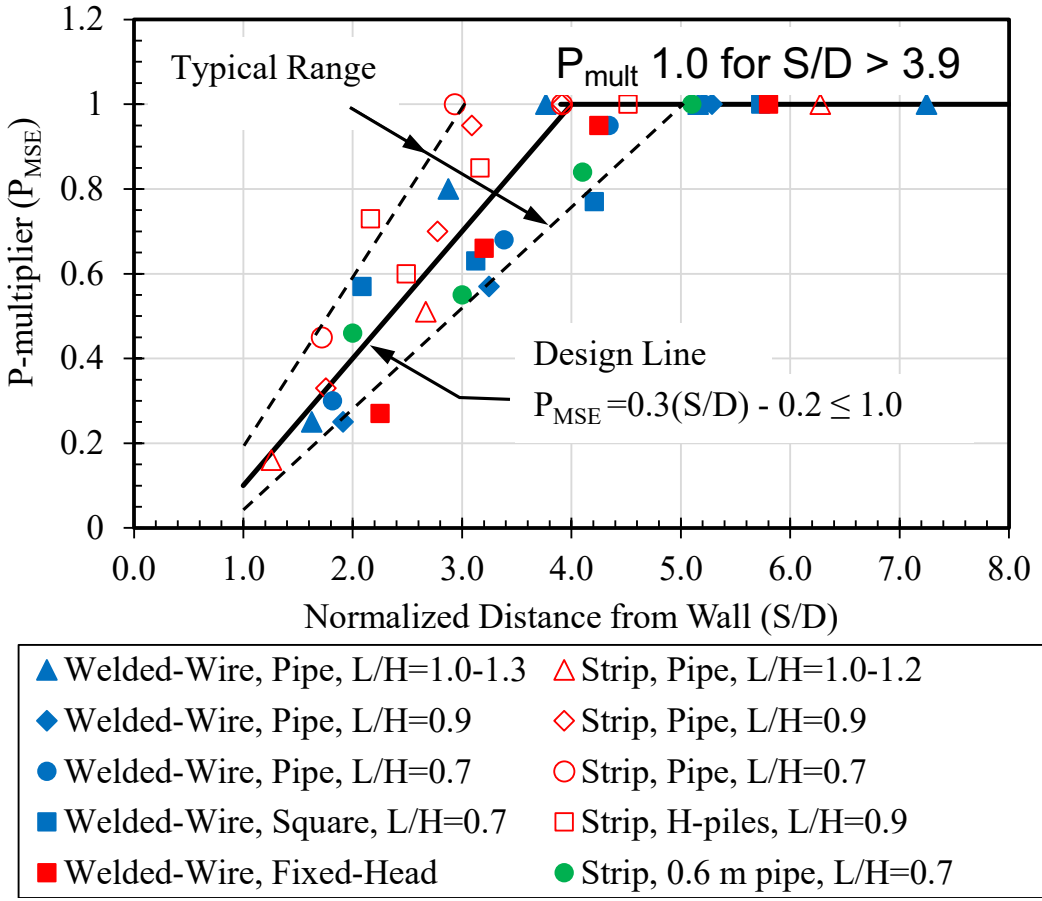
● Welded-Wire, Pipe, L/H=0.7 ○ Strip, Pipe, L/H=0.7

■ Welded-Wire, Square, L/H=0.7 □ Strip, H-piles, L/H=0.9

Additional Tests Fixed-Head Pile and 2 ft Dia. Piles

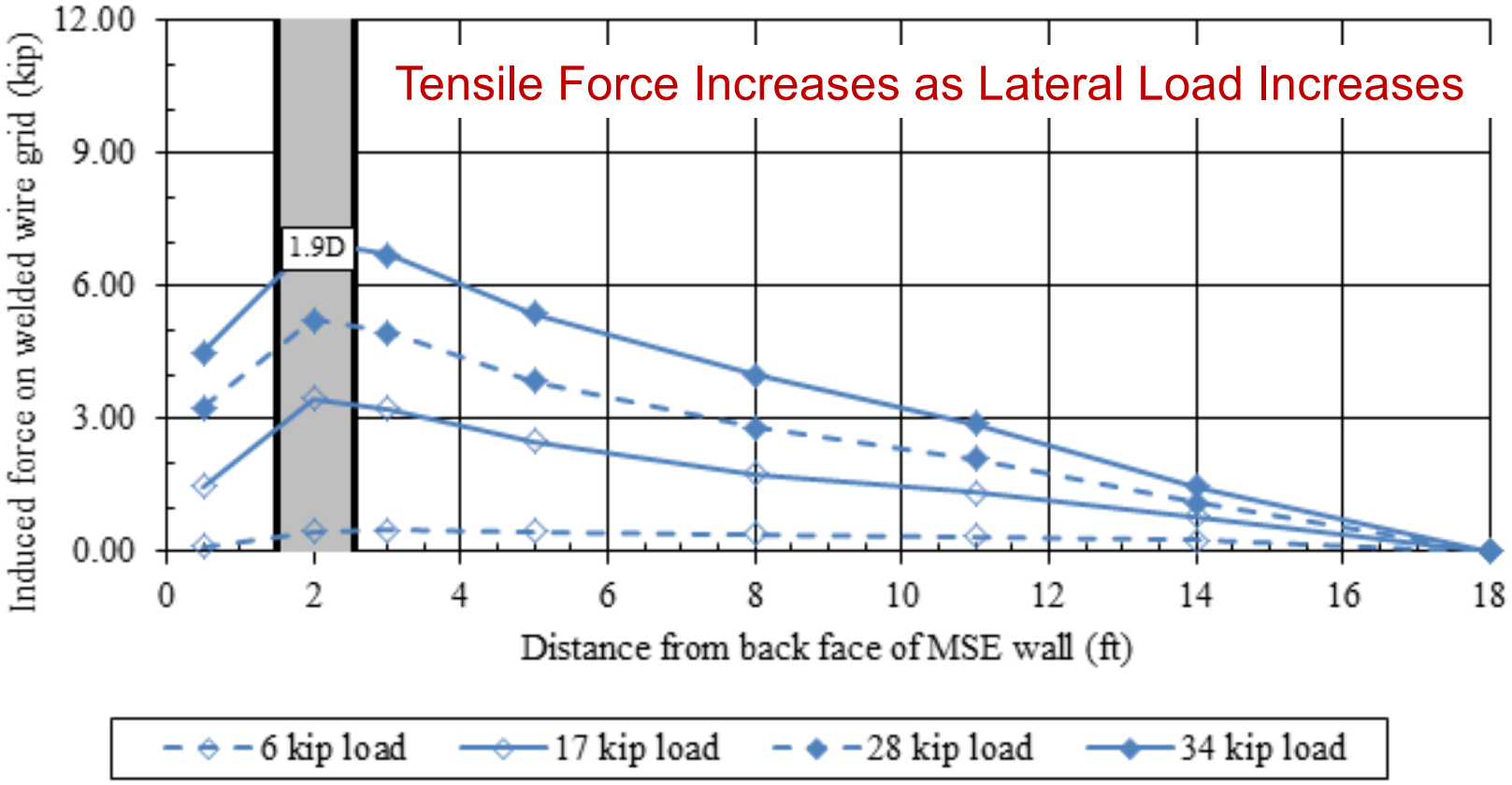


P-multiplier vs. Normalized Spacing Summary

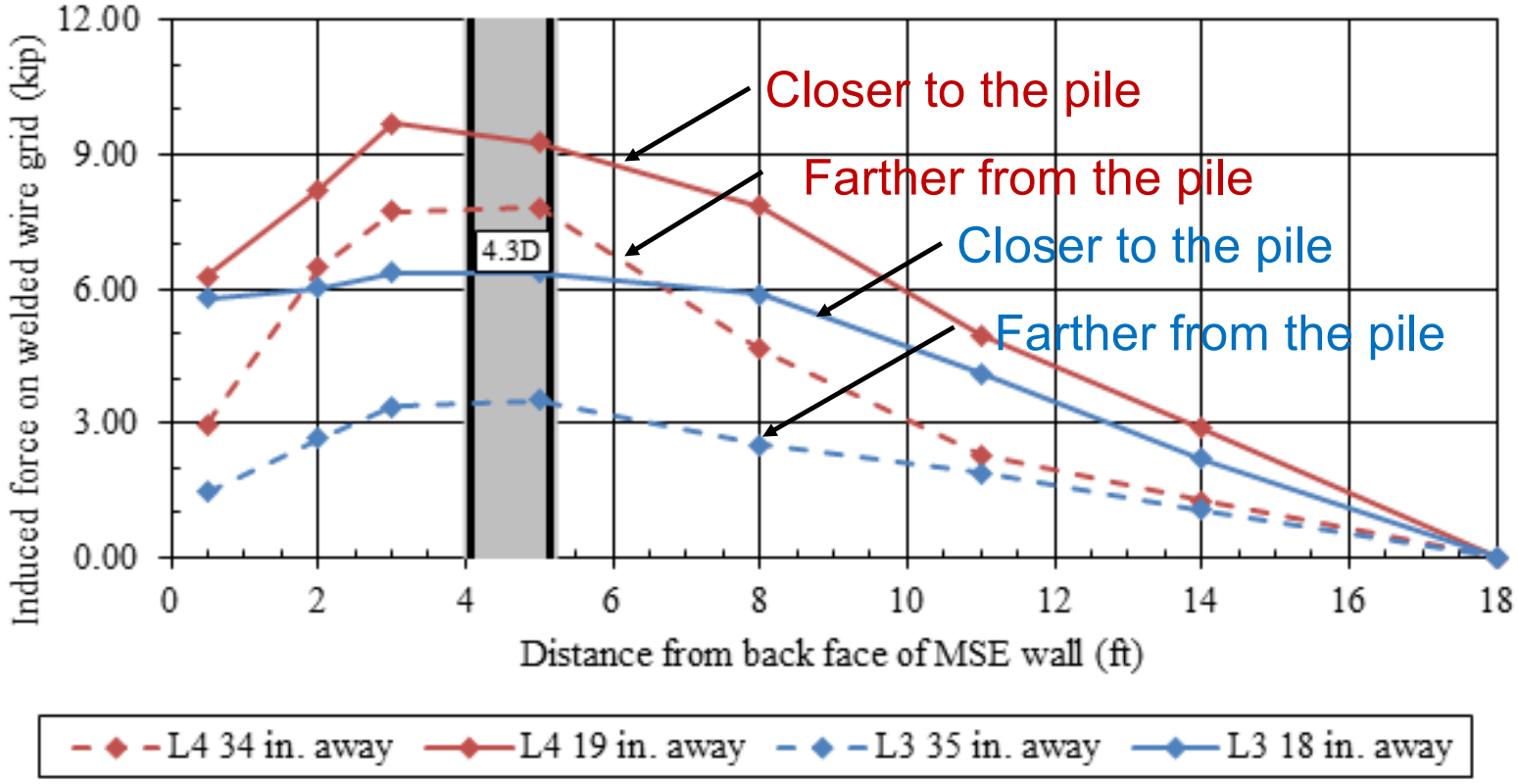


Induced Force on Reinforcements

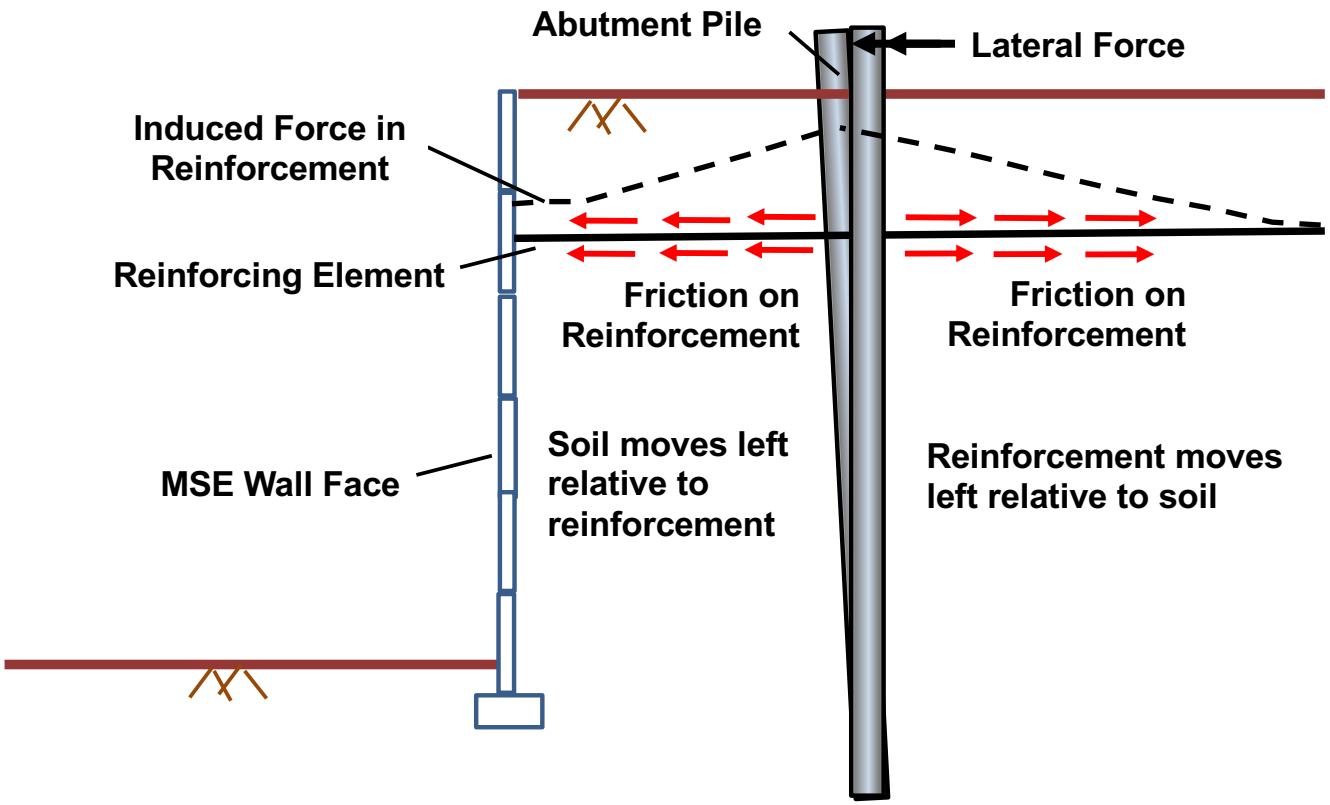
Effect of Lateral Load on Tensile Force



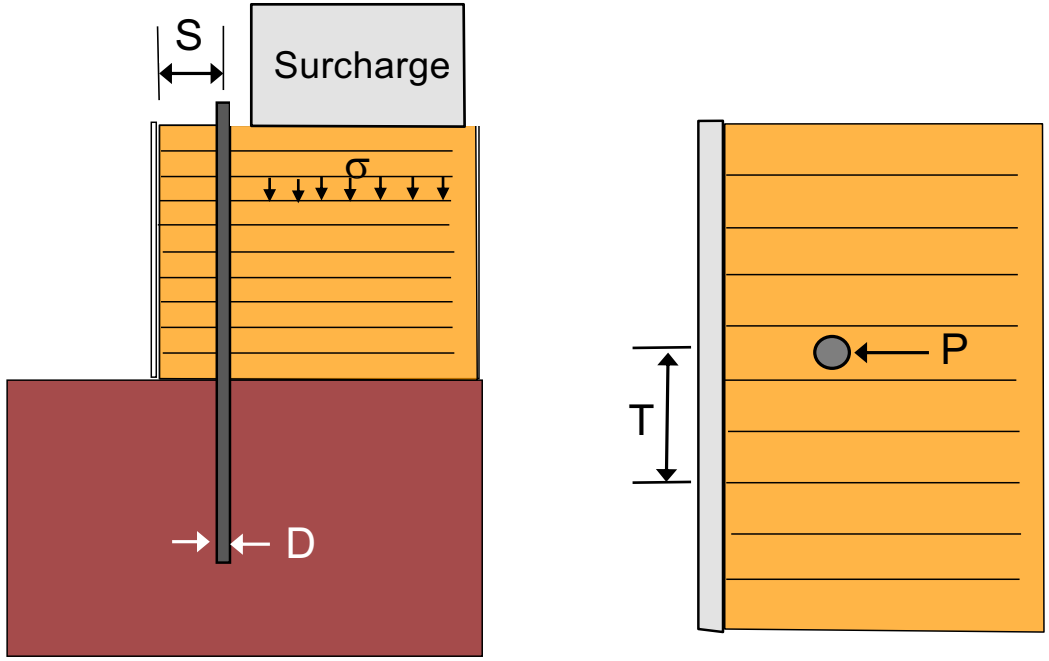
Effect of Transverse Distance on Tensile Force



Schematic of Pile-Reinforcement Interaction



Parameters Affecting Max. Reinforcement Force



P = Applied lateral load (kips)

σ = Vertical Stress (psf)

T = Transverse distance from load point (Normalized by D)

S = Distance Behind the wall (Normalized by D)

Statistical Regression Equations

Ribbed Strip Reinforcement

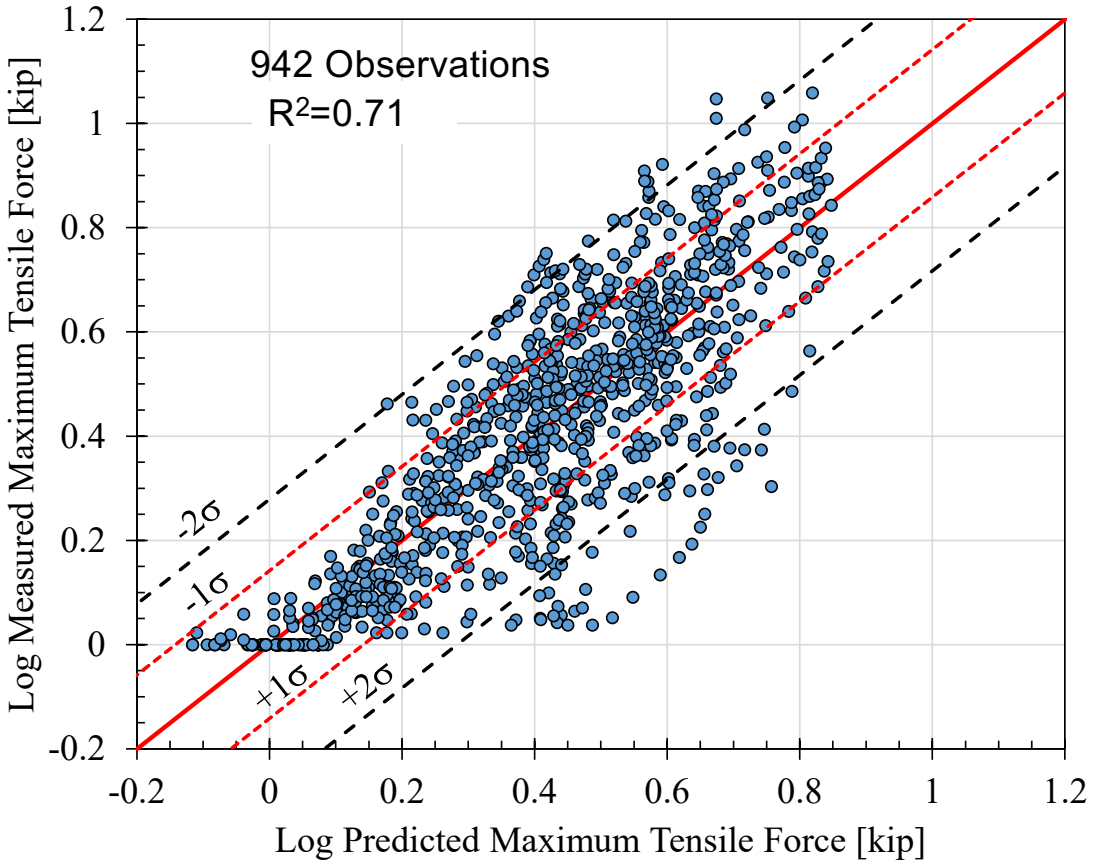
$$\Delta F = 10\text{^}\left(0.13 + 0.028P - 2.2x10^{-4} P^2 - 0.01\frac{T}{D} - 0.0021P\frac{T}{D} - 0.031\frac{S}{D} \right) - 1$$

Where:

ΔF is the maximum tensile force induced in the reinforcement (kips),
P is the pile head load (kips),
T is the transverse distance from the pile,
S is the distance from the back of wall to center of pile,
D is the pile diameter.

Measured vs Computed Induced Tensile Force

All Strip Reinforcement – Single strip



Maximum Loads of 40 to 60 kips

Statistical Regression Equations

All Welded Wire Reinforcement

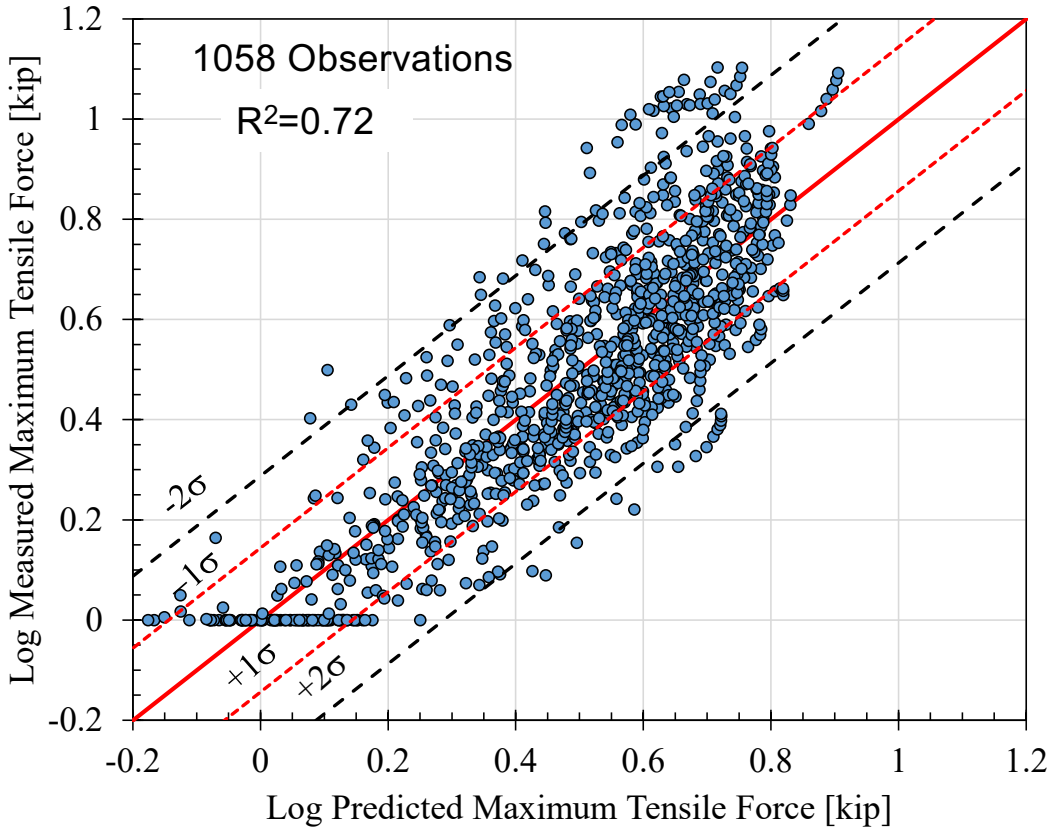
$$\Delta F = 10\text{^}\left(-0.04 + 0.027P - 2.7x10^{-4}P^2 + 5.7x10^{-4}\sigma_V - 2.6x10^{-7}\sigma_V^2 - 0.08\frac{T}{D} \right) - 1$$

Where:

ΔF is the maximum tensile force induced in the reinforcement (kips),
P is the pile head load (kips),
σ_v is the vertical stress on the reinforcement (psf),
T is the transverse distance from the pile,
D is the pile diameter

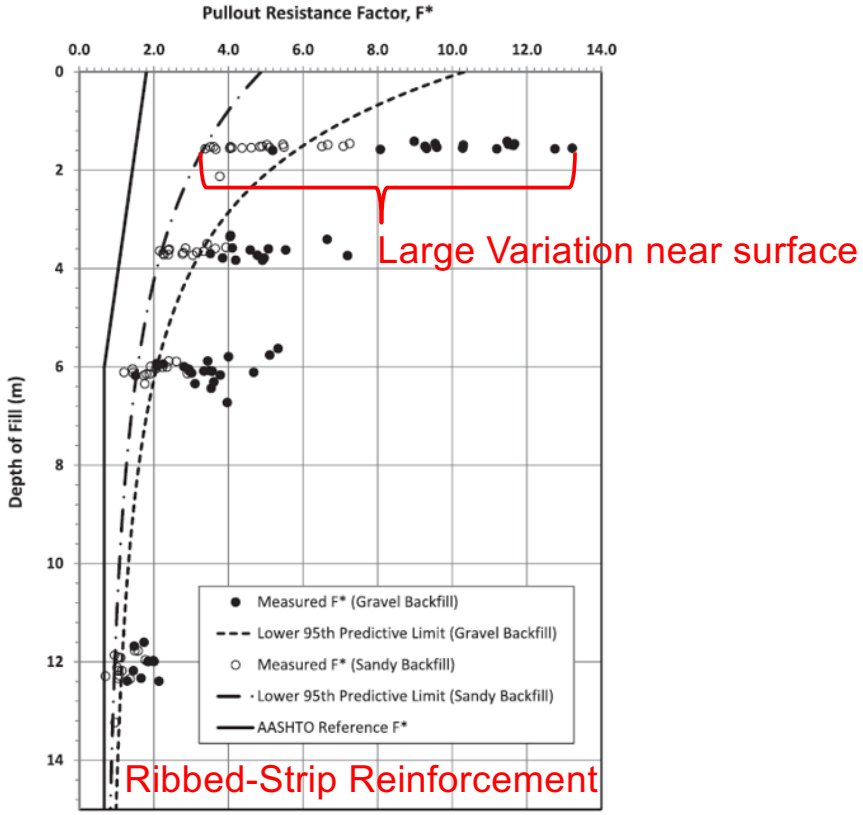
Log Measured vs Log Computed Induced Tensile Force

All Welded Wire Reinforcement – 5 wire grid

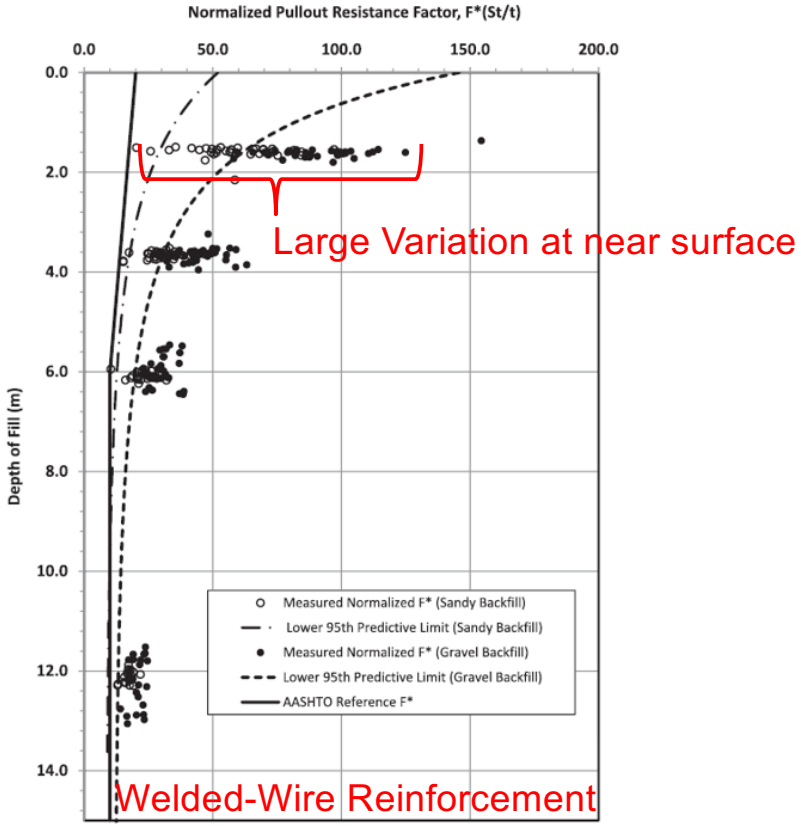


Maximum Loads of 40 to 60 kips

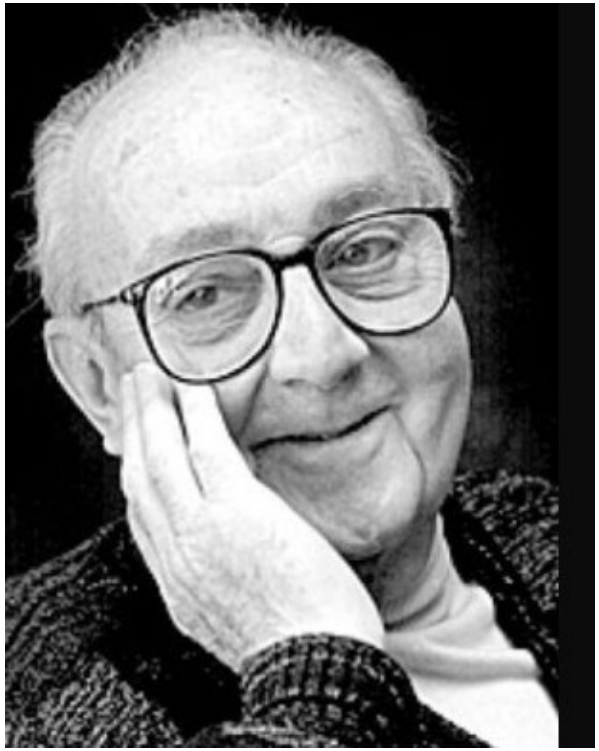
Pullout Friction Results – Texas Tech (Jayawickrama et al 2015)



Depth of fill versus pullout resistance factor for ribbed steel strips (Jayawickrama, 2014).



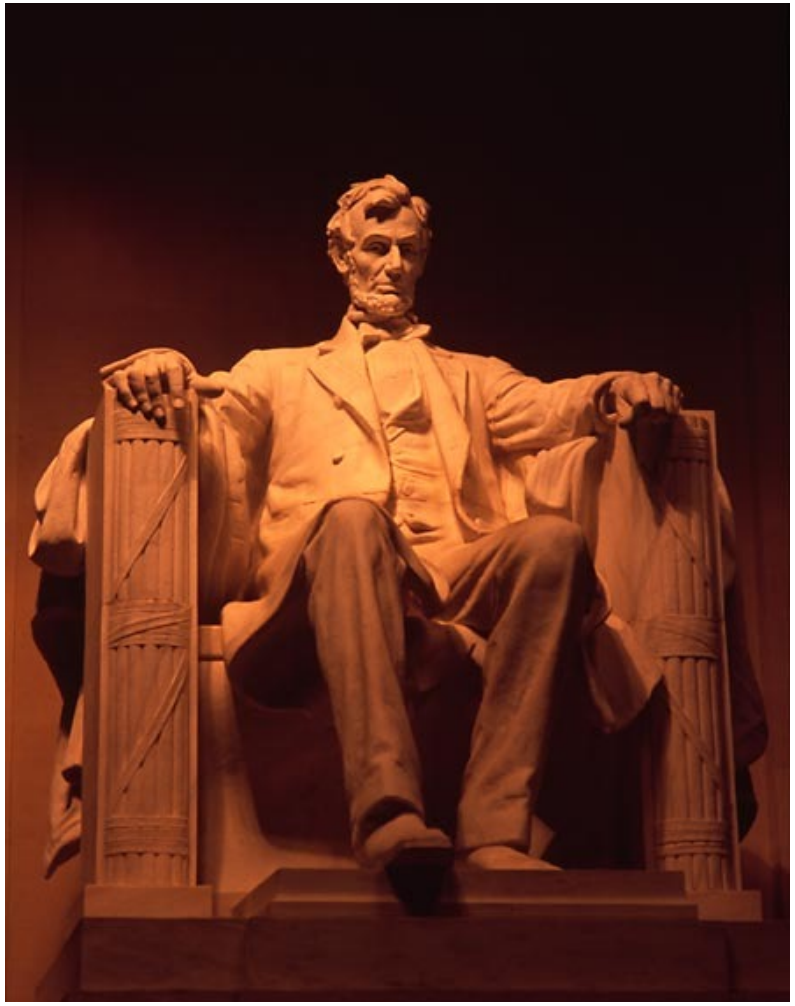
Depth of fill versus normalized pullout resistance factor for welded steel grids (Jayawickrama, 2014).



"…all models are approximations. Essentially, all models are wrong, but some are useful. However, the approximate nature of the model must always be borne in mind"

-- *George E. P. Box*

Eminent Statistician



"The trouble with quotes on the internet is that it's difficult to discern whether or not they are genuine."

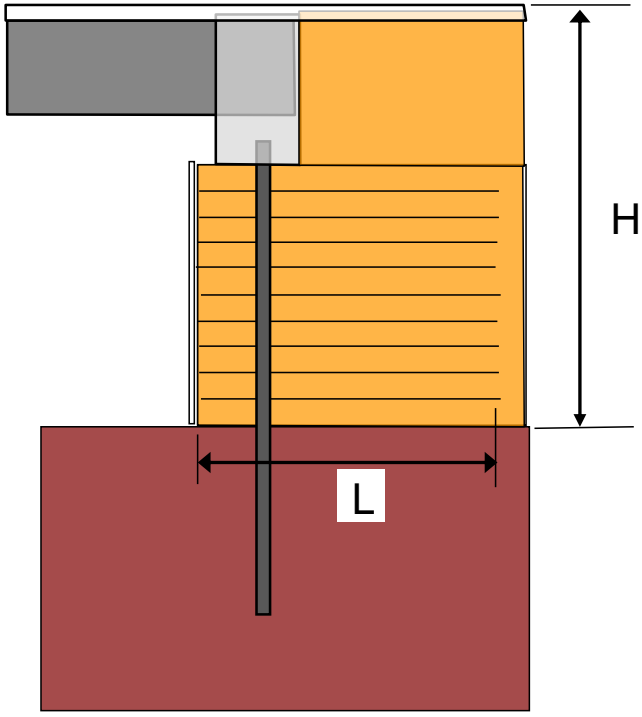
--Abraham Lincoln

Conclusions Regarding Piles Near MSE Walls

- Significant reductions in lateral resistance as piles are placed closer than about 4D from the wall
- Simple p-multiplier approach can account for reduction in lateral resistance
  - P_{mult} = 1.0 for S >4D
  - P_{mult} decreases linearly for smaller spacings
- Maximum reinforcement force:
  - Occurs near the pile location
  - Increases with applied load
  - Increases as pile is placed closer to wall
  - Decreases with transverse distance from the pile
  - Statistical regression equations can account for ≈ 72% of variation

Two Group Tests on Three Piles

Abutments Typically Involve Group loading



Ultimate Design



University of Kansas Study

- 3-foot diameter round concrete shafts
- Individual shafts spaced at 2.0 shaft diameters
- Group of three shafts spaced at 2.0 shaft diameters behind MSE wall



P-multiplier for Reduction in Resistance from Group Interaction

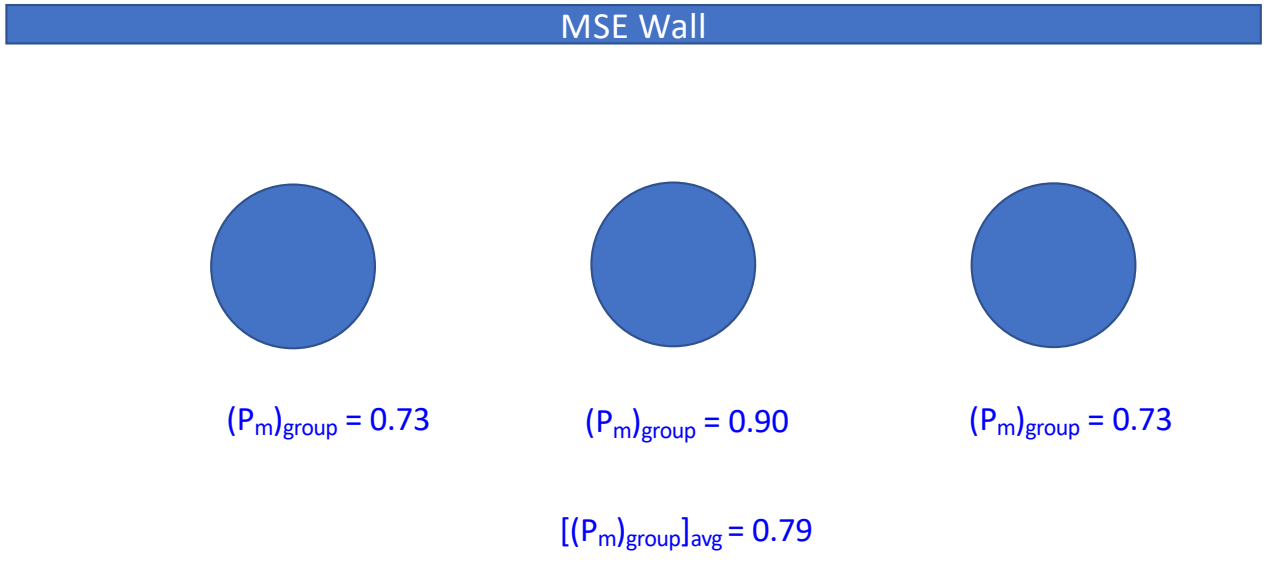
$$(P_{MSE})_{total} = (P_{MSE})_{group} * (P_{MSE})_{Single}$$

Where: $(P_{MSE})_{group}$ = the group effect p-multiplier, and

$(P_{MSE})_{wall}$ = the pile-to-wall spacing p-multiplier given = 0.3(S/D) – 0.20.

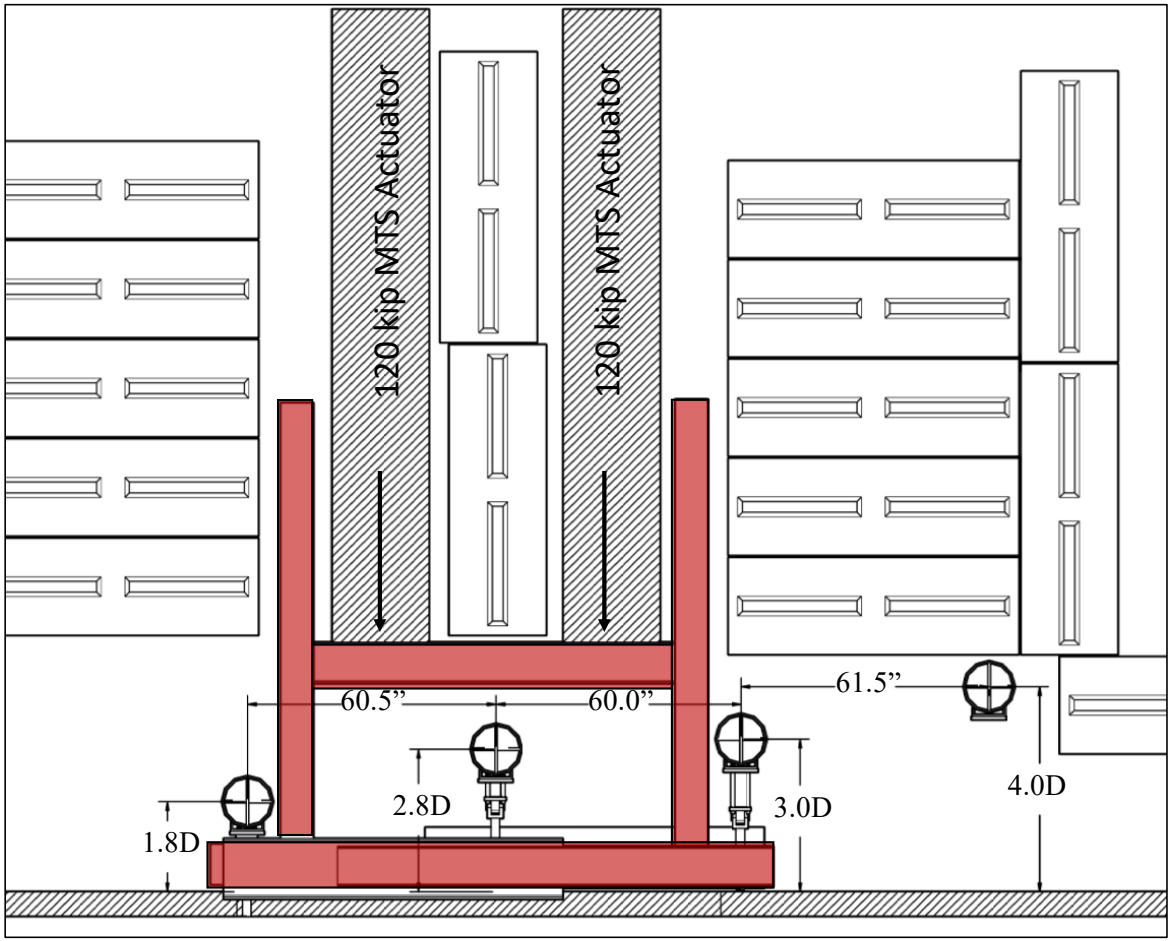
Back-Calculated Group Interaction P-multipliers, $(P_{MSE})_{Group}$

Kansas Group Test

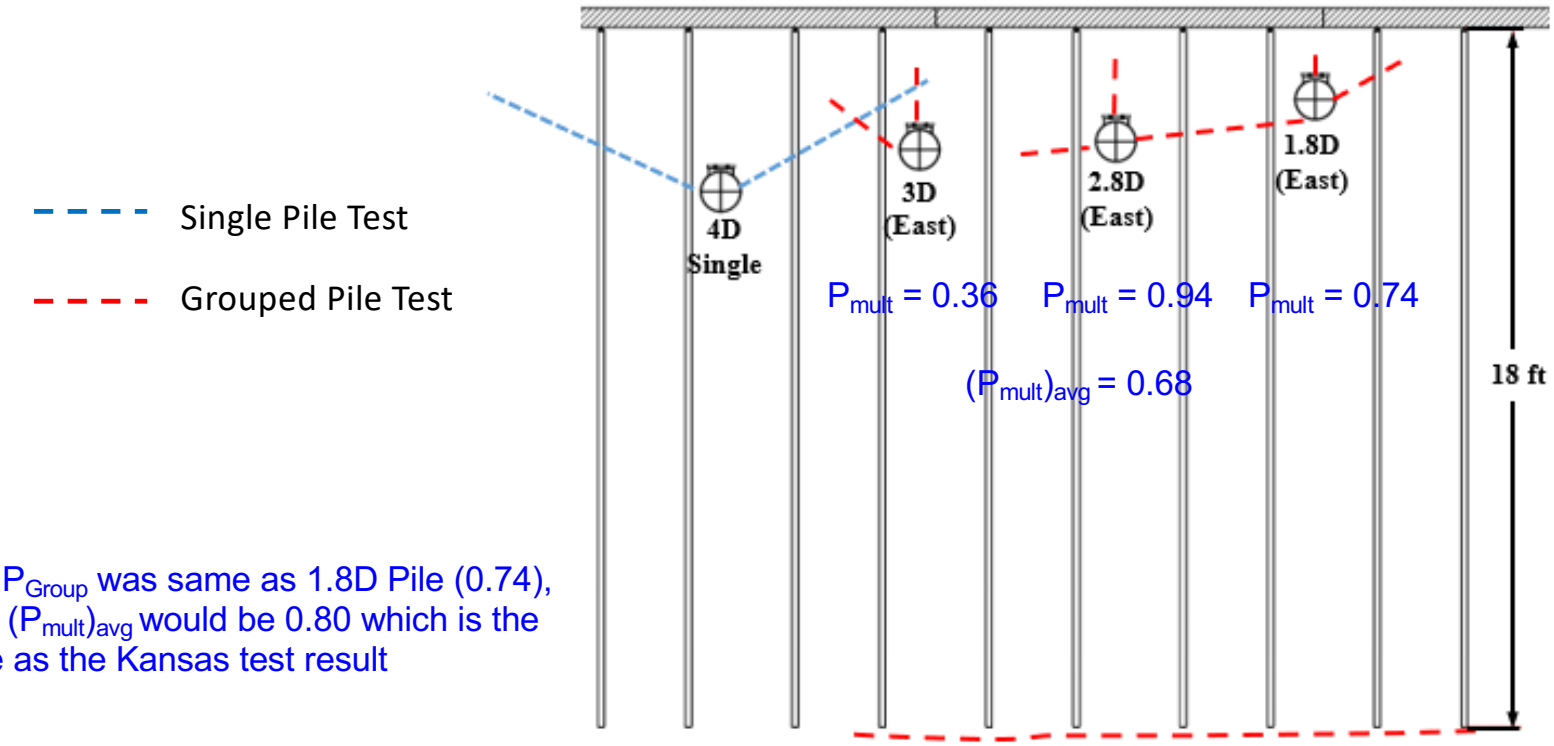


BYU Group Test

- 12.75” steel pipe piles spaced 5D apart laterally.
- Three grouped piles spaced at 1.8, 2.8, and 3.0 pile diameters from the wall.
- One individually loaded pile spaced at 4.0 pile diameters used as a control.



Back-Calculated Group Interaction P-multipliers, $(P_{MSE})_{Group}$

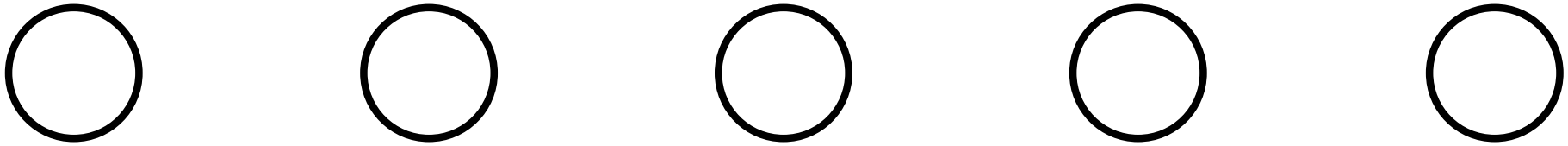


If 3D P_{Group} was same as 1.8D Pile (0.74), Then $(P_{mult})_{avg}$ would be 0.80 which is the same as the Kansas test result

Hypothetical Justification for Upper-Range p-Multiplier

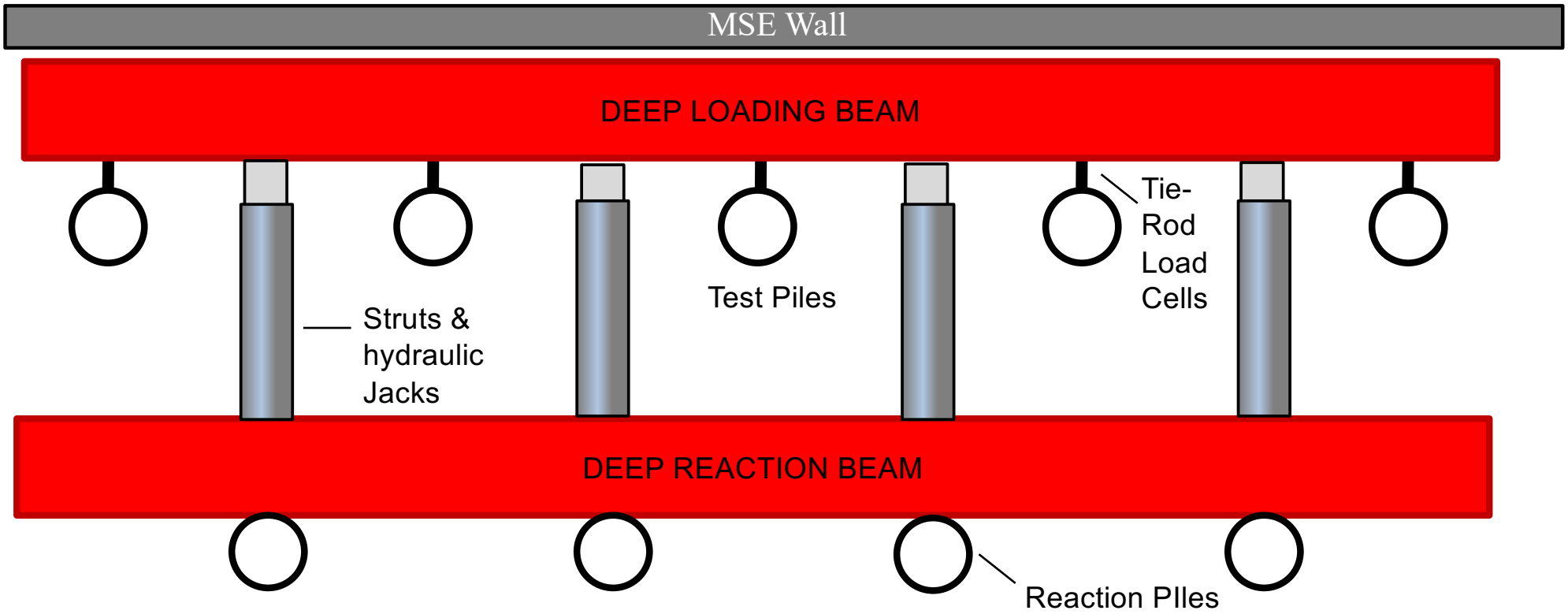
Utah Group Test

MSE Wall



$$[(P_m)_{group}]_{avg} = 0.86$$

Research Need: Lateral Group Load Test with 5 Piles



References

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Questions?






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