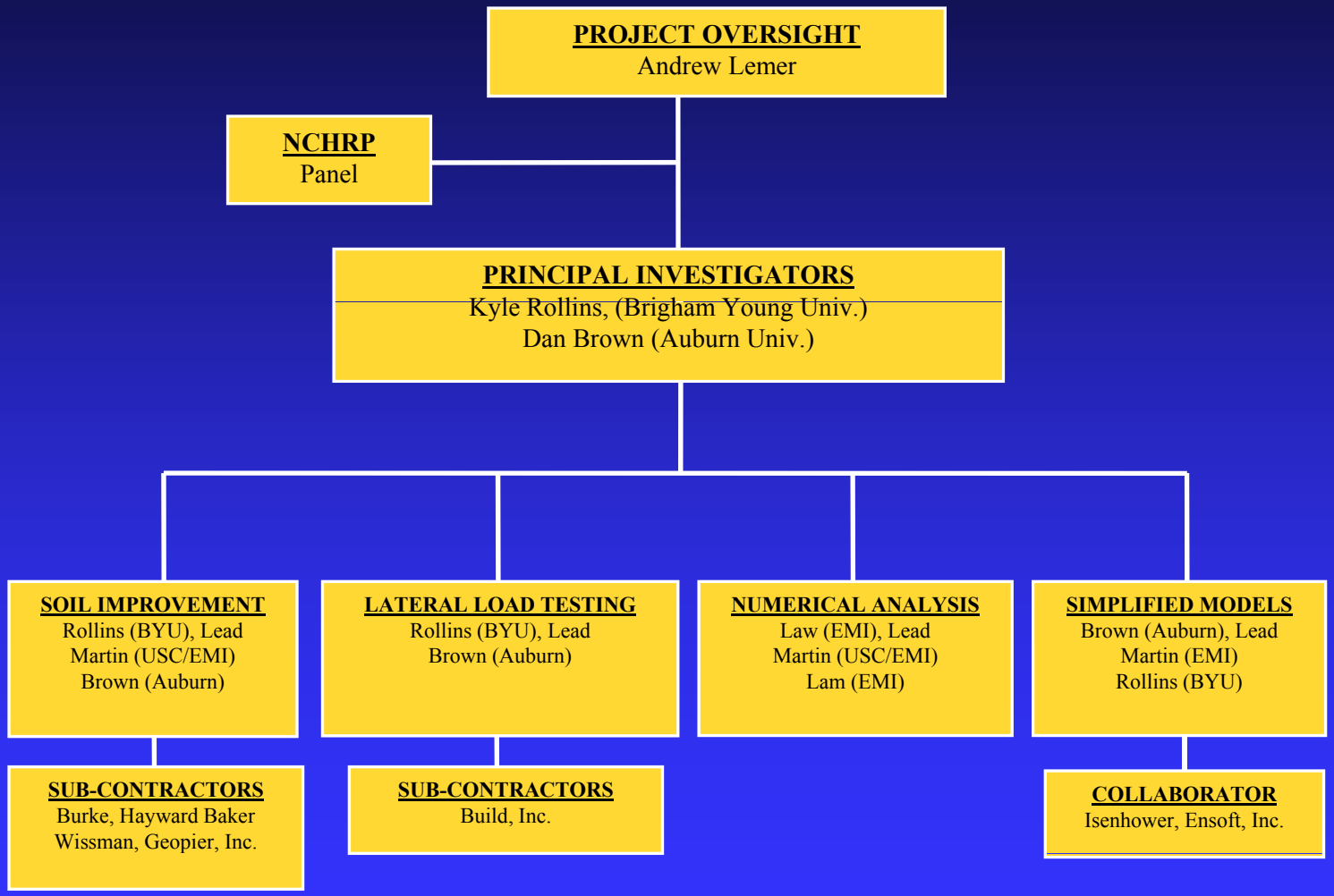
Design Guidelines for Increasing the Lateral Resistance of Highway Bridge Pile Foundations by Improving Weak Soils

Kyle Rollins,
Brigham Young University
Dan Brown,
Auburn University

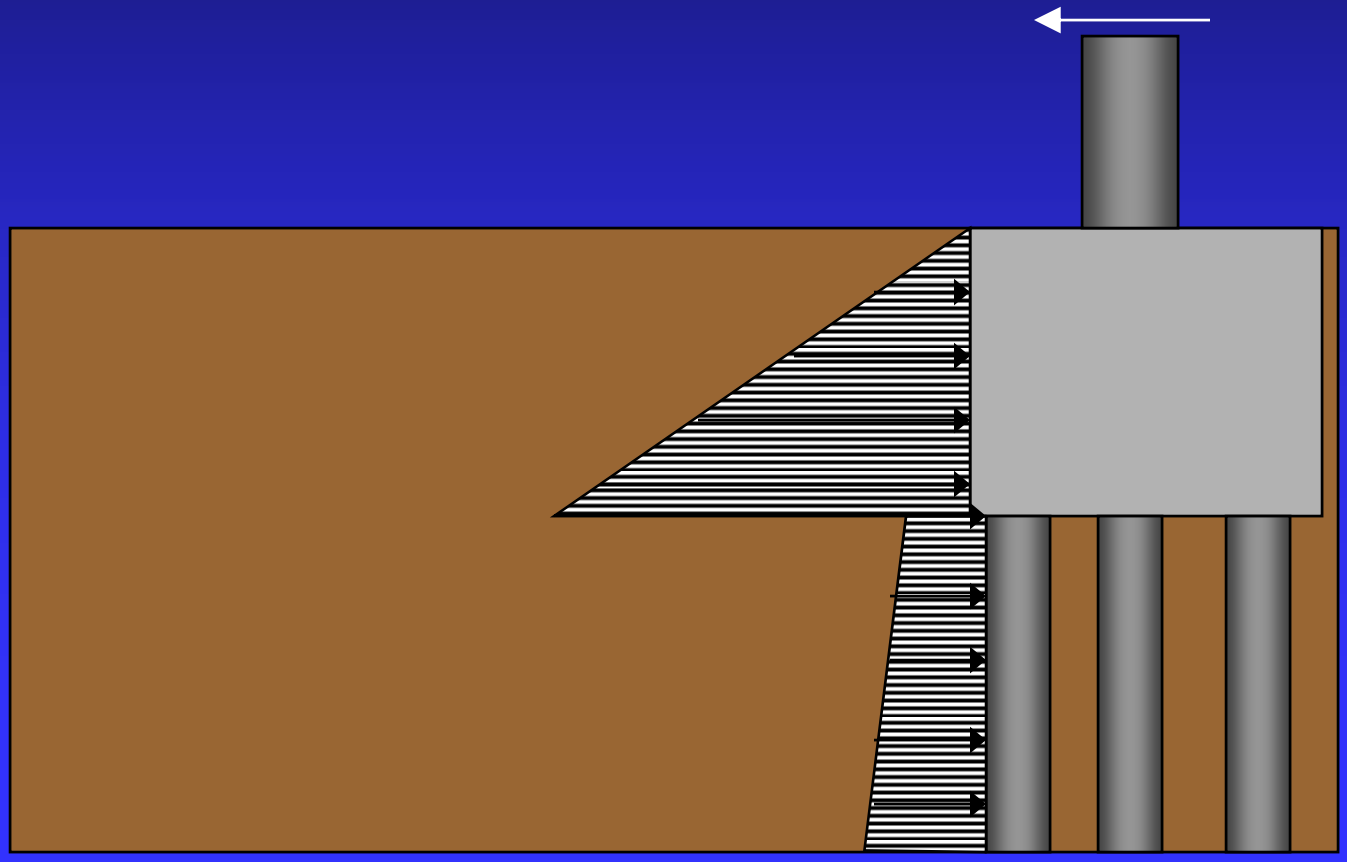
Interim Report Review
Aug. 16, 2007

Project Team

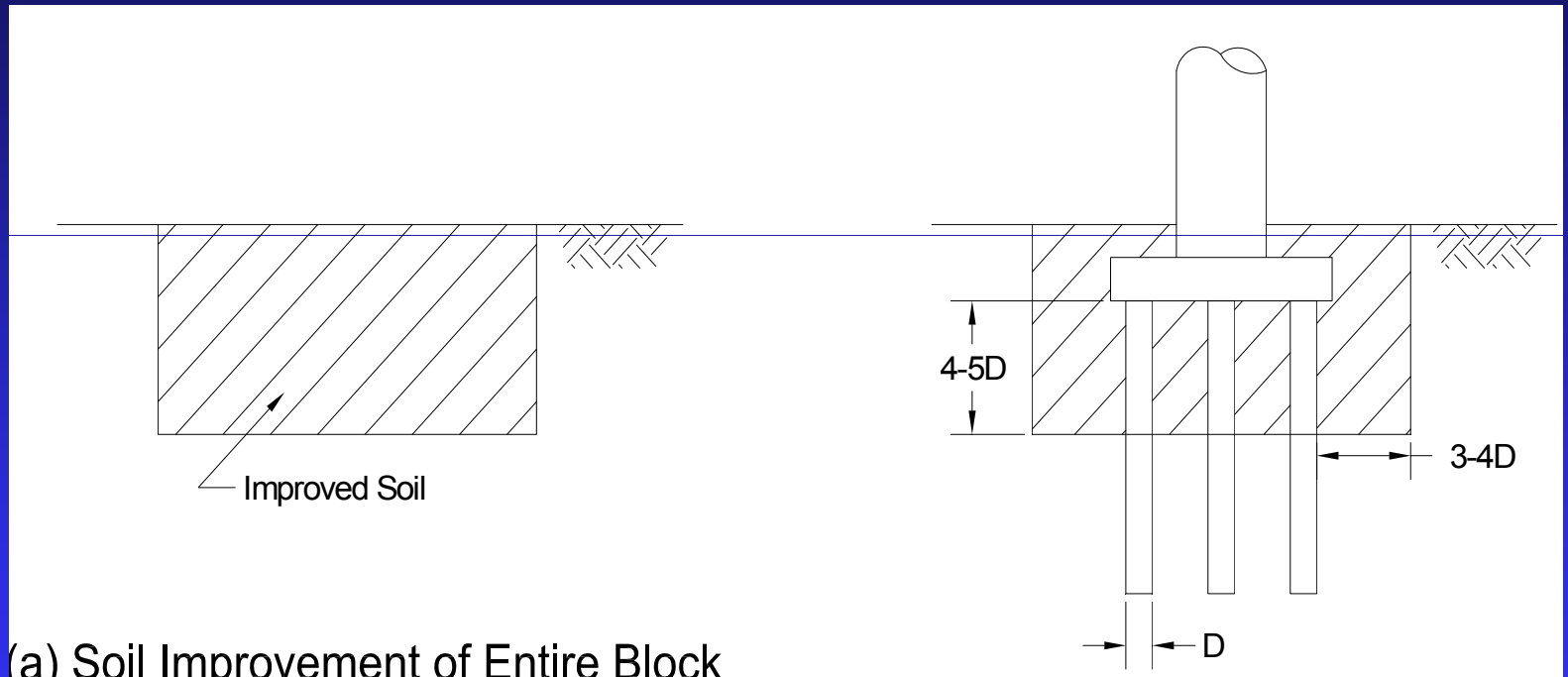


Sources of Increased Resistance

- Increased Passive Force against Pile Cap
- Increased Lateral Pile Resistance



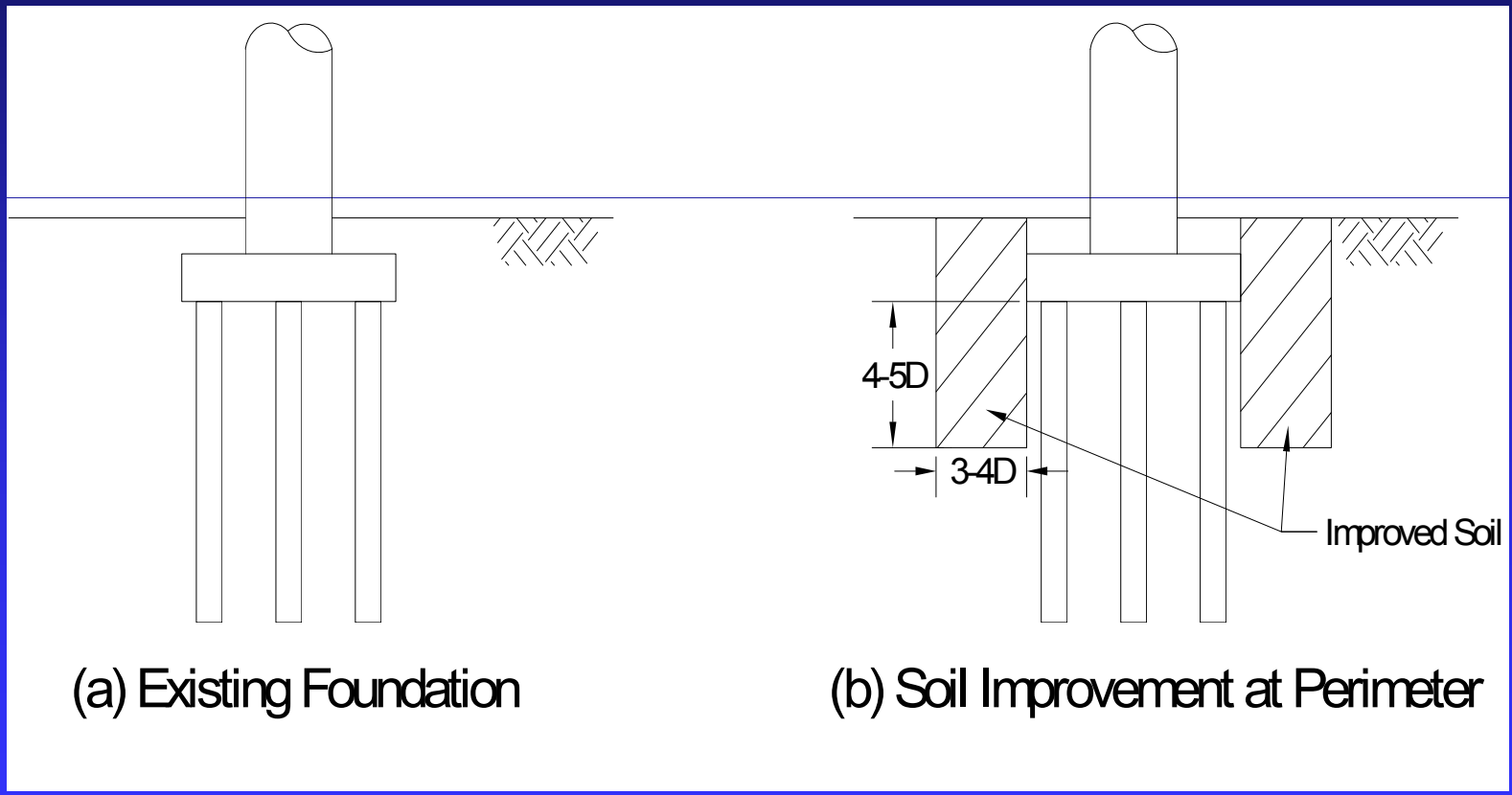
Potential Improvement Zones
(New Construction)



(a) Soil Improvement of Entire Block Prior to New Foundation

(b) Construct New Foundations

Potential Improvement Zones
(Retrofit)



First Phase

Task 1 Literature Review

Task 2 Listing on improvement techniques

Task 3 Summarize Analysis Techniques

Task 4 Develop Work Plan

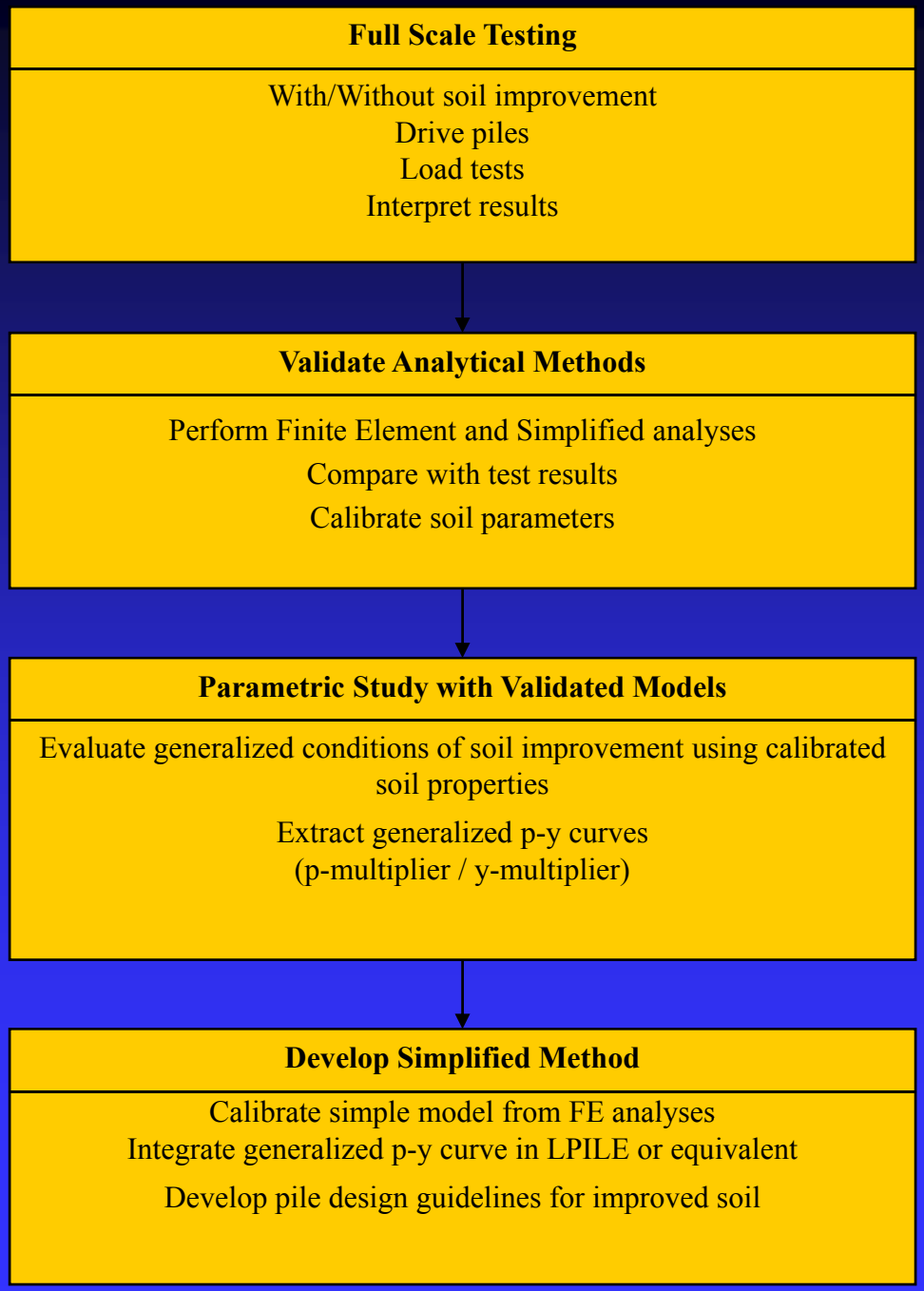
Task 5 Submit Interim Report – May 2007

One good test is worth a thousand expert opinions.

Werner Von Braun

Designer of Saturn V Moon Rocket

Approach to Development of Design Methods



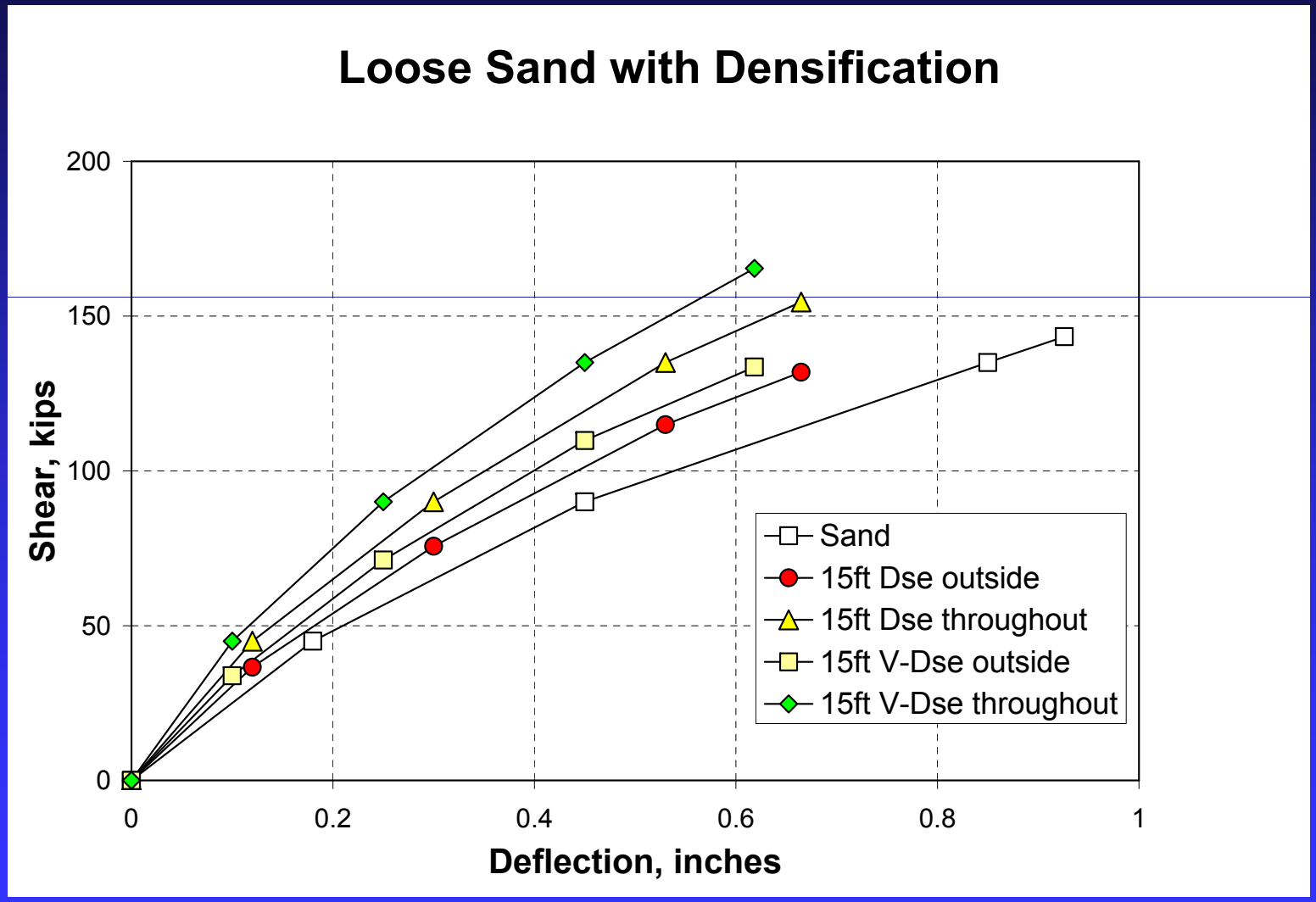
Second Phase

Task 6 Perform the Work Plan – Field Work started June 2007

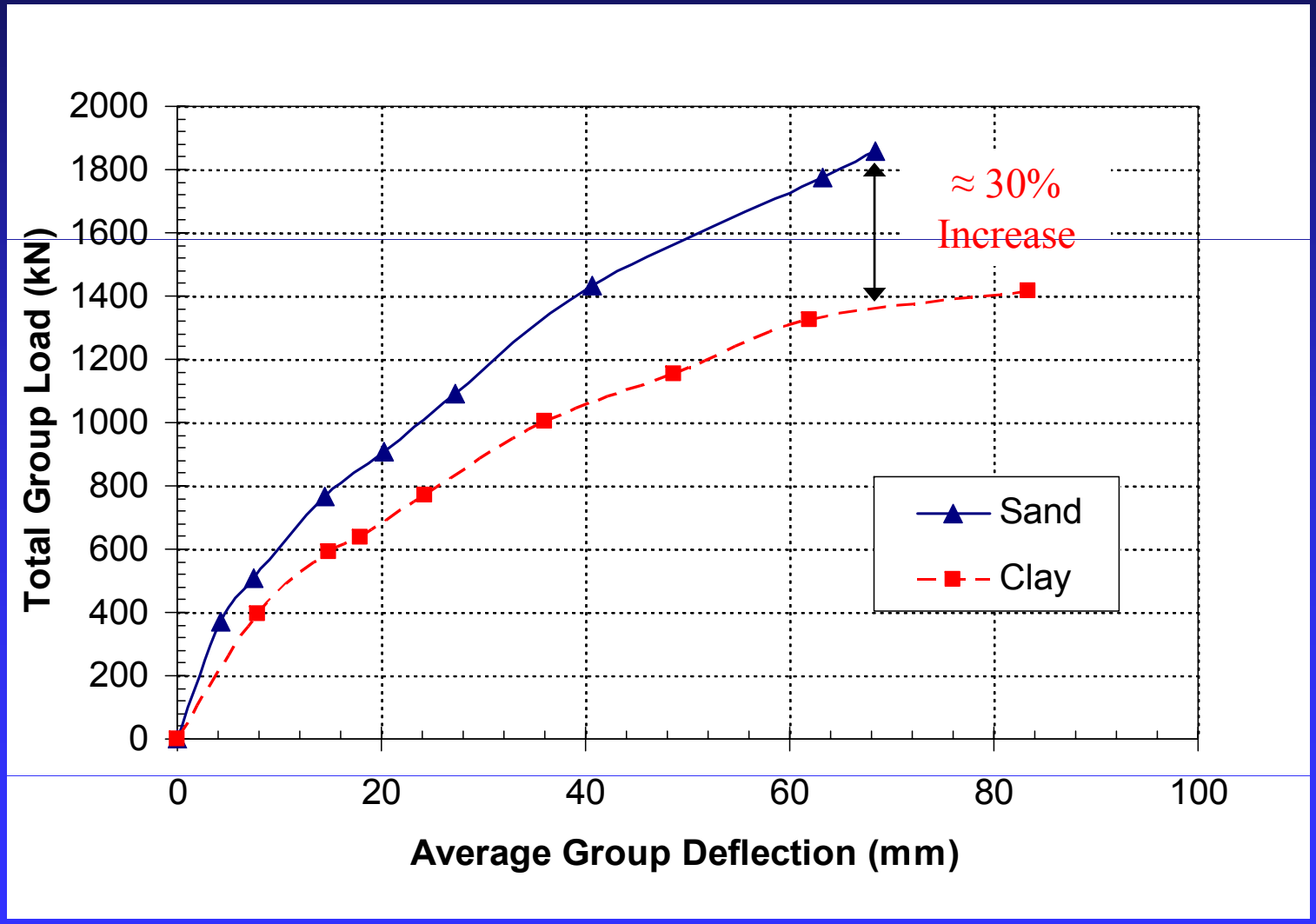
Task 7 Perform Parametric Study and Develop Design Guidelines

Task 8 Submit Final Report

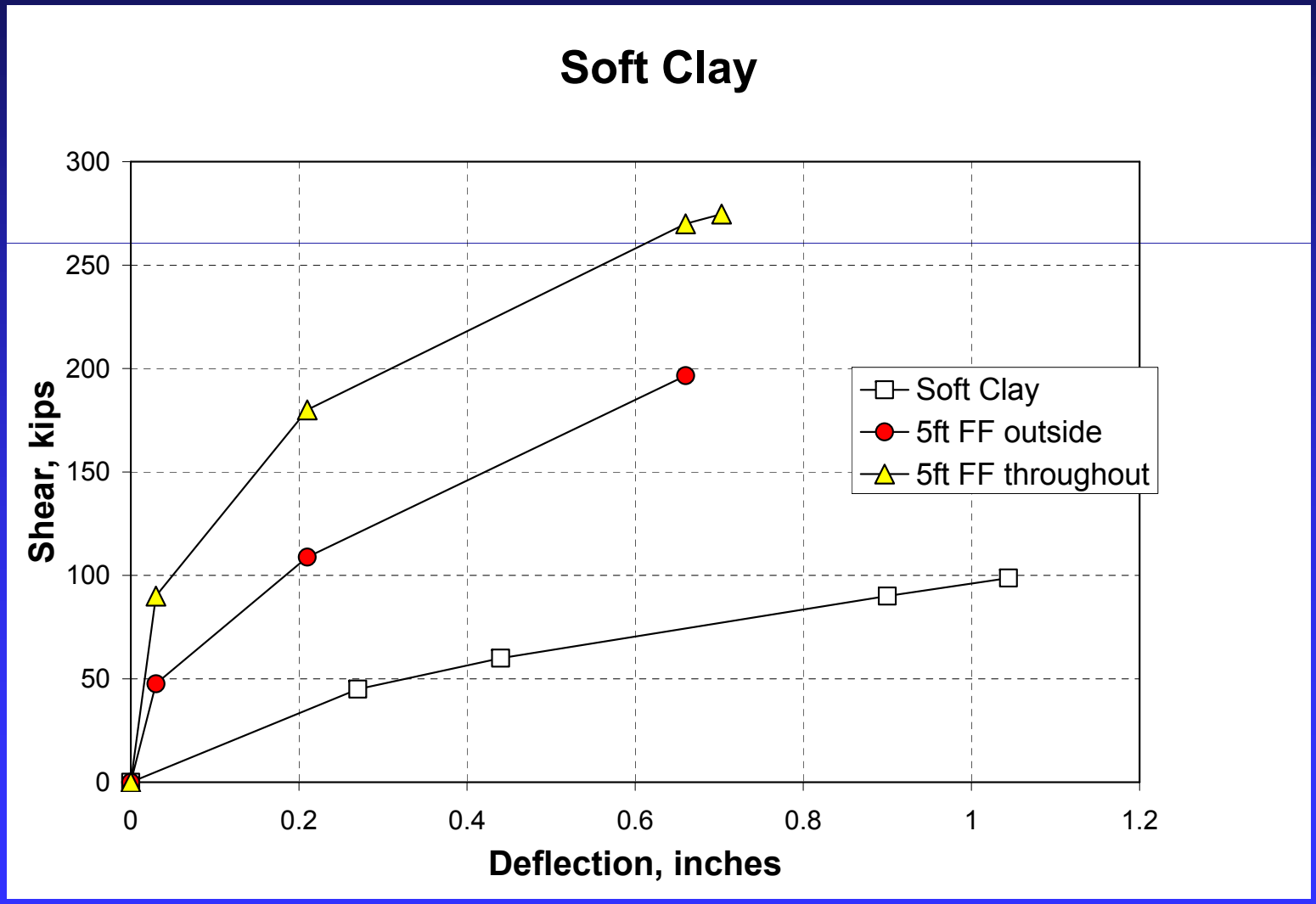
Effect of Sand Density on Lateral Resistance



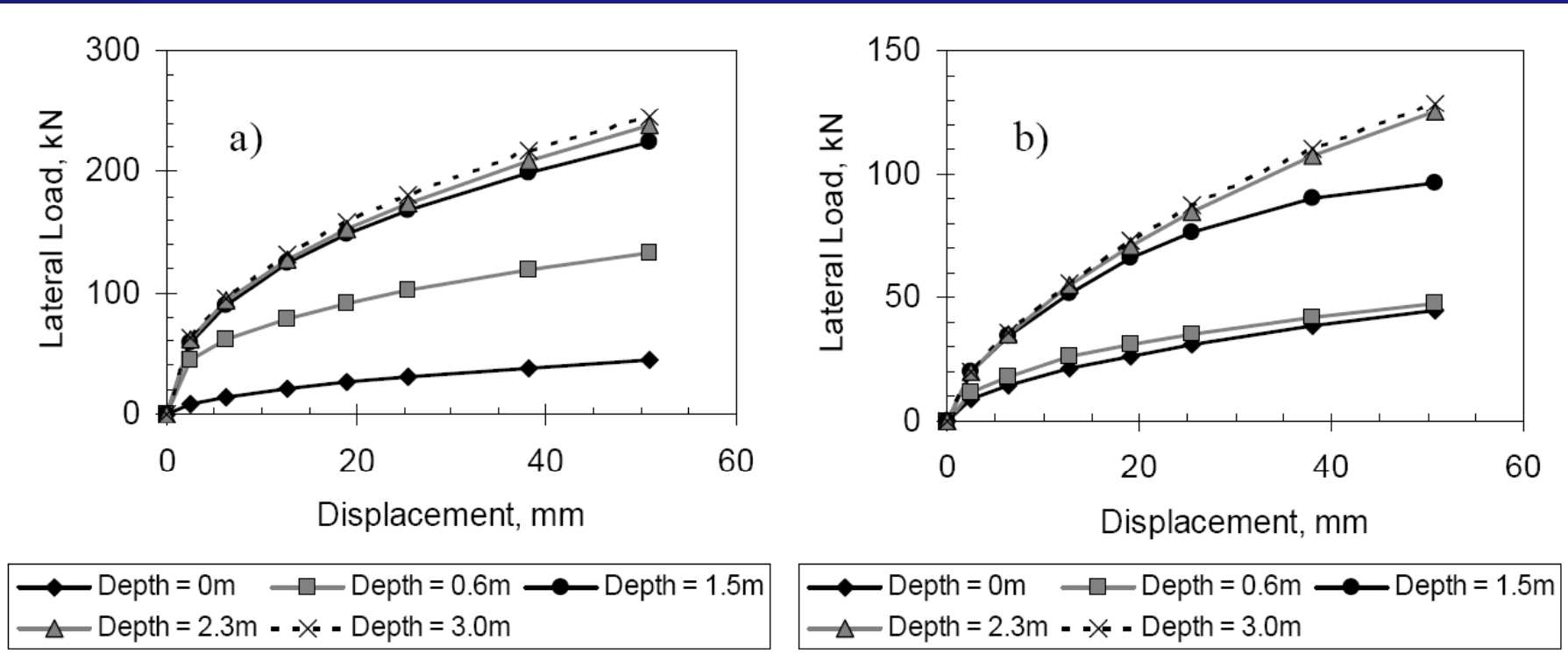
Full-Scale Pile Group Testing
(Previous BYU Testing)



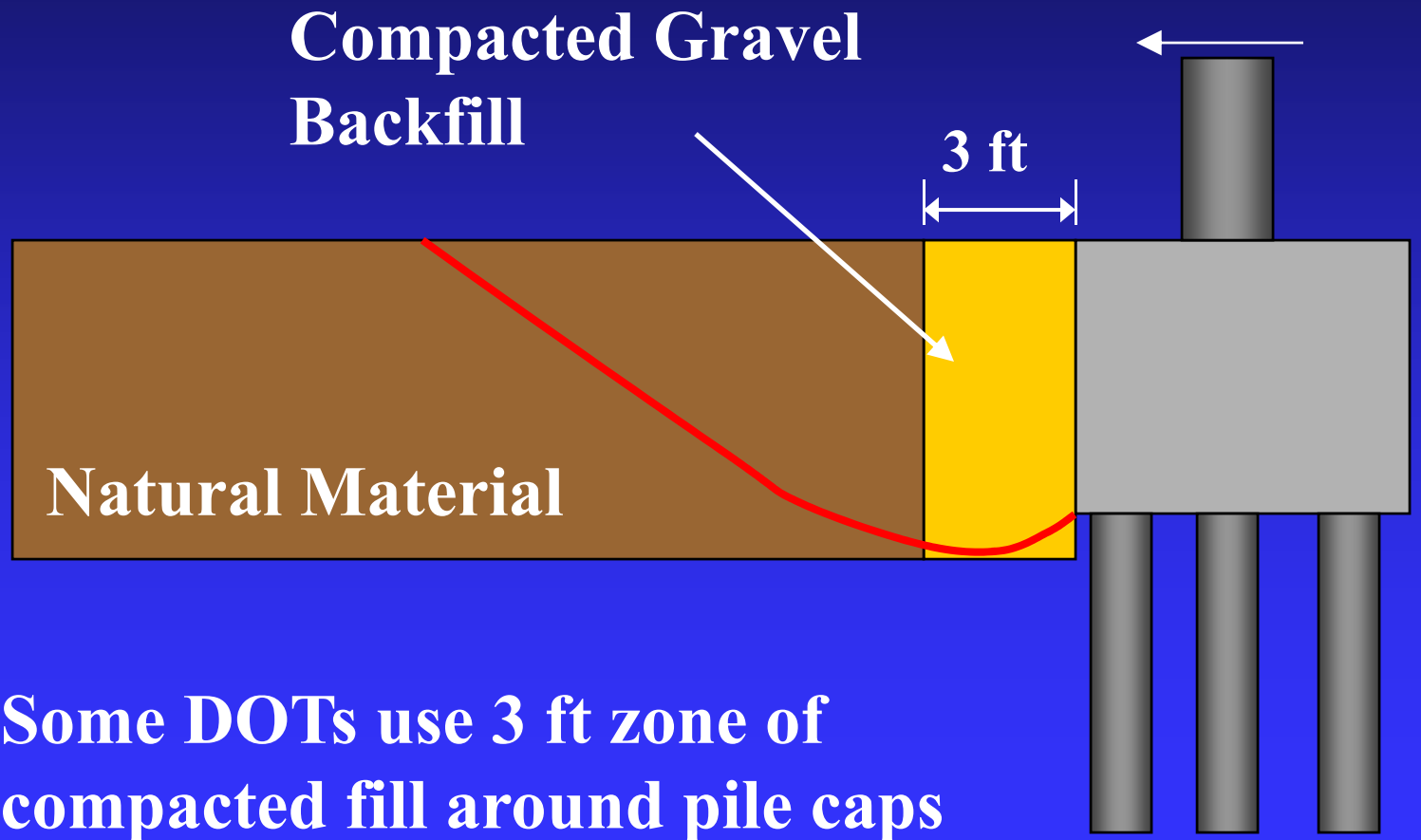
Effect of Flowable Fill on Lateral Resistance



Effect of Treatment Depth on Lateral Resistance (Weaver et al, 2007)

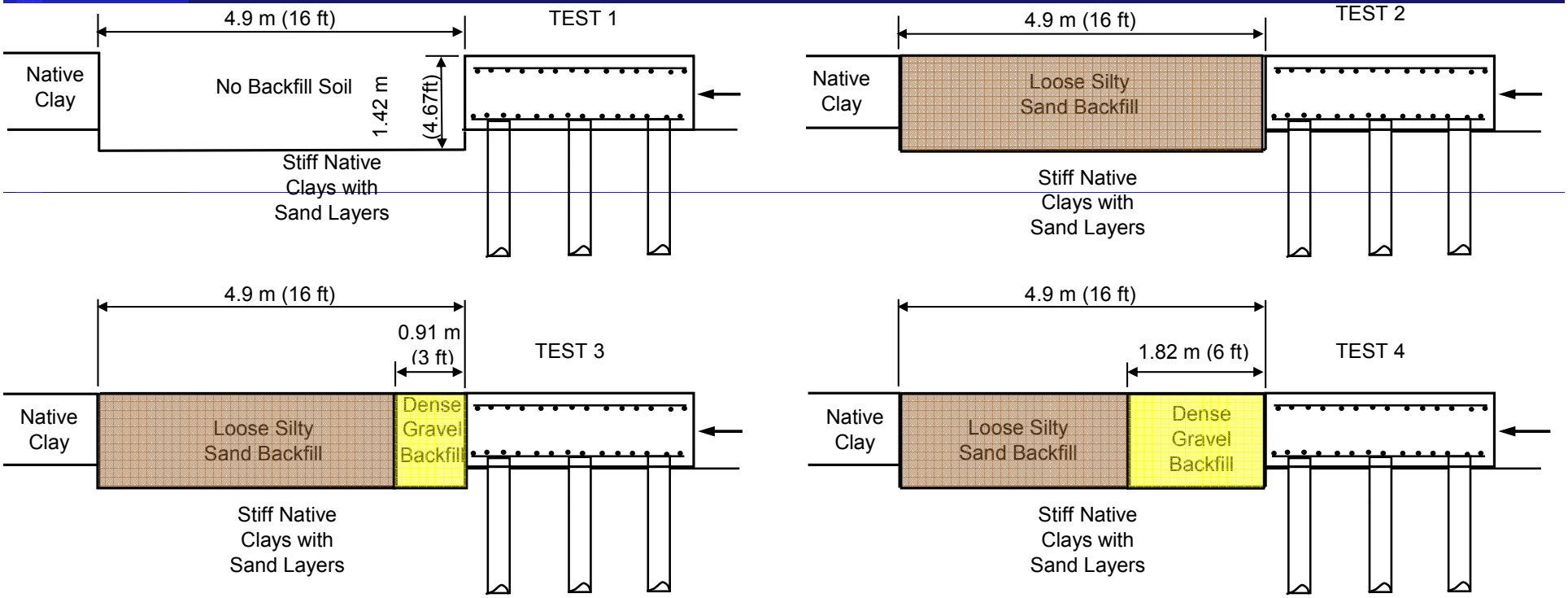


Effect of Narrow Gravel Zones on Passive Force

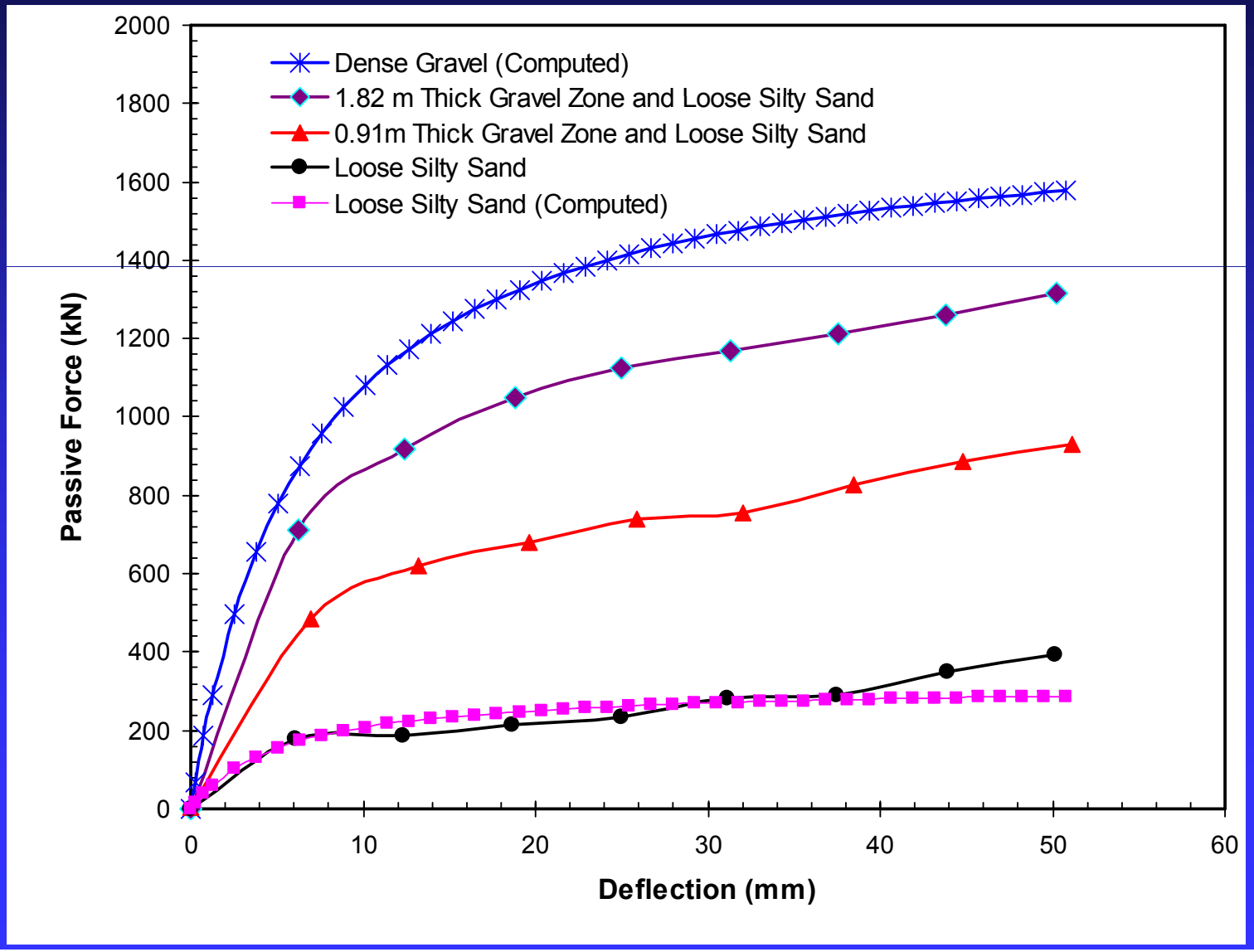


Some DOTs use 3 ft zone of compacted fill around pile caps

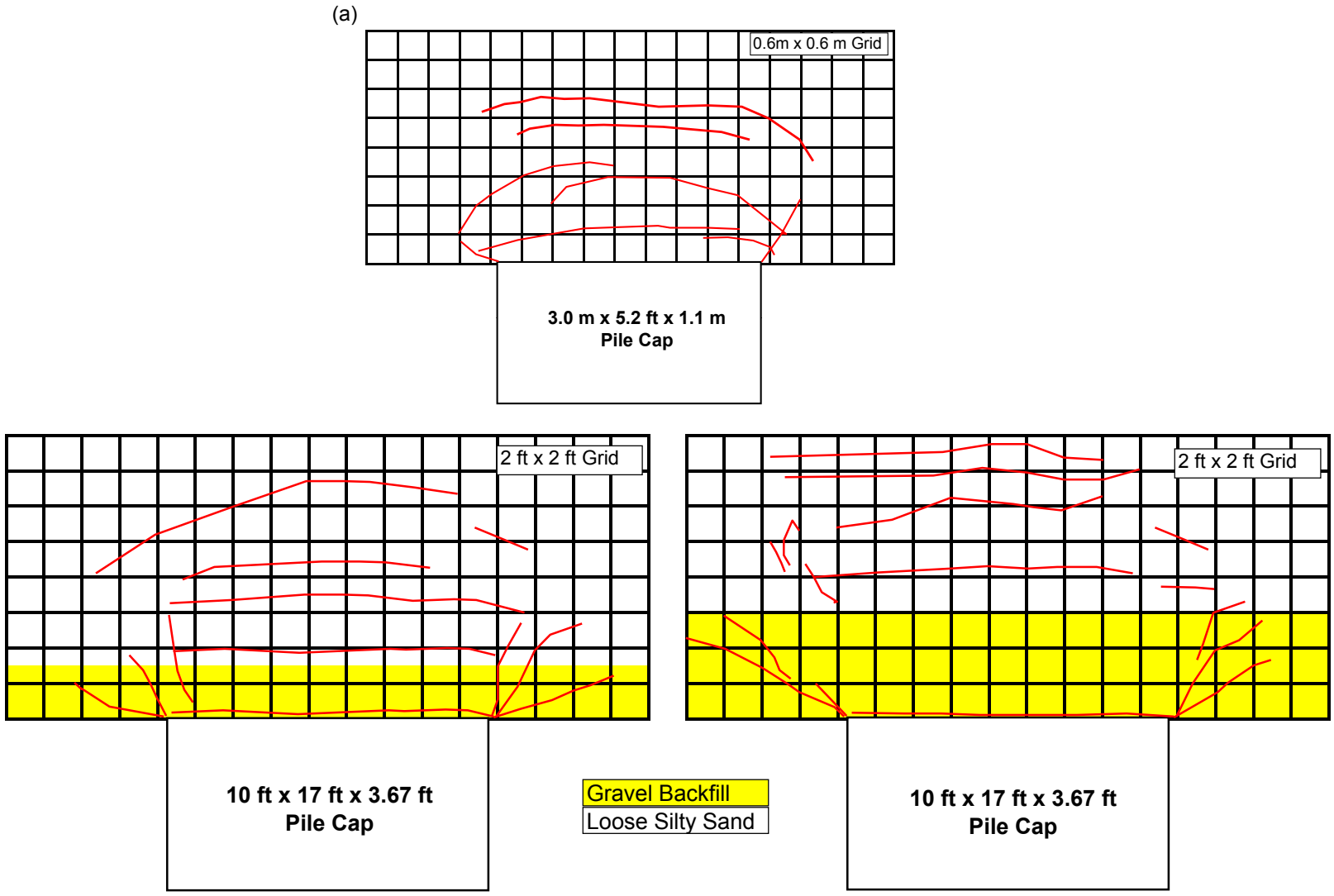
Lateral Passive Force Test Layout
South Temple Site



Passive Force-Deflection Curves



Effect of Limited Gravel Zone



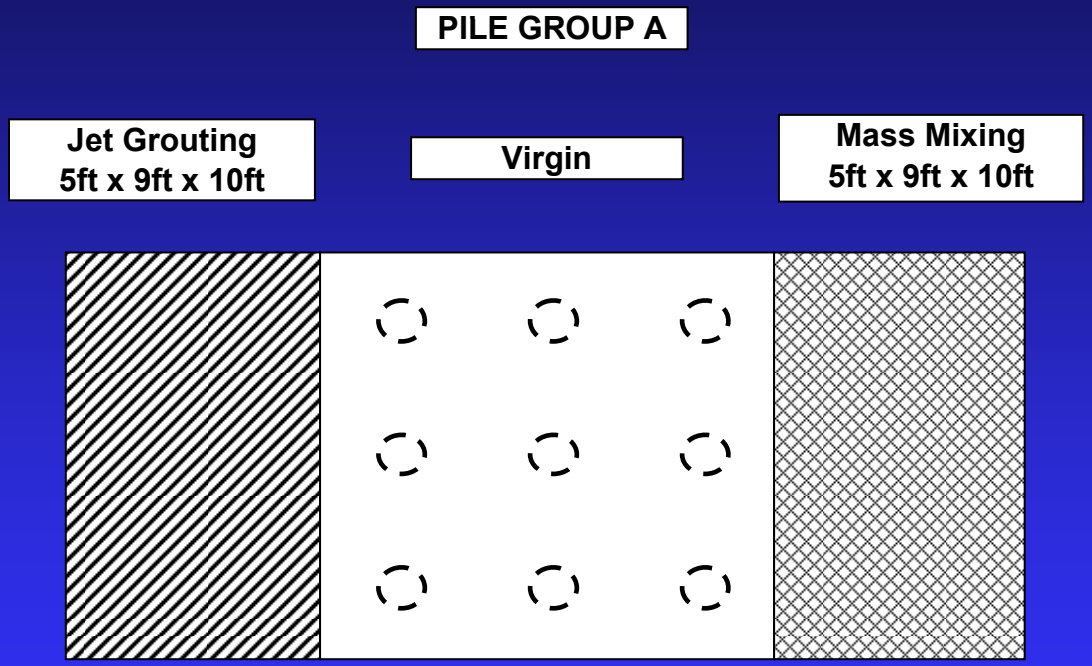
(a) 3 ft sandy gravel zone plus loose silty sand backfill

(b) 6 ft sandy gravel zone plus loose silty sand backfill

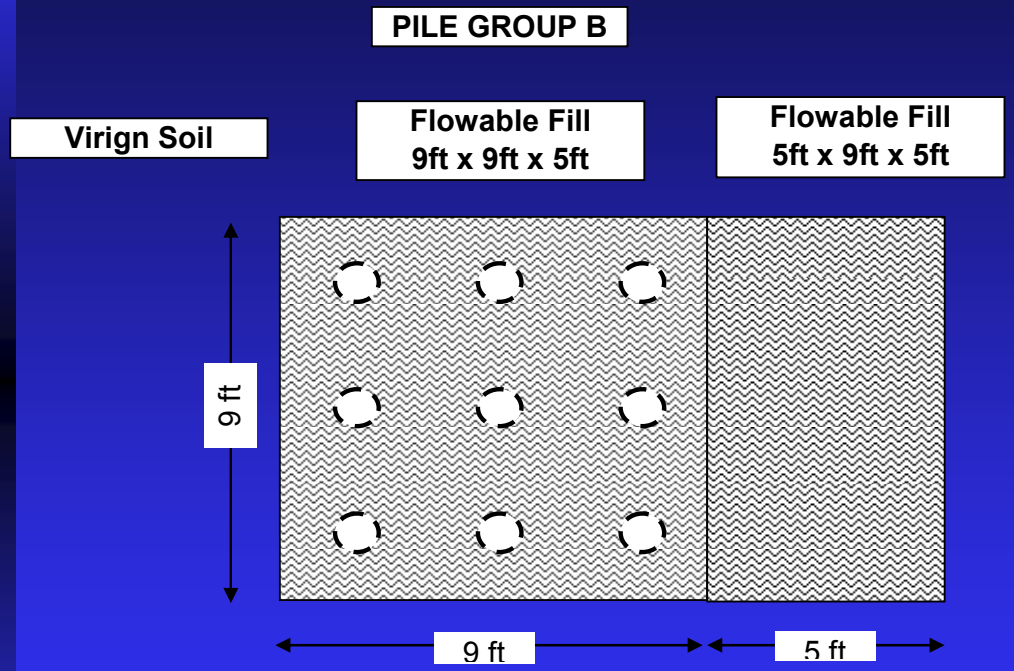
Treatment Approaches Selected for Evaluation

- Excavation and Replacement with Granular Fill (under cap and in front of cap)
- Excavation and Replacement with Flowable Fill (under cap and in front of cap
- Rammed Aggregate Piers (Geopiers) on one side of cap
- Soil Mixing (in front of cap)
- Jet Grouting (under the cap or in front)

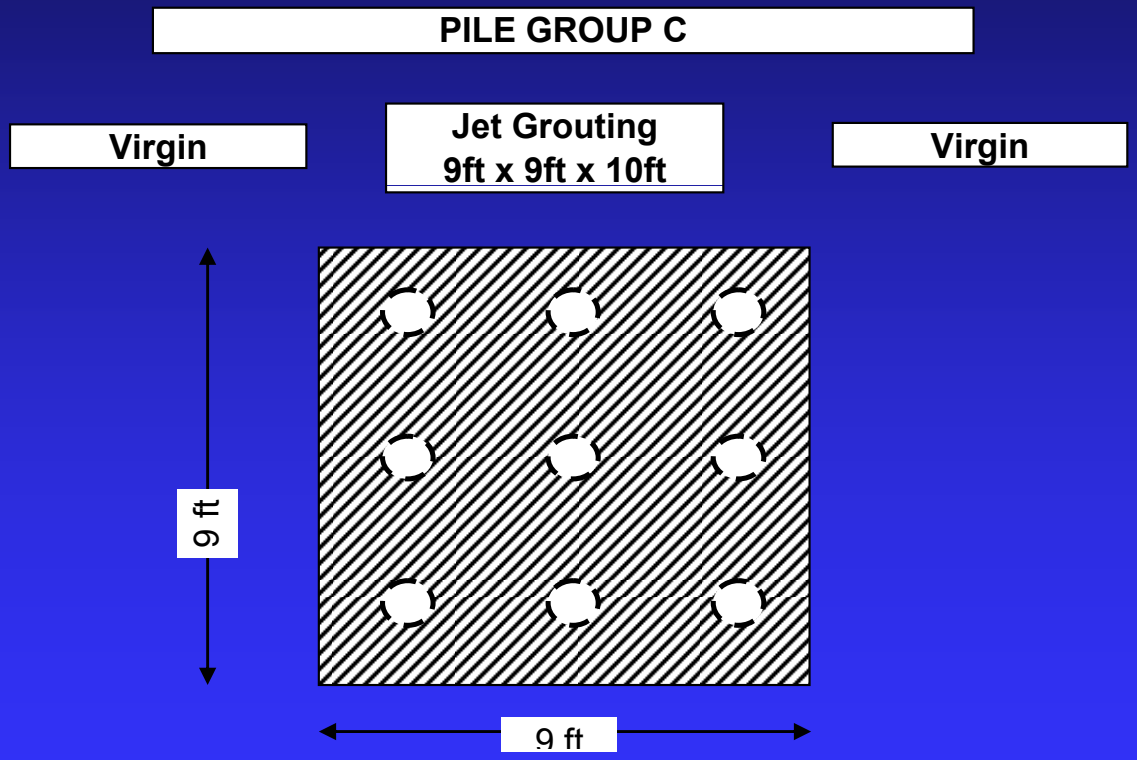
Pile Group A (1)



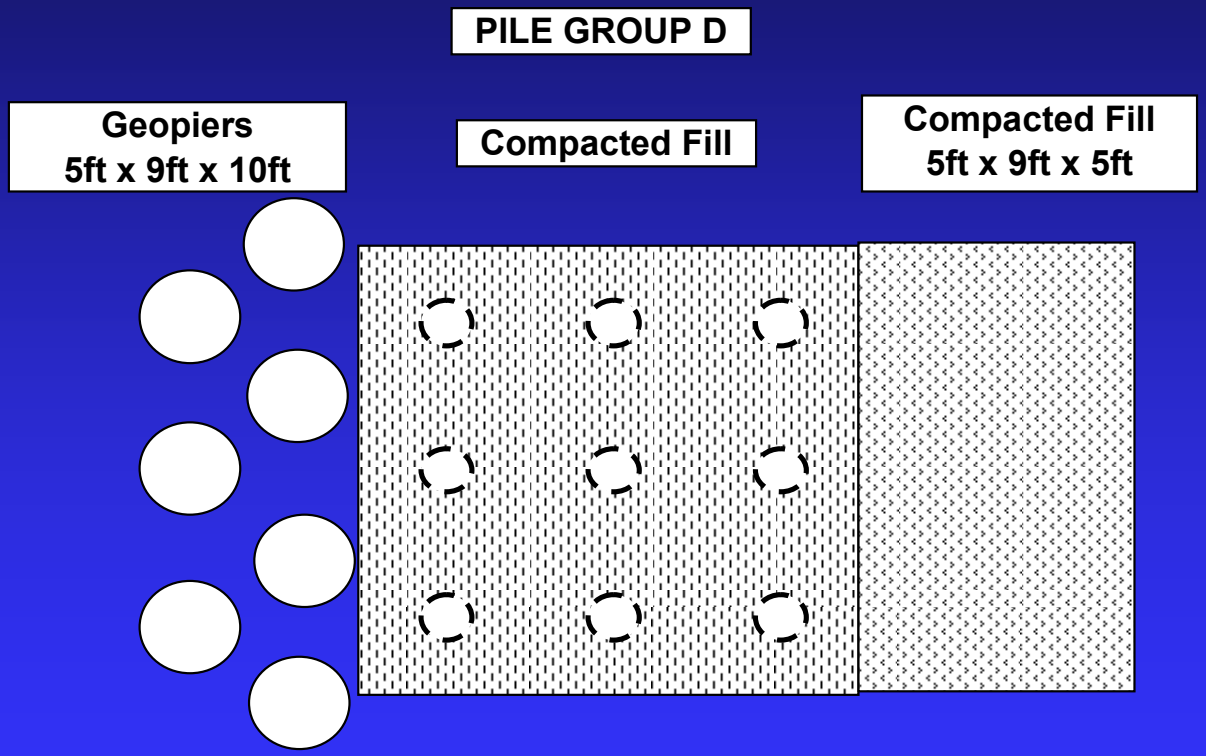
Pile Group B (2)



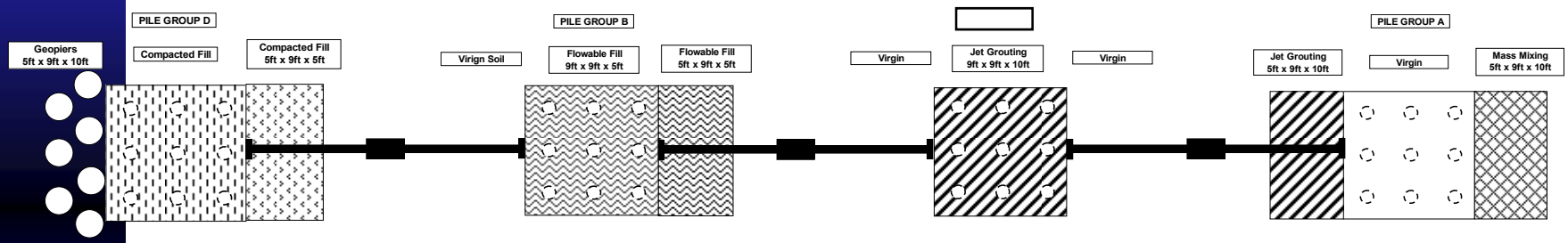
Pile Group C (3)



Pile Group D (4)



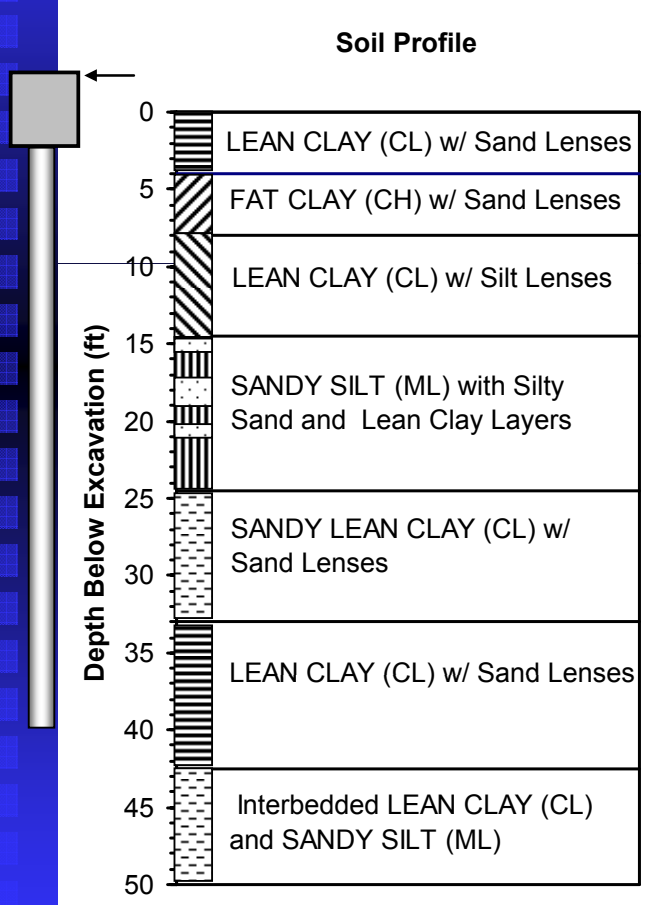
Layout of Test Pile Groups

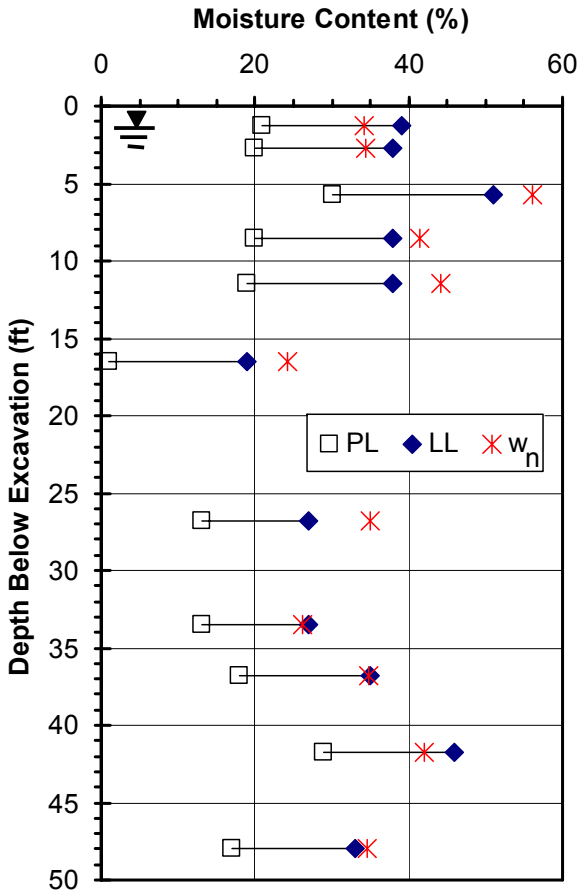


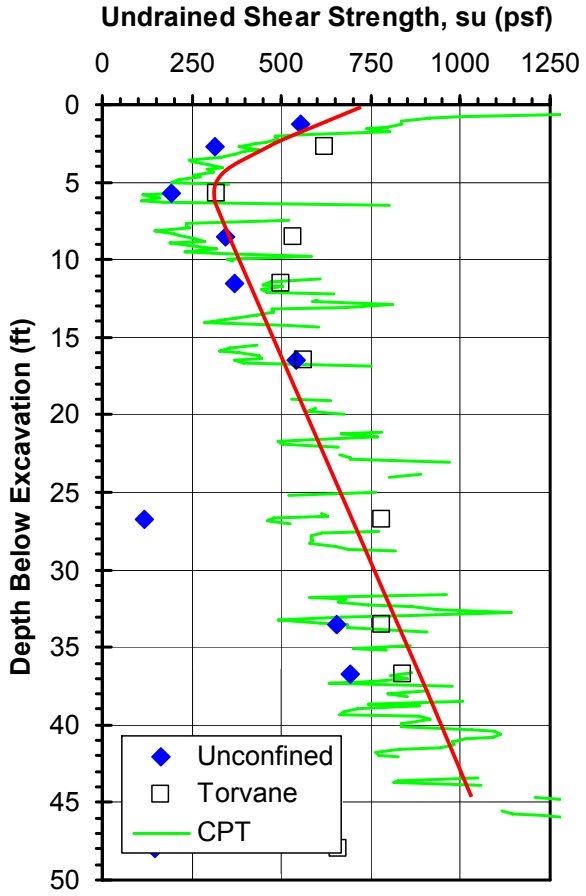
Test Site Location in Salt Lake

- Soft clay profile
- Consistent soil profile across the site
- Accessible for heavy equipment
- Access to water
- Approval to drive piles and use soil improvement methods

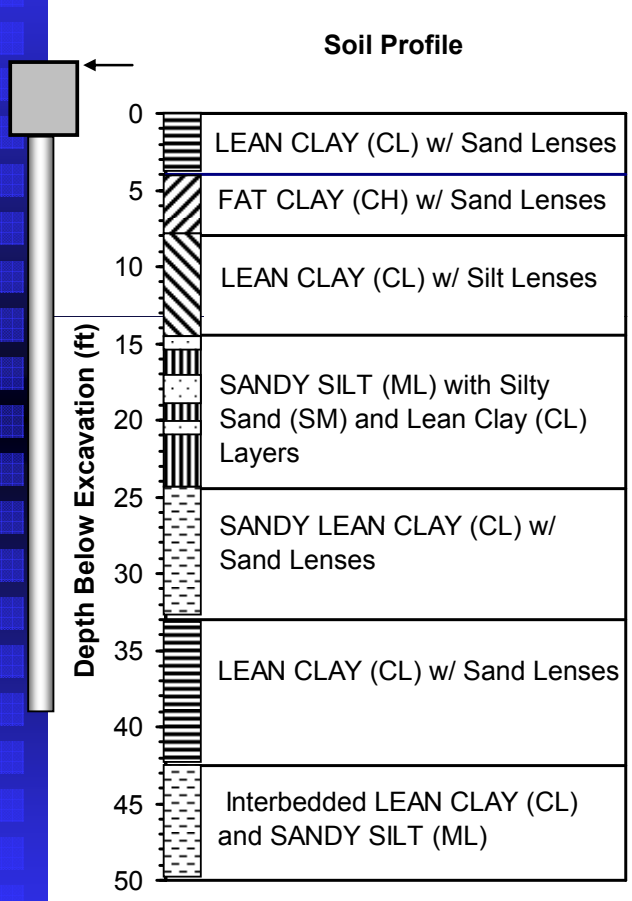
Geotechnical Site Conditions

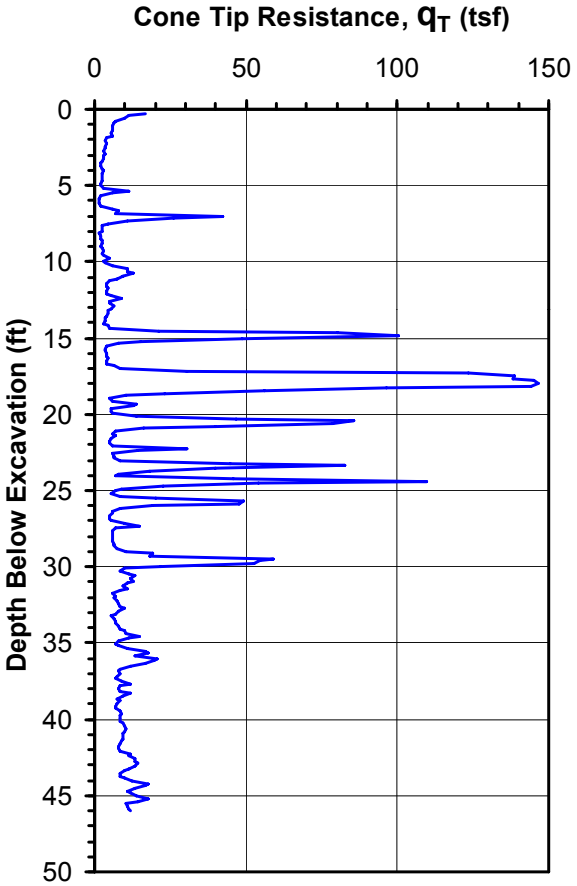


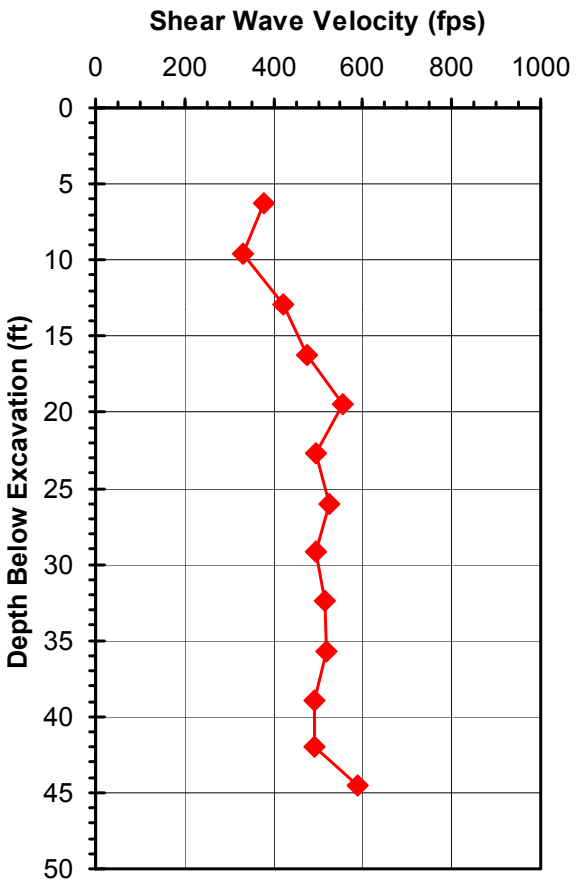




Geotechnical Site Conditions

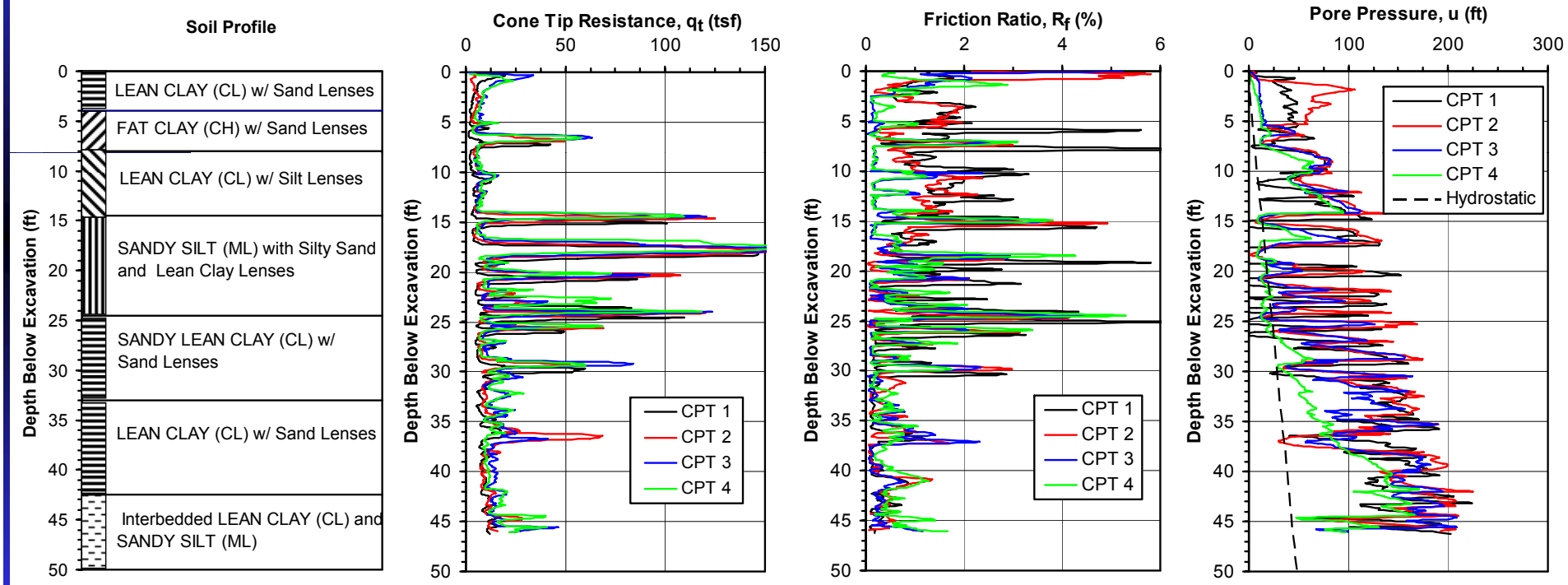






Geotechnical Site Conditions

CPT Test Comparisons



Excavation and Replacement with Granular Fill

Compaction with Trackhoe

Pile Driving

- Hydraulic Hammer (IHC S-70)
- Piles are 12.75 inch in diameter steel pipe
- Driven closed-ended to 40 feet below cap
- 36 piles in 4 groups along with single pipe pile
- Filled with concrete, reinforcing to 12 ft
- 3 ft c-c spacing in both directions

Piles in Compacted Sand Fill

Pile Driving in Flowable Fill

Cap Prior to Concrete Placement

Concrete Placement for Corbel

Hydraulic Actuators

- 2 – 600 kip actuators
- 60 gpm pump unit
- Portable generator
- Computer controlled load system

Shape Accelerometer Arrays

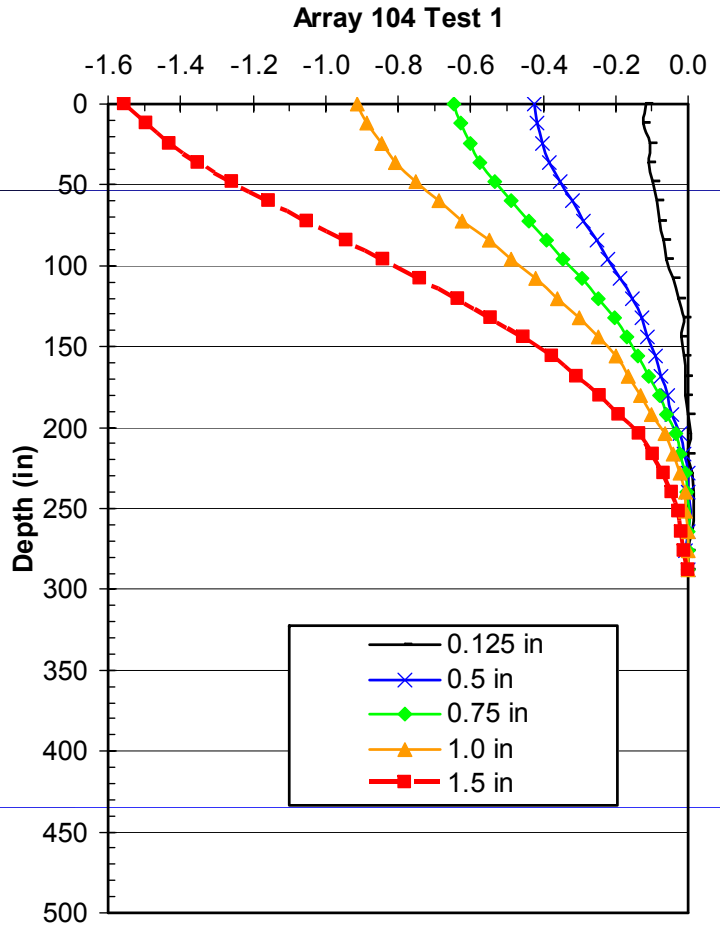
- Flexible tubing with triaxial accelerometers at 1 ft intervals to 24 ft
- Provides continuous readout of deflection versus depth
- Arrays in center pile of each row
- Comparison with inclinometer for front and back rows

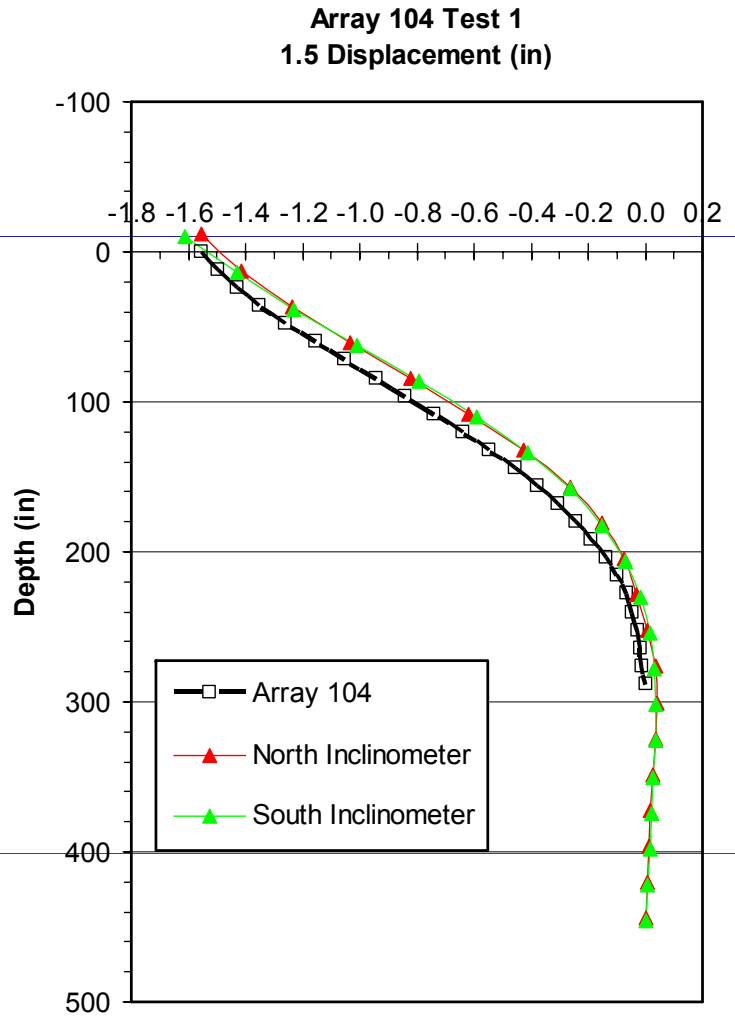
String potentiometers

- 6 String pots on each cap
- 2 at load elevation
- 2 at front and back of corbel
- 2 at back of top and bottom of corbel
- Reference Frame

Test 1 Untreated Soil

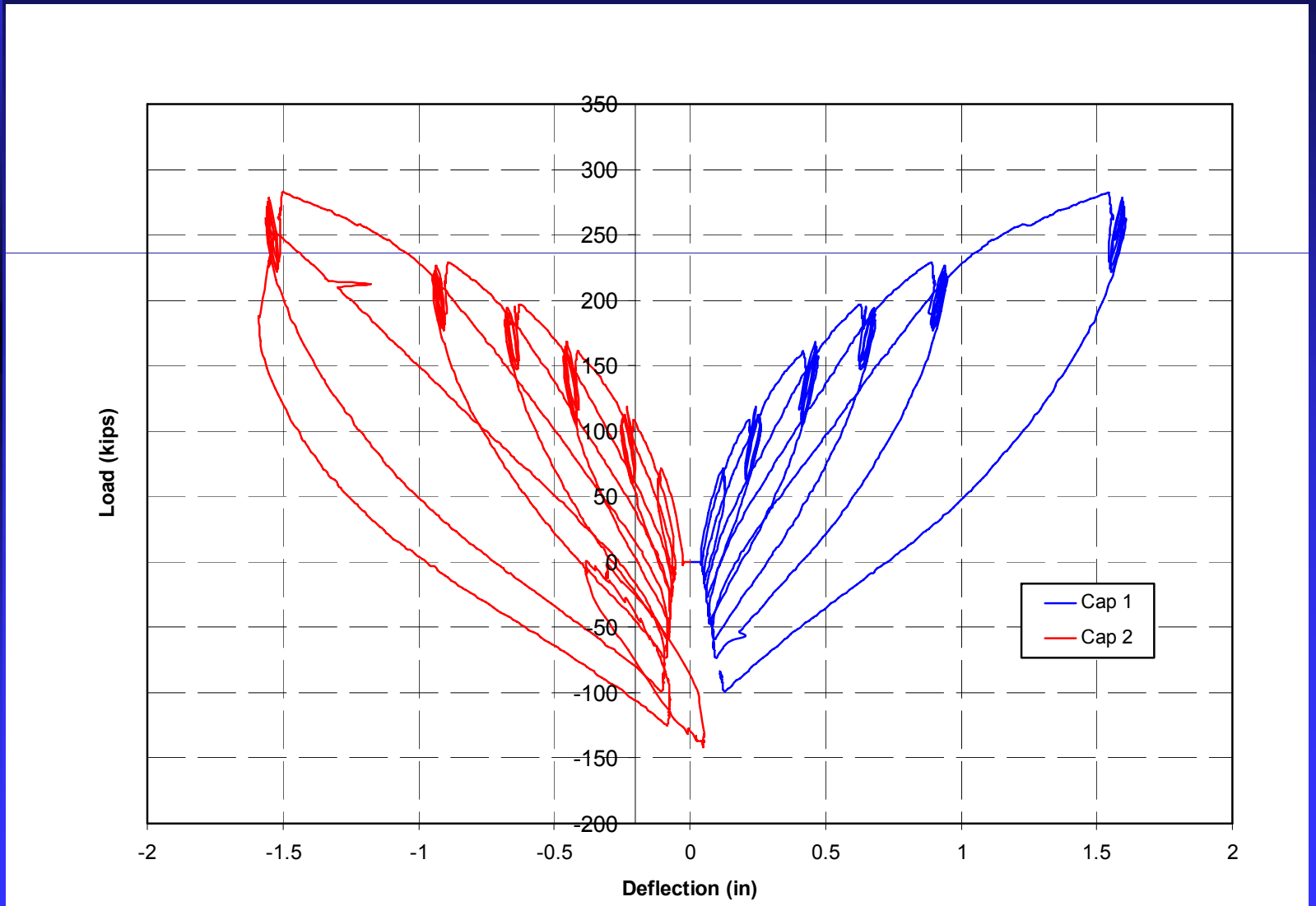
Deflection vs. Depth Curves





Test 1 Cap 1 and 2 Untreated Soil

Load vs. Deflection Curves



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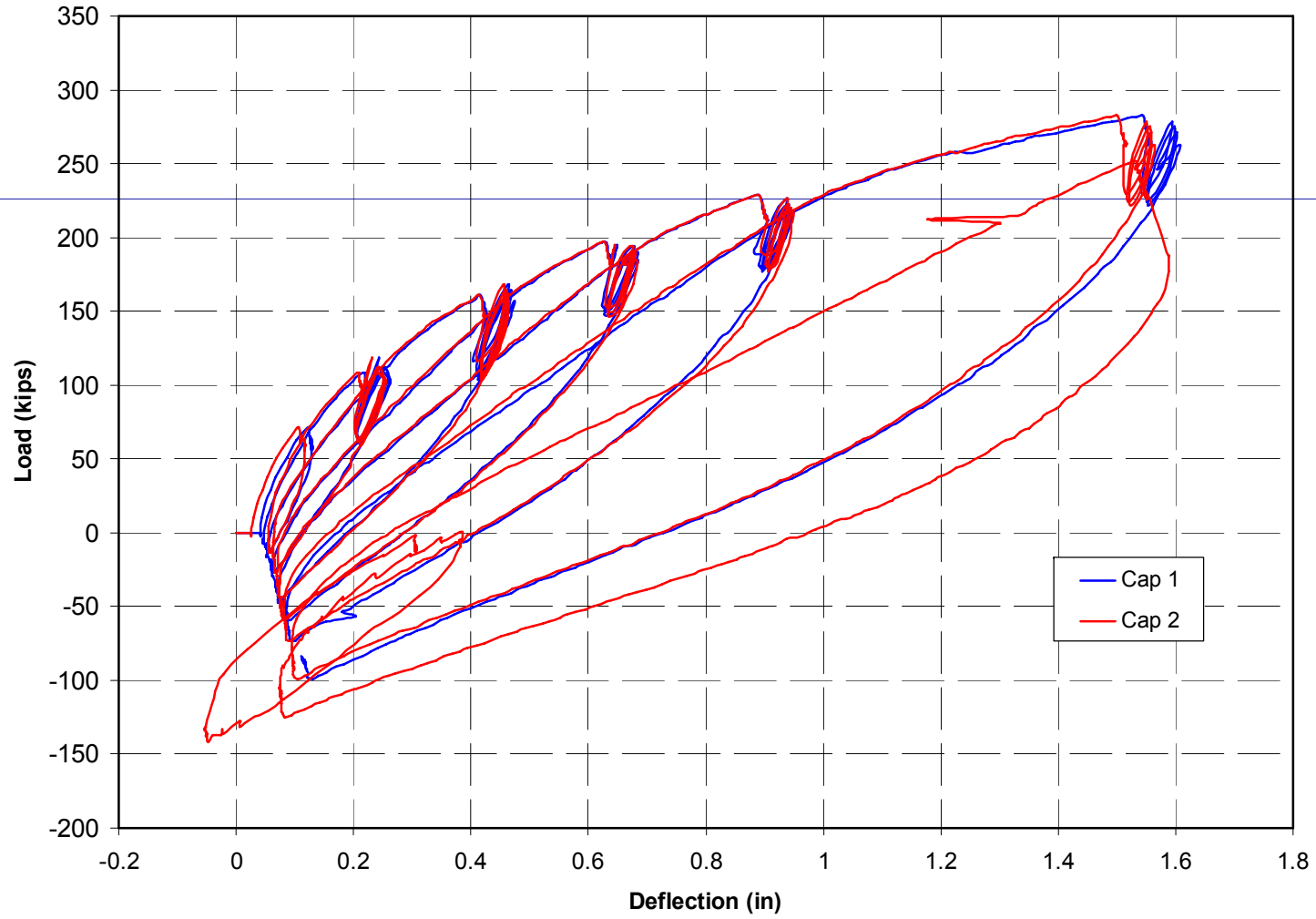
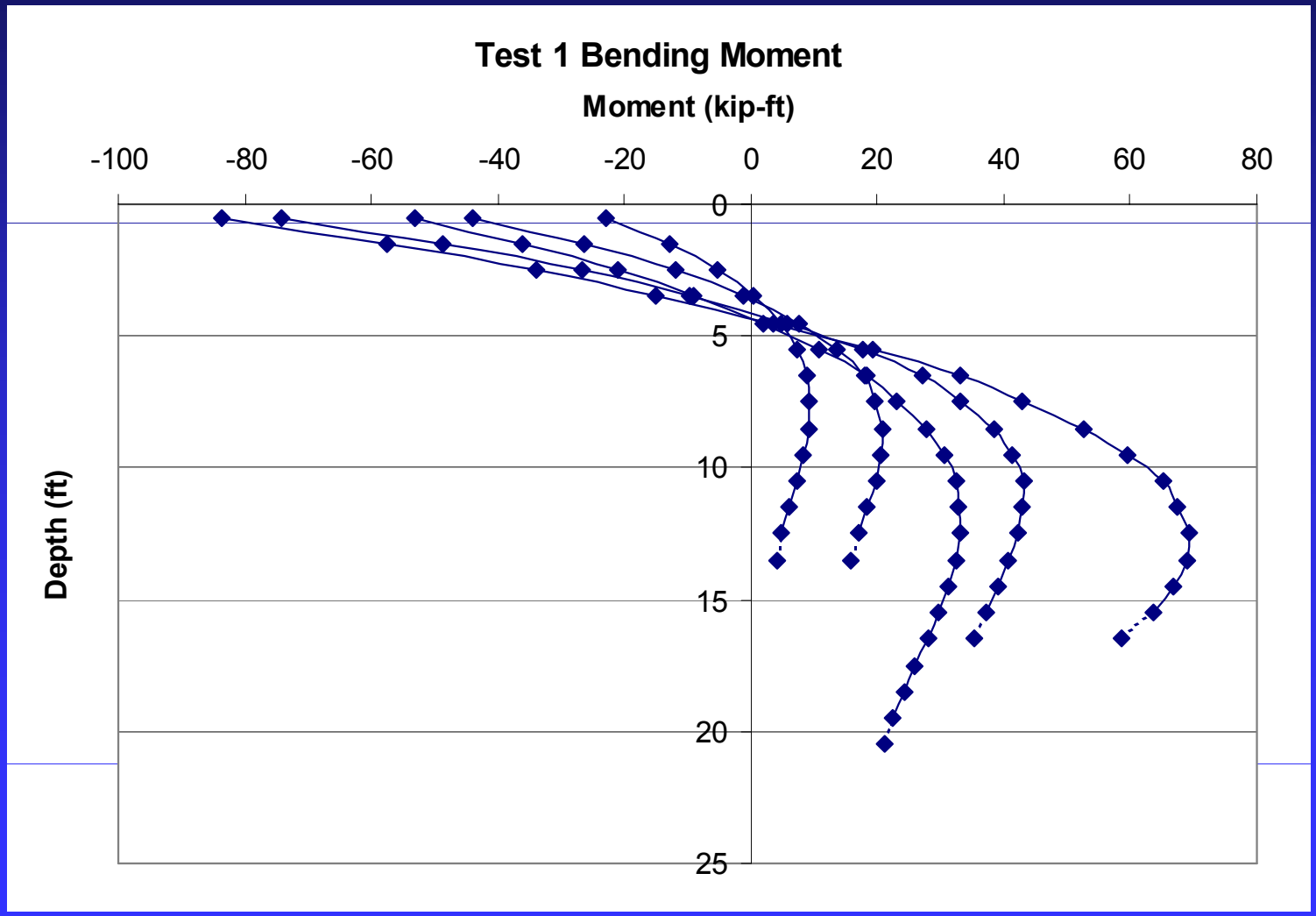
Load vs. Deflection Curves

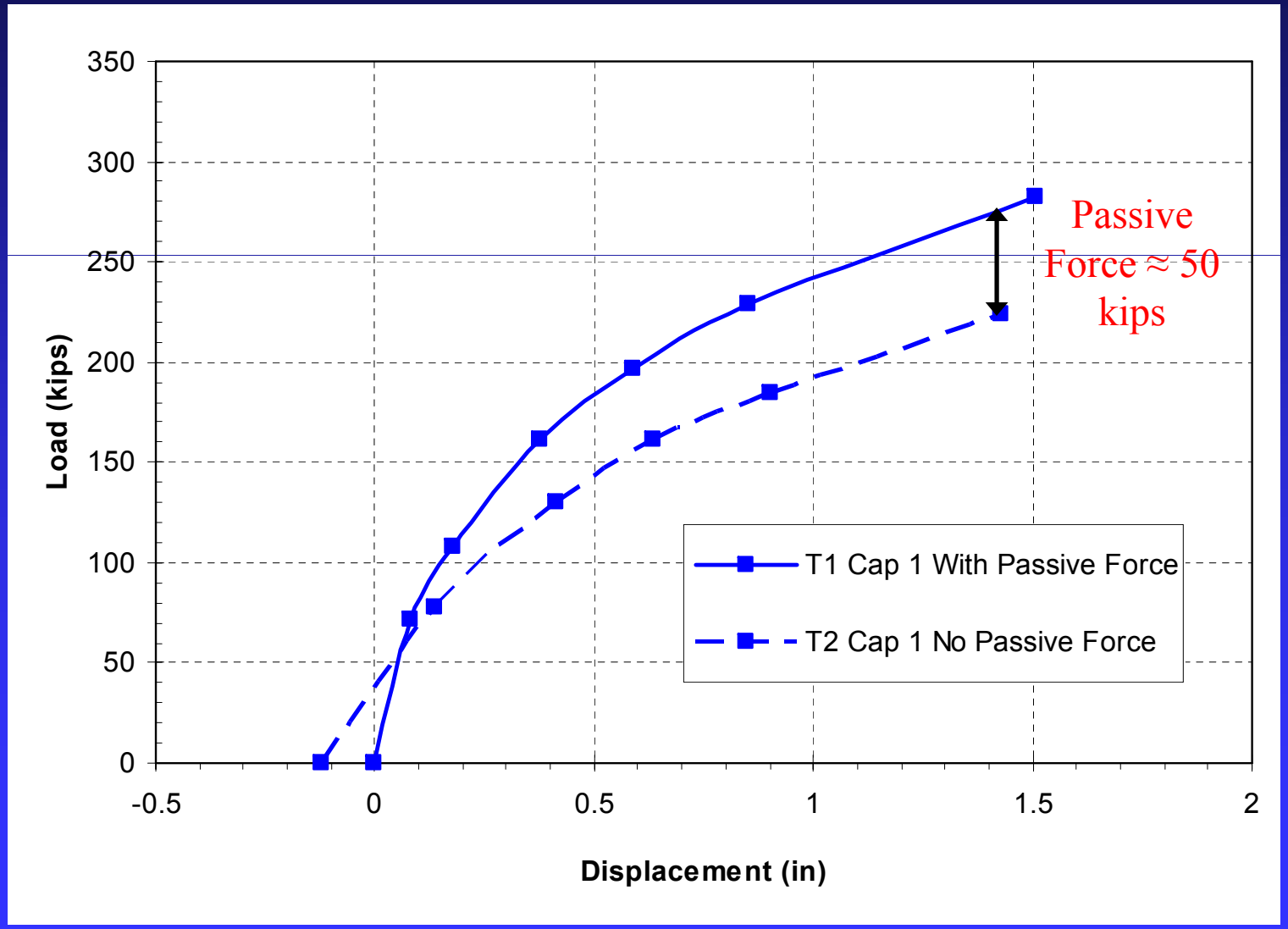


Moments from Shape Array

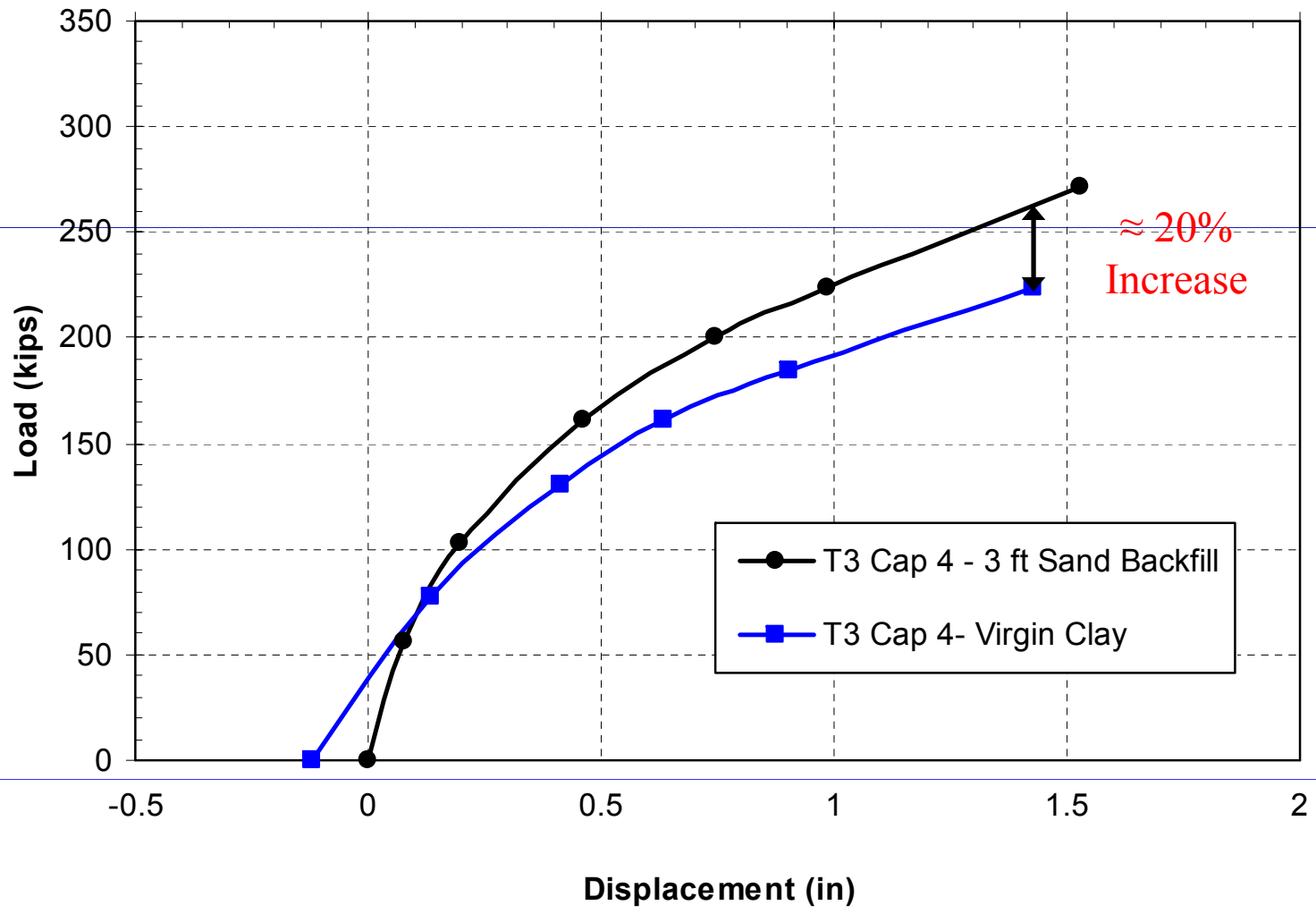


Shear zones

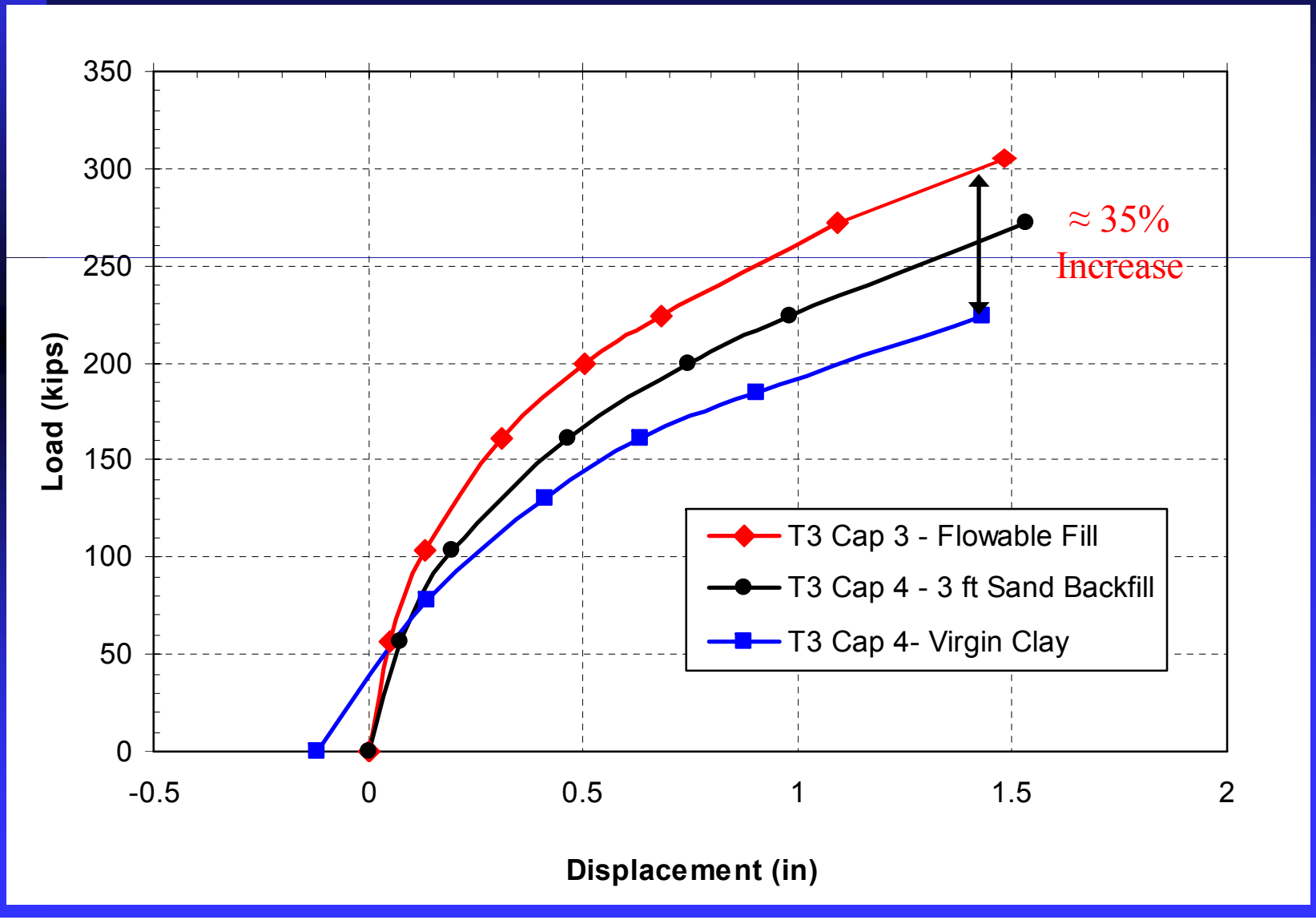
Passive Force on Cap in Clay



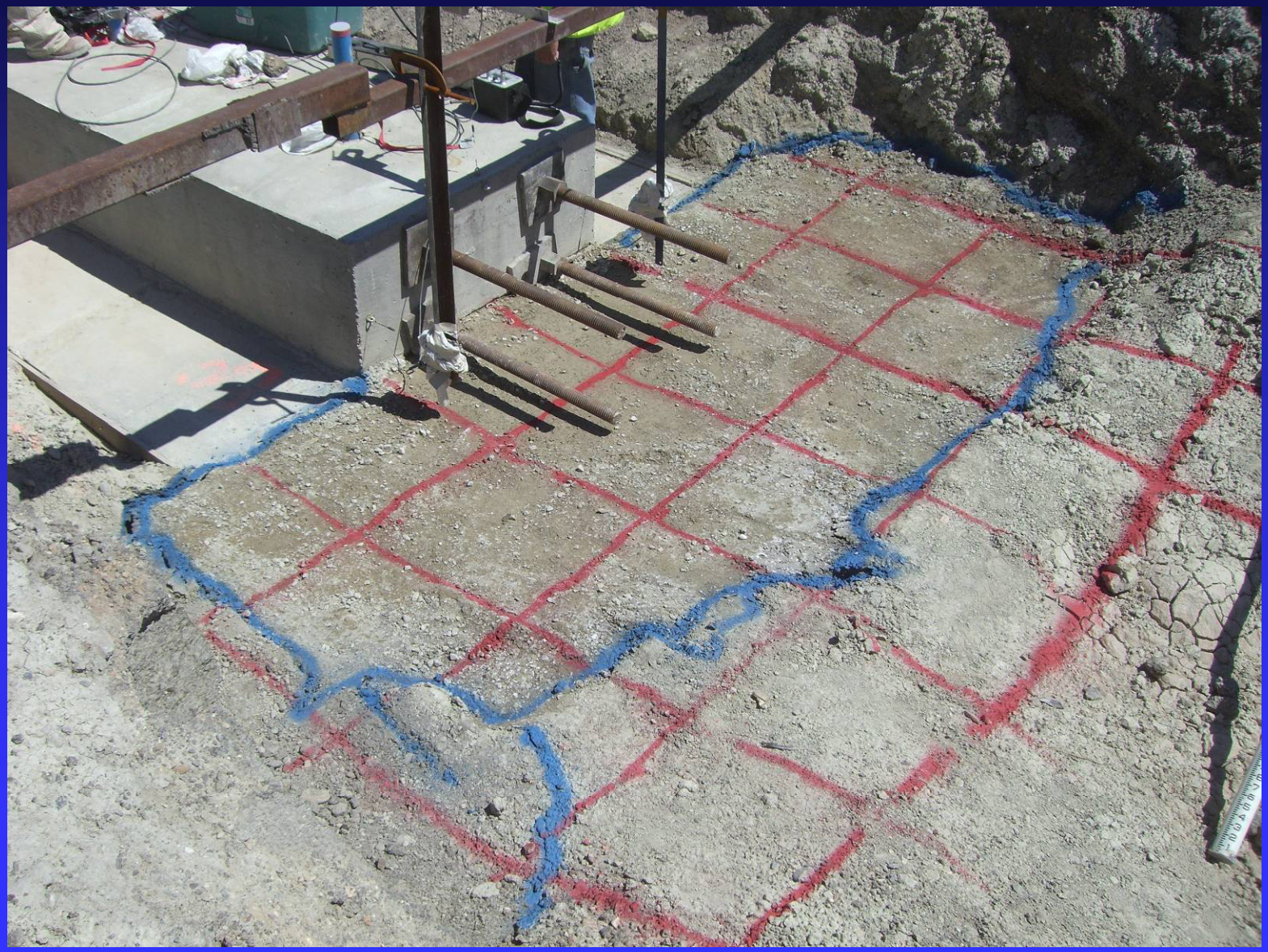
Increased Resistance from Sand Backfill



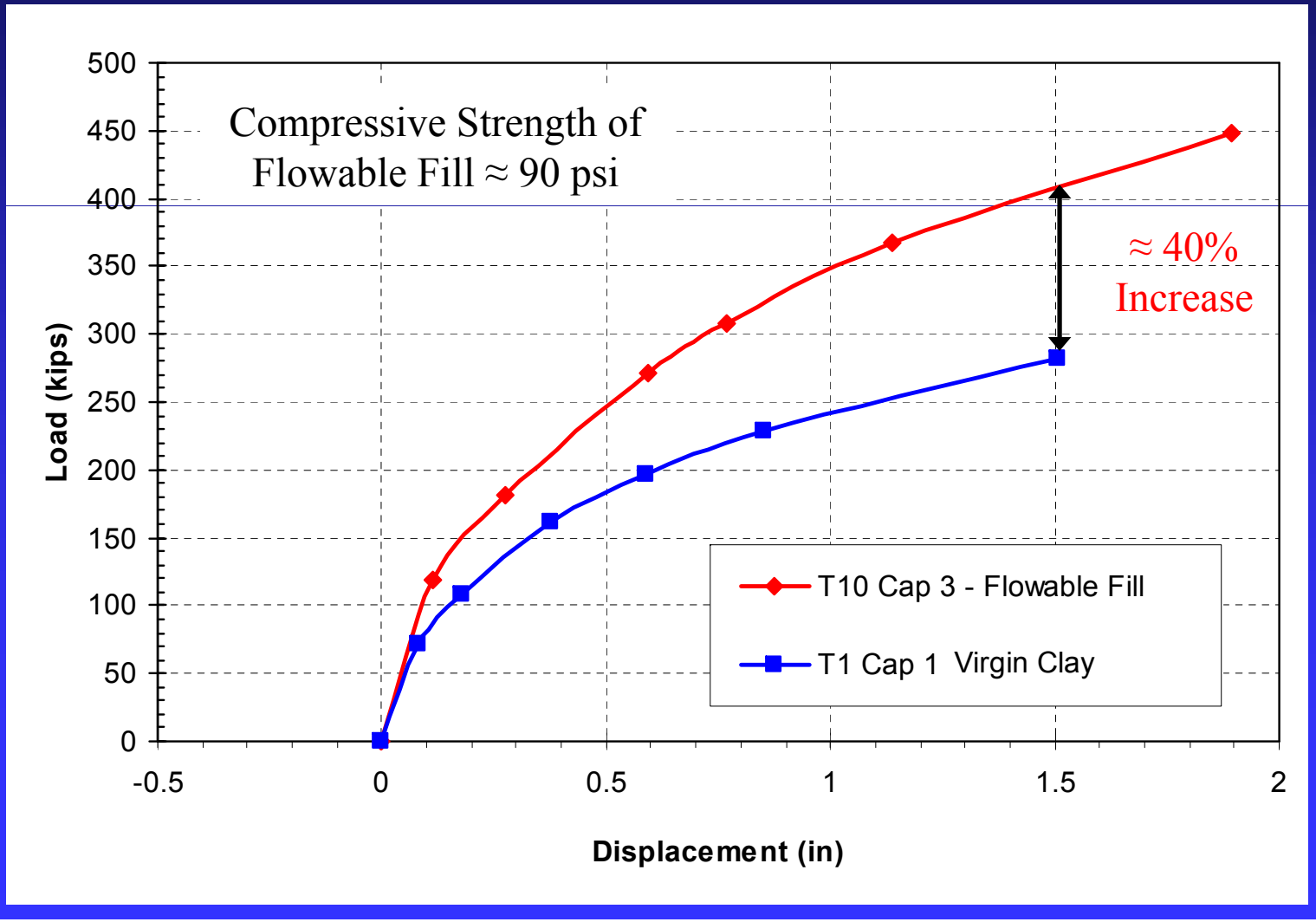
Increased Resistance from Flowable Fill



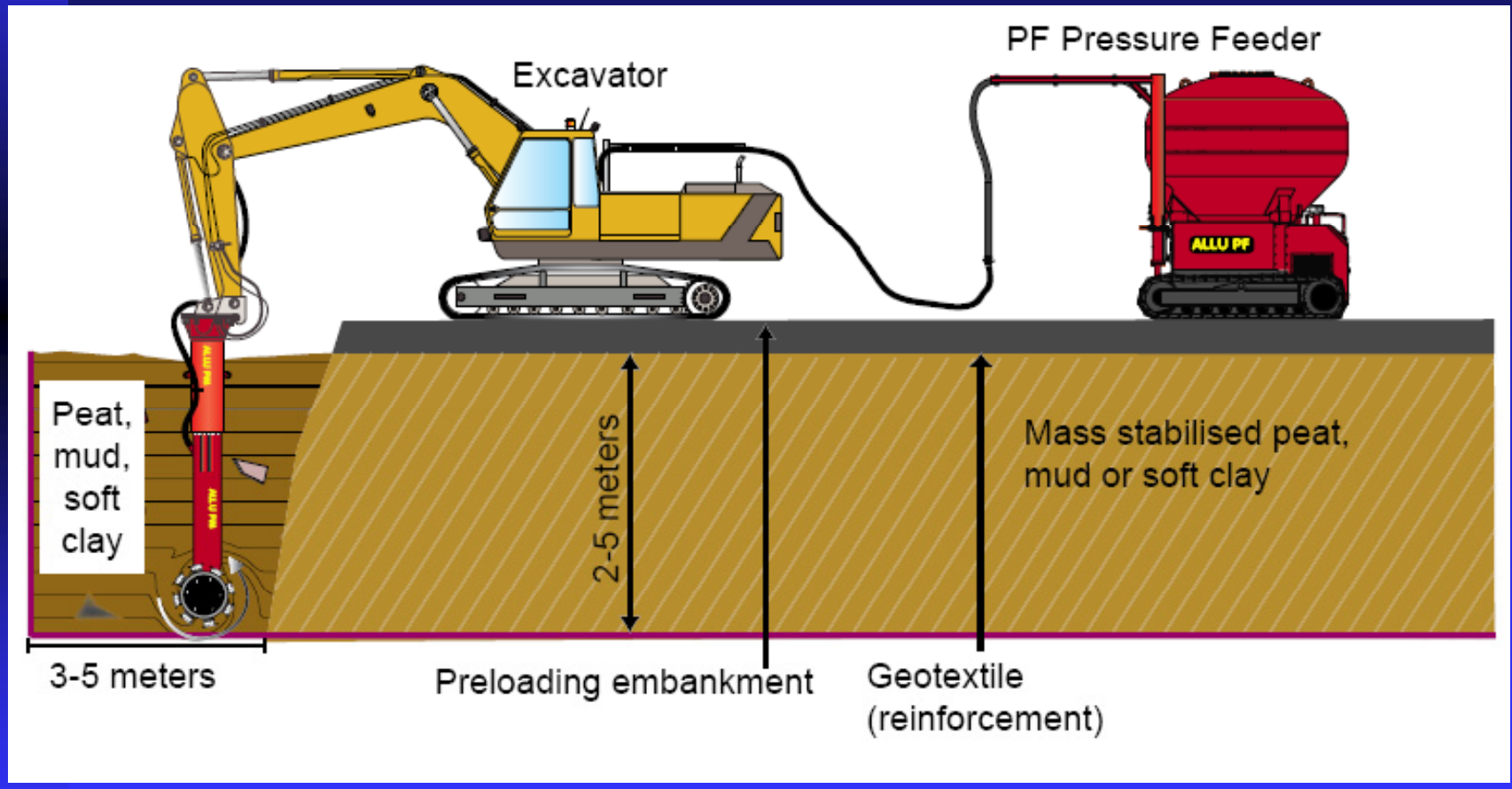
Failure Pattern Around Flowable Fill



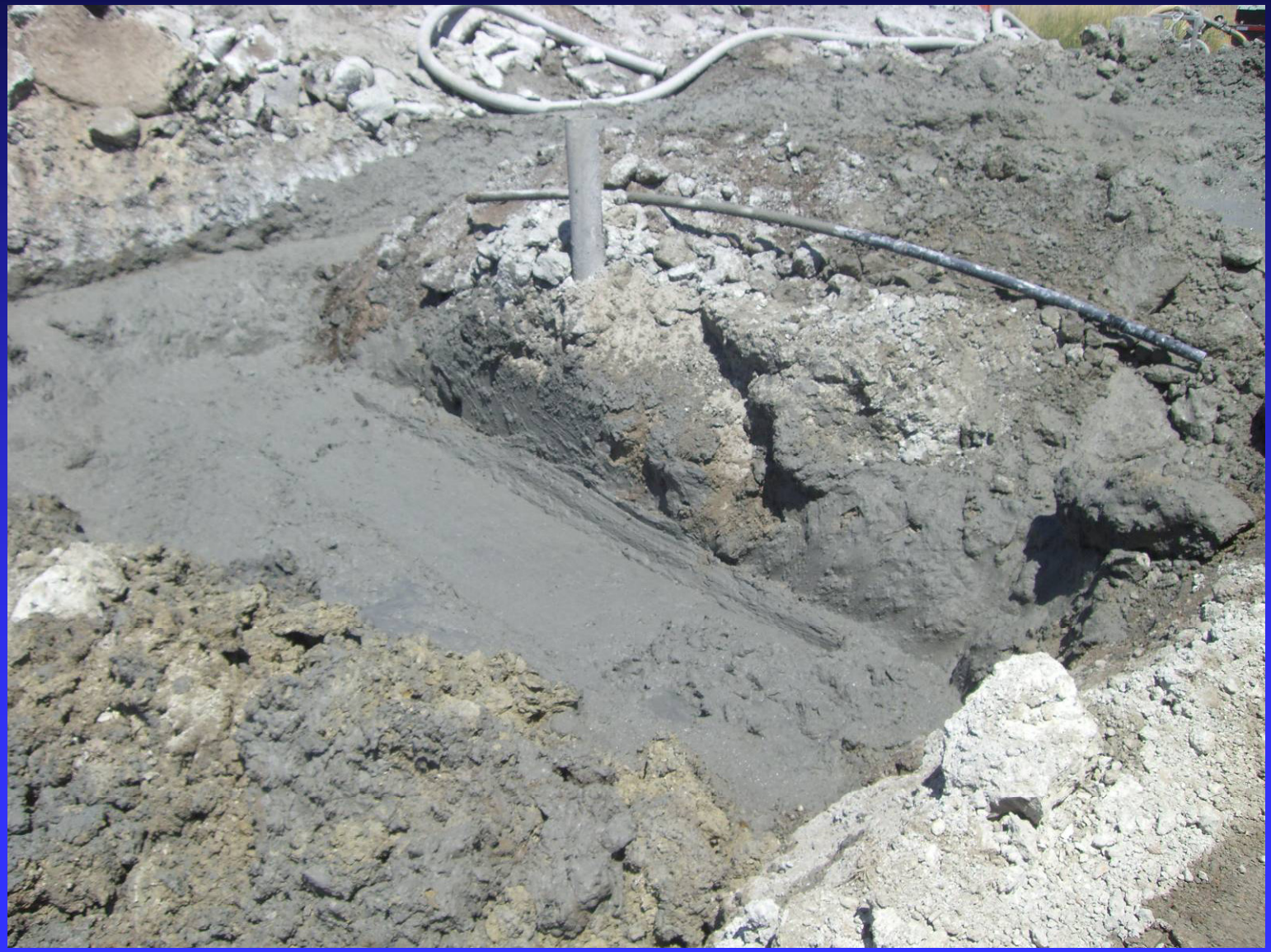
Increased Resistance from Flowable Fill



Soil Mixing by Blocks

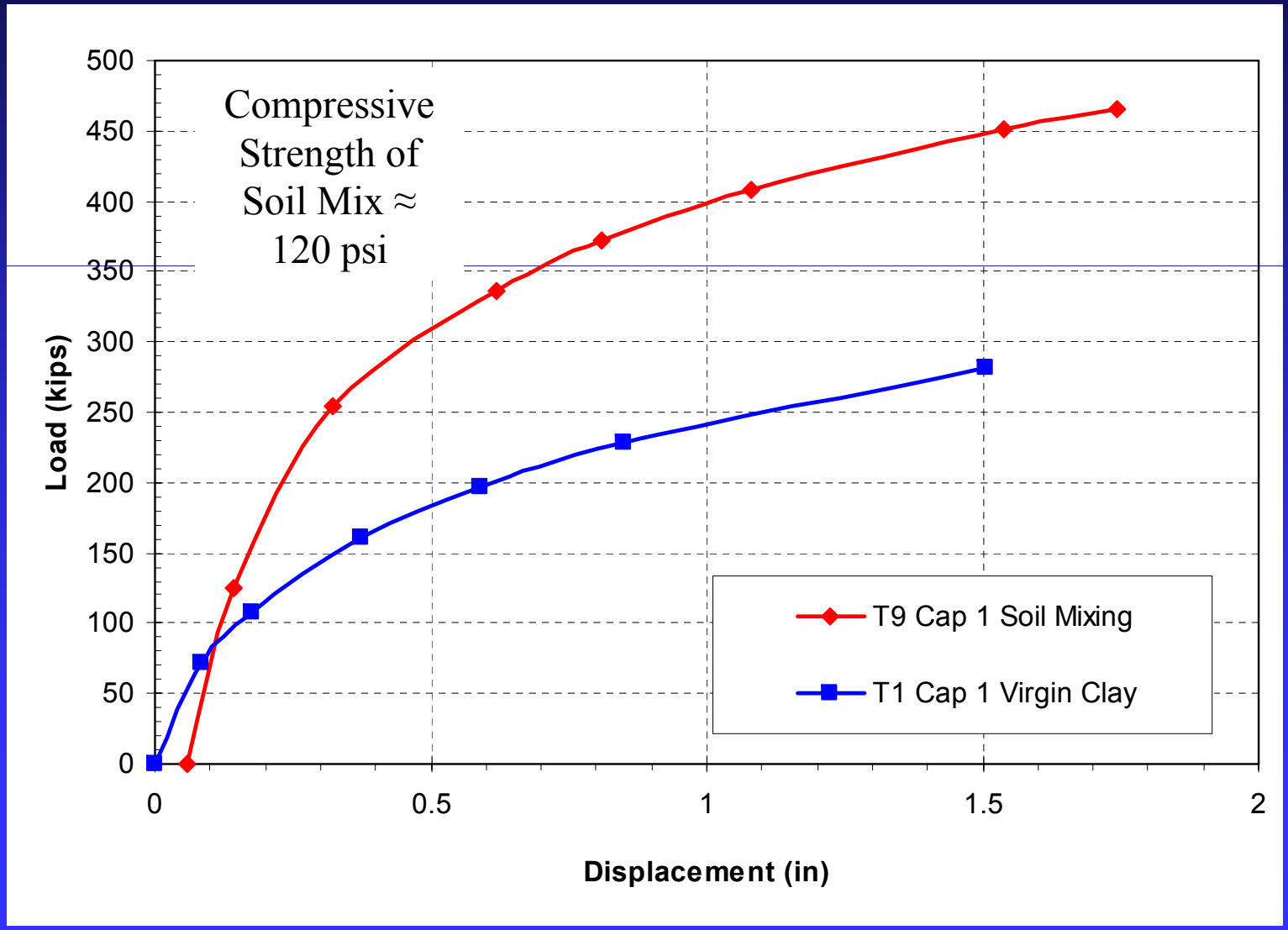


Soil Mixing

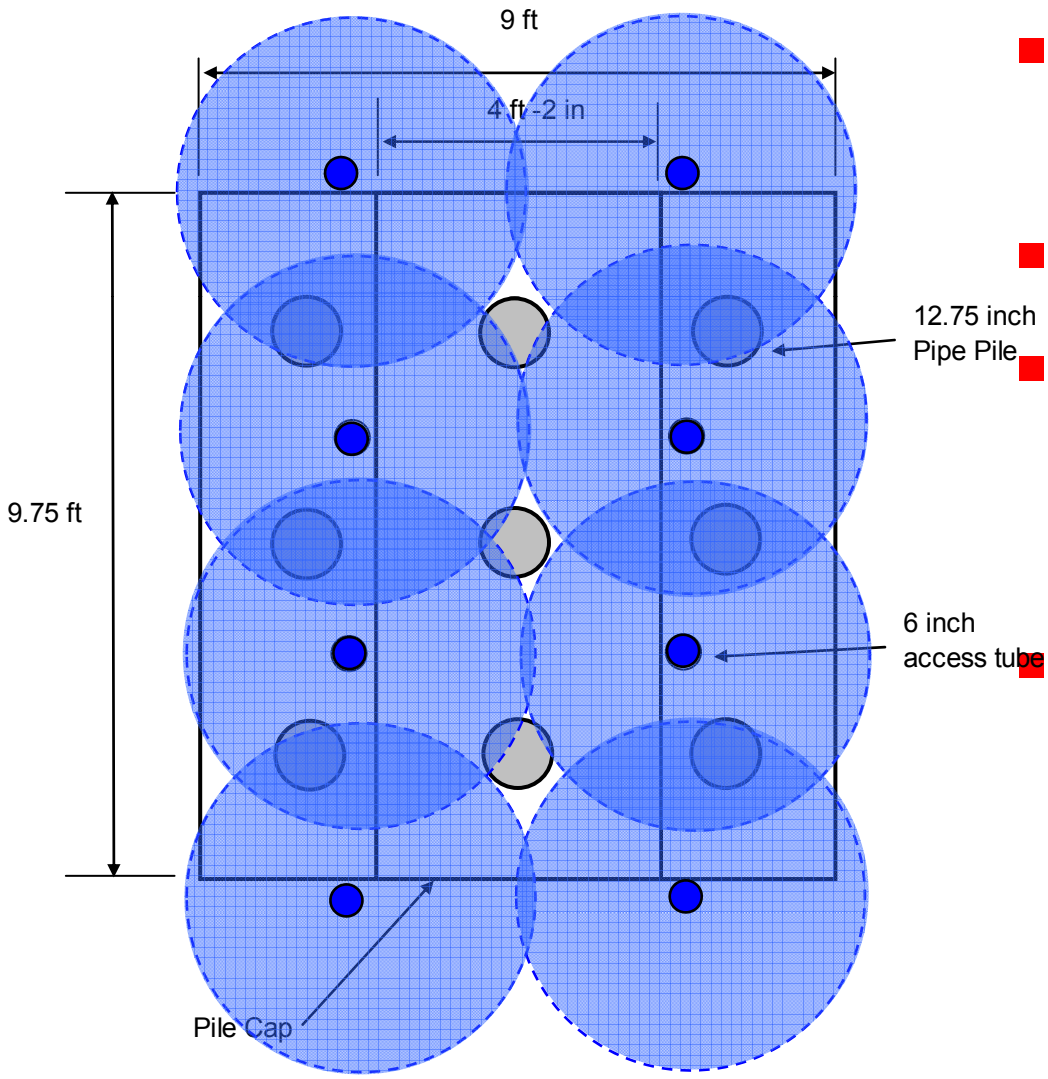


Increased Resistance from Soil Mixing

(Improvement on One Side Only)

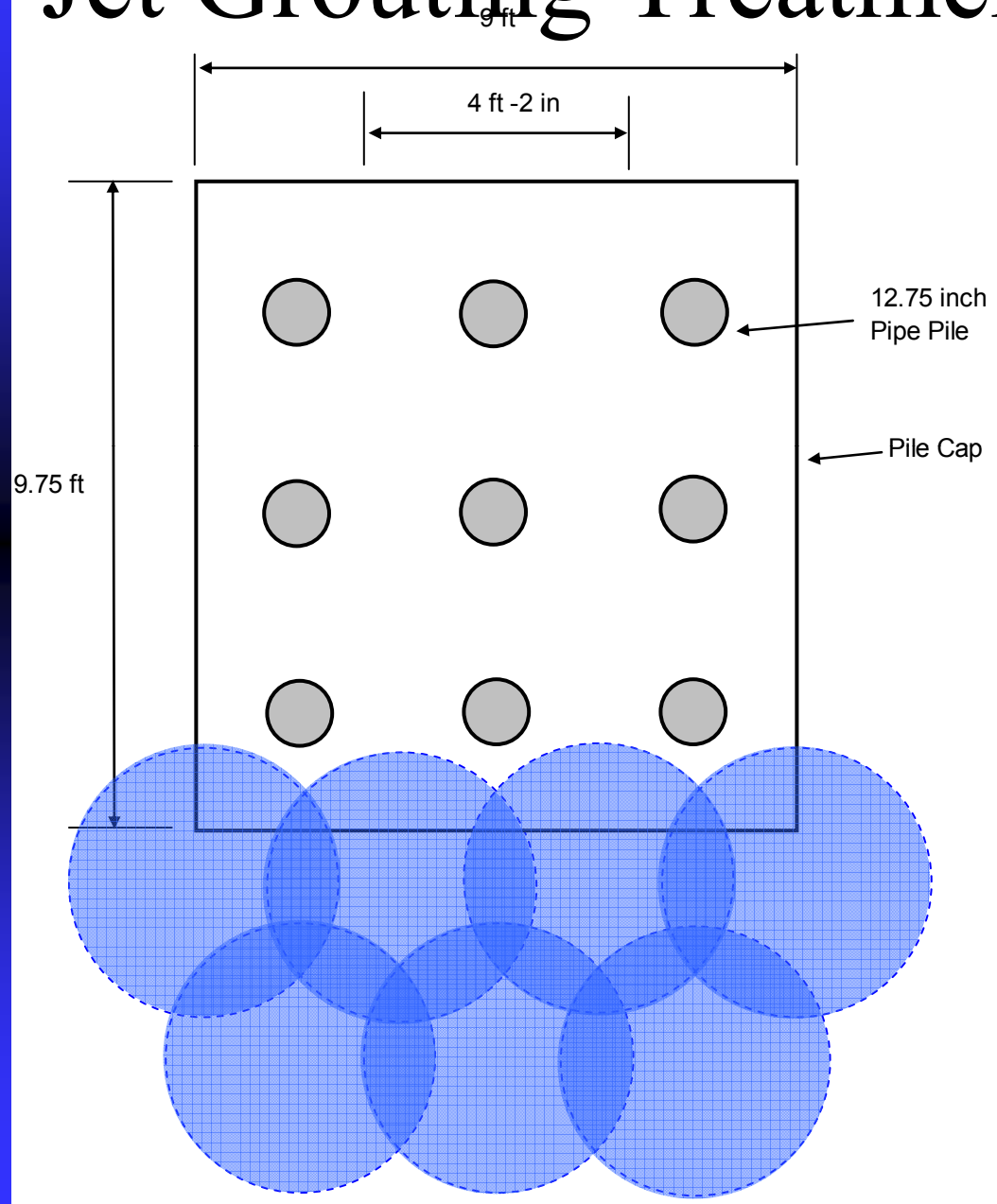


Jet Grouting Treatment Pattern



- 8 jet grout columns
- 5 ft diameter
- Complete coverage under cap
- 2.5 ft treatment zone in front of pile cap

Jet Grouting Treatment Pattern

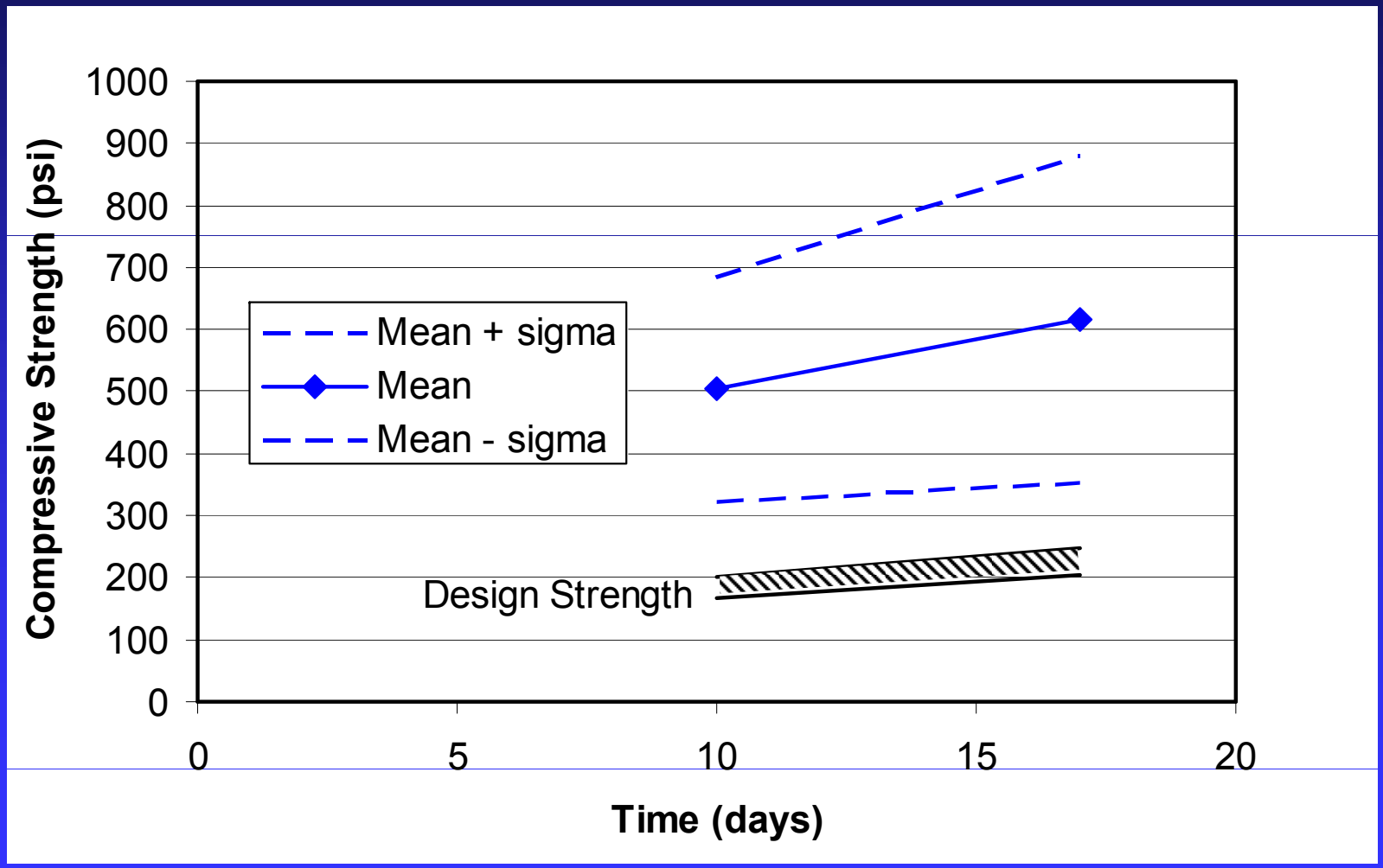


- 7 jet grout columns
- 4 ft diameter
- 5 to 6 ft treatment zone under and in front of pile cap

Jet Grouting Drill

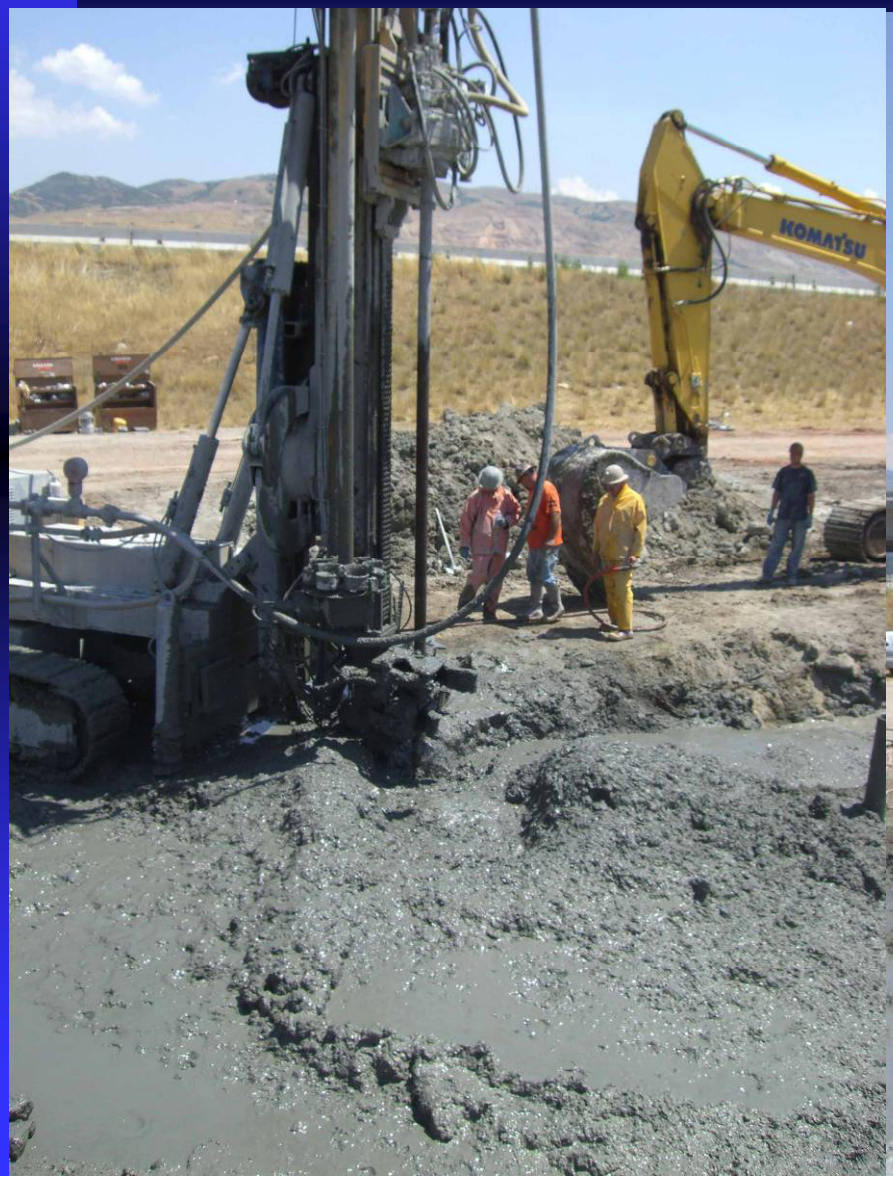
Jet Grouting Quality Control

Compressive Strength Testing

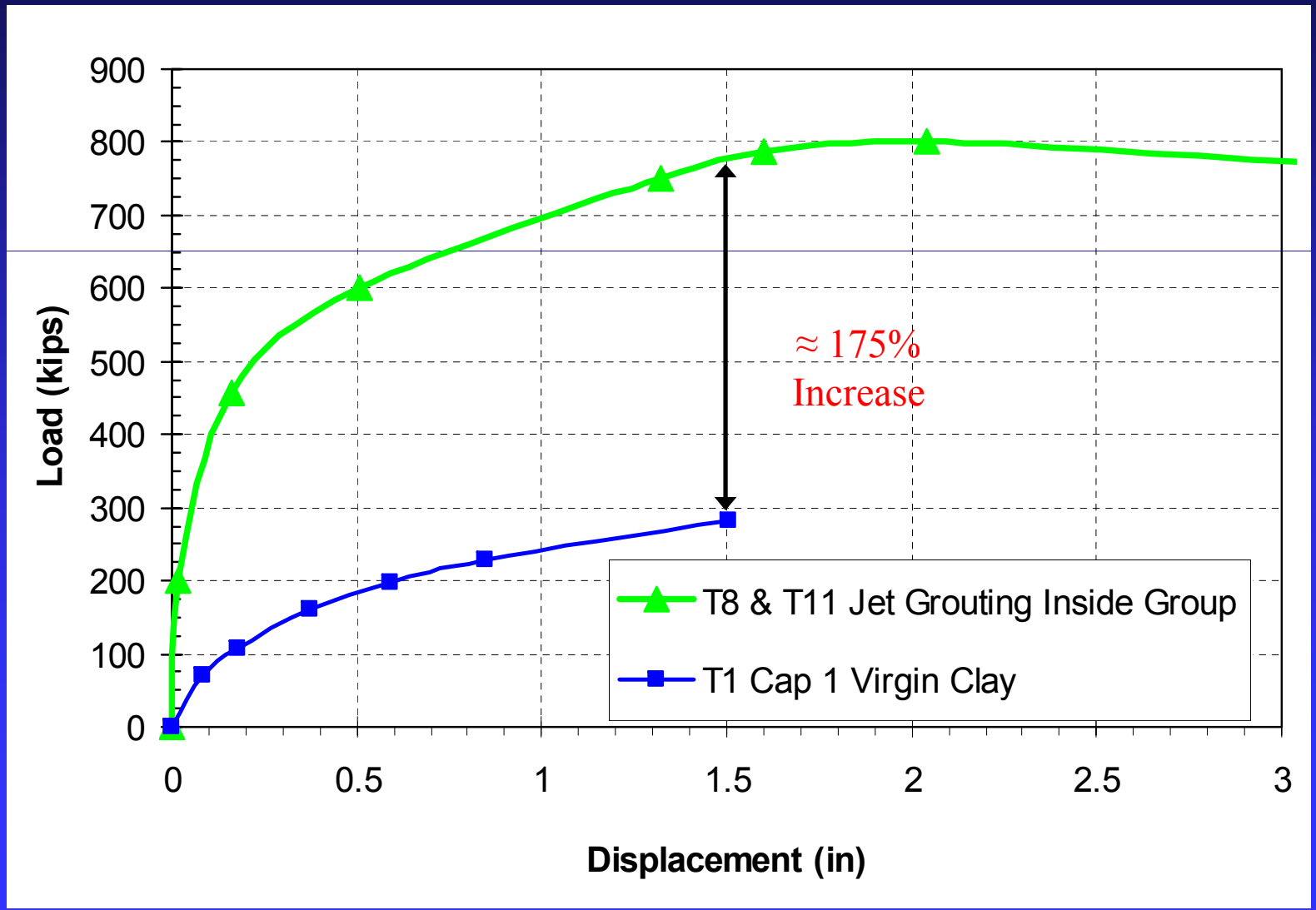


Prior to Jet Grouting

Jet Grout Mess

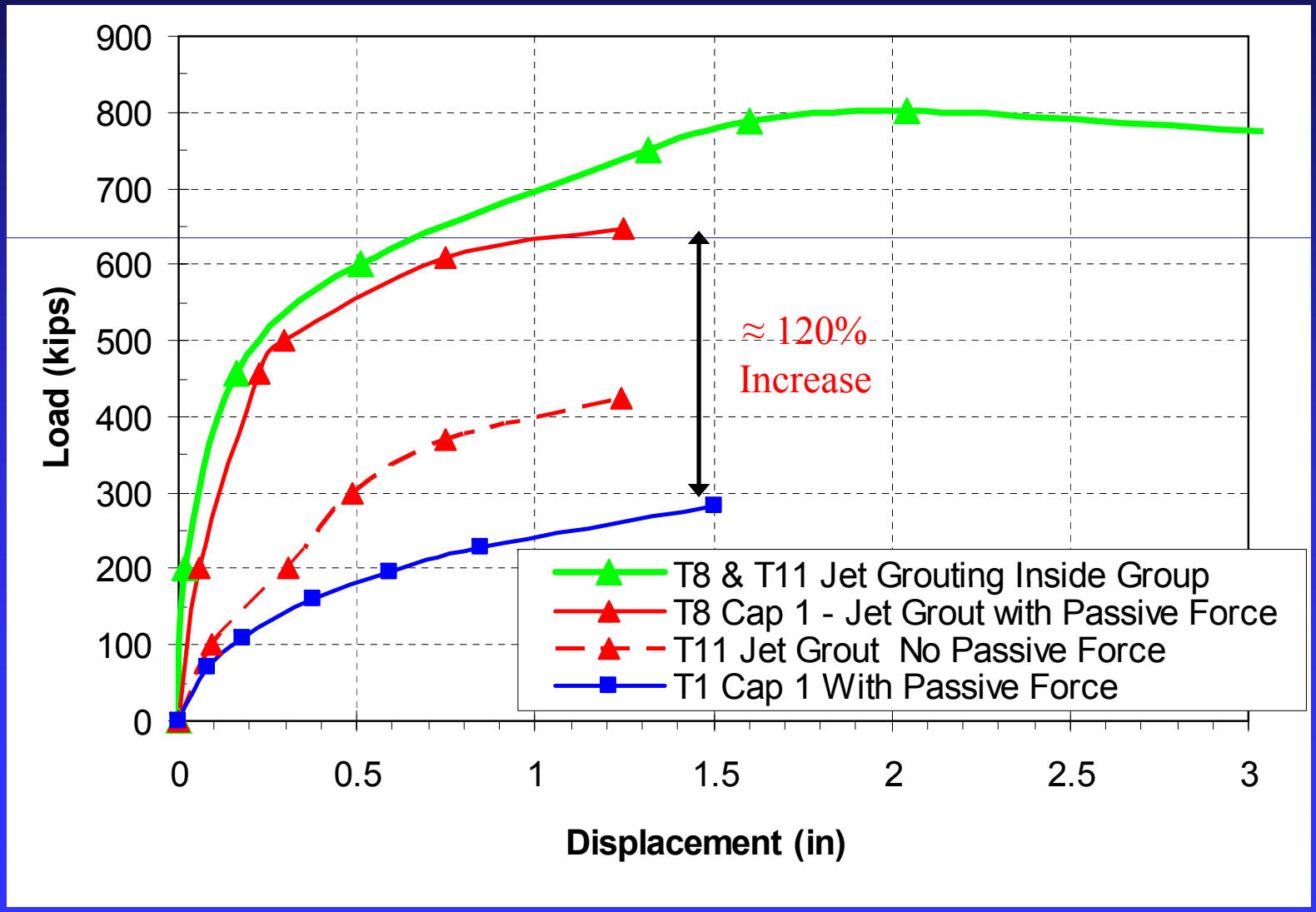


Increased Resistance from Jet Grouting
(Grout Zone Throughout)

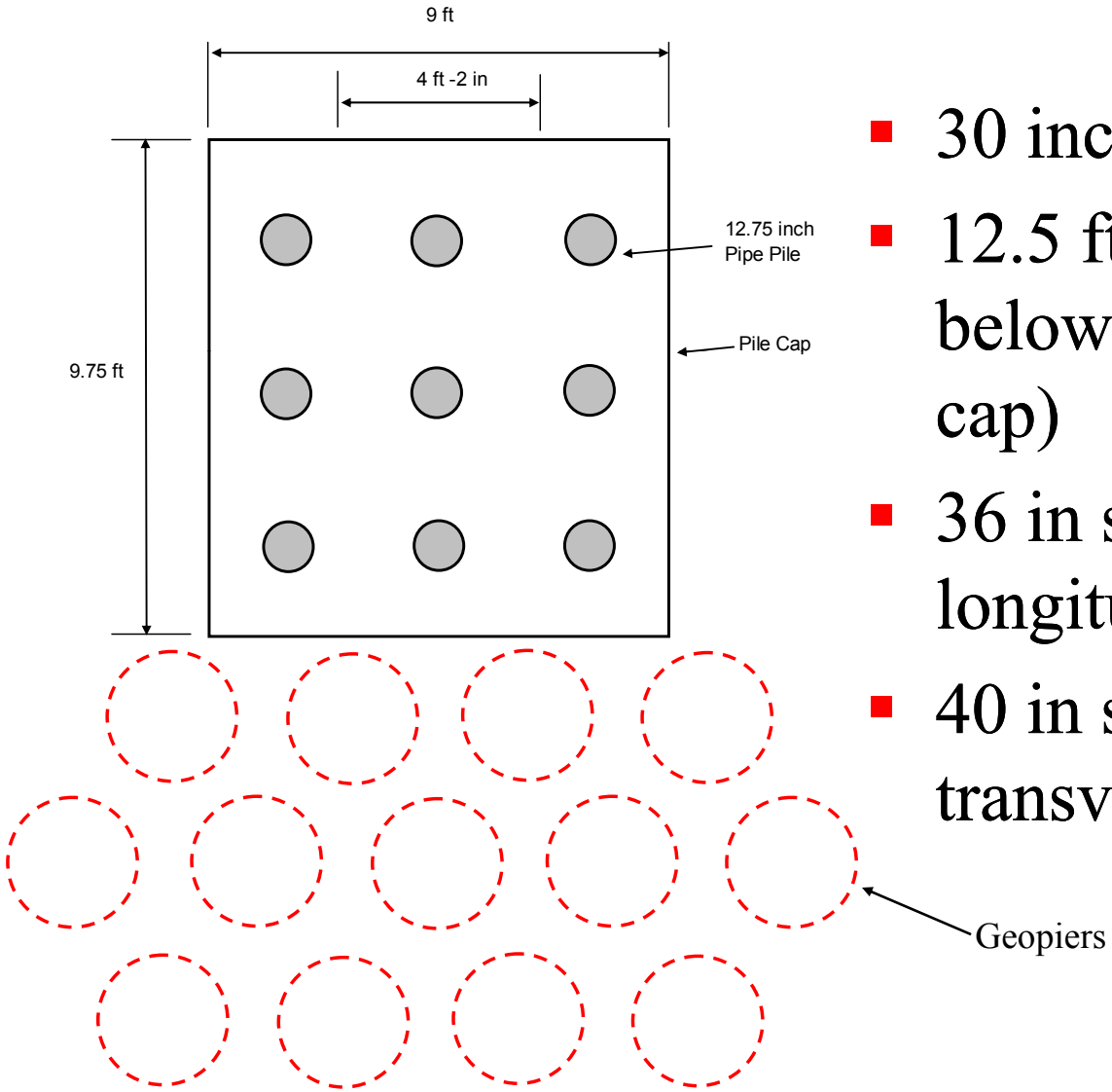


Increased Resistance from Jet Grouting

(Grout Zone on One Side Only)

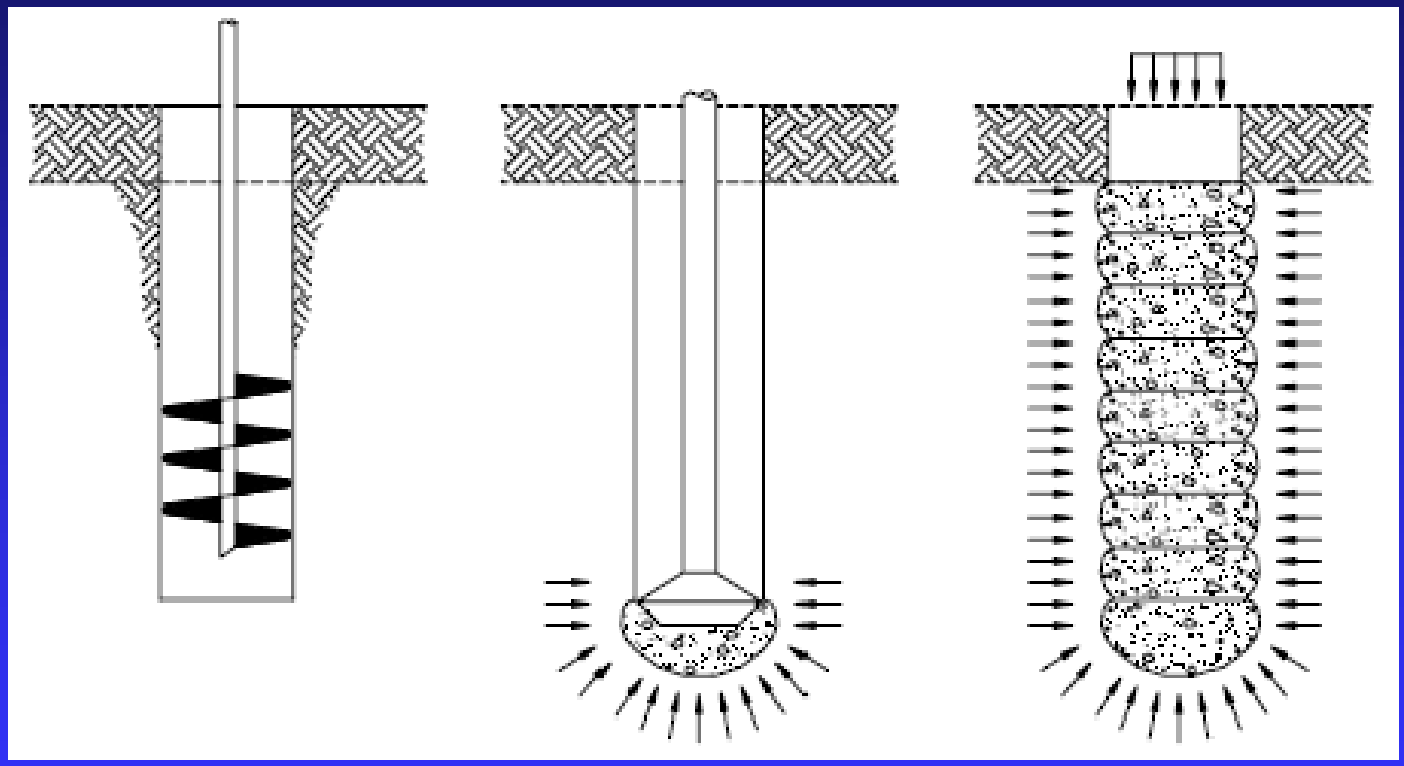


Rammed Aggregate Pier Layout



- 30 inch diameter pier
- 12.5 ft deep (10 ft below the base of the cap)
- 36 in spacing longitudinally
- 40 in spacing transverse

Rammed Aggregate Pier Construction



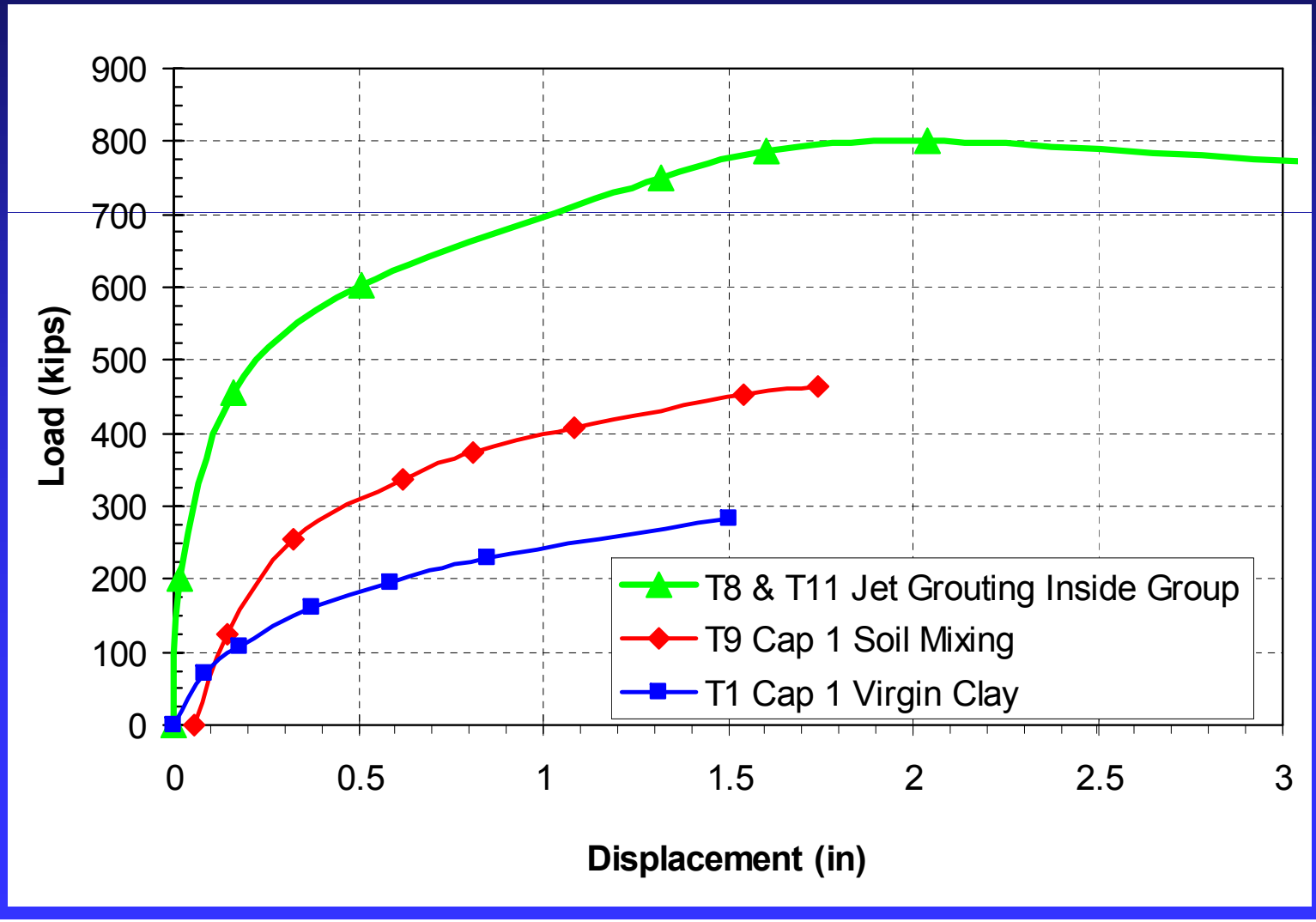
Excavate Hole

Compact Base Gravel

Compact Gravel Lifts

Trench Through Geopiers

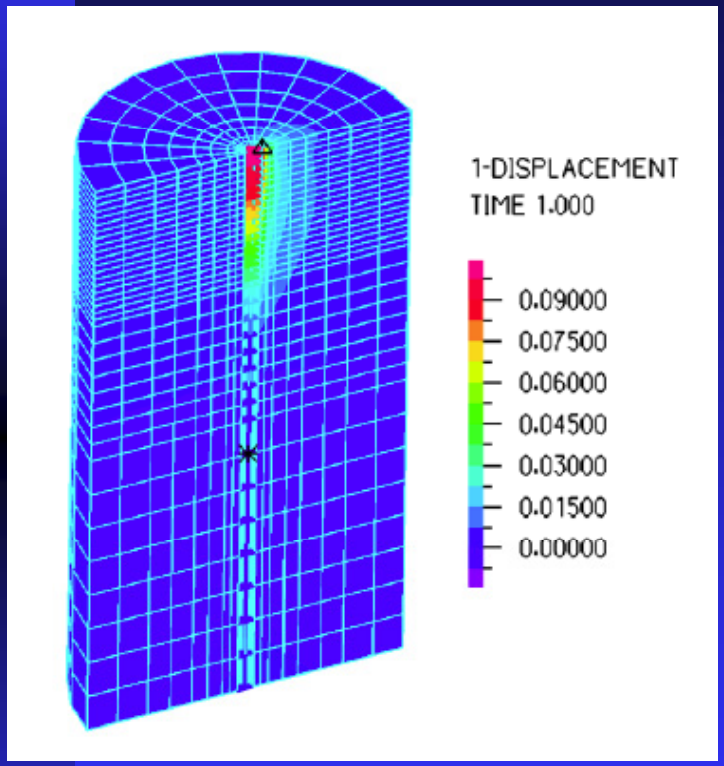
Comparison of Resistance from Various Treatment Methods



Increased Resistance from Various Treatments - Summary

- Geopiers – 10 to 20% increase
- Compacted Sand – 20 to 30% increase
- Flowable Fill
  - 20 psi to 30 psi – 30% increase
  - 90 psi – 50% increase
- Soil Mixing (120 psi)- 60% increase
- Jet Grouting – 125% to 175% increase

FEM Analysis – Earth Mechanics, Inc.



- Analysis of Single Pile –Axi-symmetric (Untreated)
- Analysis of Pile Group -3D (Untreated)
- Analysis of Pile Group (Jet Grouting inside and then outside) – 3D symmetric
  - Calibration with Field Results
  - Parametric analysis of strength
  - Parametric analysis of treatment depth
  - Parametric analysis of treatment width
- Analysis of Pile Group (Soil Mix/Flowable Fill)
  - Calibration
  - Parametric Study

Development of Design Approach (Dan Brown-Auburn)

- Calibration with field and “virtual” load tests with simplified model
  - P-y curve approach
  - LPILE modifications
- Development of design guidelines based on test results and analyses