

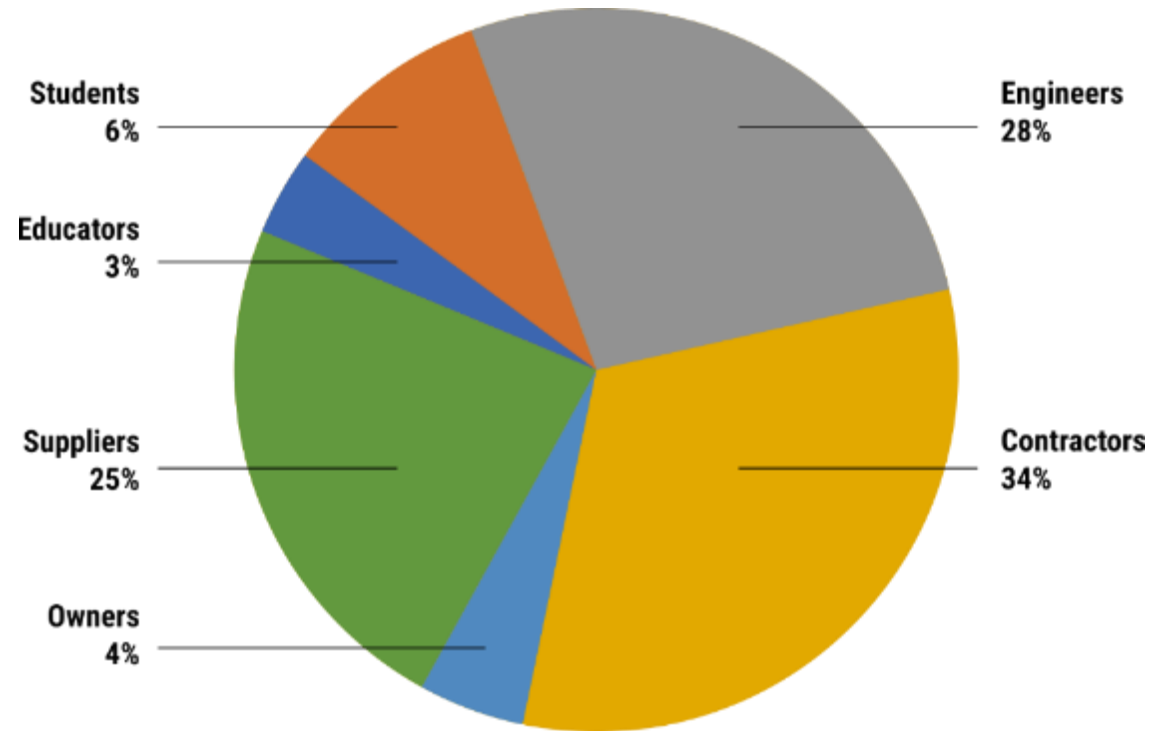
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GEI



Consultants

Findings on Exploration, Design and QA in Rigid Inclusion Projects

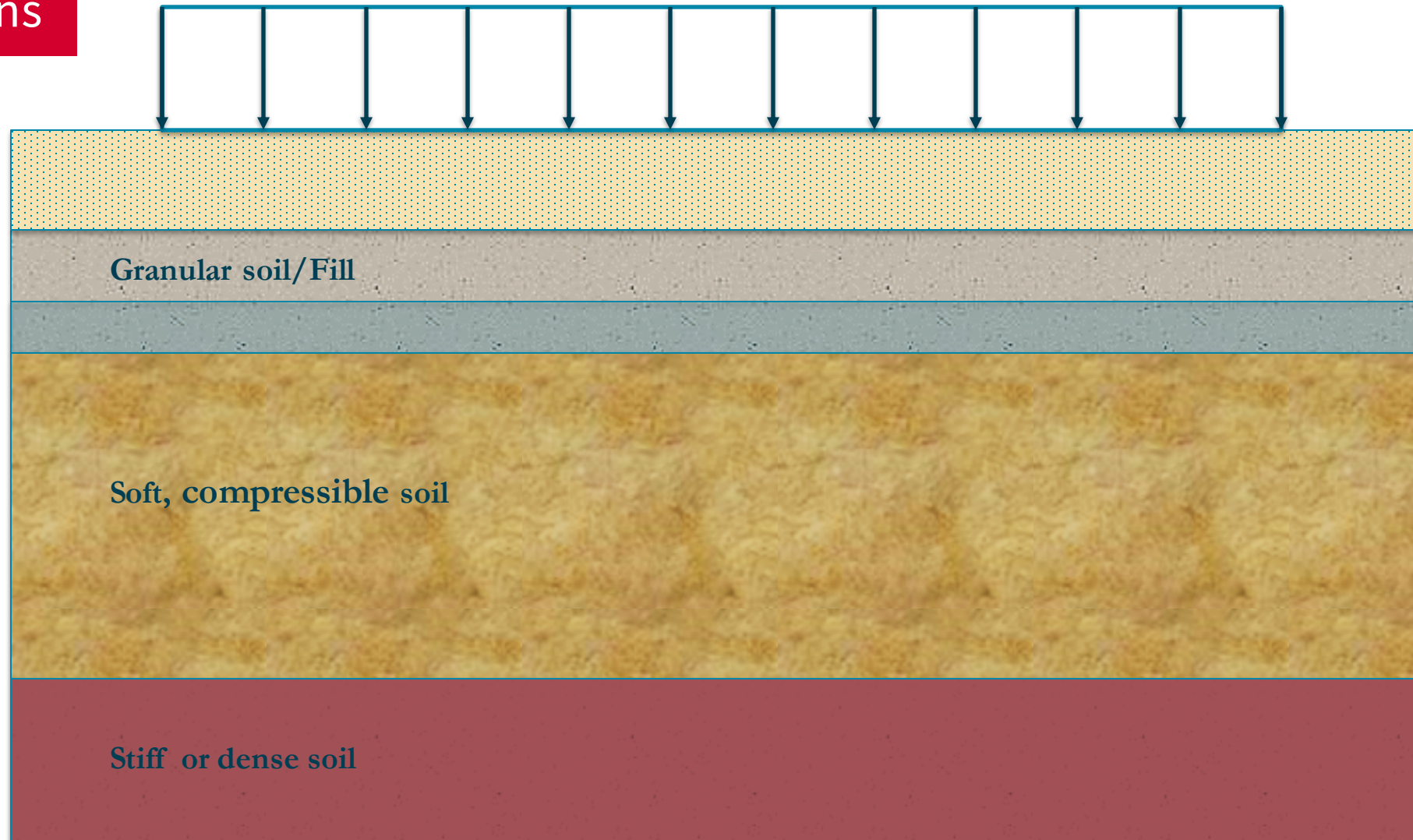
Dr. Jesús Gómez, P.E., D.GE., Vice President

November 2023

Outline

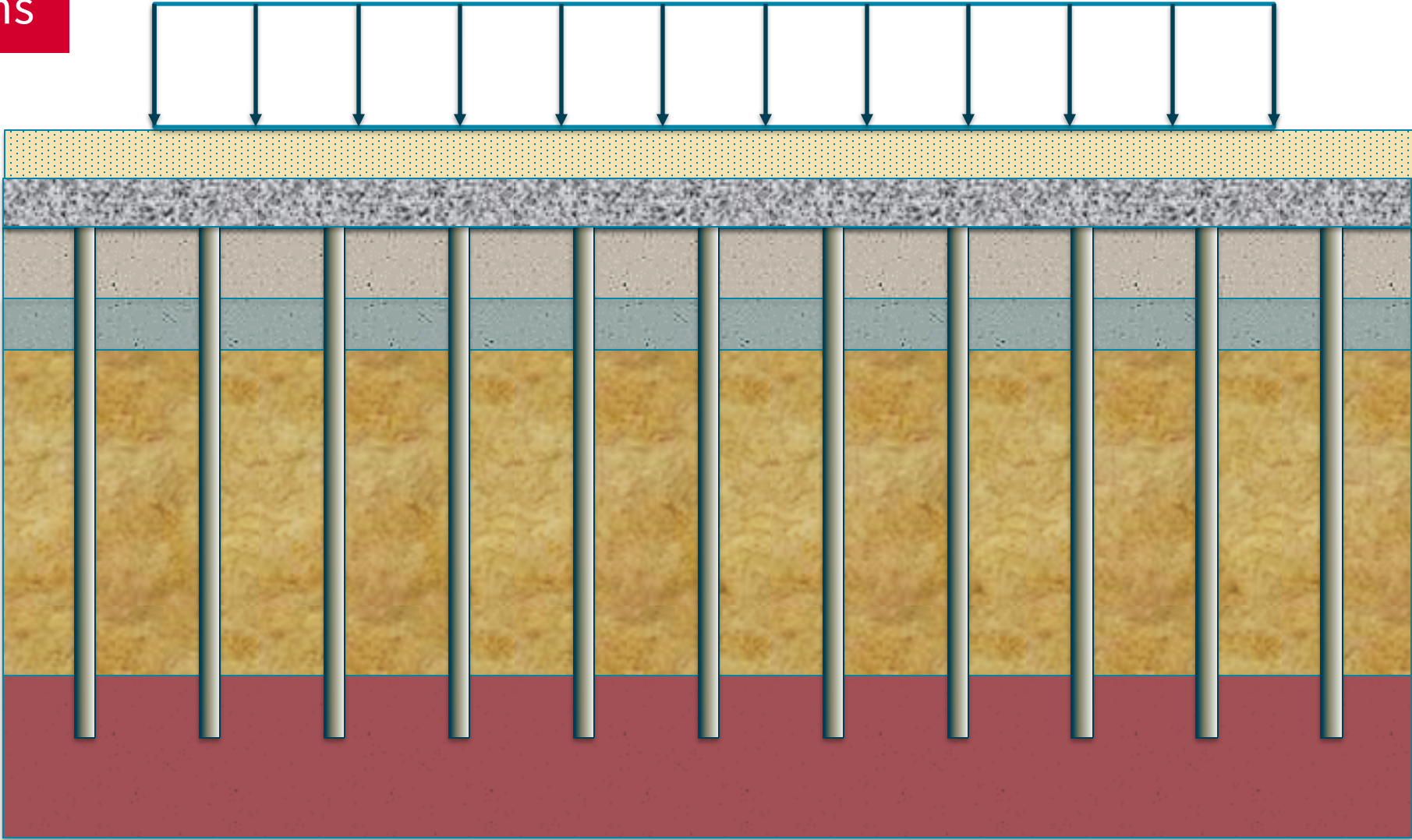
- **Rigid Inclusion Overview**
- **CPT Overview**
- **La Olmeca Refinery**
- **QA/QC**
 - **Instrumented Load Testing**
 - **Interpretation of Production Installation Logs**
- **Summary**

Rigid Inclusions



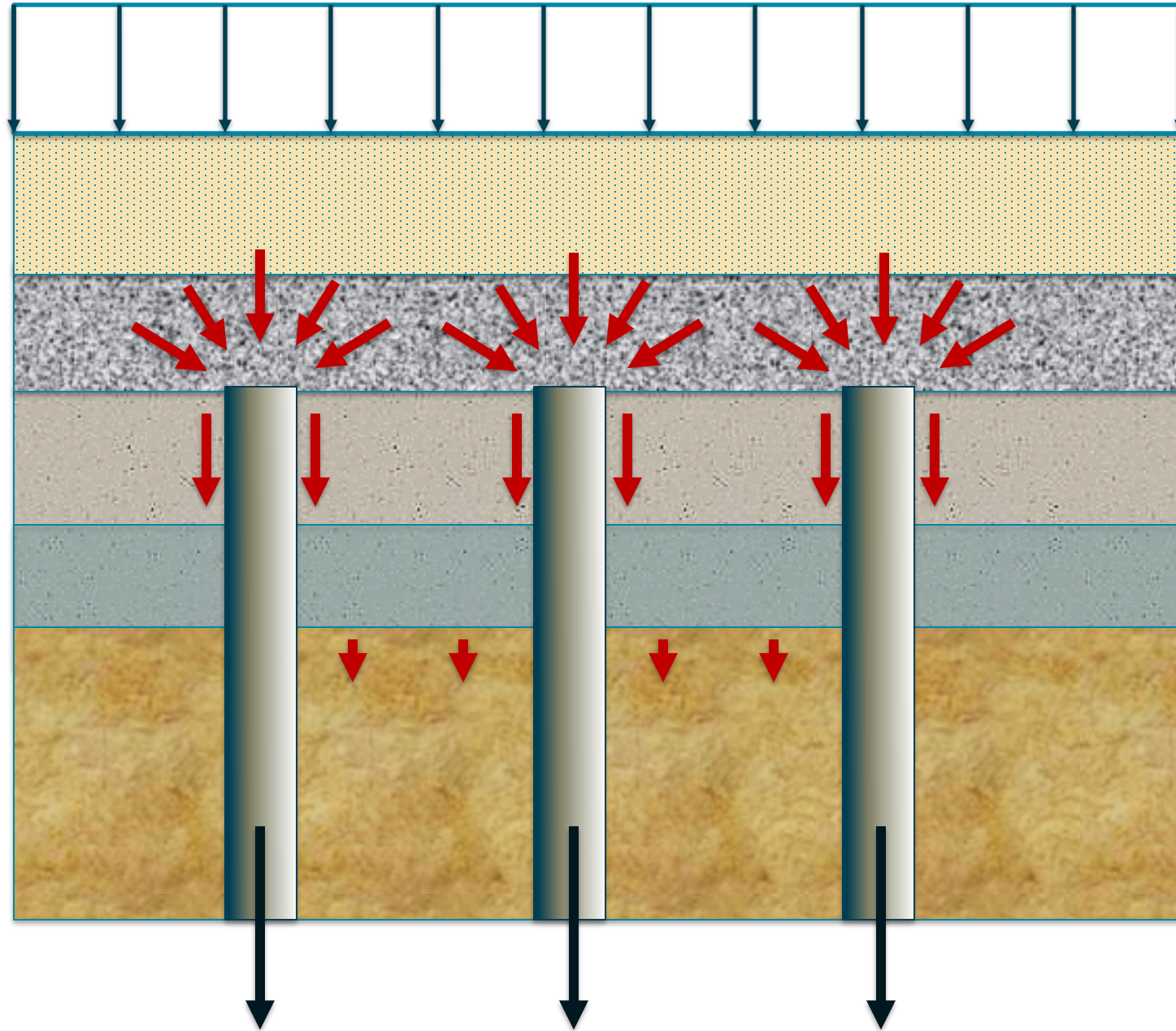
Rigid Inclusions

Load Transfer Platform

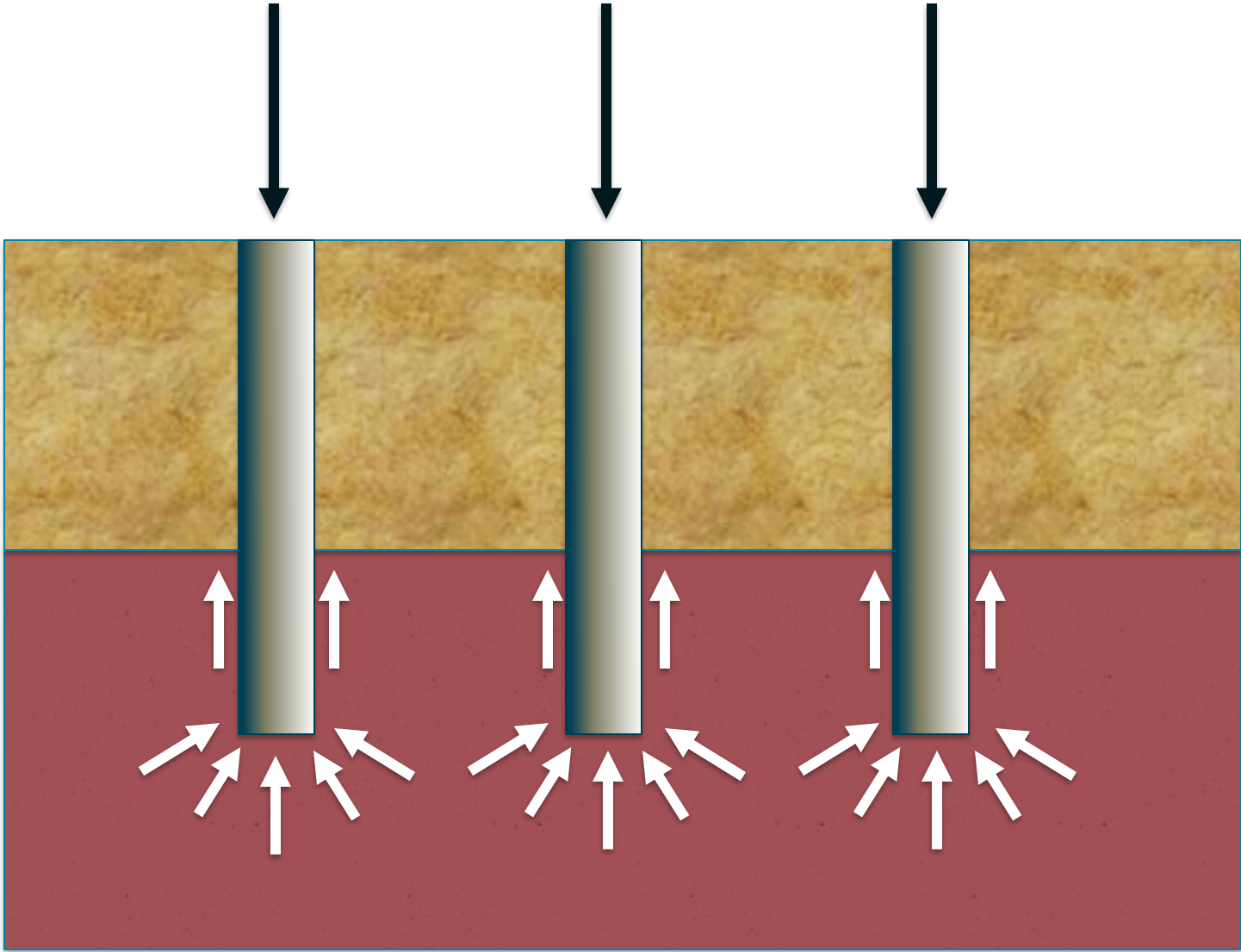


Rigid Inclusions

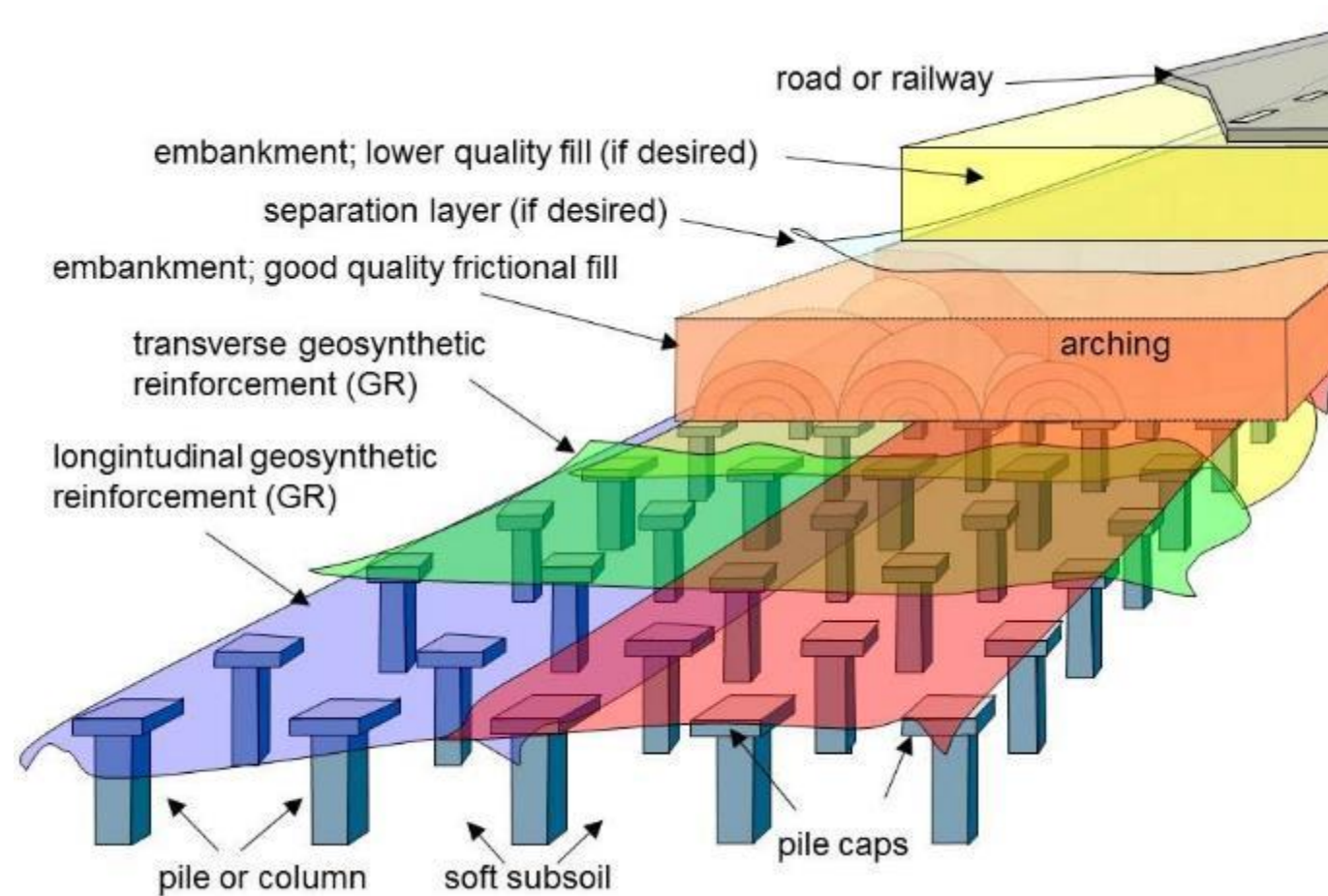
Load Transfer Platform



Rigid Inclusions



Rigid Inclusions



Taken from Van Eekelen (2015)



Rigid Inclusions



Taken from Orsmond W (2012)

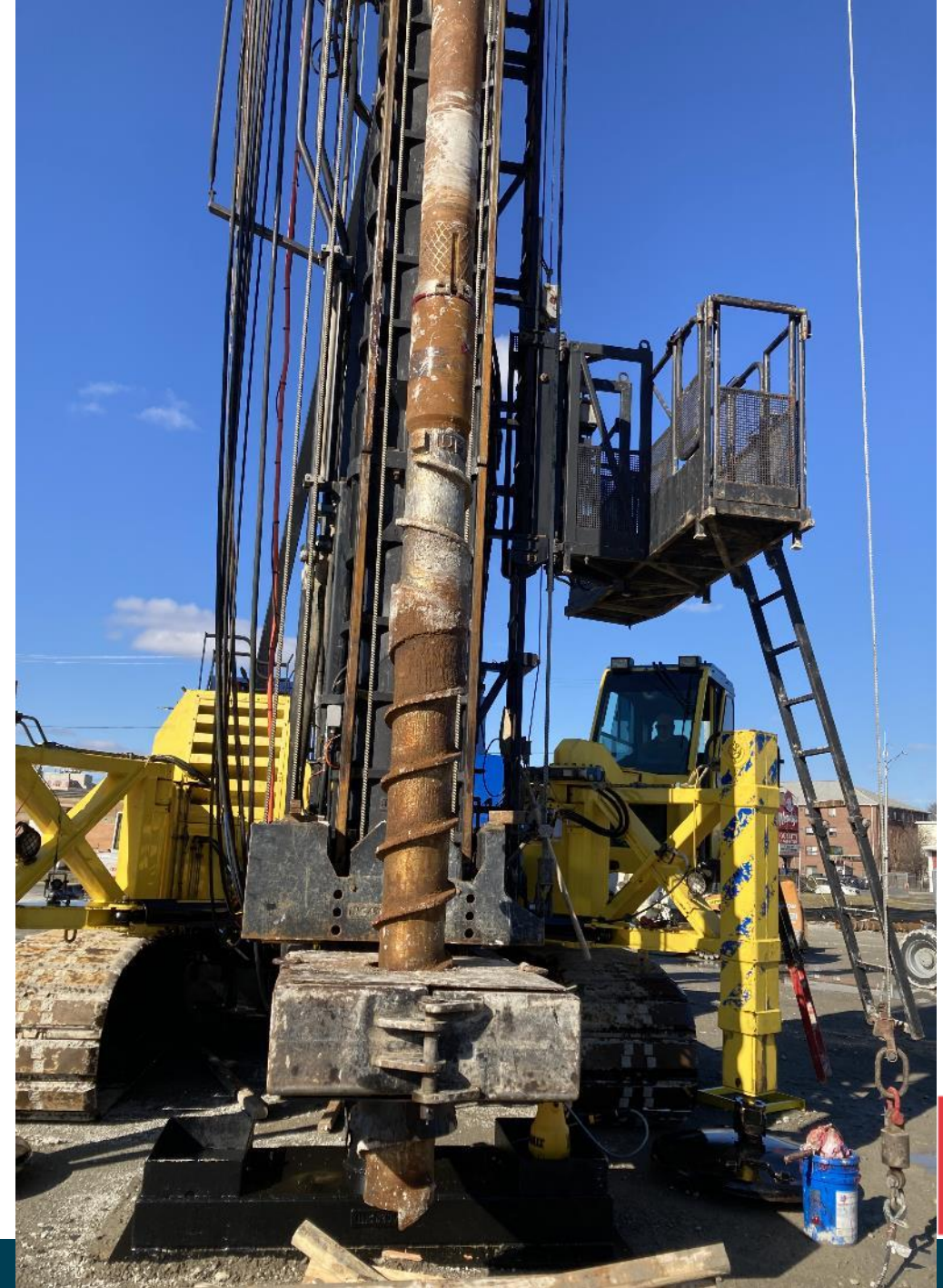


Rigid Inclusions

- **Typically, Displacement Augercast Pile (DACP) system used**
- **Zero or near-zero spoils**
- **Soils compressed or displaced during auger insertion**
- **Grout injected under pressure during tool removal**
- **Measurement While Drilling (MWD)**

Morris-Shea Rigid Inclusion Installation



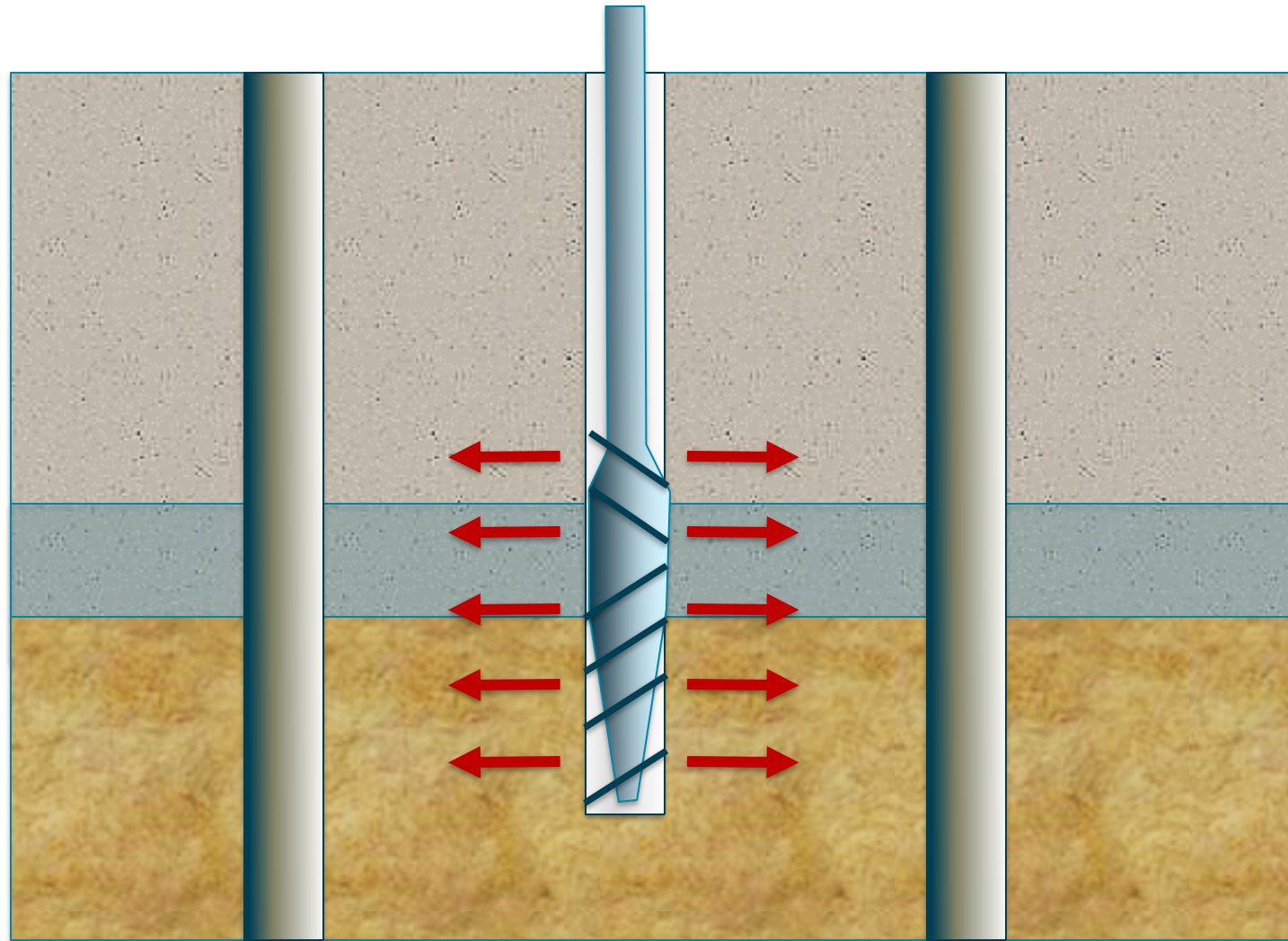


Rigid Inclusions

Kiewit Foundations



Rigid Inclusions



Rigid Inclusions

Morris-Shea Bridge Company

MORRIS-SHEA
BRIDGE COMPANY, INC.

Rigid Inclusions Pile Drill Log

Job Site Data

JOB NAME:
JOB NUMBER:
OWNER:
CLIENT:

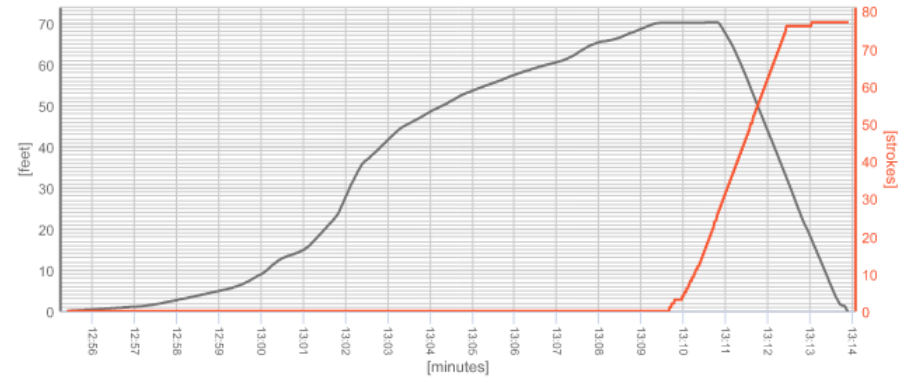
Pile No: RP7, Type: Reaction

DATE
START TIME
END TIME
TOTAL TIME
RIG. LINES
OPERATOR: Manuel Perez Roa

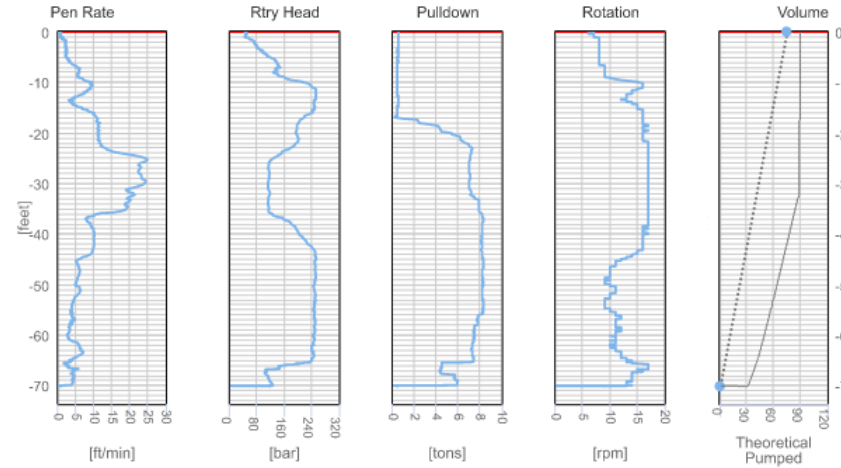
PILE LENGTH [ft]: 70.2
PILE DIAMETER [in]: 14
STROKES: 77
PUMP CALIB. [cy/str]: .043
OVER BREAK: 19%

Time Scale (0:18:28)

Depth & Strokes

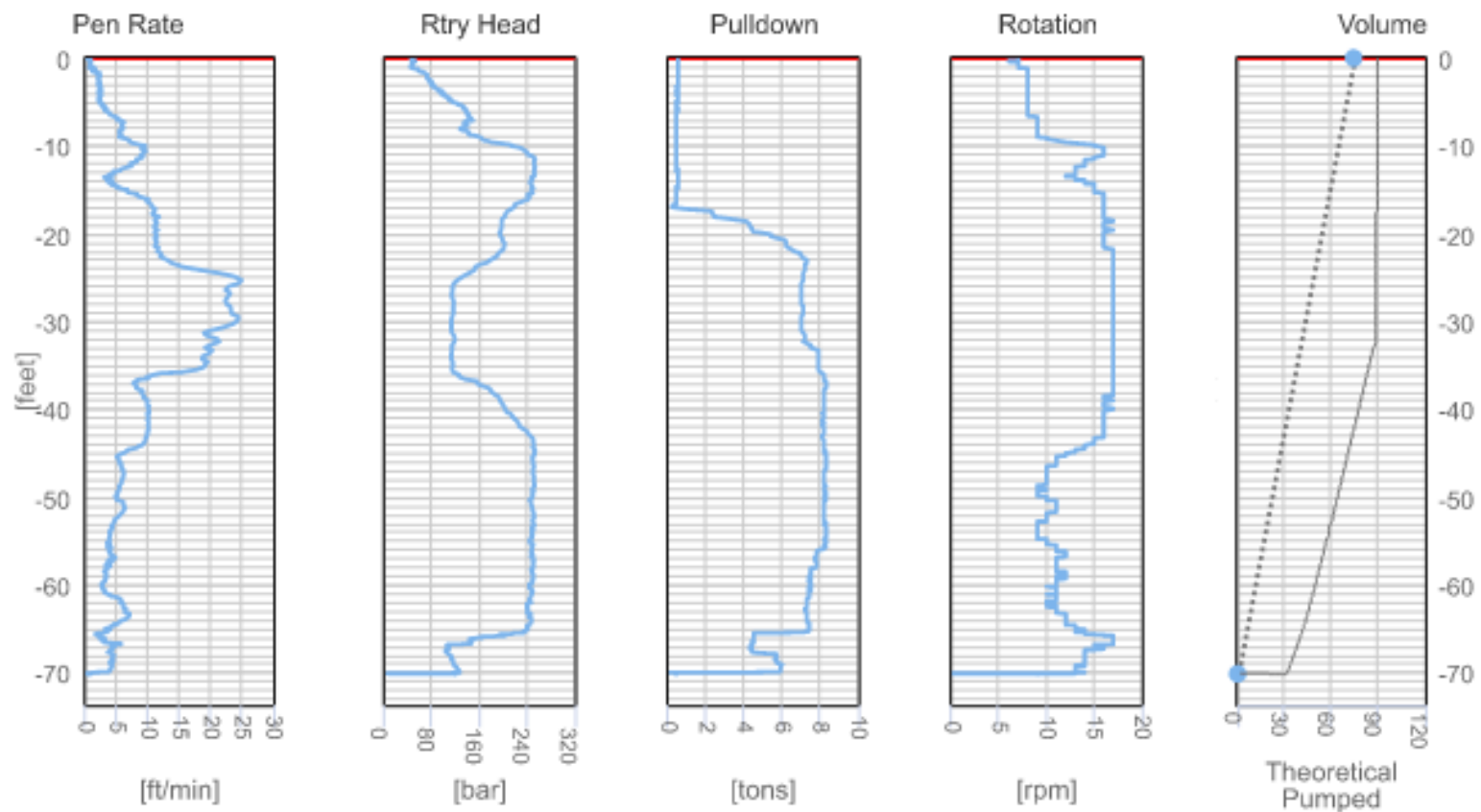


Depth Scale (-70.2 ft.)



Rigid Inclusions

Depth Scale (-70.2 ft.)



Rigid Inclusions



Rigid Inclusions

- **Design:**
 - **Diameter, spacing, depth of elements**
 - **Composition and thickness of LTP**
- **To meet:**
 - **Vertical bearing capacity and**
 - **Settlement requirements**
 - **Sometimes:**
 - **Mitigate liquefaction-induced settlement**
 - **Support lateral loads**
 - **Withstand lateral spreading**
 - **Inhibit liquefaction?**

Rigid Inclusions

- **Rigid inclusions are not deep foundations**
- **In large footings and mat foundations bearing capacity usually not critical**
- **Most often, serviceability controls design:**
 - Total settlement
 - Differential settlement
 - Sagging

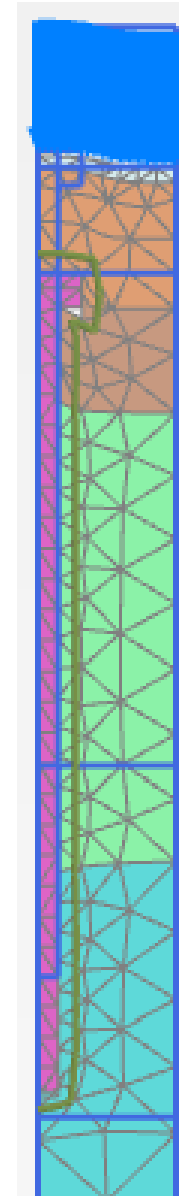
Design based on interaction between LTP, soil and Rigid Inclusions

- **Numerical analyses are typical**



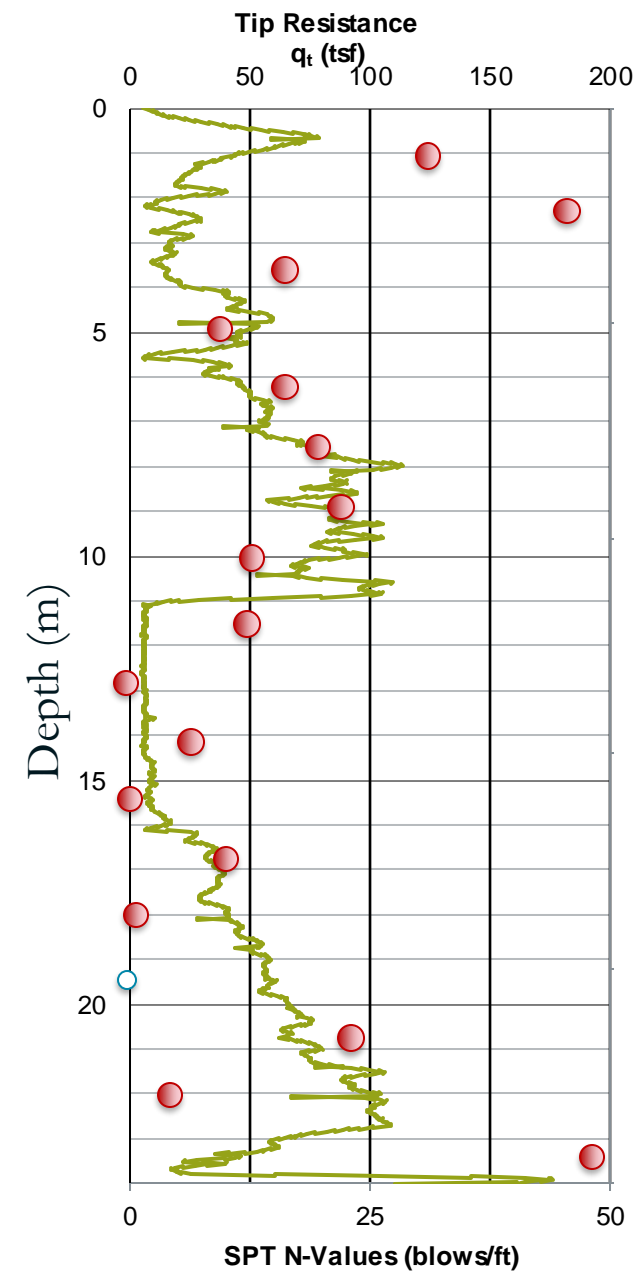
Rigid Inclusions

- **Deformation analyses critical. Usually FEM**
- **Accurate soil modeling is crucial**
- **Important to know presence and frequency of thin layers**
- **Often, available geotechnical information insufficient**
- **We find it difficult using only SPT**



CPT versus SPT

- CPT:
 - Continuous subsurface information
 - Interpretation of drained and undrained soil properties
 - No specimens unless special fitting used
- SPT:
 - Intermittent data points with no information between tests
 - Likely more sources of error
 - Specimens



CPT Overview

- Continuous Testing
- More reliable measurements than from SPT
- **Small strata changes easily discernable**
- Indication of Soil Behavior Type
- **Pore pressure measurements (dynamic and dissipation)**
- Supplement with borings (SPT, undisturbed samples and lab testing)
- 3-10 times faster than conventional drilling
- **Correlations with soil properties**



Refinería Olmeca



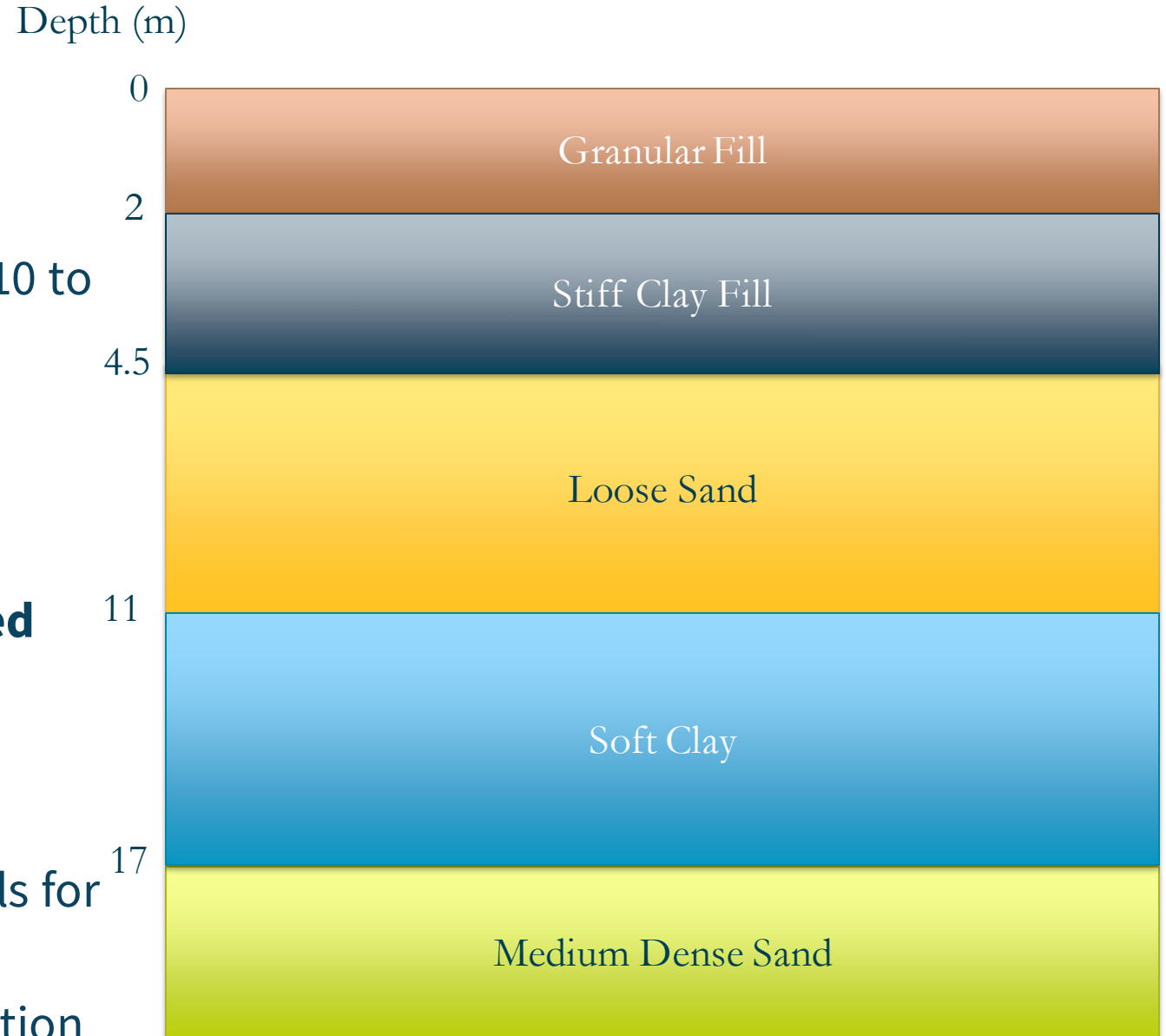


PEMEX

1 80 78 9288

Refinería Olmecca

- Industrial Site with heavy loads
- Loose sand susceptible to liquefaction, 10 to 20% fines
- Soft clay susceptible to long term consolidation settlement
- **Mitigate compression of soft soil**
- **Mitigate effects of liquefaction-induced settlement**
- Extensive pre- and post-installation CPT campaign
- Pre-installation CPTs to characterize soils for design
- Post-installation CPTs to assess liquefaction

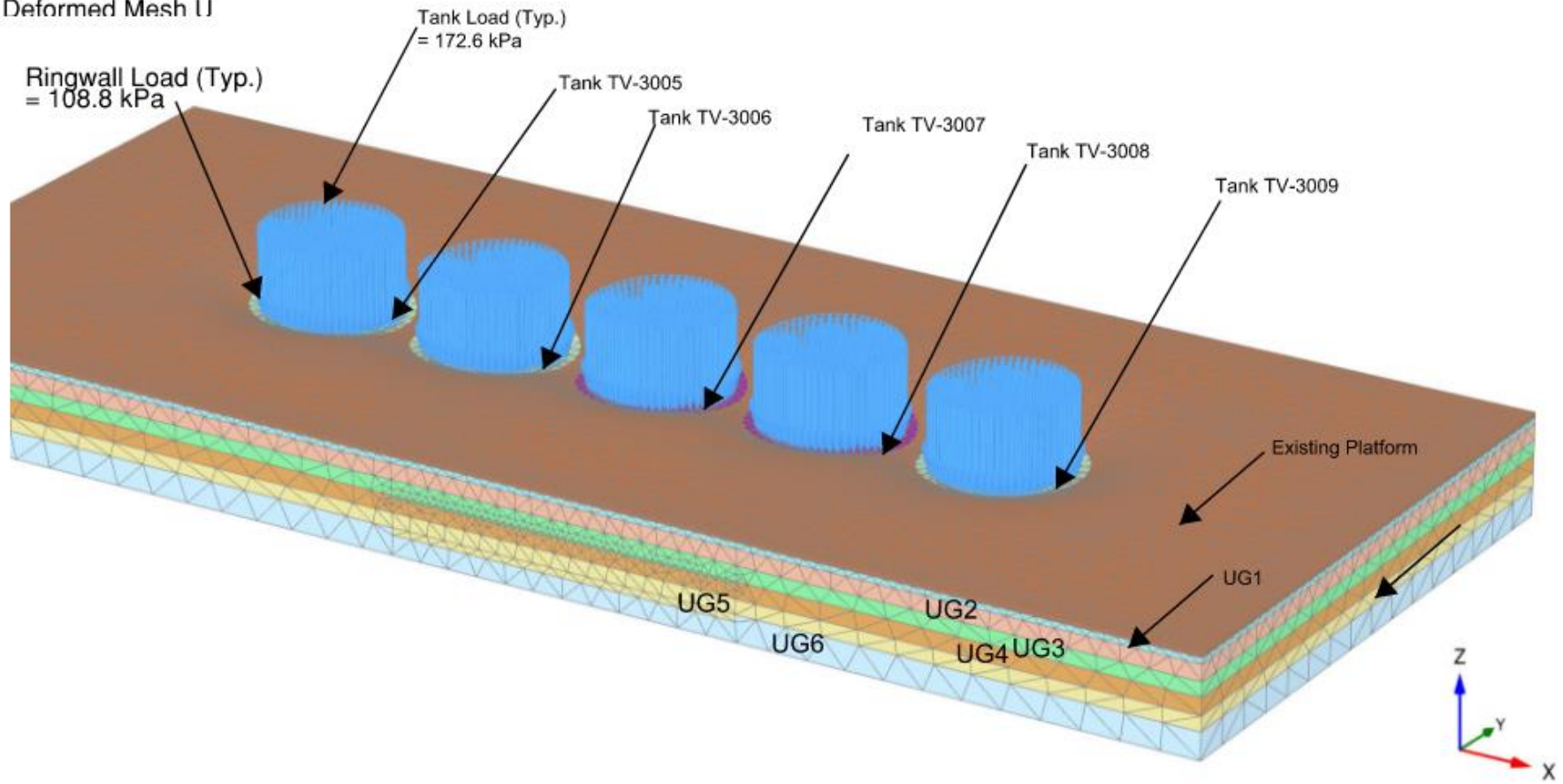




Refinería Olmeca

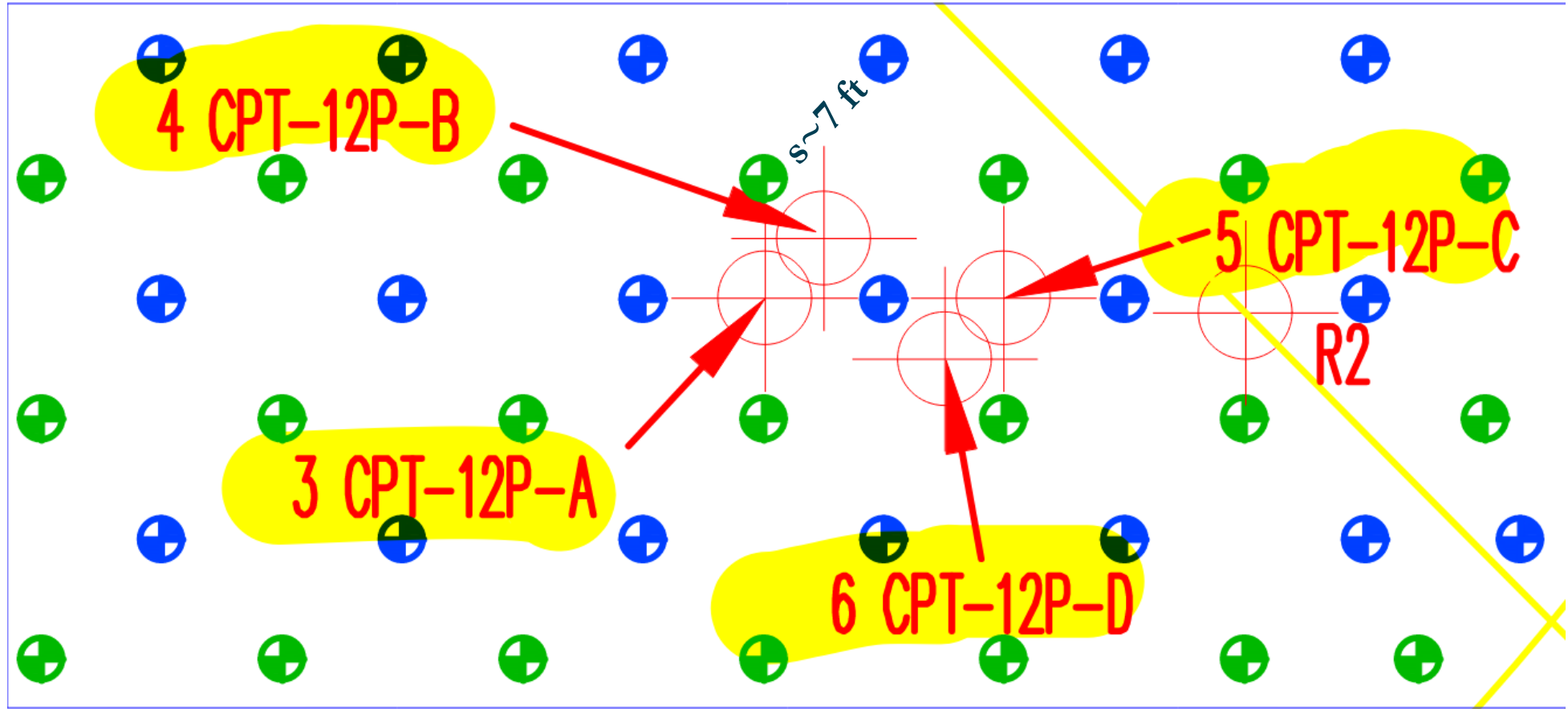
3D GLOBAL MODEL

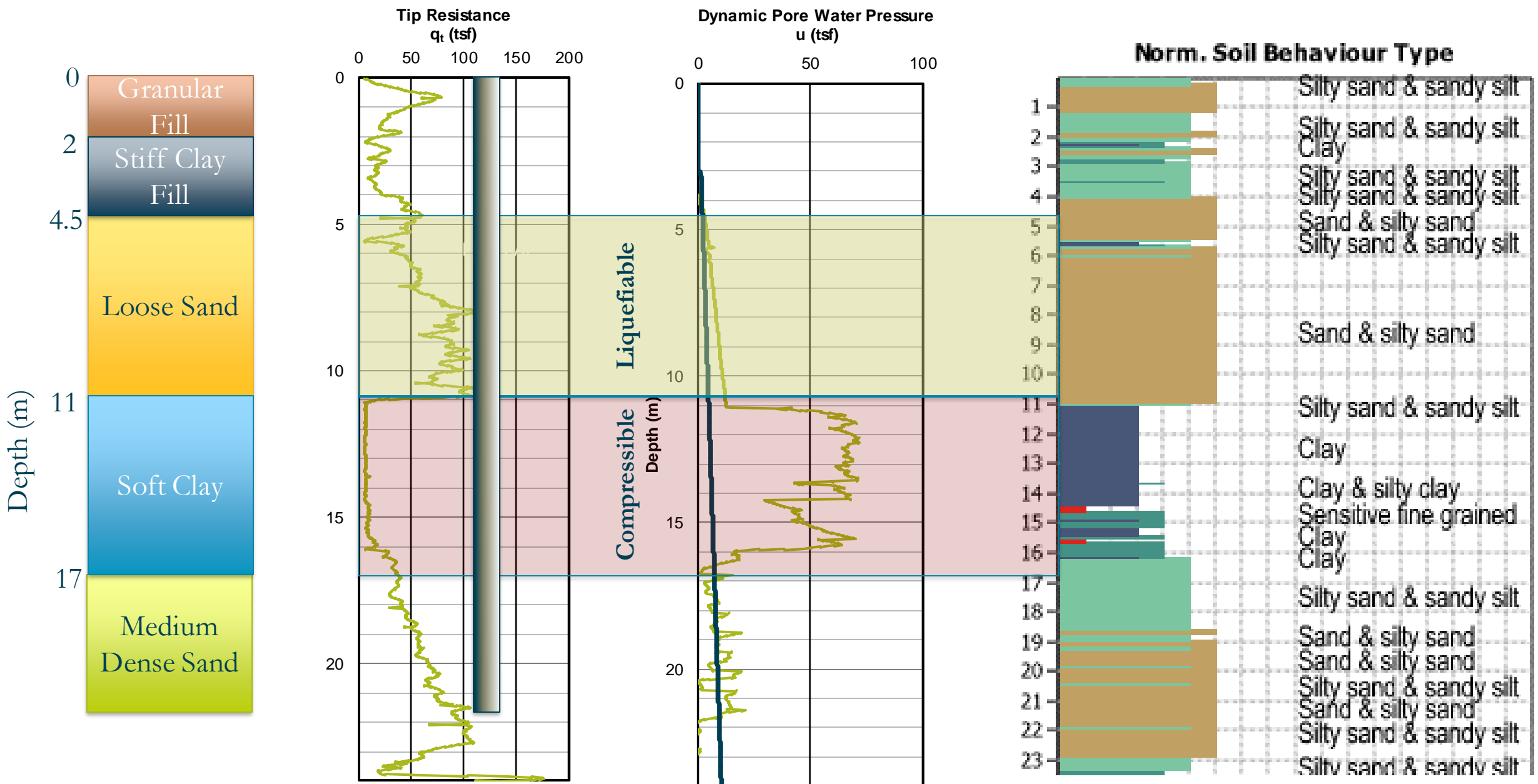
Deformed Mesh IJ



Deformed mesh |u| (scaled up 100 times)
Maximum value = 0.1588 m (at Node 71137)

Refinería Olmeca





Depth (m)

Tip Resistance
 q_t (tsf)

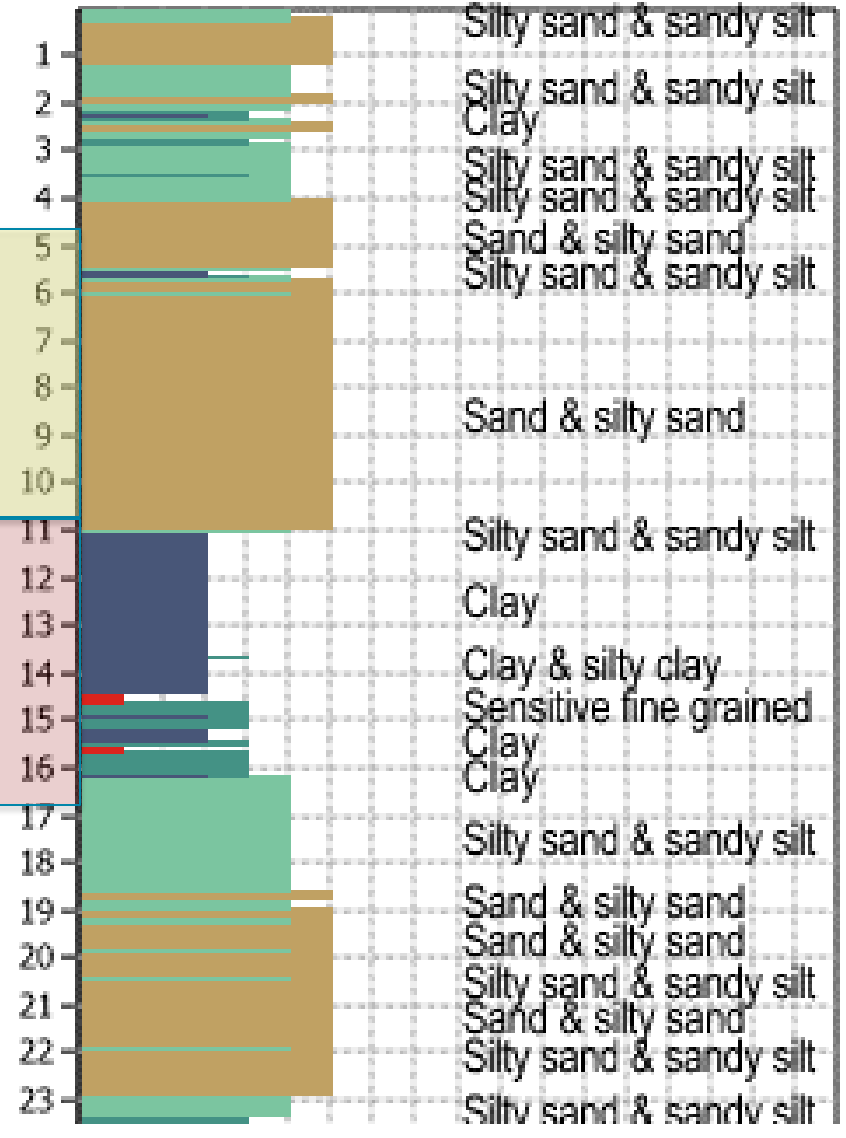
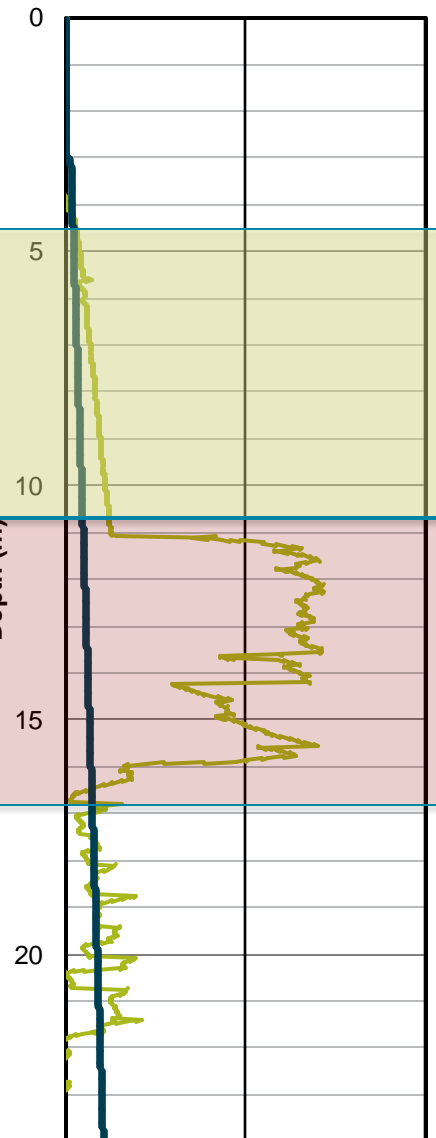
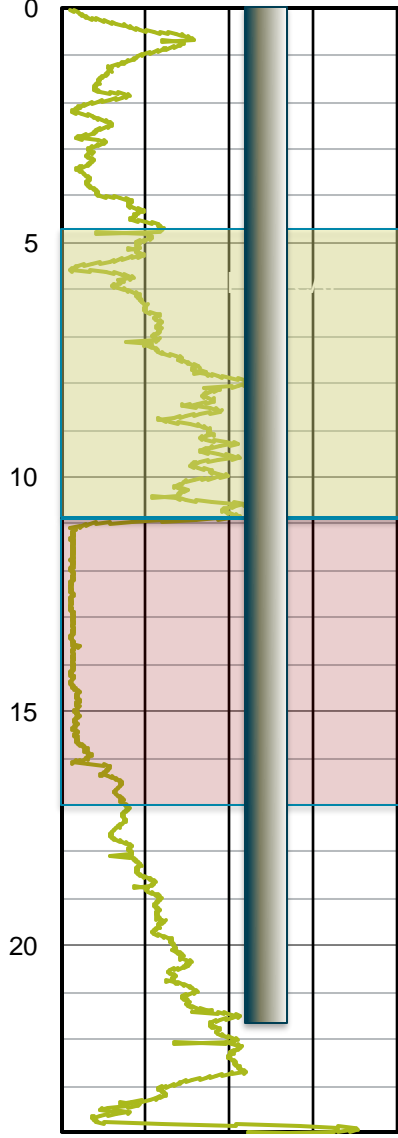
Dynamic Pore Water Pressure
 u (tsf)

Norm. Soil Behaviour Type

0 50 100 150 200

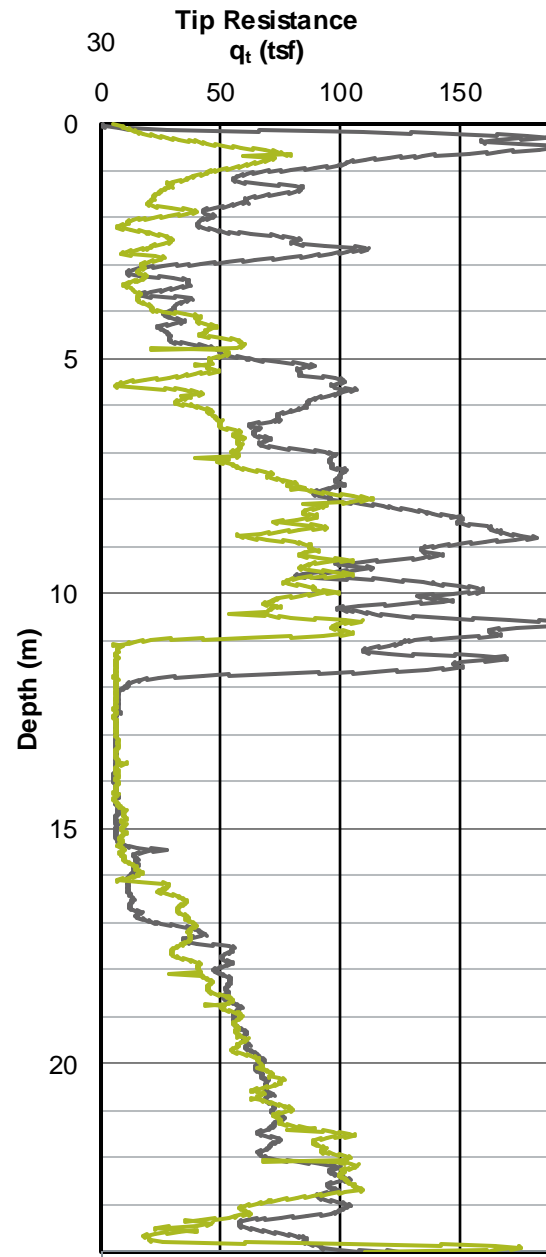
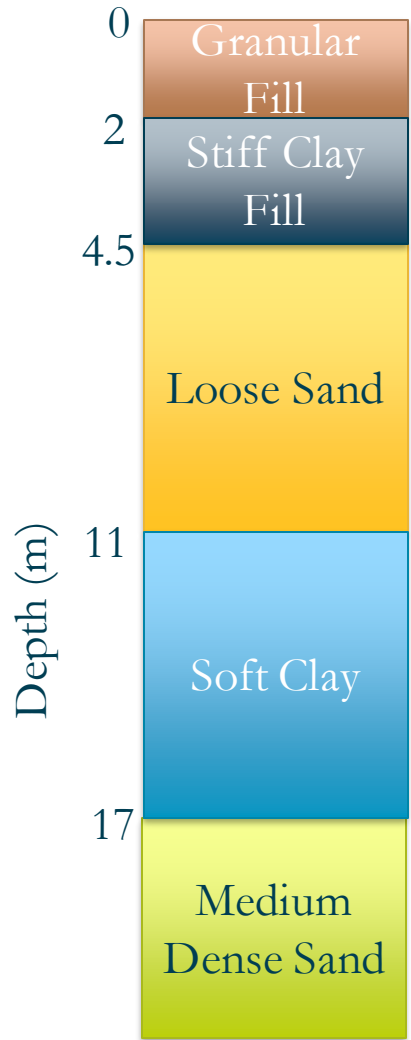
0 50 100

0 Granular Fill
2 Stiff Clay Fill
4.5 Loose Sand
11 Soft Clay
17 Medium Dense Sand

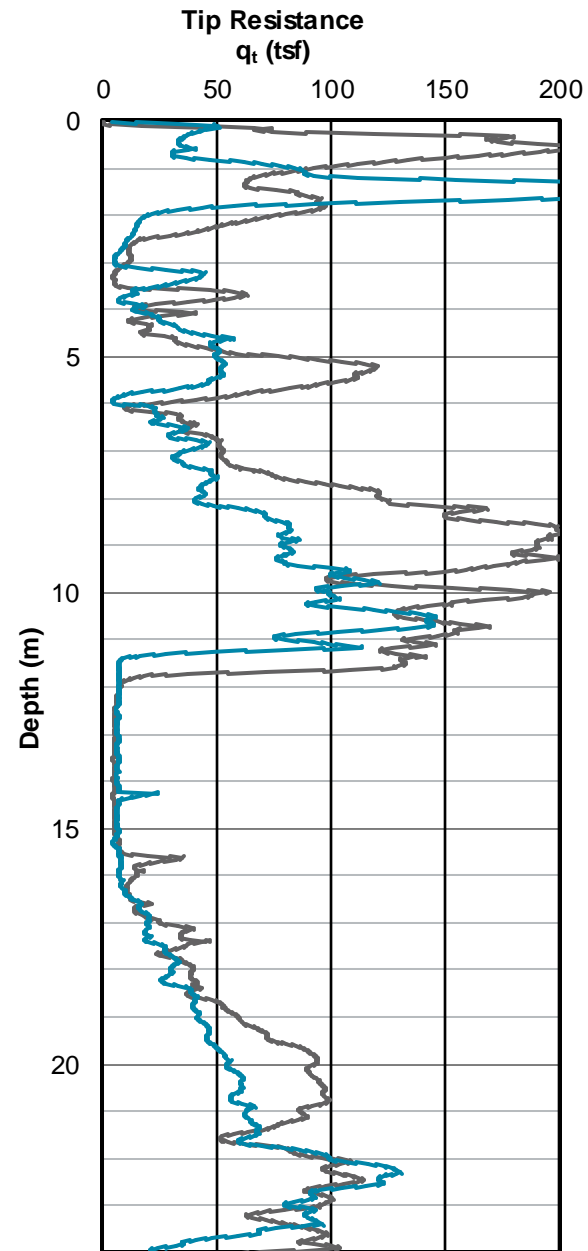


Liquefiable

Compressible



— Post-Installation — Pre-Installation

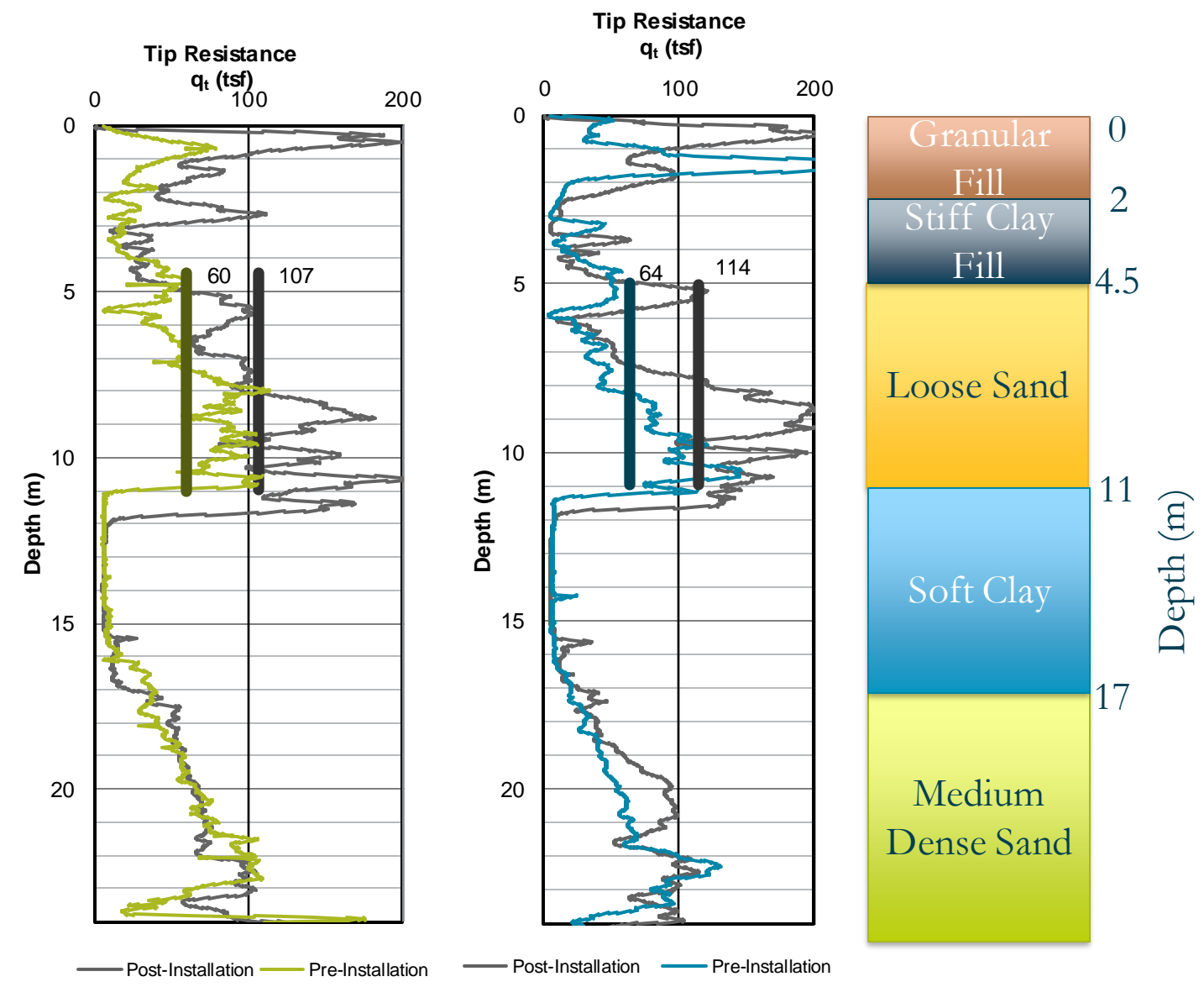


— Post-Installation — Pre-Installation

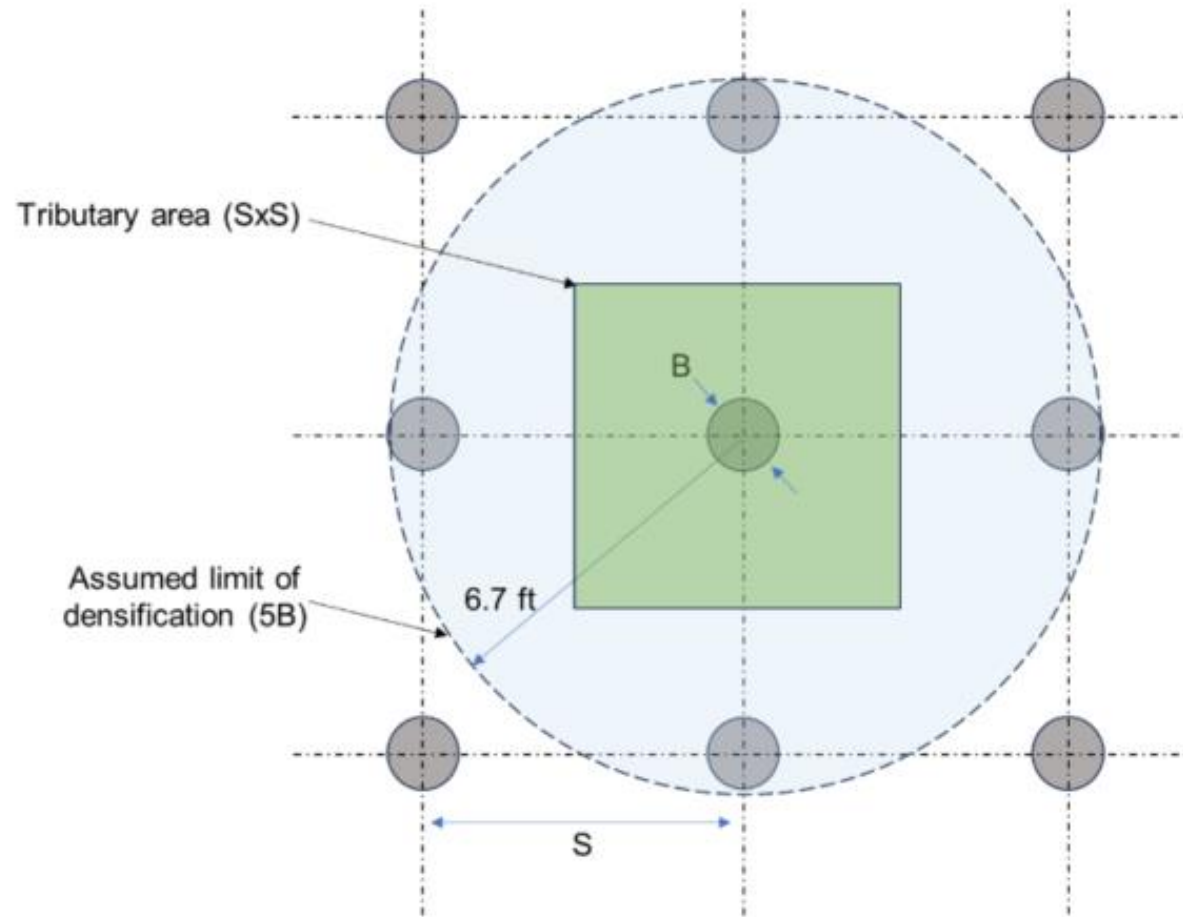
Significant increase of tip resistance after RI installation

Strength increase

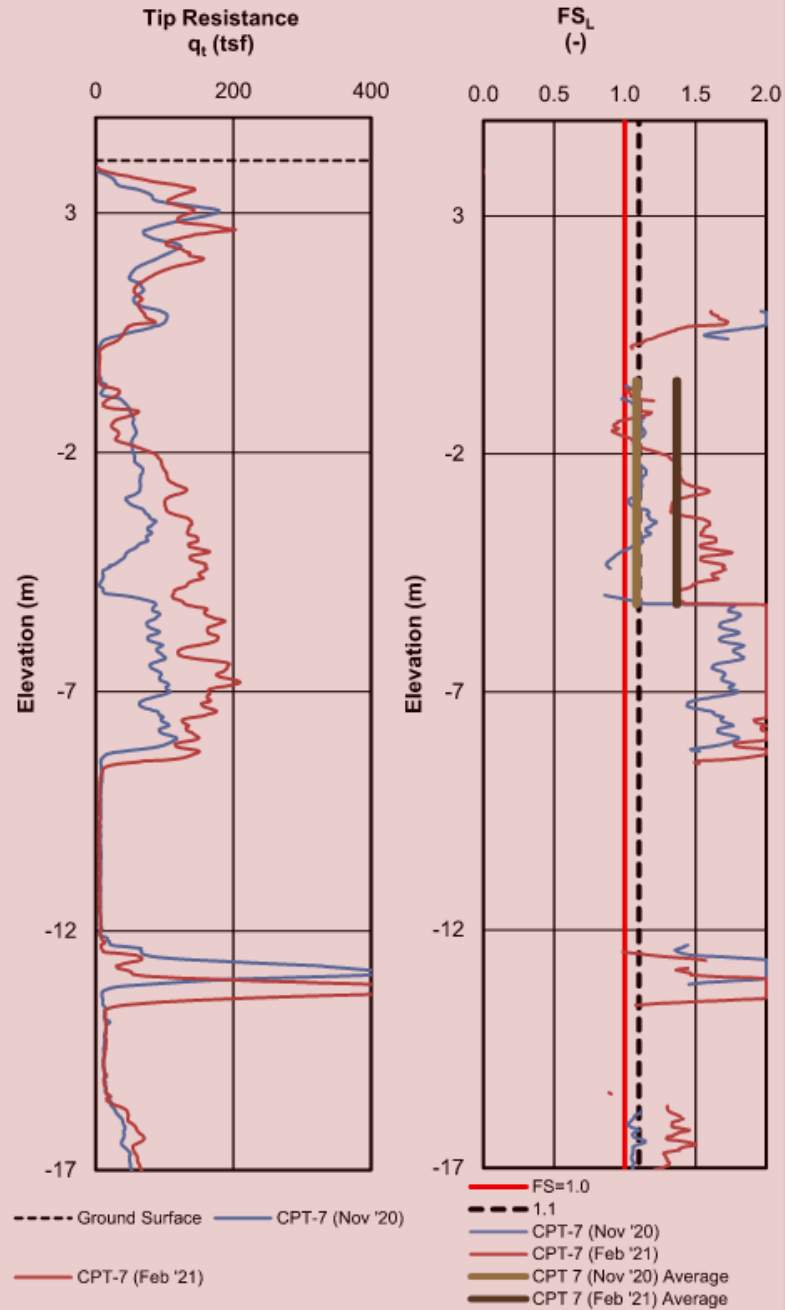
- About 78% increase in average q_t in loose sand
- Suggests increase in friction angle from about 32° to 41°



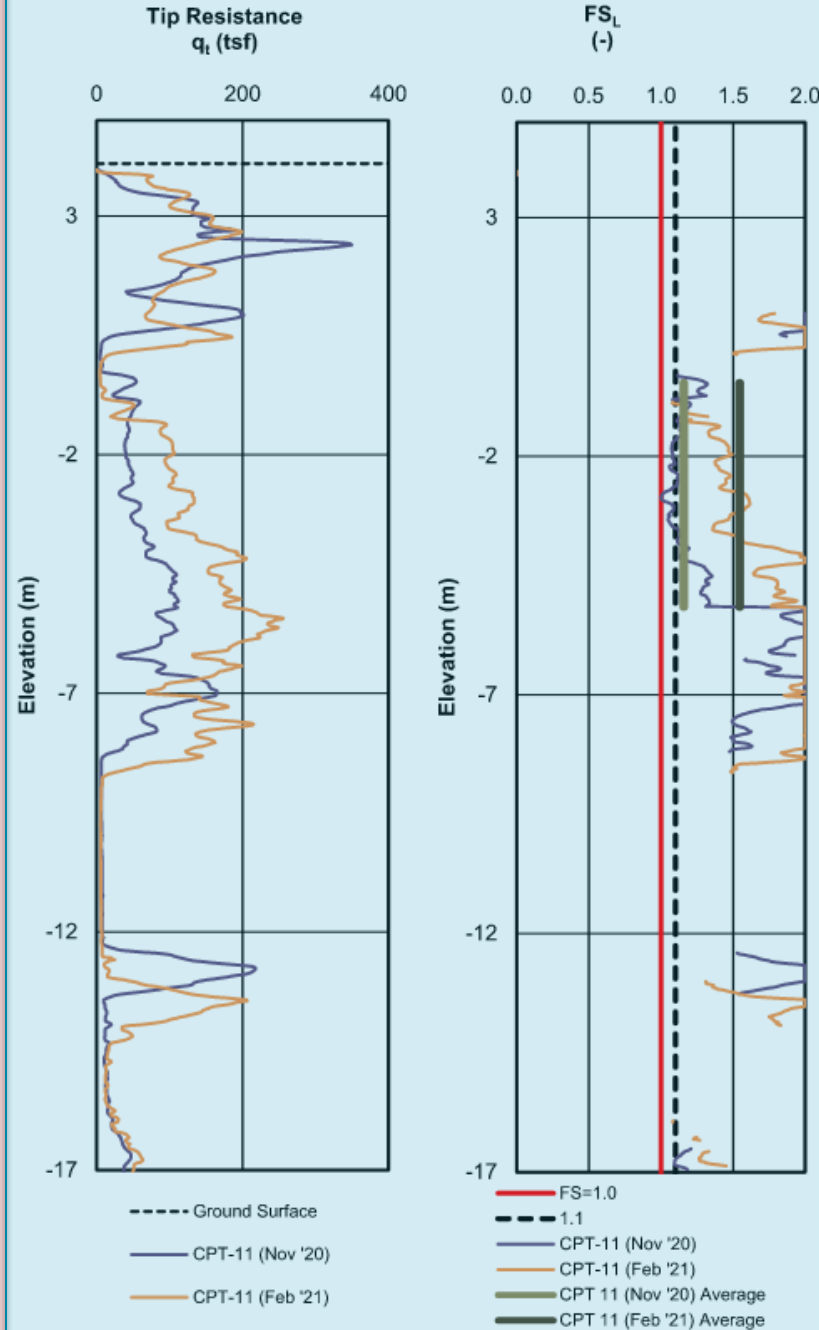
Liquefaction



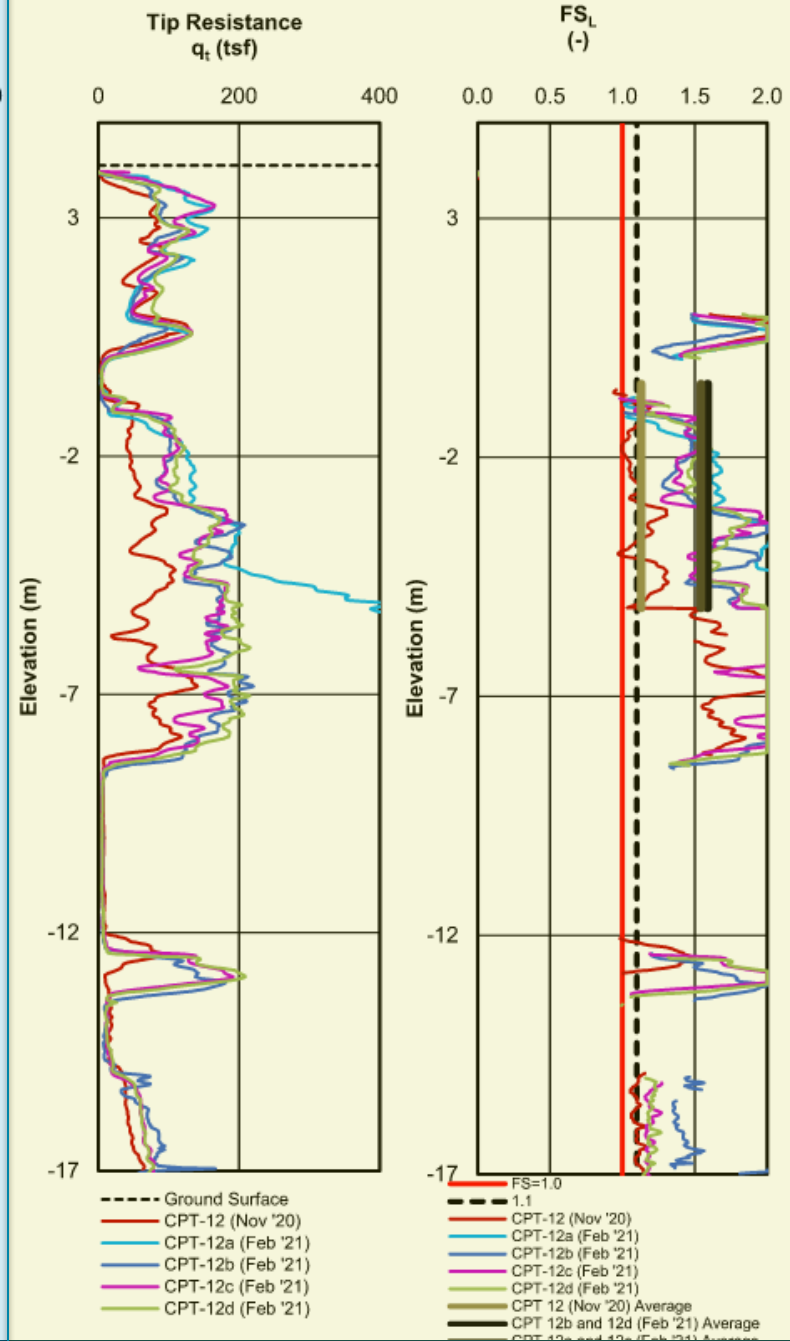
CPT-7 Liquefaction Assesment



CPT-11 Liquefaction Assesment

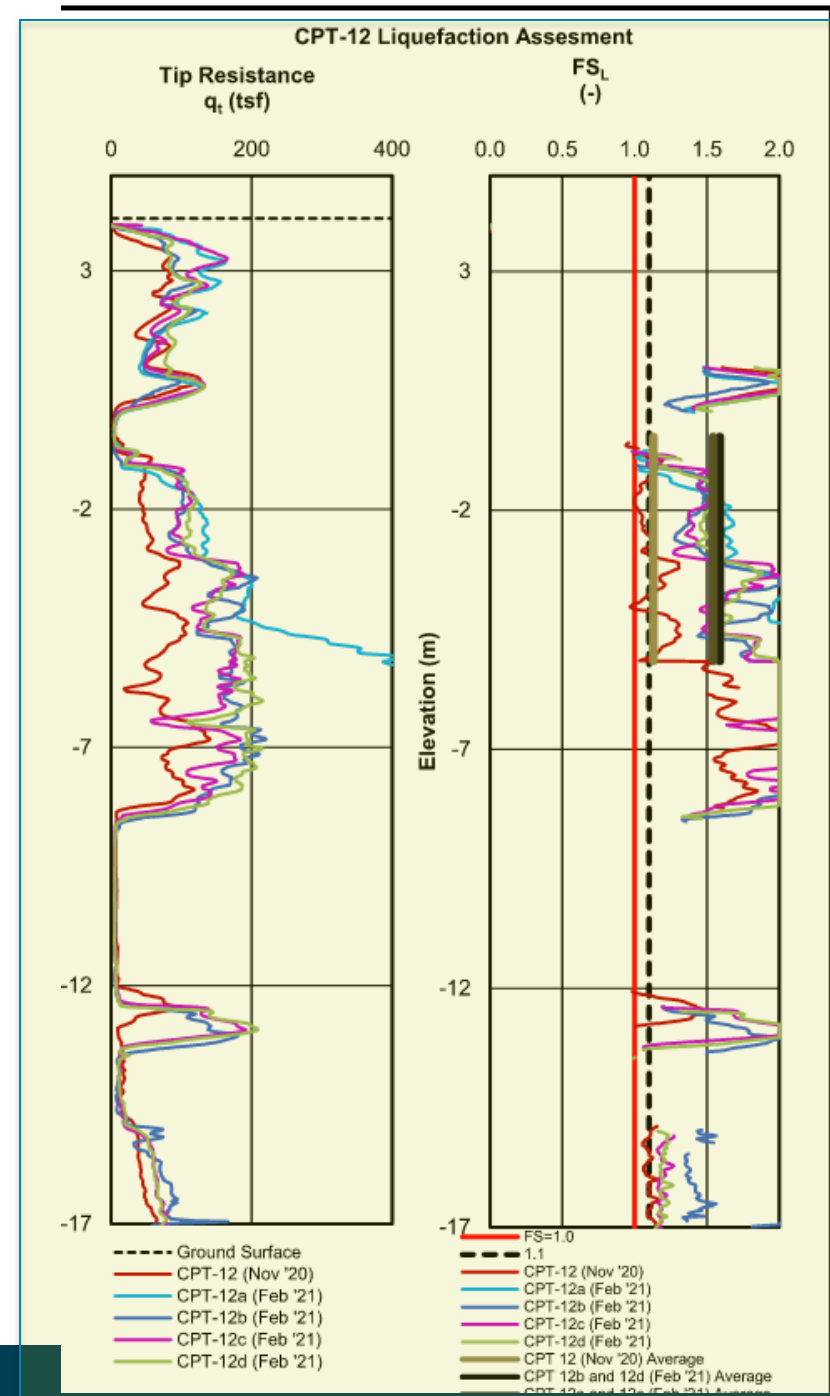


CPT-12 Liquefaction Assesment

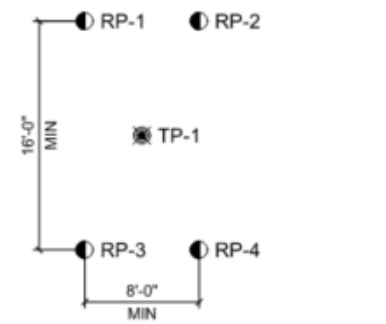
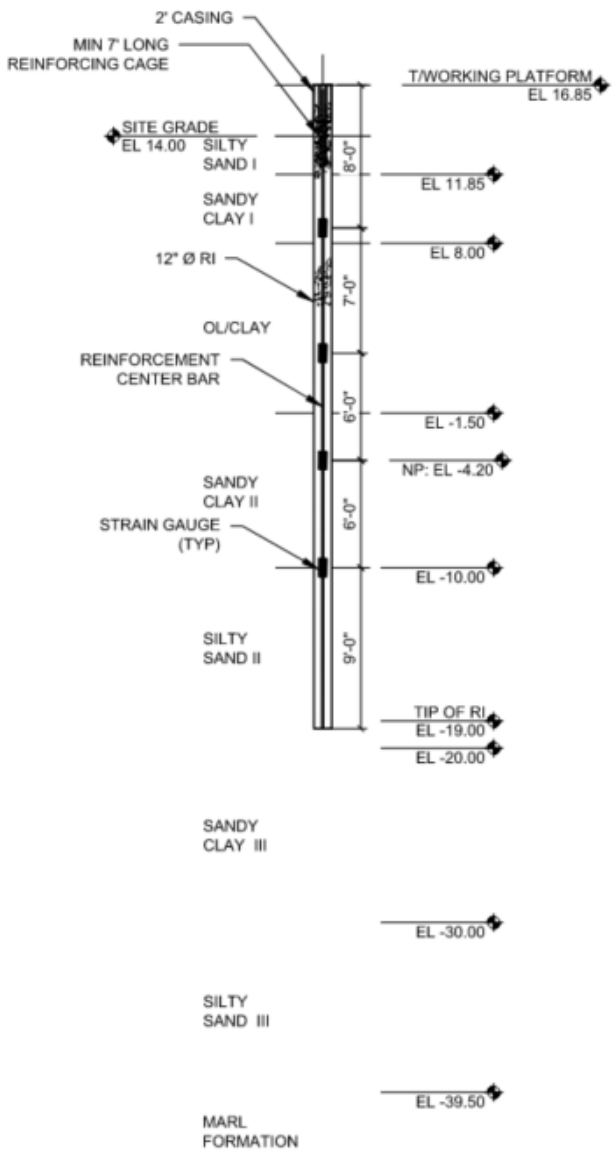


Liquefaction

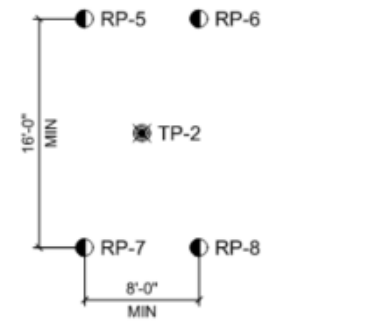
- Increase in FS against liquefaction from 1 or lower to 1.5 in loose sand
- Likely due to increase in:
 - Density
 - Lateral confinement
- Similar results obtained by others at same site
- Similar results obtained at Huntington Beach in California
- Simple method of estimation of final density worked well



Load Testing



4 TEST PILE 1 LAYOUT
NO SCALE



5 TEST PILE 2 LAYOUT
NO SCALE



6 TEST PILE 3 LAYOUT
NO SCALE

3 TP-3 - 12" Ø DISPLACEMENT TEST RIGID INCLUSION
NO SCALE

SAVANNAH, GEORGIA MORRIS SHEA BRIDGE COMPANY, INC. 609 SOUTH 20TH STREET IRONDALE, AL 35210		TEST PILE DETAILS
Project 2302883	SEPTEMBER 2023	LT-03

Load Testing



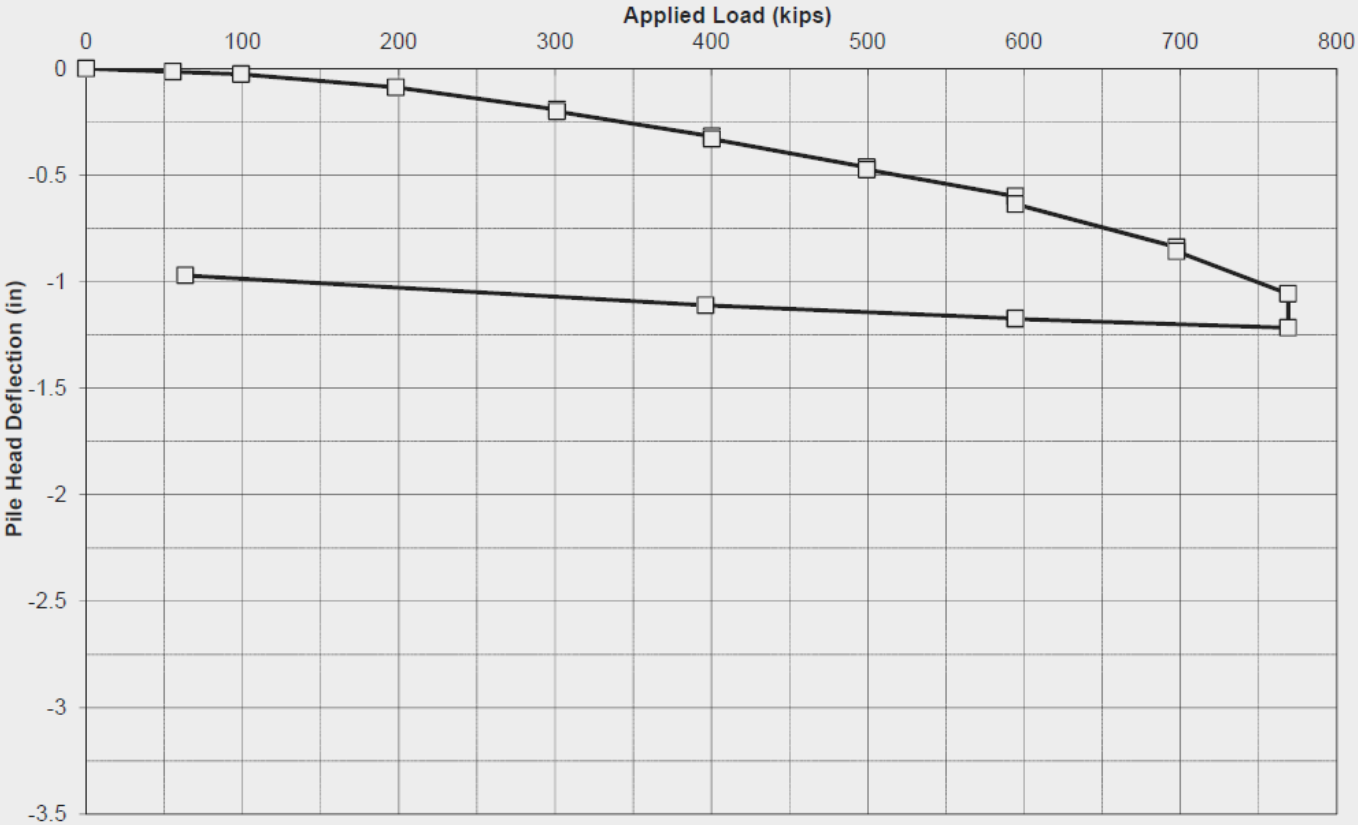
Load Testing



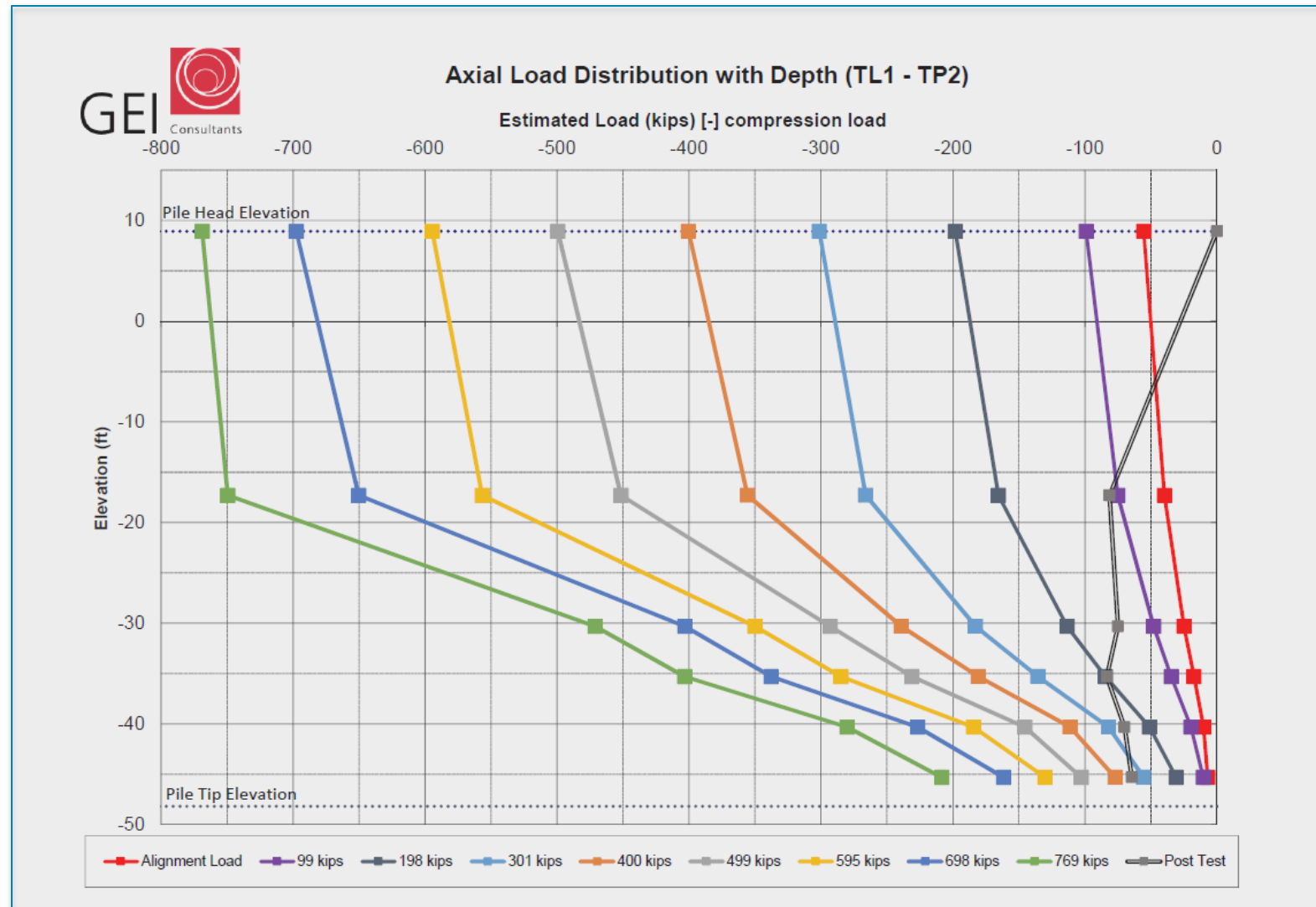
Load Testing



Pile Head Deflection vs Axial Load (TL1 - TP2)



Load Testing



Morris-Shea Bridge Company
Job 1528, Heavy Haul Road
Rigid Inclusions Pile Drill Log

MORRIS-SHEA
 BRIDGE COMPANY, INC.

Job Site Data

JOB NAME: Heavy Haul Road
 JOB NUMBER: 1528
 OWNER:
 CLIENT: Schnabel Engineering, LLC

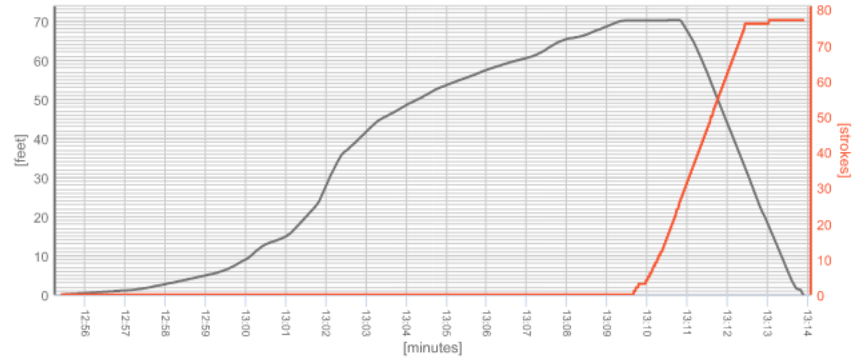
Pile No: RP7, Type: Reaction

DATE: 3/3/2022
 START TIME: 12:55pm
 END TIME: 1:13pm
 TOTAL TIME: 0:18:28
 RIG: DR123
 OPERATOR: Manuel Perez Roa

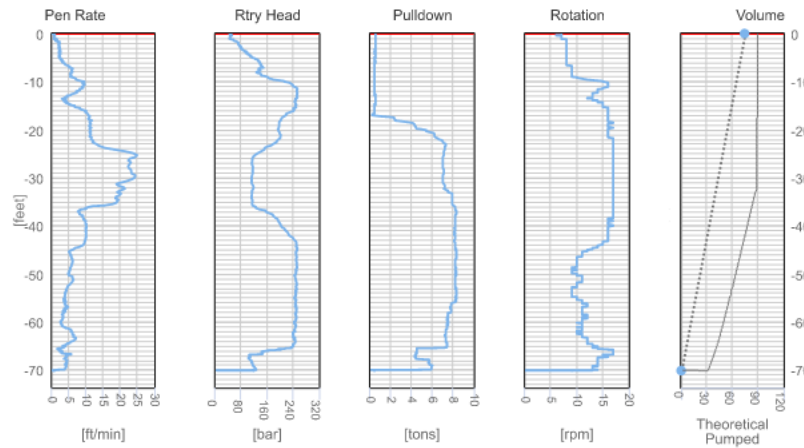
PILE LENGTH [ft]: 70.2
 PILE DIAMETER [in]: 14
 STROKES: 77
 PUMP CALIB. [cy/str]: .043
 OVER BREAK: 19%

Time Scale (0:18:28)

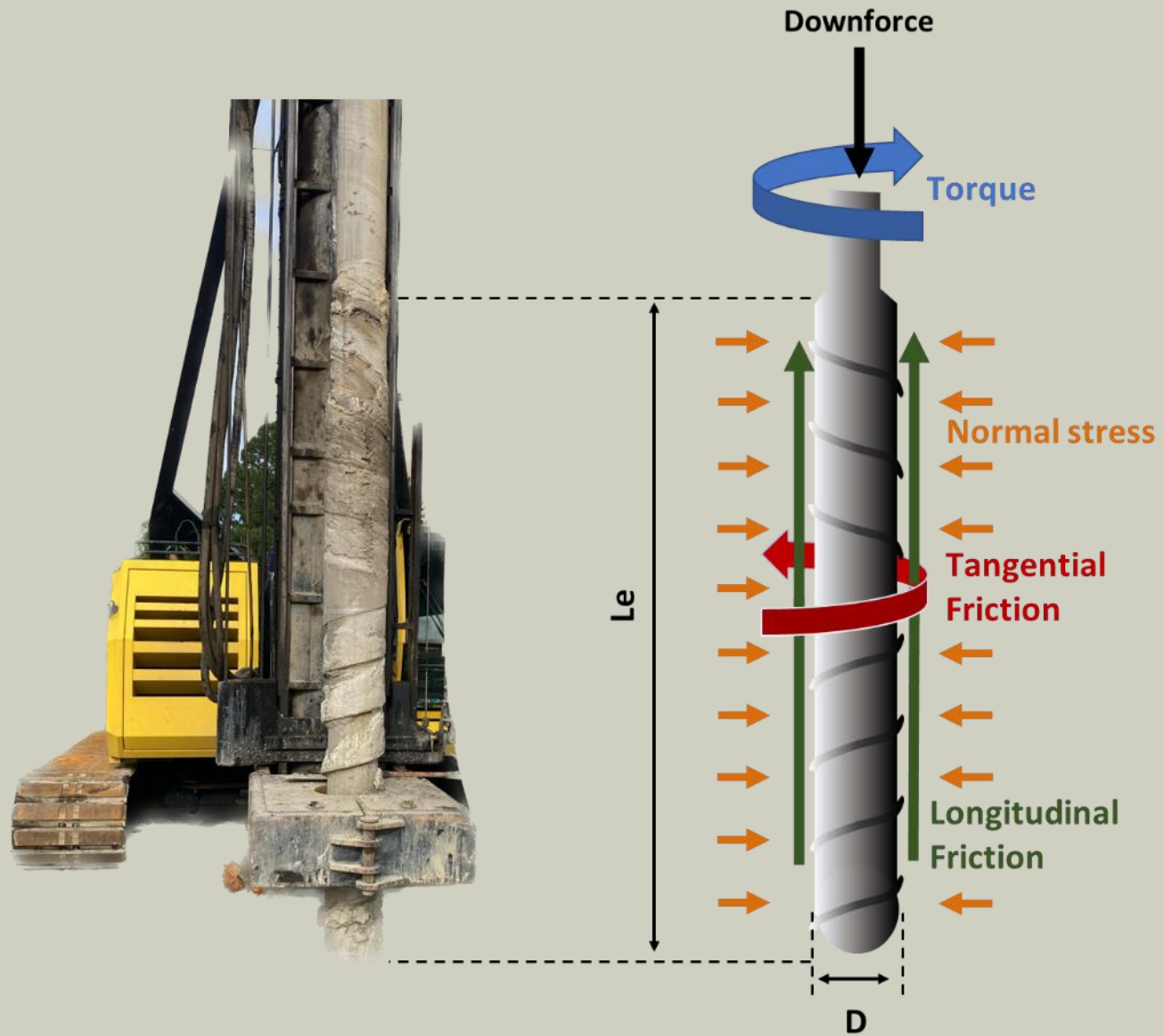
Depth & Strokes

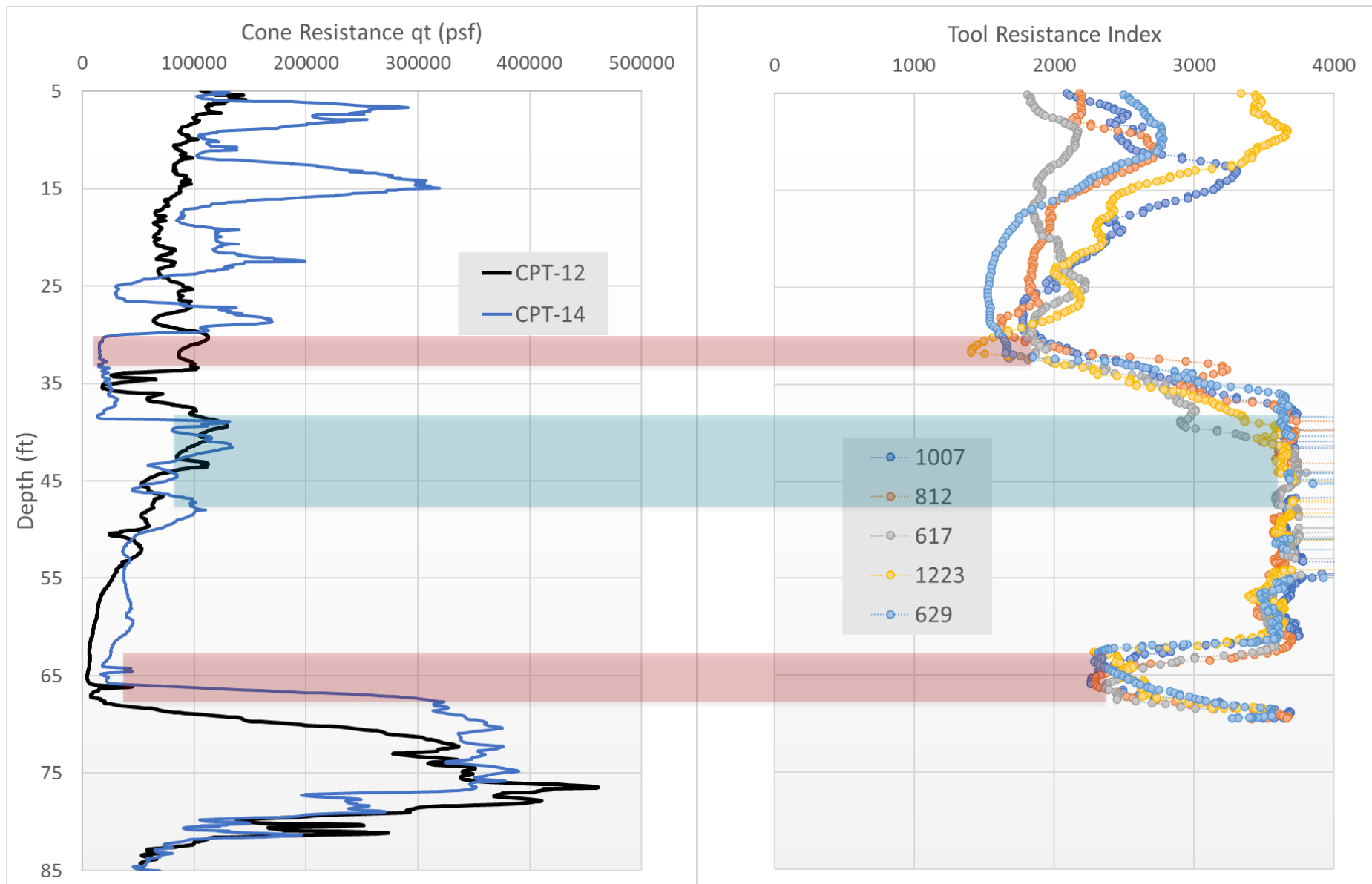


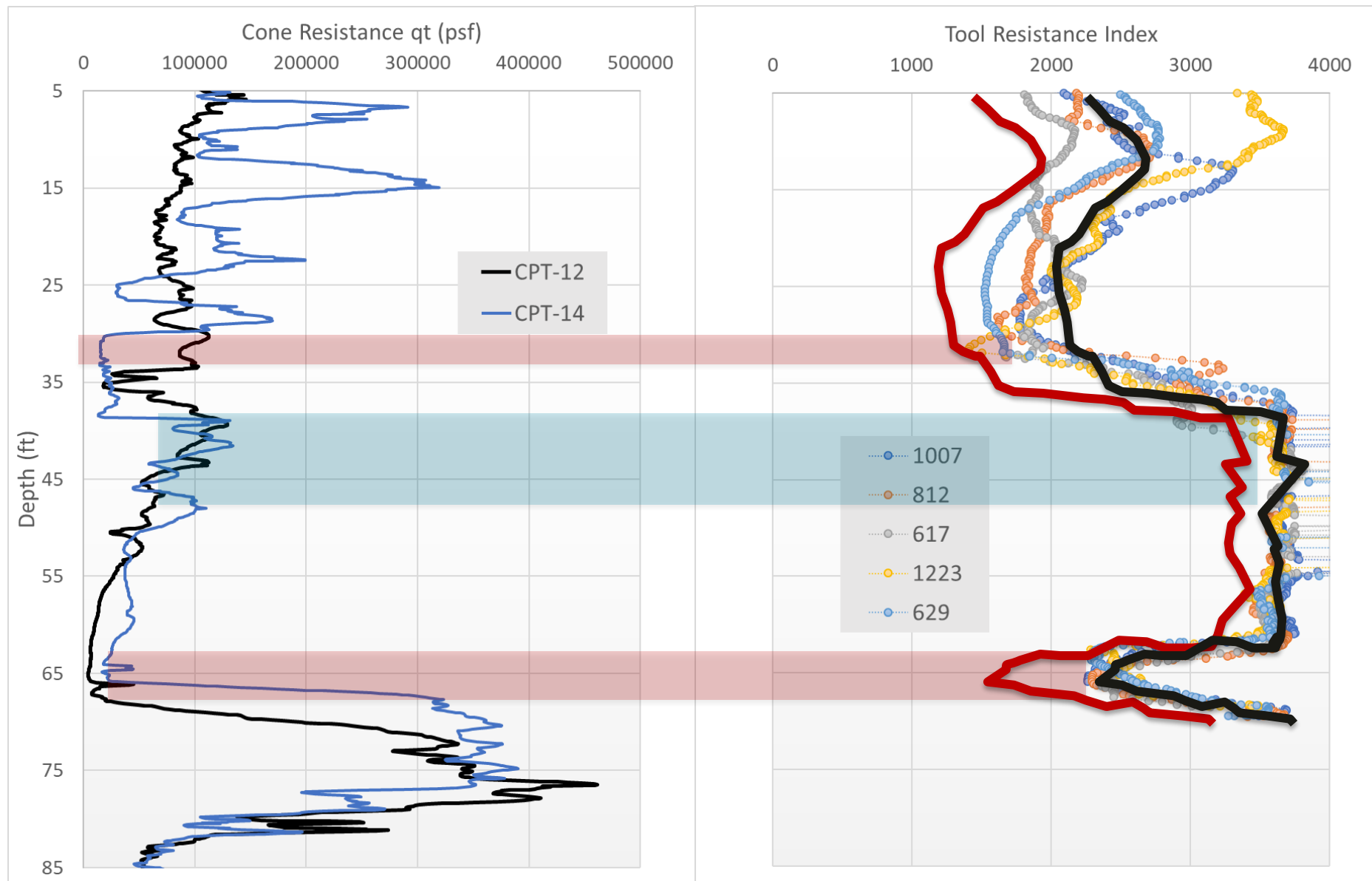
Depth Scale (-70.2 ft.)

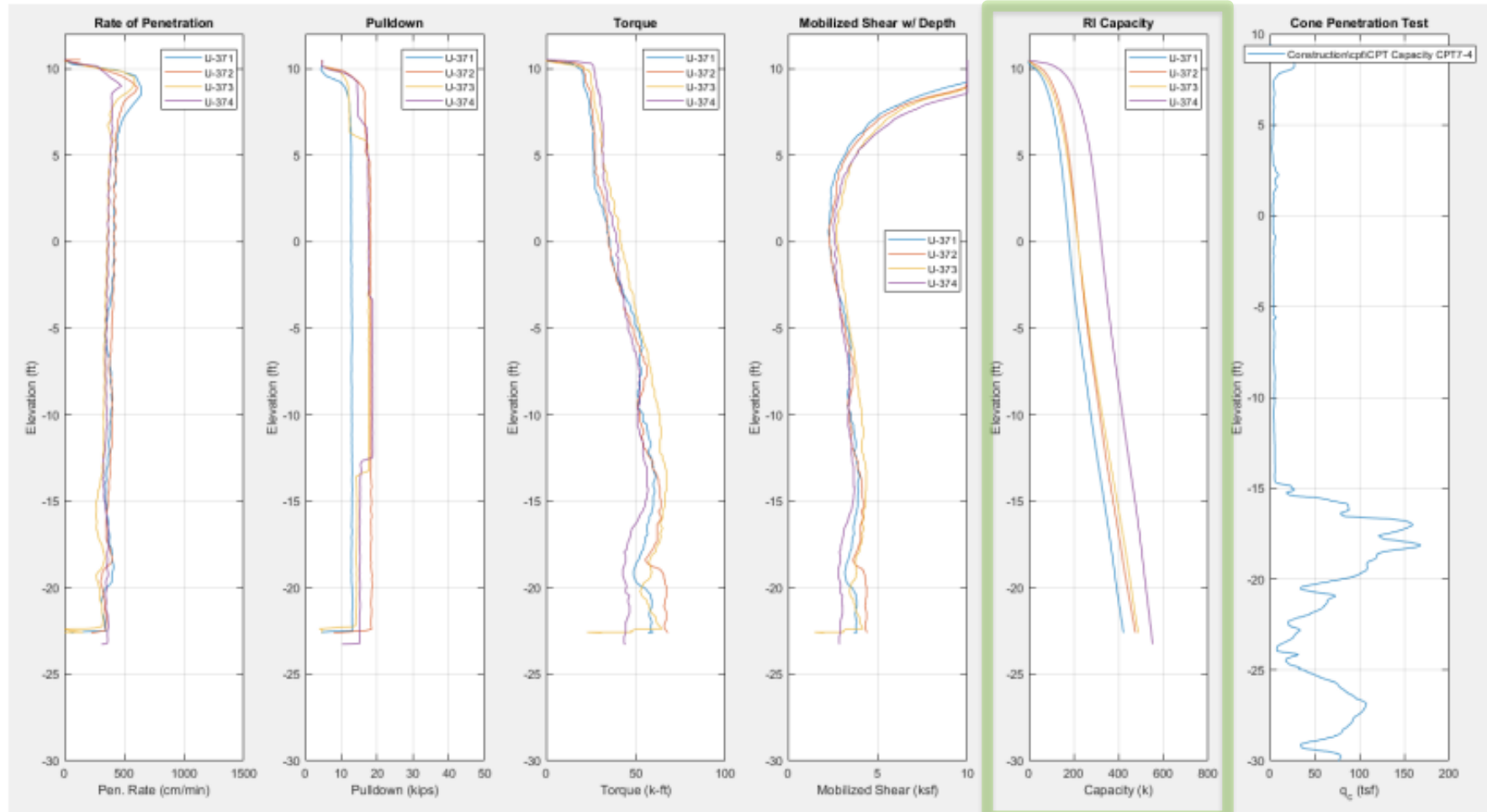


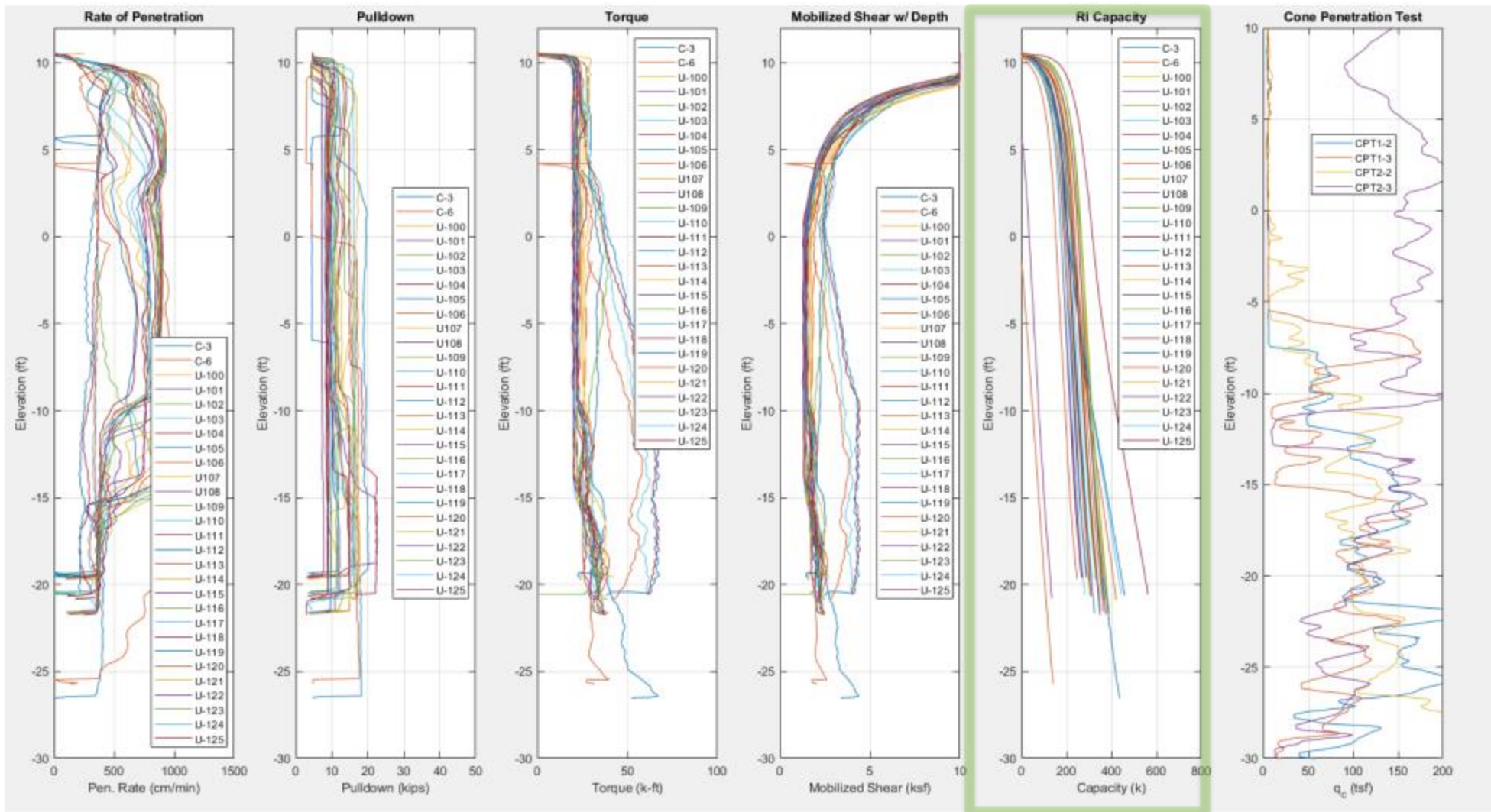
Rigid Inclusions

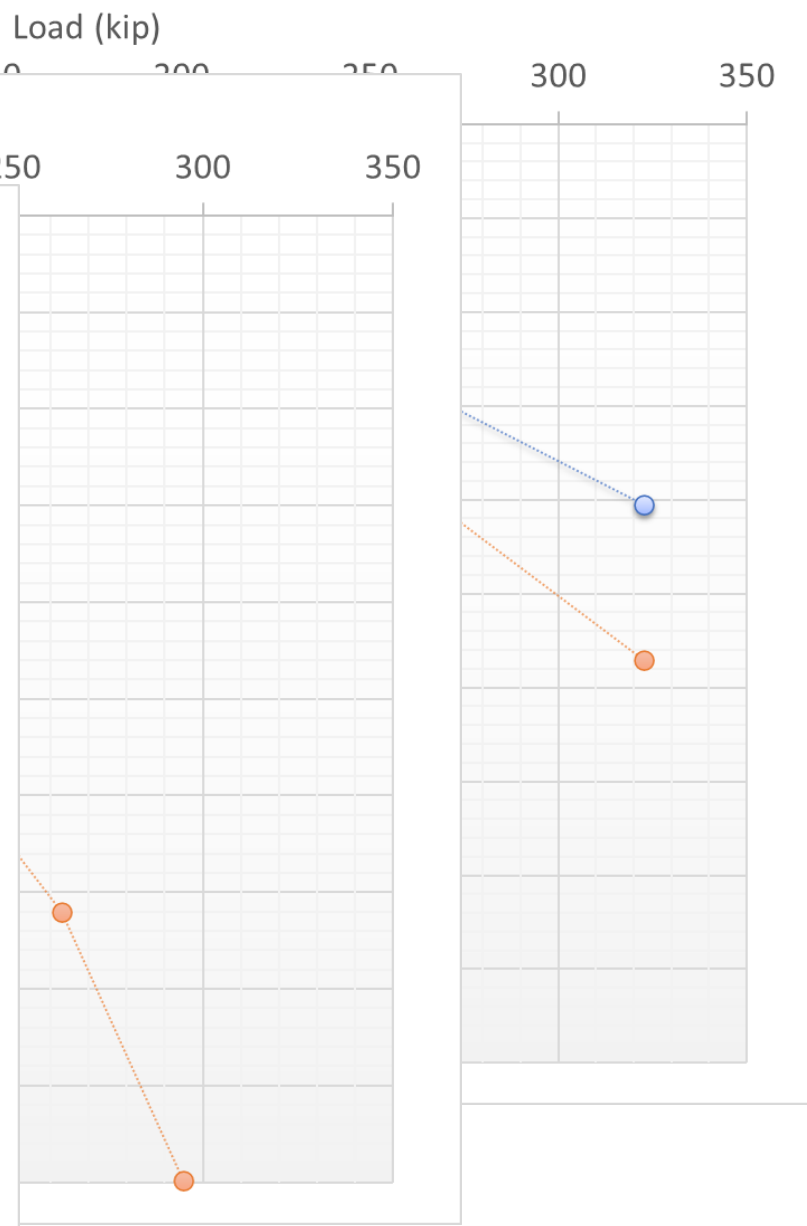
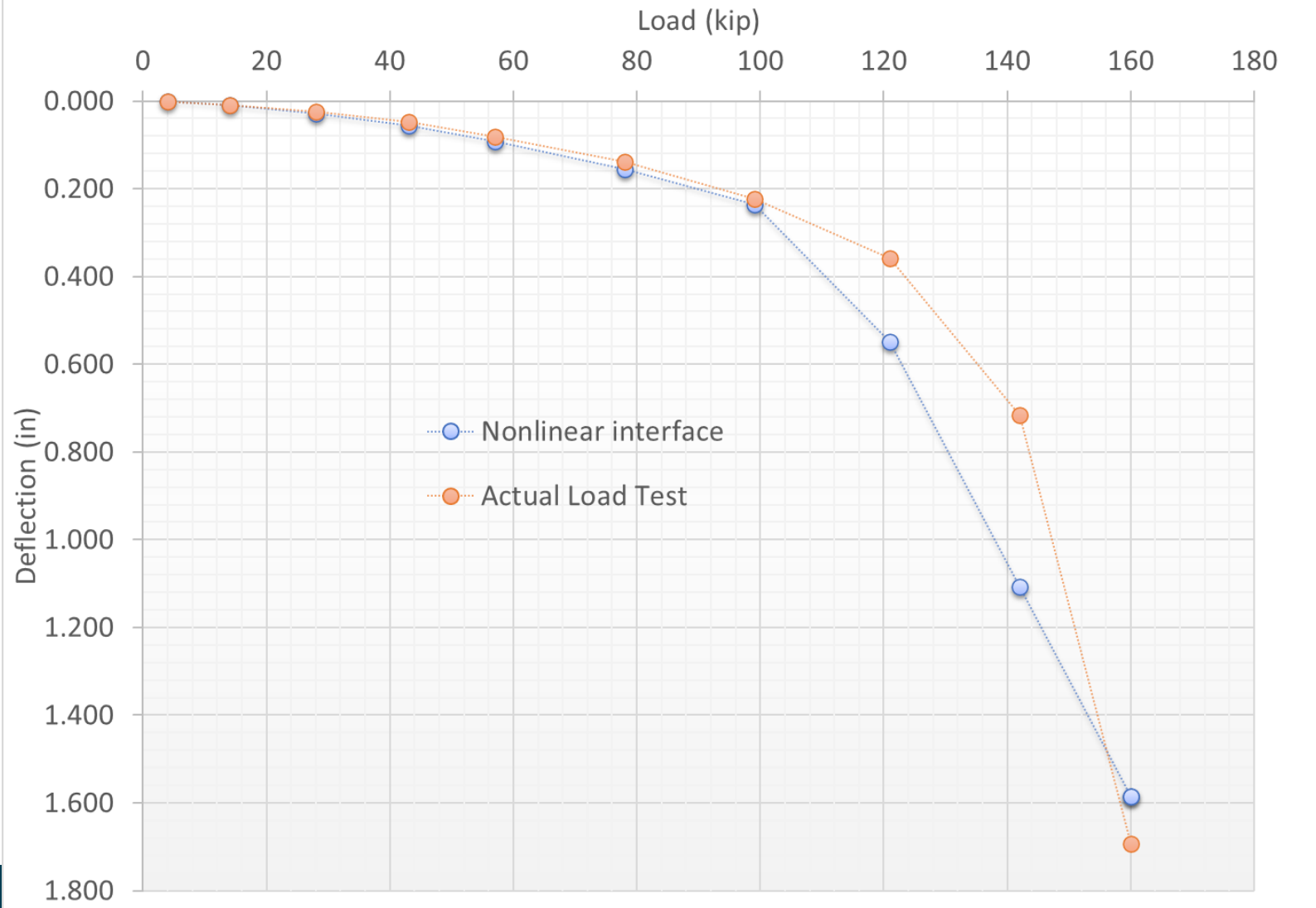












Conclusions

CPT invaluable for:

- Site characterization during design
- Assessment of magnitude of ground improvement
- Verification of installation quality

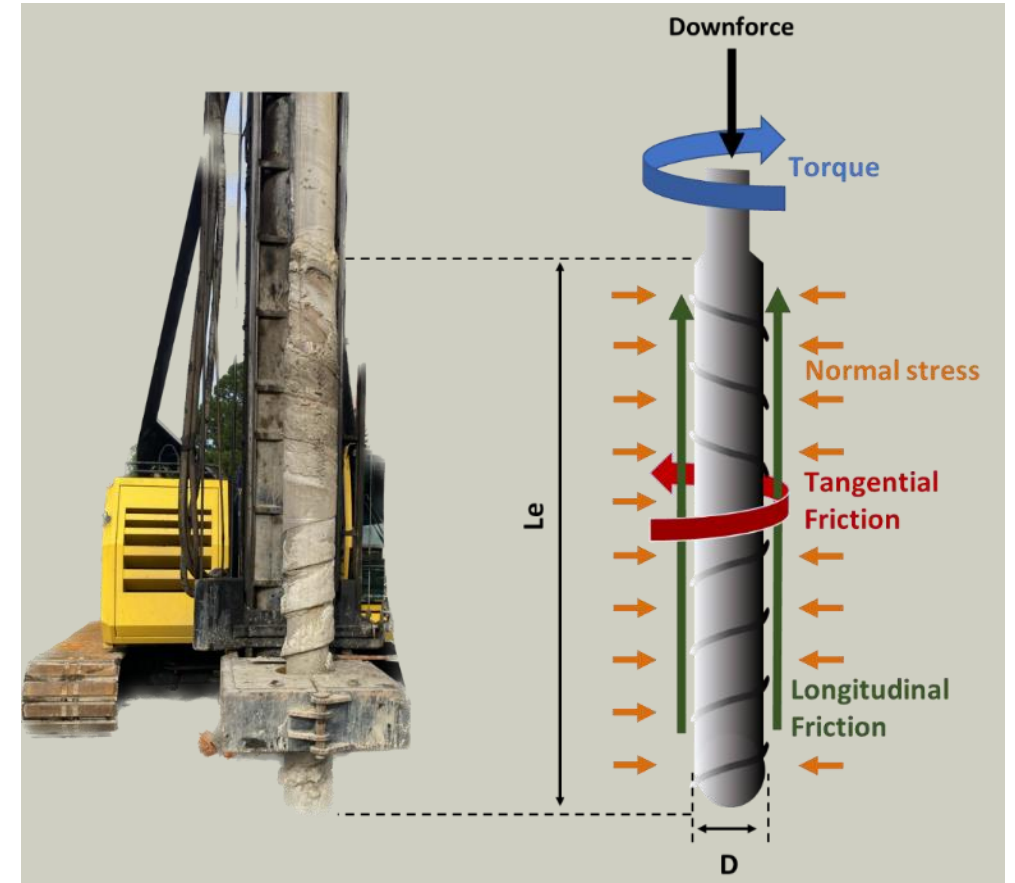
Be aware:

- Careful coordination to co-locate pre- and post- installation CPTs
- Post-installation CPTs at least 1 week after installation



Conclusions

- Significant densification of granular soils and large lateral pressures
- Each rigid inclusion is a site probe in itself
- Use of installation parameters for efficient performance assessment is possible
- Current work shows good prediction of axial resistance from installation parameters



Thank you

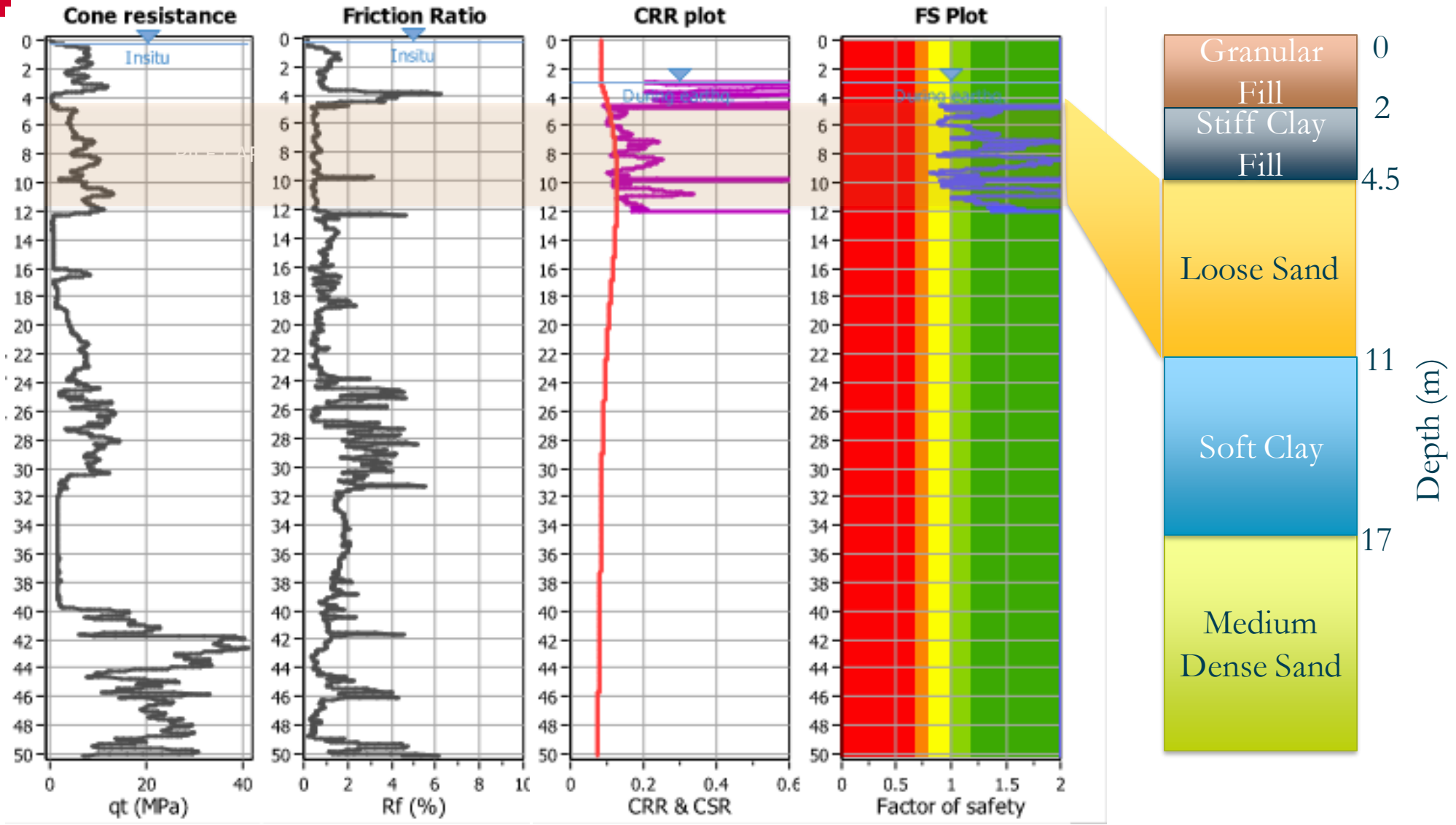
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Jgomez@geiconsultants.com



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Liquefaction



Liquefaction

