Measuring While Drilling (MWD) for Geotechnical Applications

58th Annual Geotechnical Engineering Conference

University of Kansas

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What is MWD?

- A series of sensors are placed on a drill rig to measure drilling resistance
- Long used in energy drilling to improve drilling efficiency
- Provides high-resolution subsurface profiles from routine drilling, reducing uncertainty
- Recent research supports soil and rock assessment, foundation capacity prediction, and construction QA/QC



MWD instrumentation (early 2000s)



MWD instrumentation (2016)

MWD Applications in Florida

Site Investigation and Characterization

- MWD-assisted rock coring
- Soil and rock assessment – MWD Quick Method

Bored Pile QA/QC

- Drilled shafts
- Auger-cast piles

FDOT MWD Test Method: FM 5-625
“Measuring While Drilling (MWD) for Geotechnical Applications”

Site Characterization MWD – Design



Bored Pile MWD – Construction QA/QC



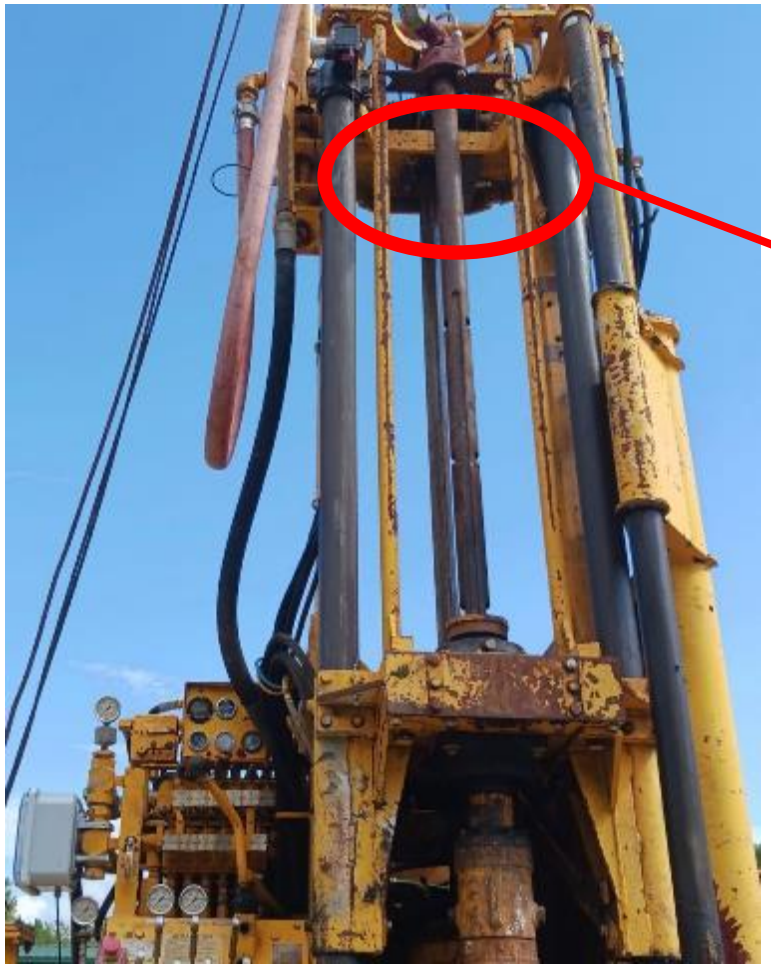
Depth and Penetration Rate







Rotational Speed







Flow Rate and Injection Pressure



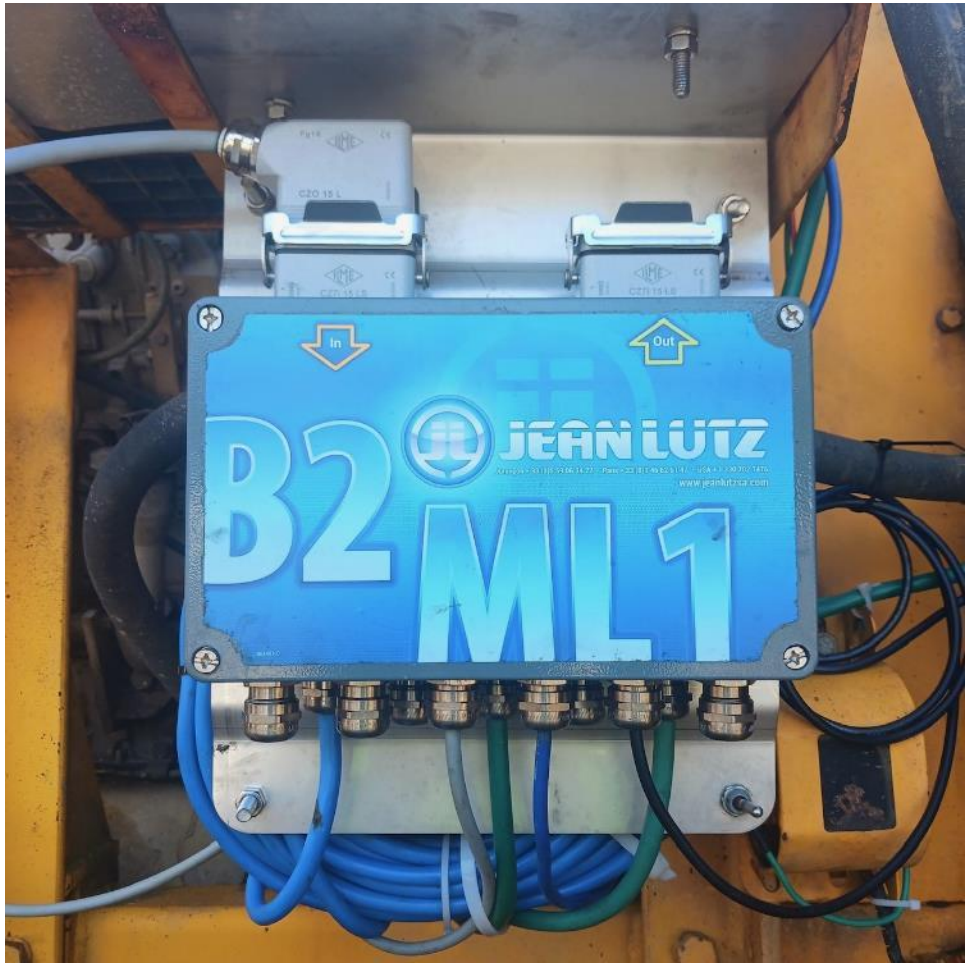




Vortex Flow Meter

Magnetic Flow Meter

Junction Box and DAQ Module

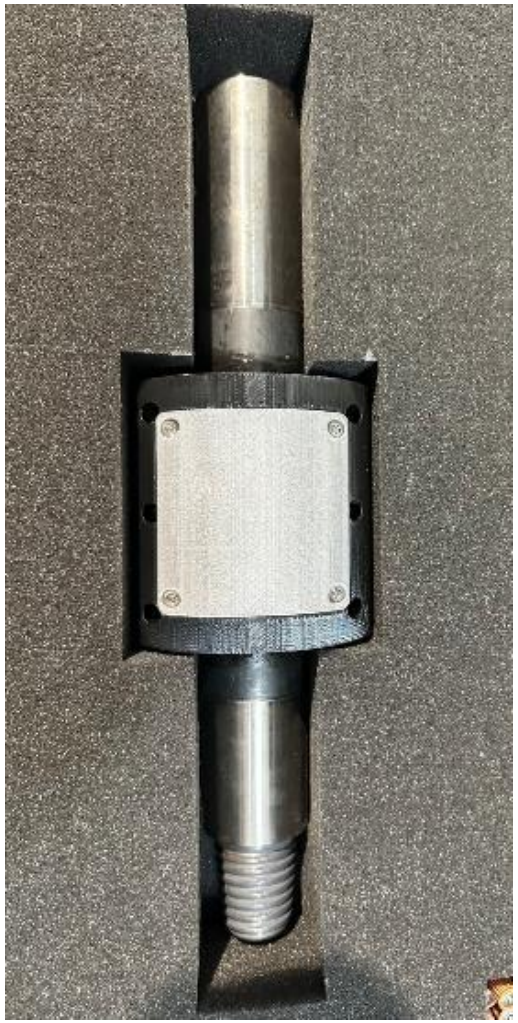






MWD.one™

Wireless drill rod transducers to measure torque, crowd, & vibration







AWJ Rods

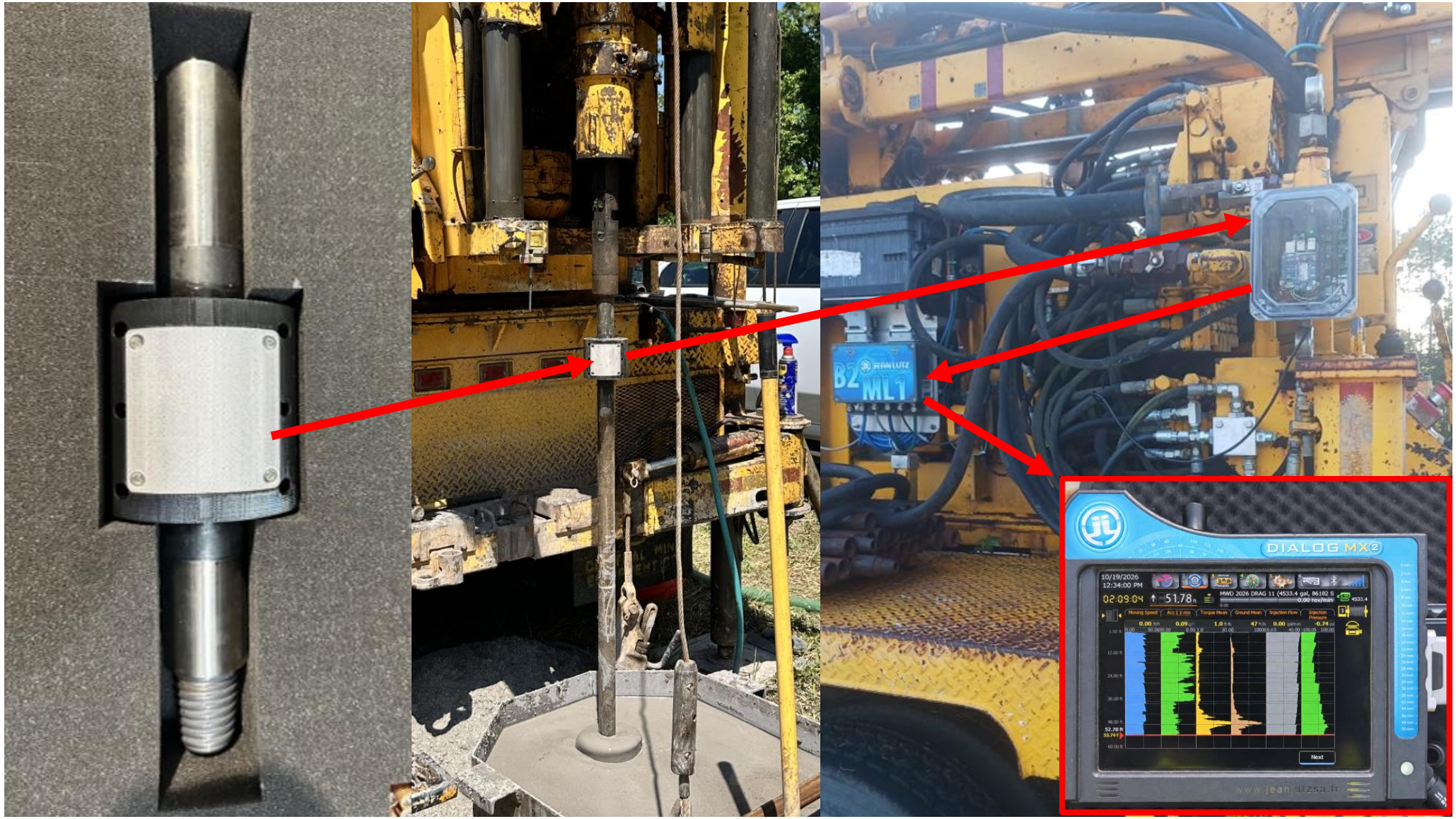
NWJ Rods



HSA Subs



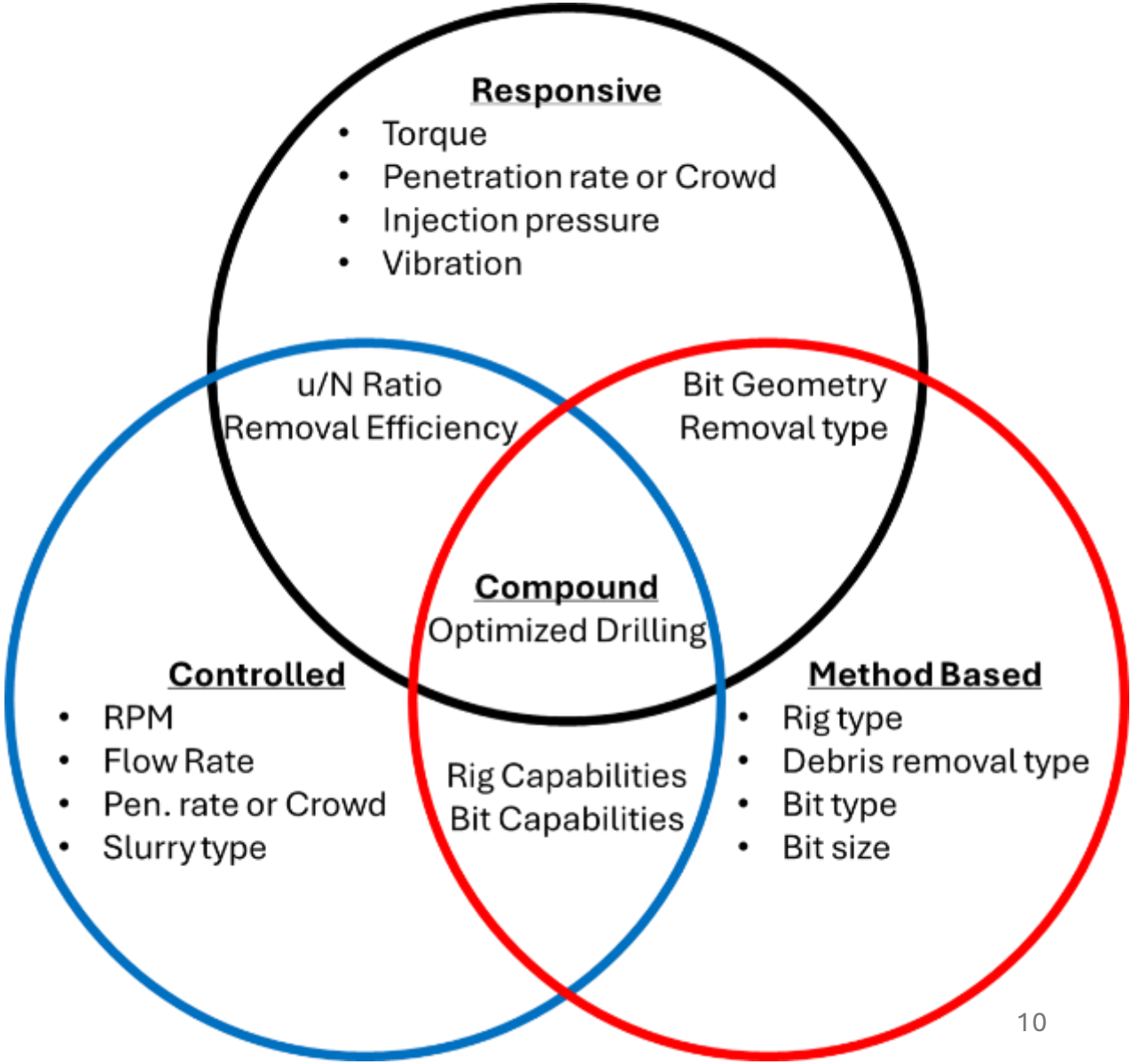
Torque, Crowd, and Vibration (TCV)



Drilling Parameters Categories

1. **Method-based parameters**
   - Parameters that reflect the drilling application
2. **Controlled drilling parameters**
   - Parameters that are typically controlled by the drill rig operator
3. **Responsive drilling parameters**
   - Parameters that are dependent upon method-based parameters, controlled parameters, and the strata encountered during drilling

- **Compound drilling parameters**
  - A combination of individual drilling parameters that enhance the measurable drilling response due to changes in the strata encountered (e.g., **specific energy**)



Mechanical Specific Energy

Specific energy is the energy required to excavate a unit volume of soil/rock

$$Specific\ Energy\ (e) = \frac{F}{A} + \frac{2\pi NT}{Au}$$

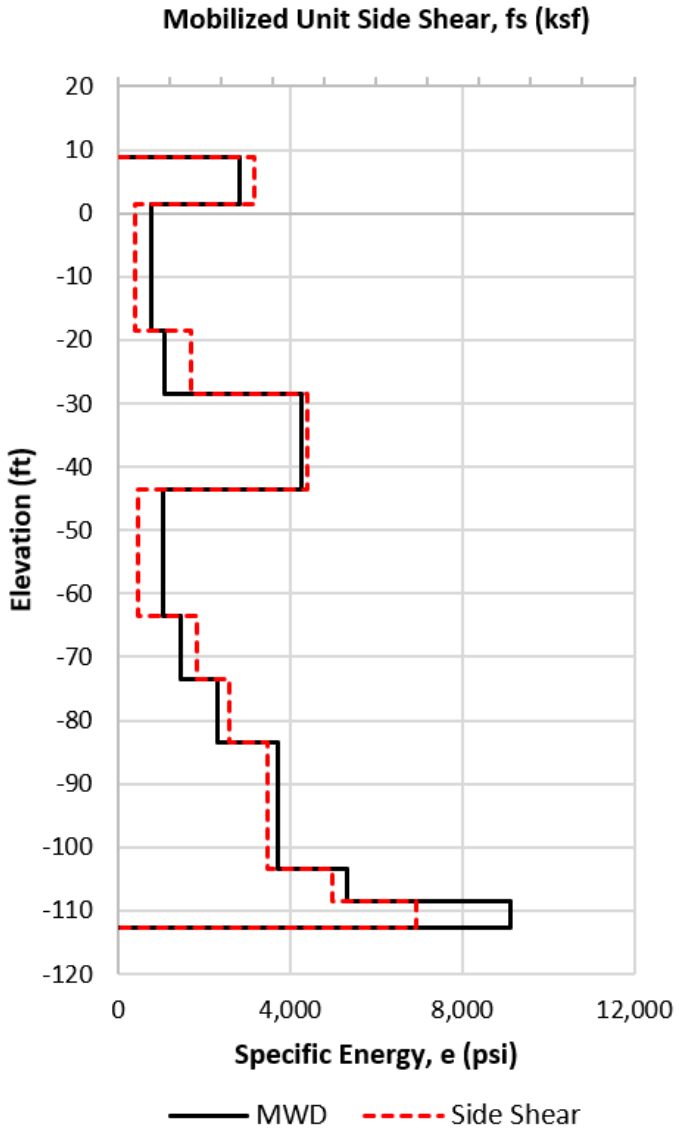
F = Crowd or downward axial force (lbf)

N = Rotational speed (RPM)

T = Torque (in-lbs)

u = Penetration rate (in/min)

A = Cross-sectional area of the excavation (in^2)

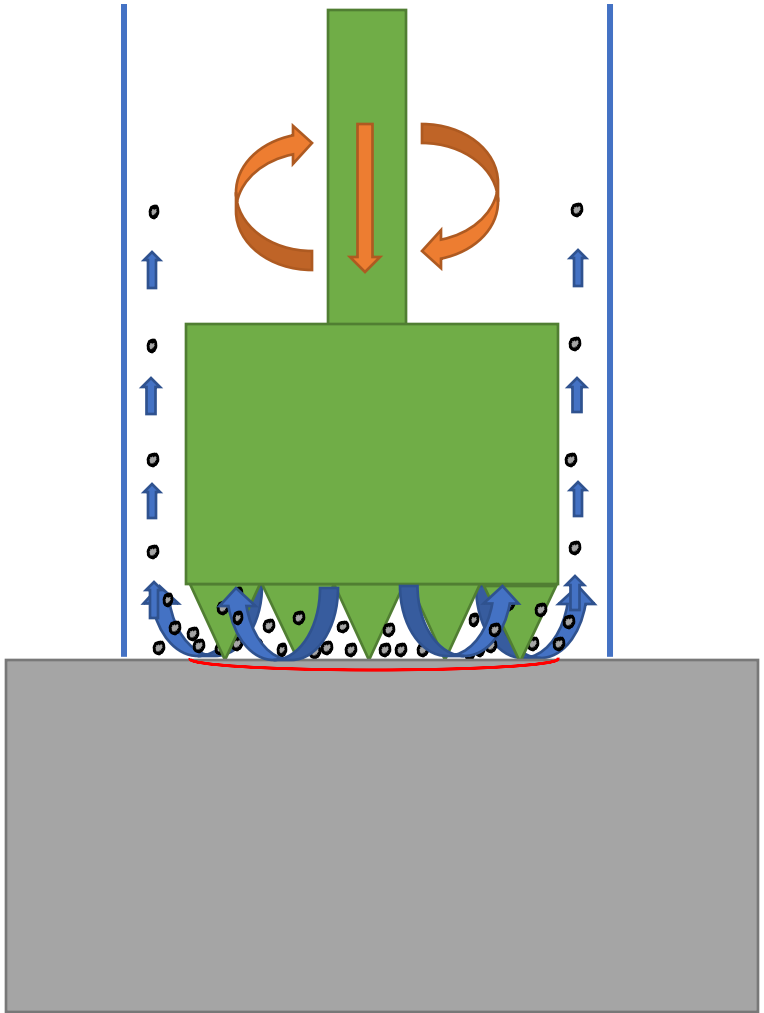


Three Phases of Rotary Drilling: Historical Development

- **Teale (1965): Established the conceptual basis**
  - Described high specific energy at insufficient thrust, an efficient operating range, and renewed inefficiency as the drilling tool becomes overloaded
- **Detournay et al. (2008): Formalized the three-phase model**
  - Explained and experimentally supported three drilling regimes **governed by penetration per rotation** and frictional contact at the bit–rock interface
- **Rodgers et al. (2021): Quantified operational limits for rock coring**
  - Demonstrated the inefficient, optimized, and destructive phases and established drilling parameter relationships needed to preserve core quality and reliably assess rock strength using MWD

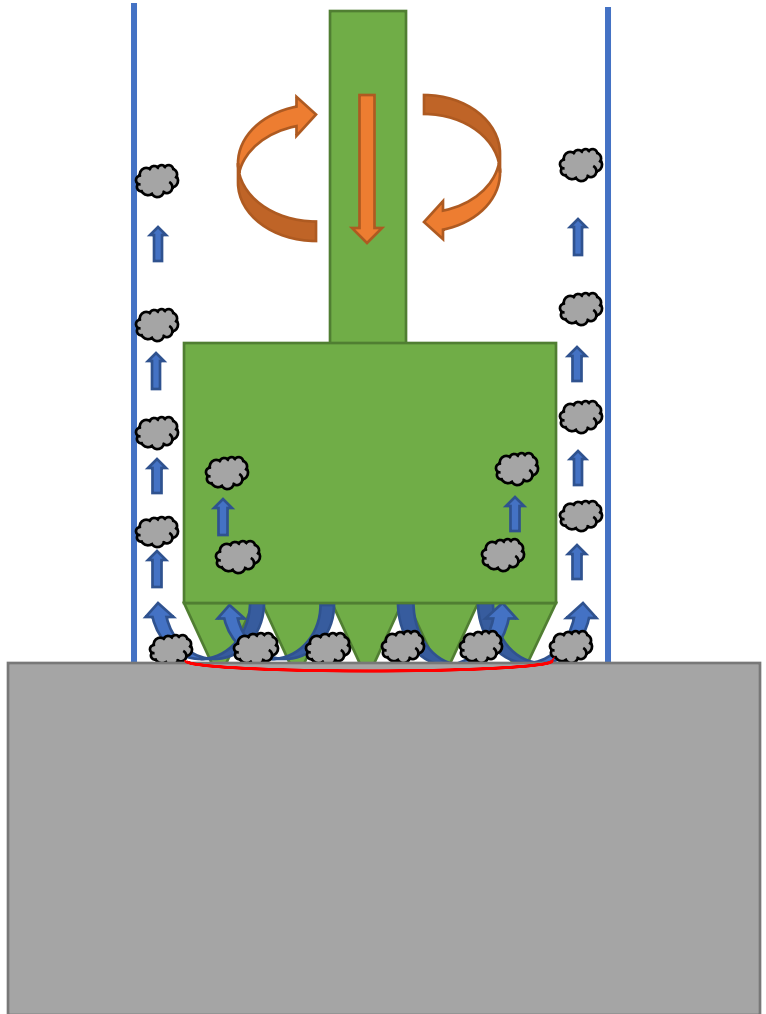
Phase 1 - Inefficient Drilling

- Inefficient crowd (F) applied
- Minimal penetration/rotation (u/N)
- Energy generated from baseline friction, not cutting
- Minimal excavation from input energy
- MWD strength assessment NOT viable



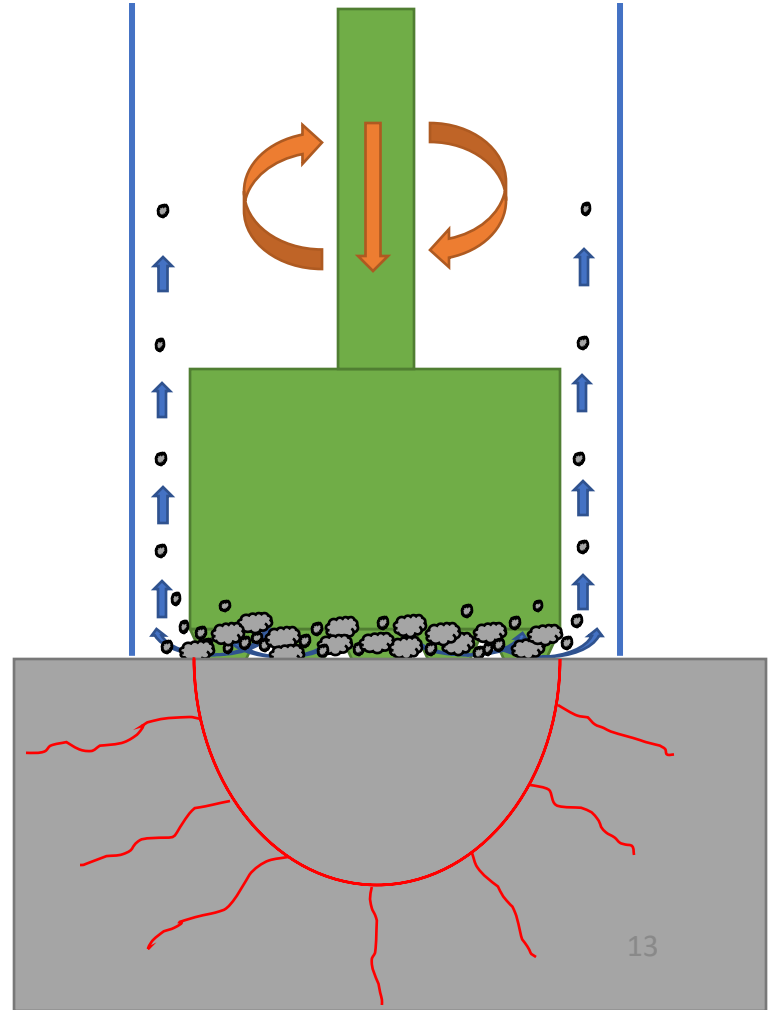
Phase 2 - Optimized Drilling

- Optimized penetration/rotation (u/N)
- Efficient removal of drilled debris
- Minimal energy loss in the system
- Minimal disturbance to soil/rock
  - Optimized core REC and quality
- MWD strength assessment viable

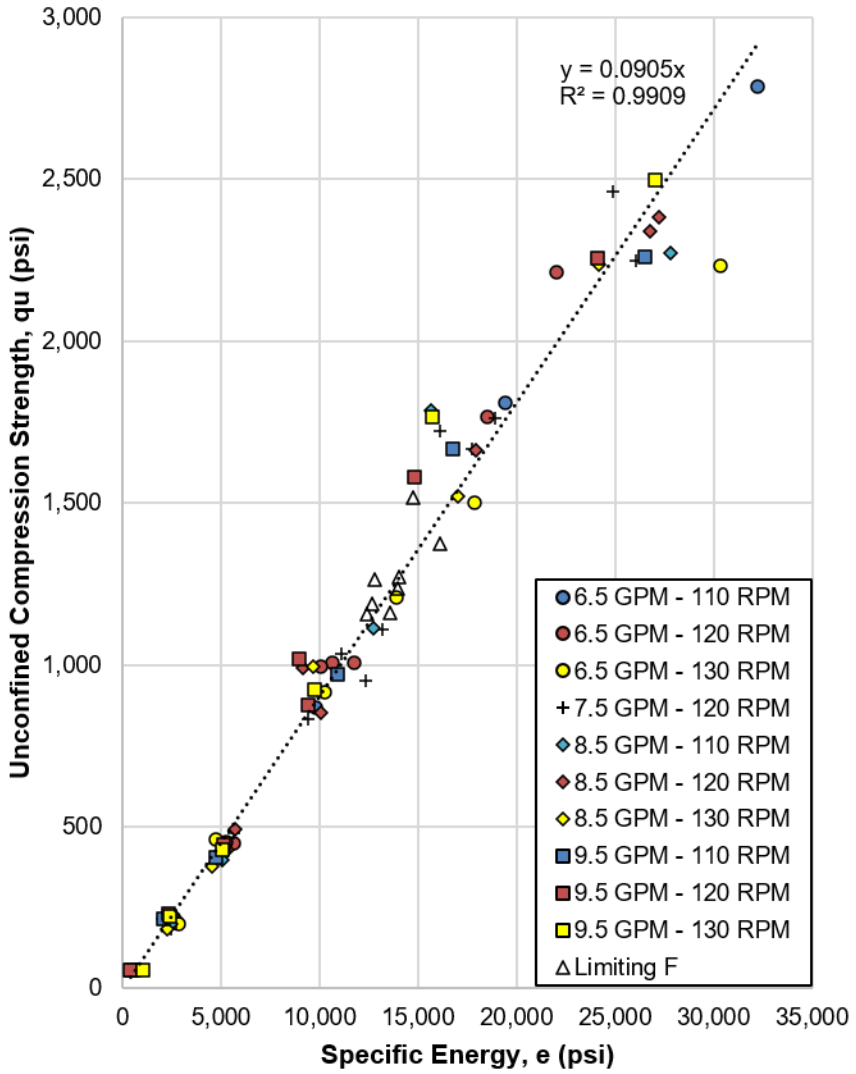


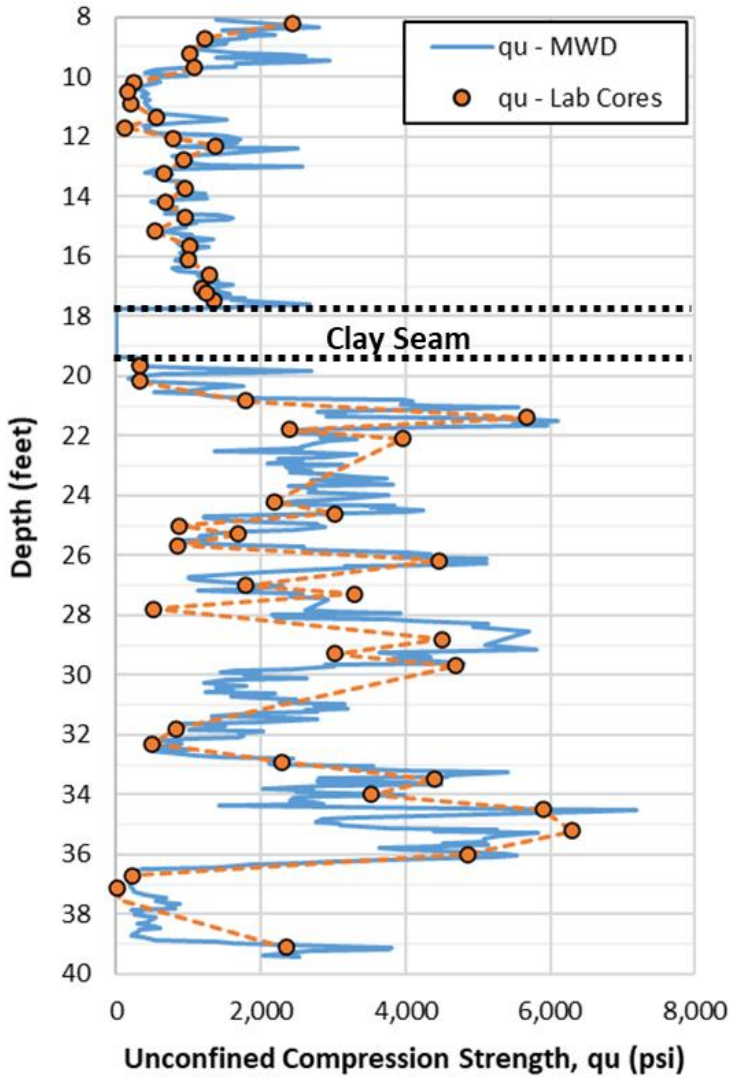
Phase 3 - Disturbed Drilling

- Overcrowding the bit
- Inefficient flushing
- Increased frictional resistance
- Large energy requirement
- Disturbed soil/rock before assessment
- MWD Strength assessment NOT viable

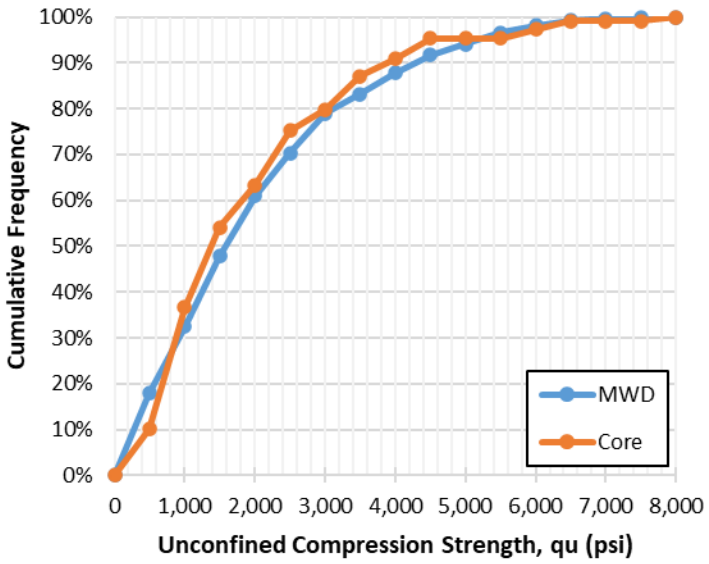


MWD for Site Characterization – Rock Coring





Perry Florida – 5 Borings Summary of Site Statistics - qu (psi)		
Stats	MWD	Lab Cores
Mean	1,923	1,884
Median	1,558	1,381
Std Dev	1,484	1,515
CV	0.77	0.80
Max	7,997	7,697
Min	41	66
Count	1,353	155



Rodgers et al. (2021)

The Effects of Phase 3 Drilling

OL – Phase 2 | Stall – Phase 3 | MOC – Phase 3

(a)  (b)  (c) 

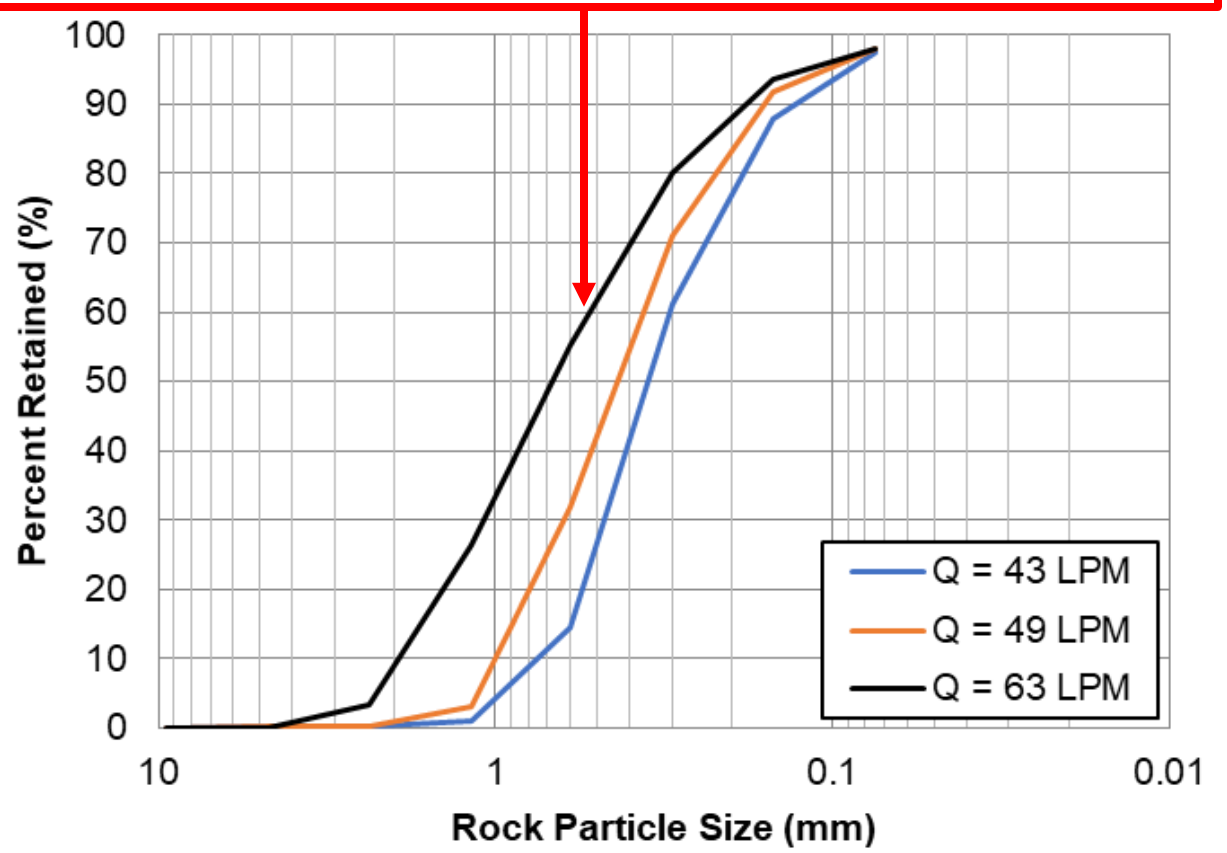
Drilling Parameter	Core Run Averages (qu ≈ 3,000 kPa)		
	(a) OL	(b) Stall	(c) MOC
u (cm/min)	17.5	14.5	25.7
N (rpm)	120	116	115
u/N (cm/rev)	0.147	0.124	0.224
T (N-m)	32	149	323
F (N)	992	5,765	12,242
Q (LPM)	30	29	28
e (kPa)	32,302	206,346	235,304
MWD q_u (kPa)	3,100	19,900	22,700
Core q_u (kPa)	3,000	3,000	3,000

(Rodgers et al. 2021)

Breaking Rock Particles into Smaller Sizes

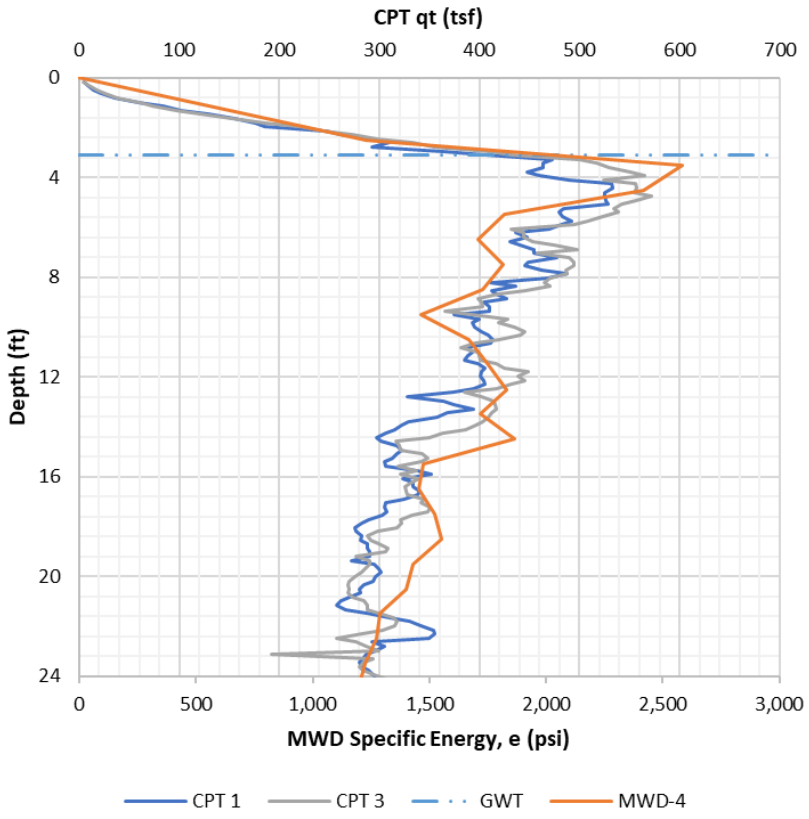
Sieve Size	Percent Retained		
	43 LPM	49 LPM	63 LPM
#4	0.1	0.1	0.0
#8	0.2	0.2	3.4
#16	1.1	3.0	26.5
#30	14.6	32.0	55.3
#50	61.3	71.1	80.1
#100	87.9	91.9	93.5
#200	97.6	98.1	97.9
Fineness Modulus	**2.63**	**2.96**	**3.57**
Sp. Energy (kPa)	**61,200**	**48,300**	**42,300**
Pen. Rate (cm/min)	**9.7**	**9.7**	**11.0**

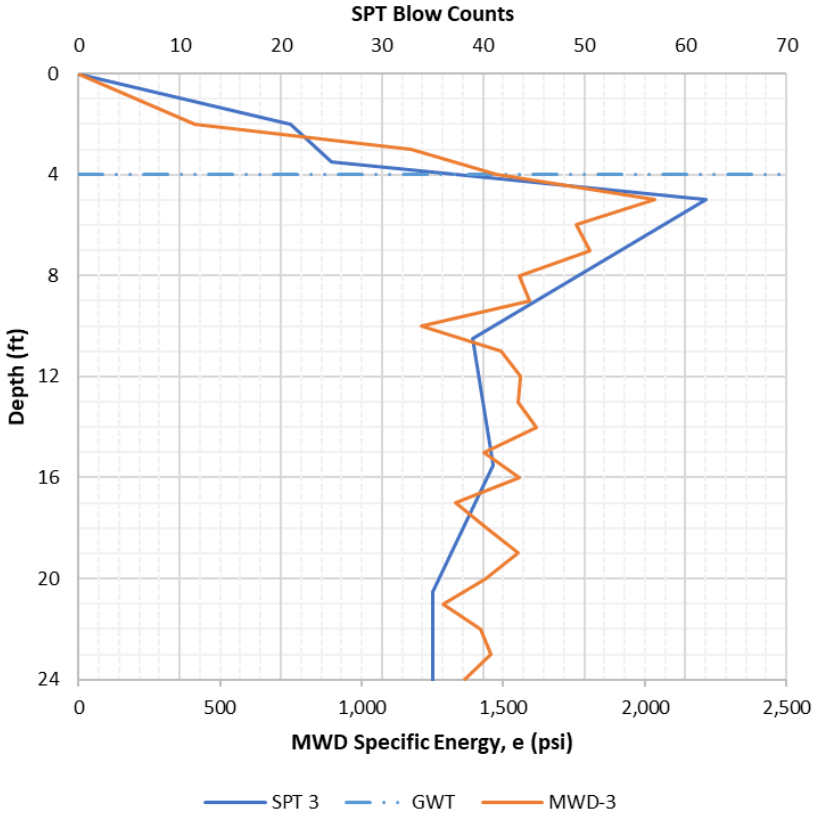
Increasing the flow rate allowed larger rock particles to be removed (confirmed by larger fineness modulus), increased the penetration per rotation, and minimized the energy requirement



(Rodgers et al. 2021)

MWD for Soil Characterization







Method Development

- Iterative development using a drag bit
- Six development sites covered a wide range of Florida materials
- Highly plastic clay was the limiting condition
- Optimized u/N and flow for efficient drilling and cleaning
- Developed reliable and repeatable method for Florida soils and rock

Controlled Environment



UF/FDOT Field Trials



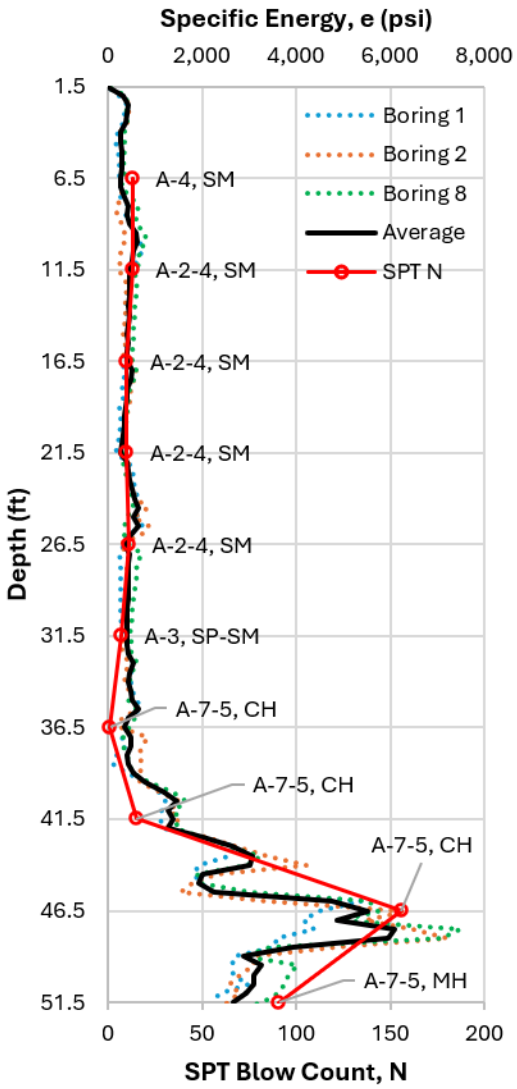
Consultant Implementation

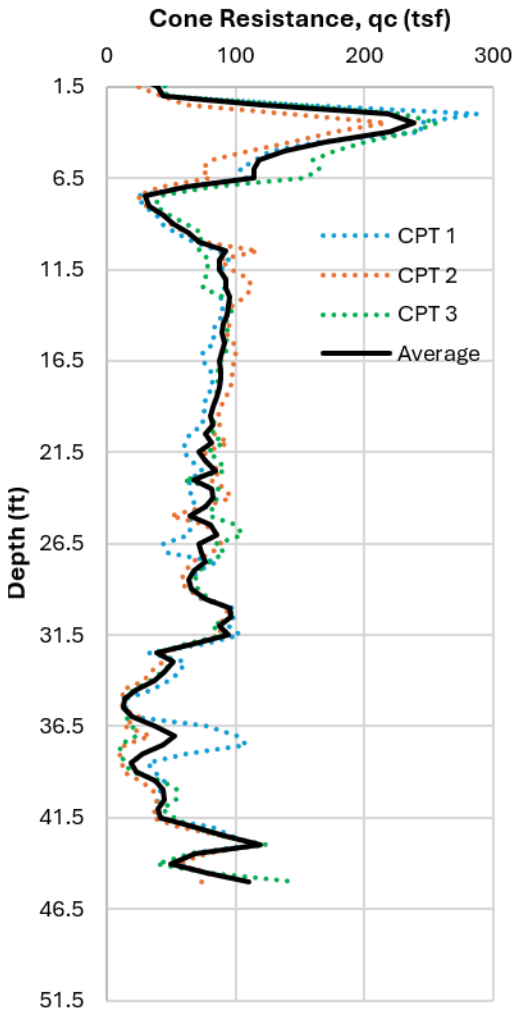


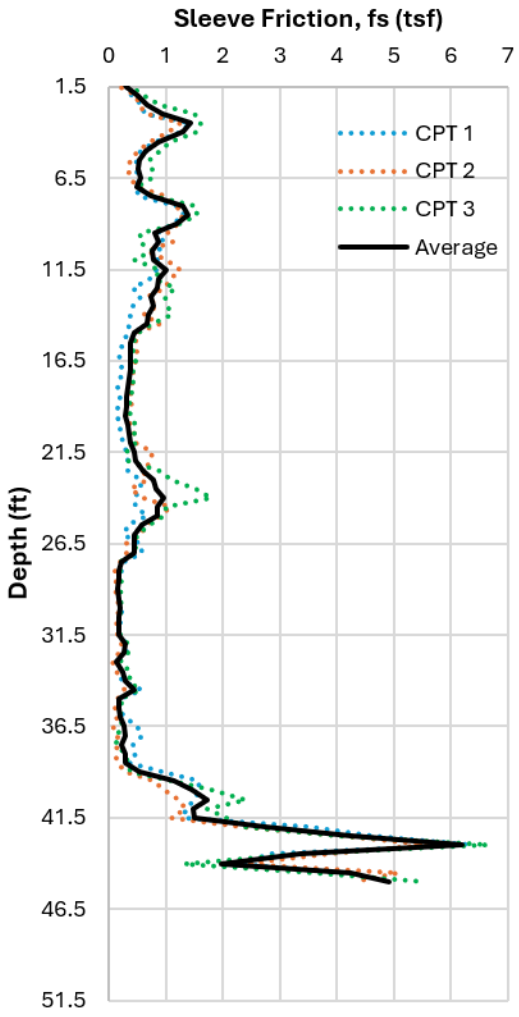
Proper Cutting → Balling/Smearing



MWD, CPT, and SPT at Hawthorne







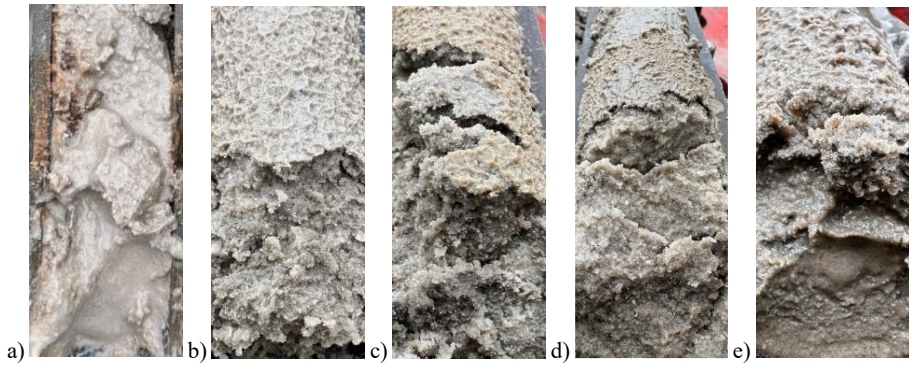


Figure 1. SPT split spoon soil samples collected at a) 5-ft, b) 15-ft, c) 20-ft, d) 25-ft, and e) 30-ft.

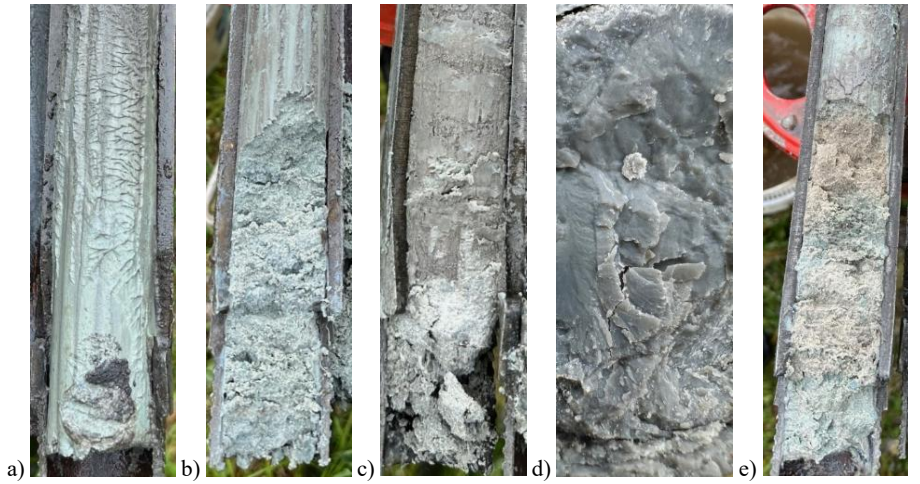
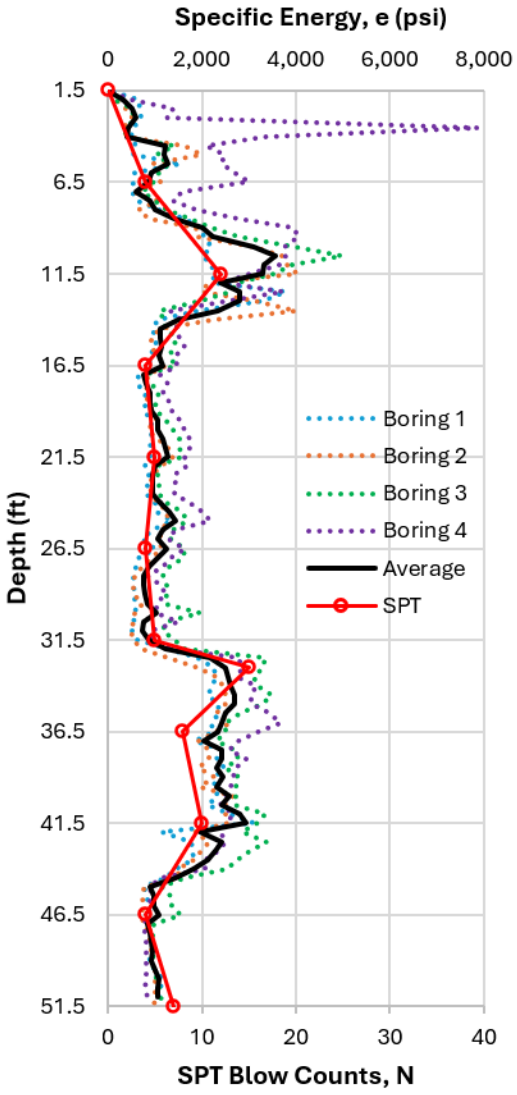
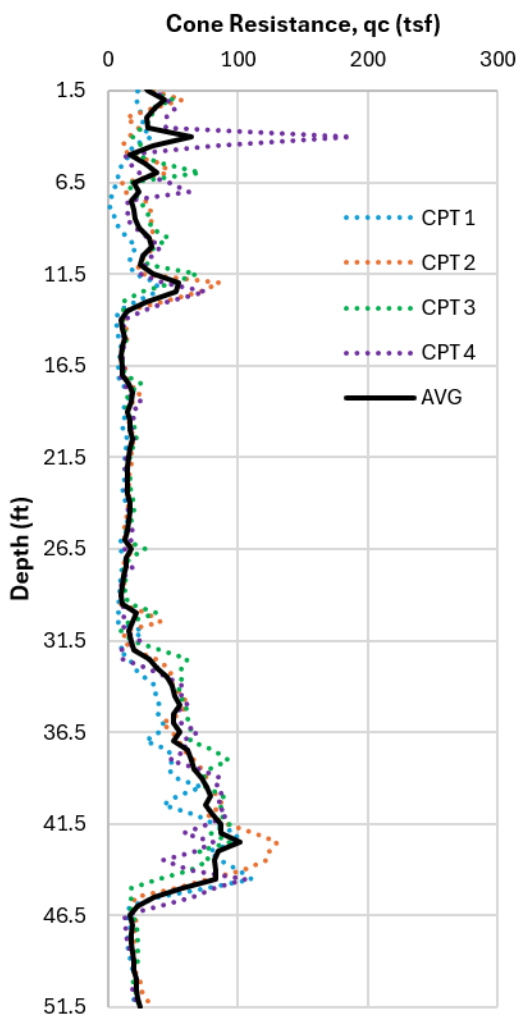
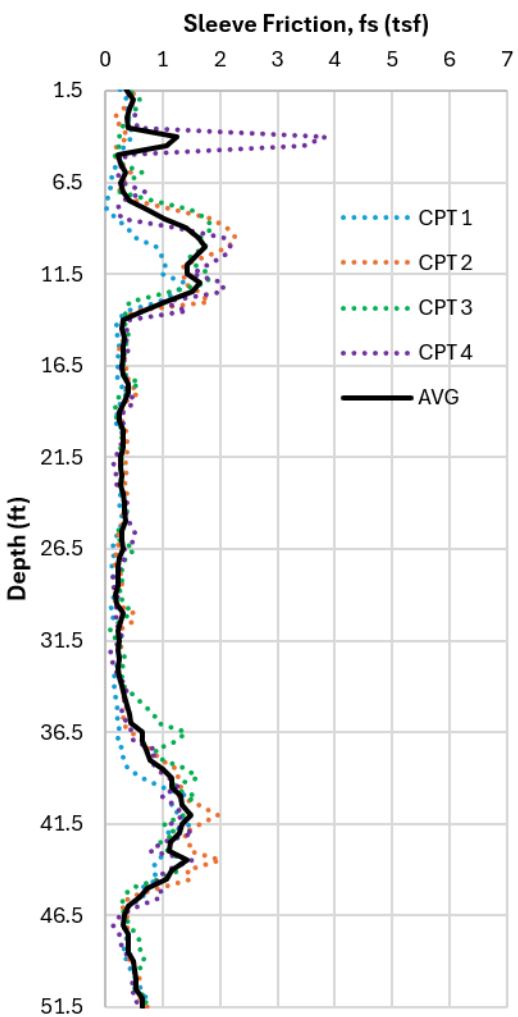


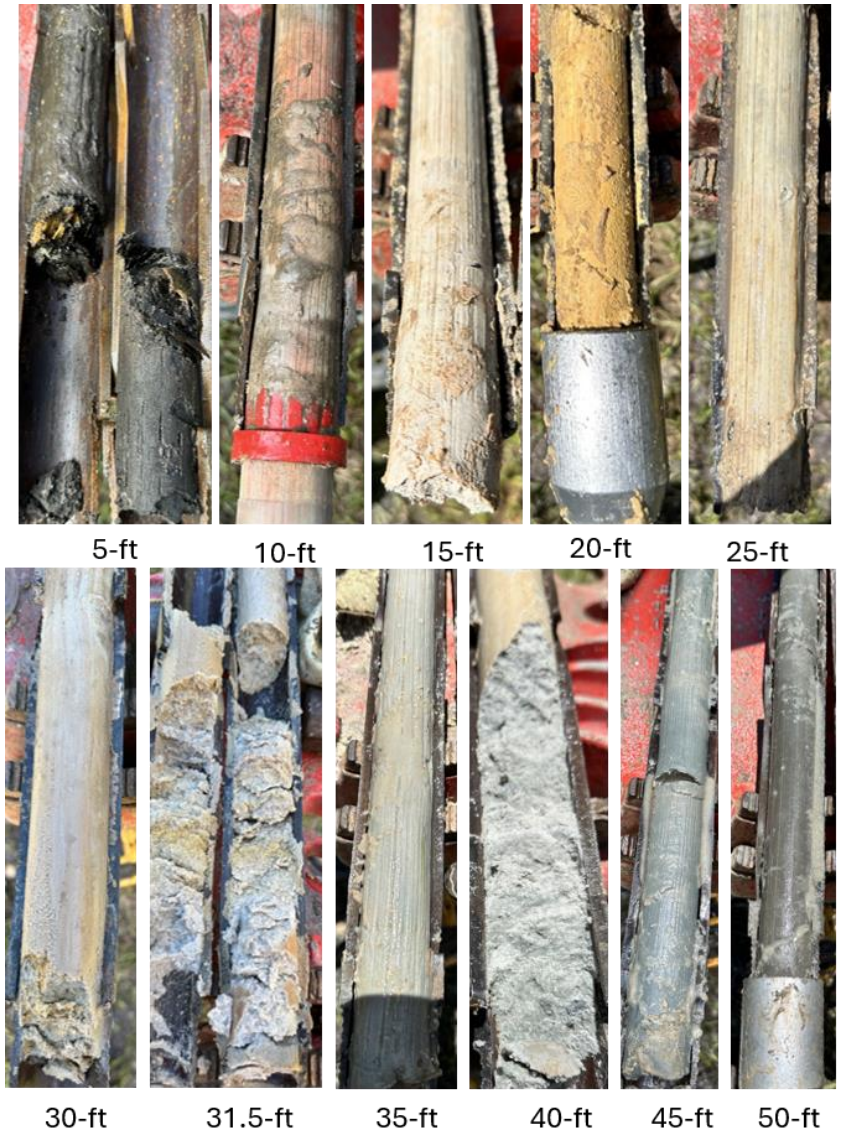
Figure 1. SPT split spoon soil samples collected at a) 35-ft, b) 40-ft, c and d) 45-ft, and e) 50-ft.

MWD, CPT and SPT at Starke



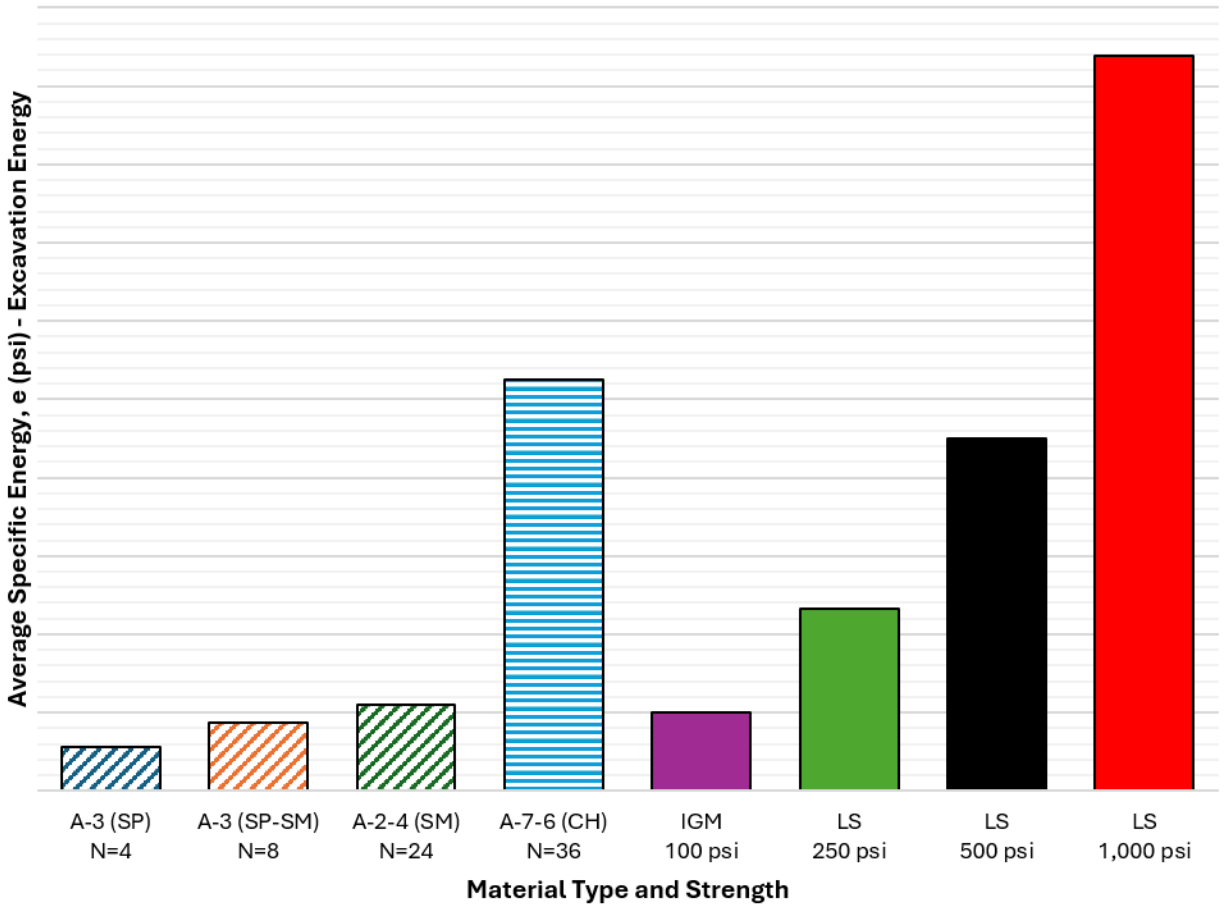




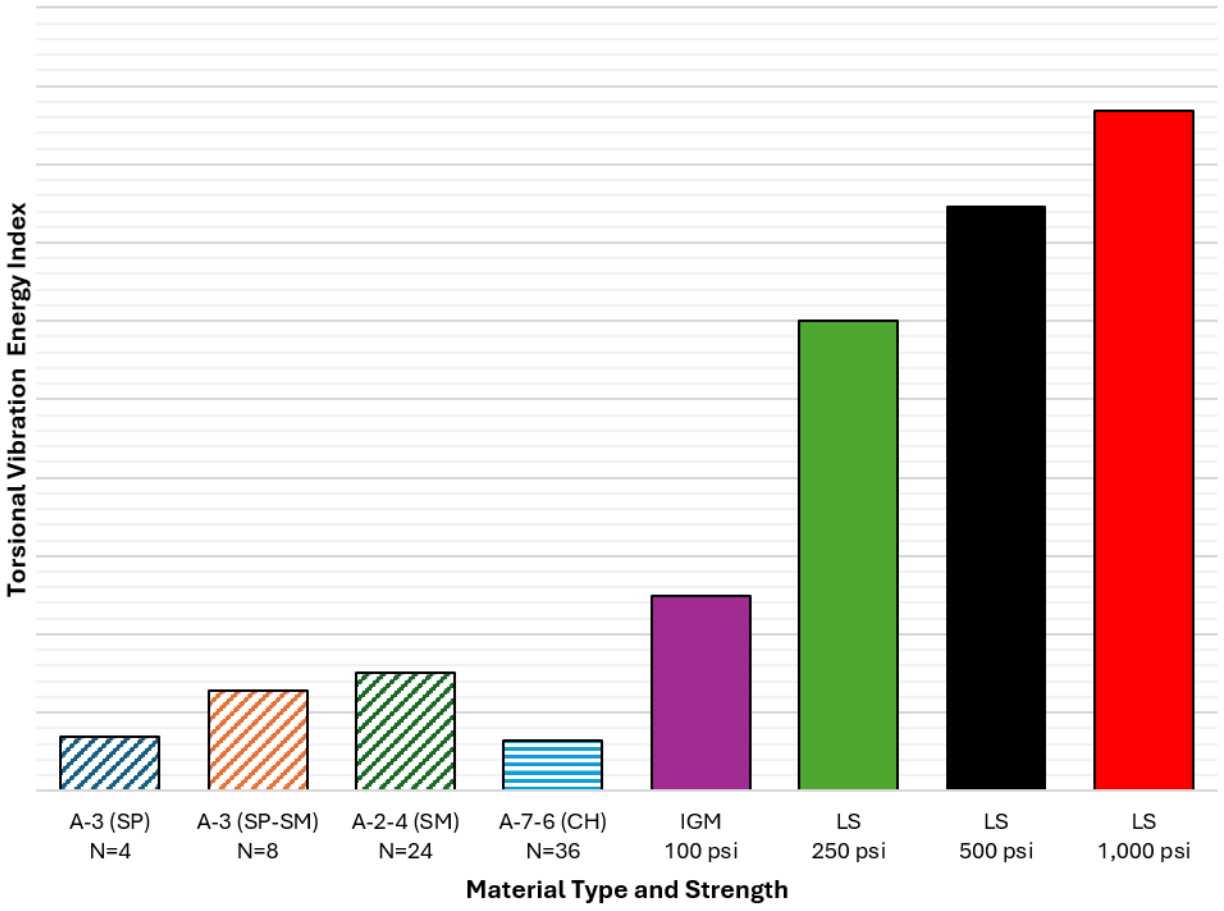


The Next Evolutionary Step of Geotechnical MWD

Magnitude of Work

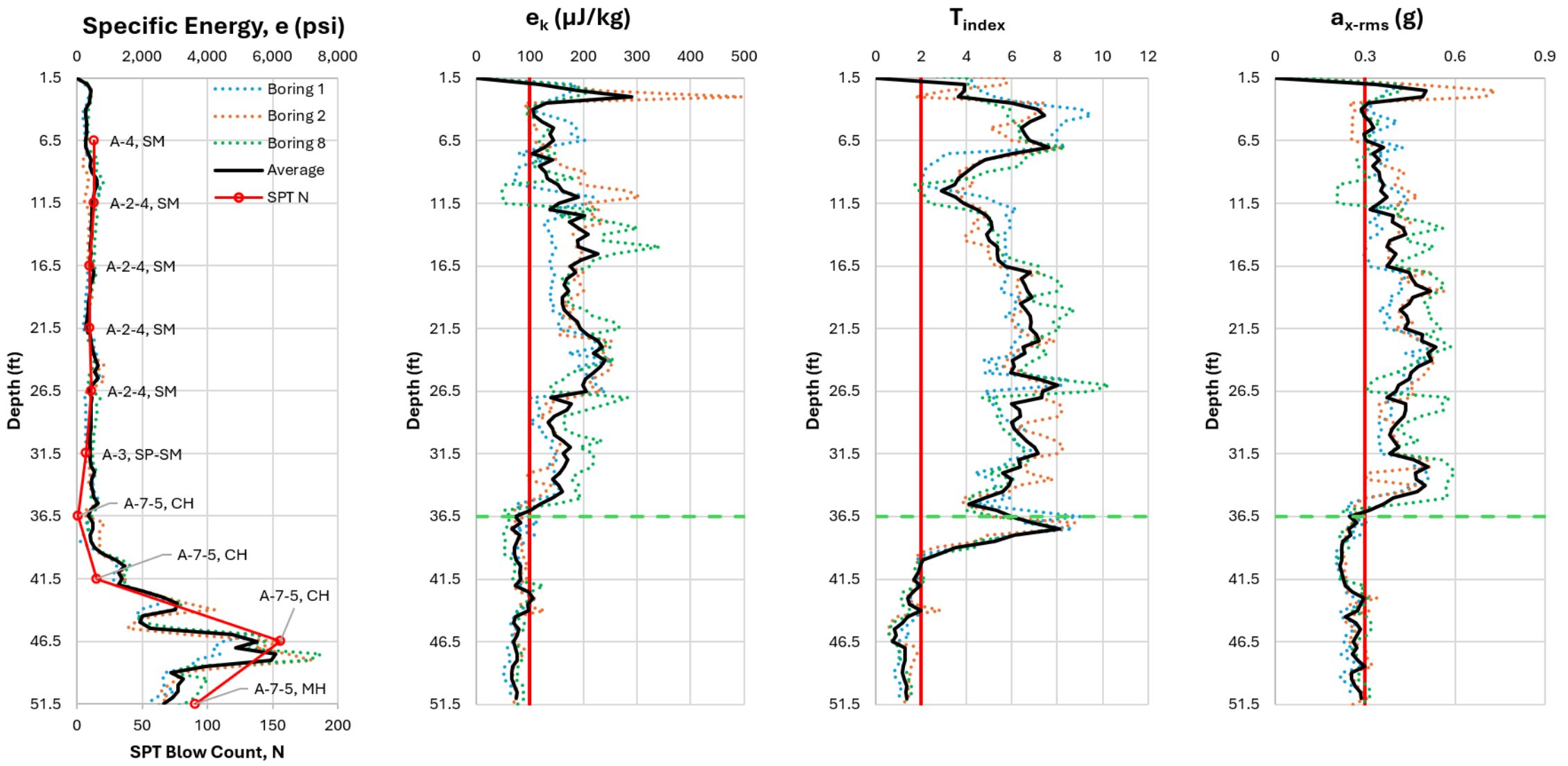


Character of Work



Specific Energy measures the magnitude of the work; vibration and strain waves describe the character of the work

Delineating Sand and Clay with MWD

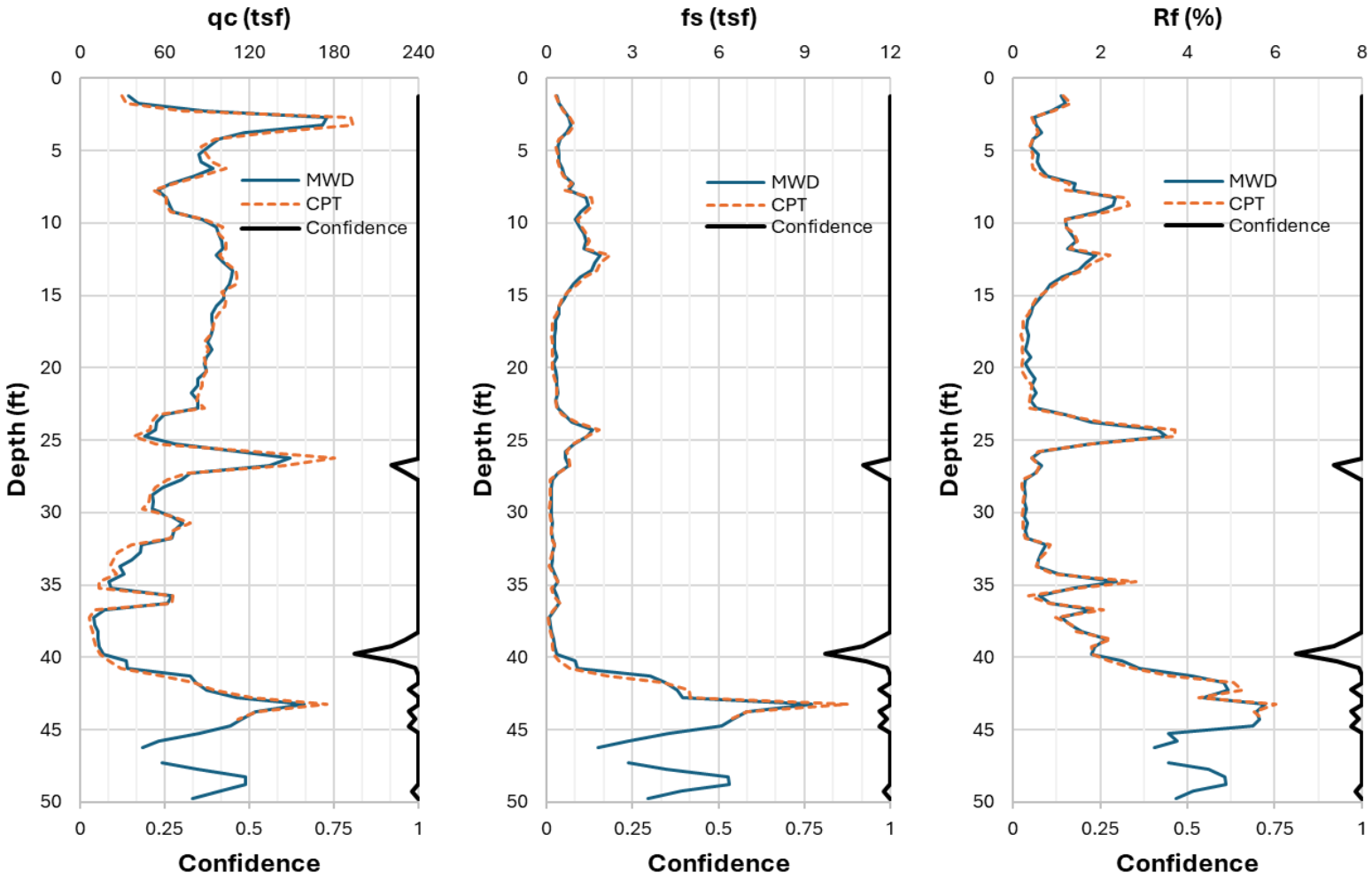


The Future of Geotechnical MWD

Advancing MWD from a qualitative observation tool to a quantitative, energy-based characterization system!

Physics-Based MWD Model

- **13 physics-based MWD features**
  - Site and depth were not used as predictors
  - Reference data: SPT, CPT, laboratory classification, and rock UCS
- **Material classification**
  - Sand, clay, and rock (4 FL sites)
  - 5-fold cross-validation accuracy: **98.6% ± 1.7%**
  - Training accuracy: **100%**
- **MWD → CPT Prediction Accuracy**
  - qc (tip resistance): $R^2 = 0.96$
  - fs (sleeve friction): $R^2 = 0.98$
  - Rf (friction ratio): $R^2 = 0.99$

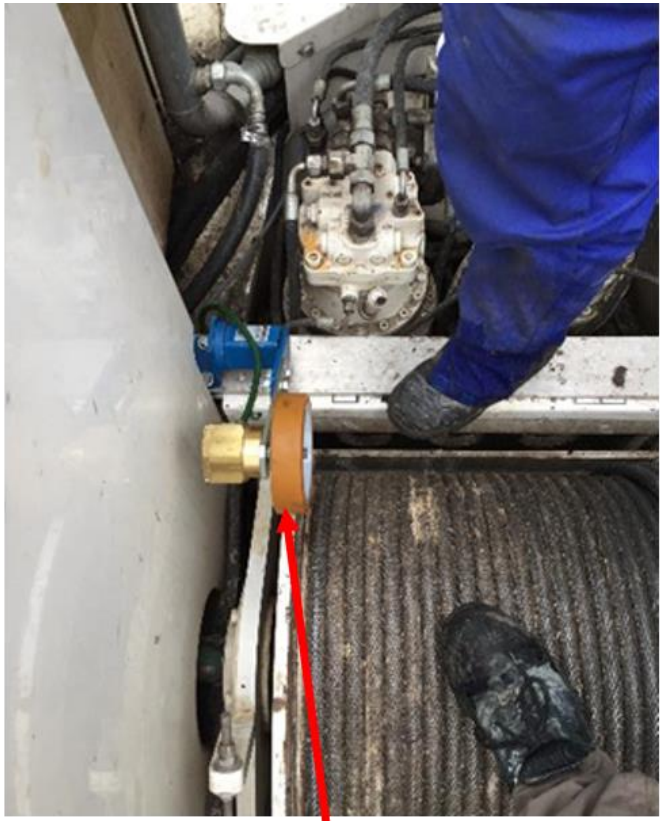


Rodgers et al. 2026

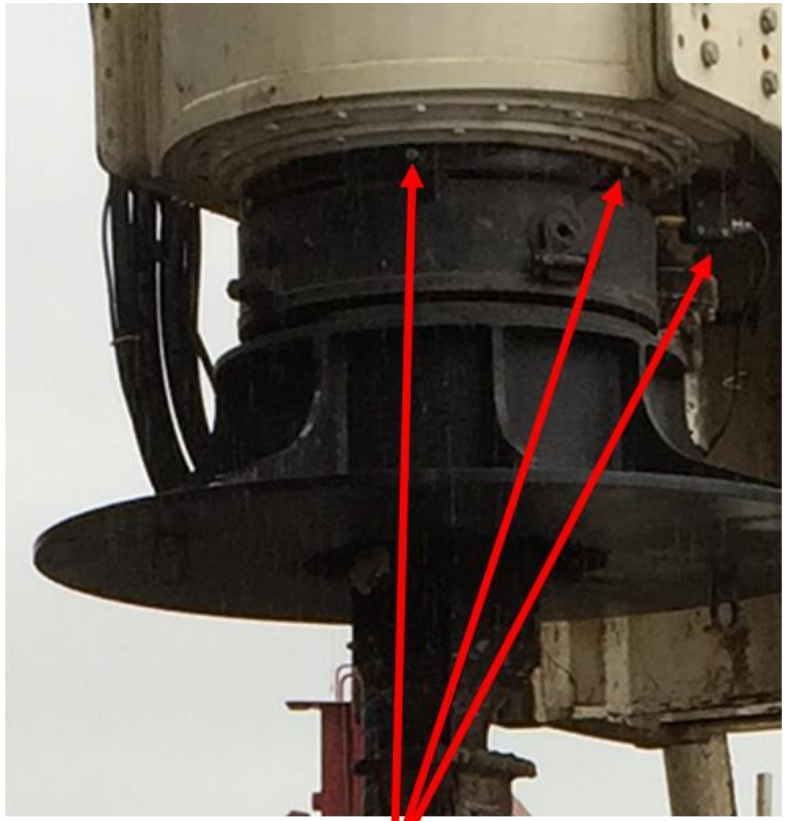
MWD for Bored Pile Construction QA/QC



Equipment Installation



Depth sensor mounted on the outer rim of the main cable winch

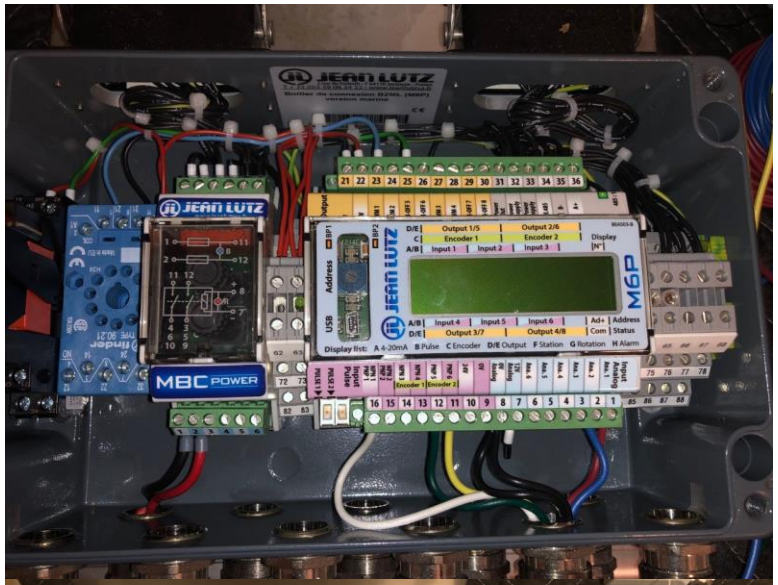


Proximity sensor mounted on the base of the rotary table. Steel bolts mounted on rotary head



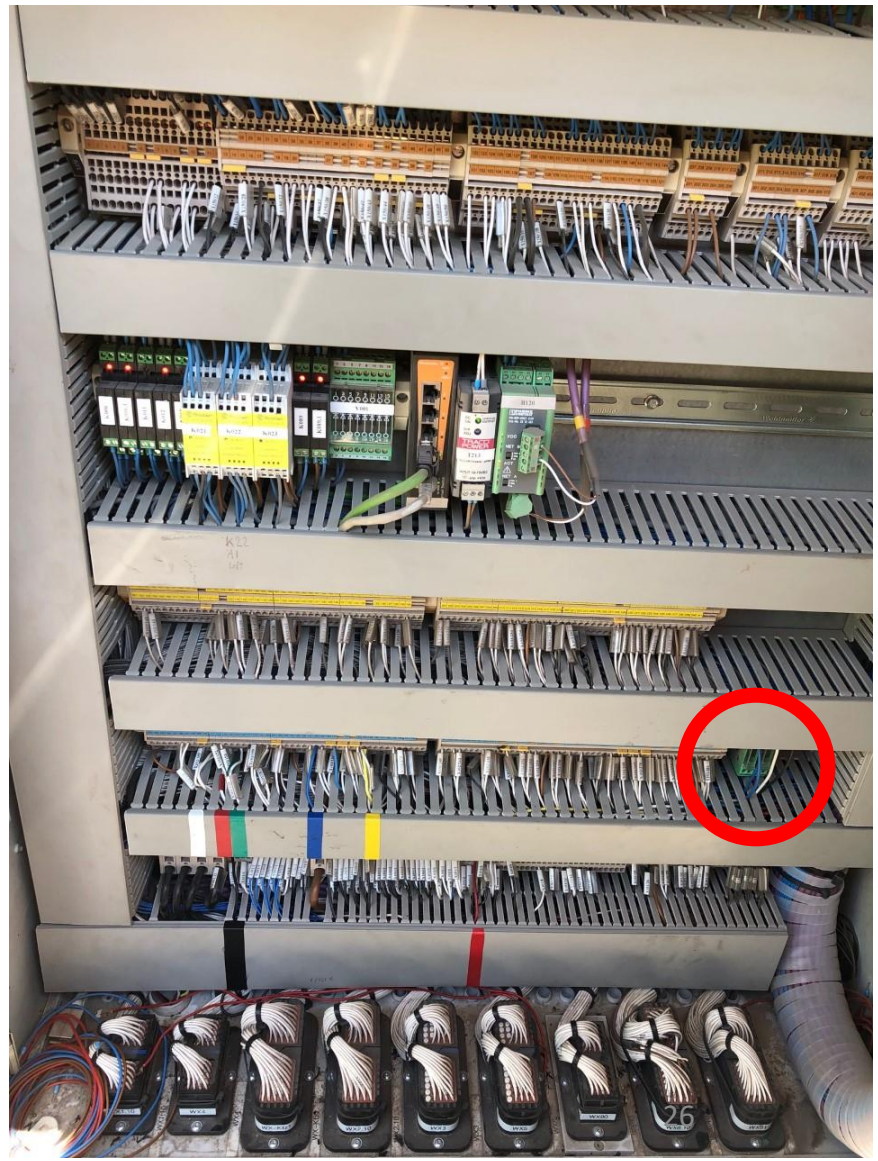
Torque and crowd sensors tapped into hydraulic lines

Tapping into Drill Rigs with Installed Sensors

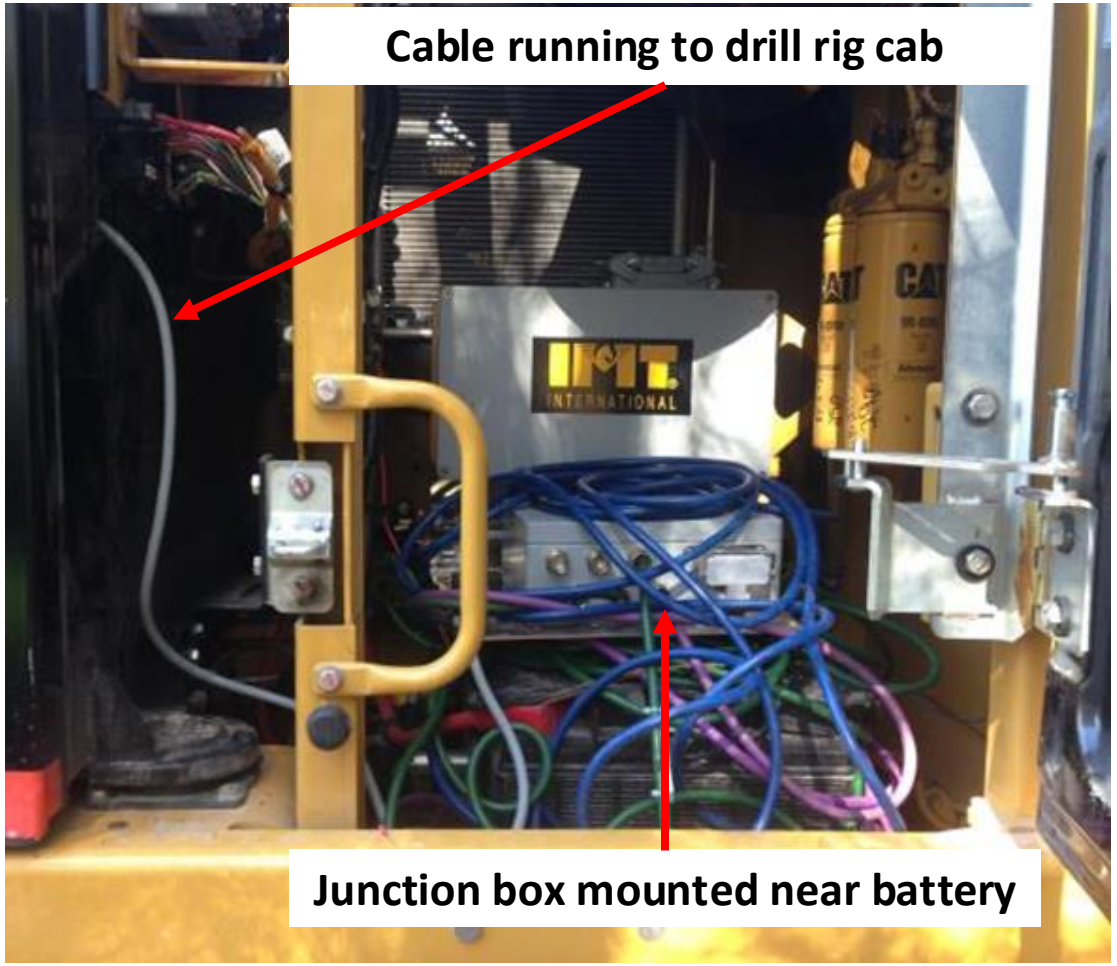




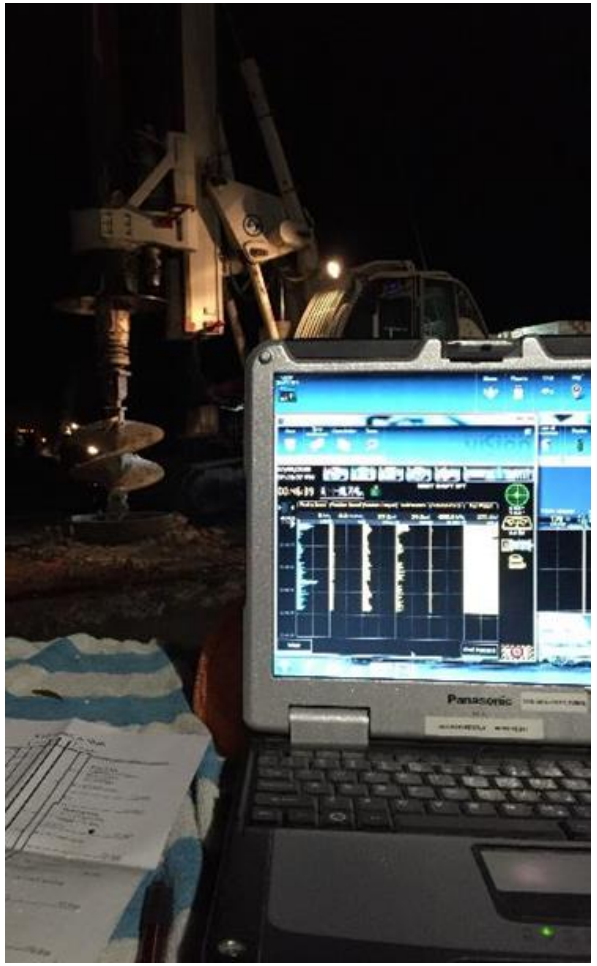




Remote Wireless Monitoring

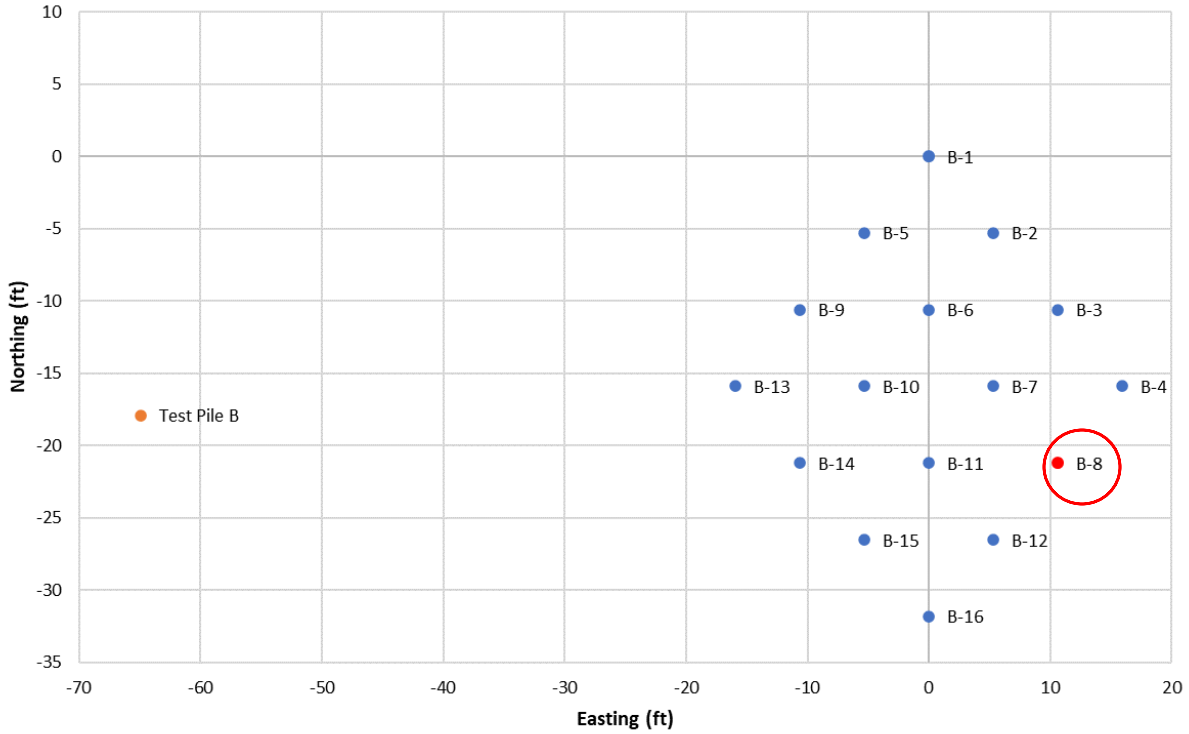


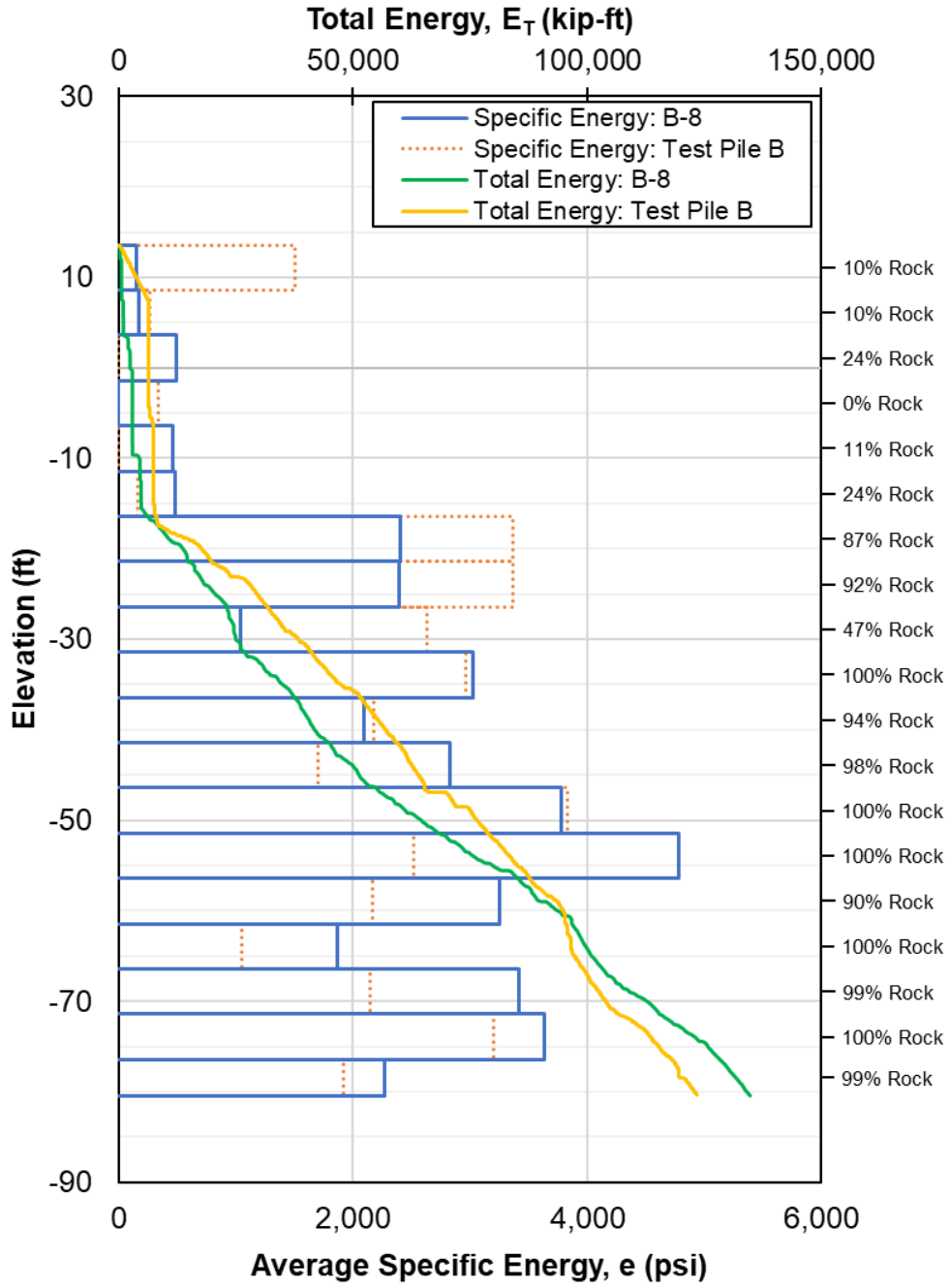




ACIP Pile MWD QA/QC
-Specific Energy & Total Energy-

- Production pile B-8 strength profile is compared to Test Pile B strength profile
- Production pile B-8 indicates more total energy than the test pile location
  - Builds confidence in the constructed pile

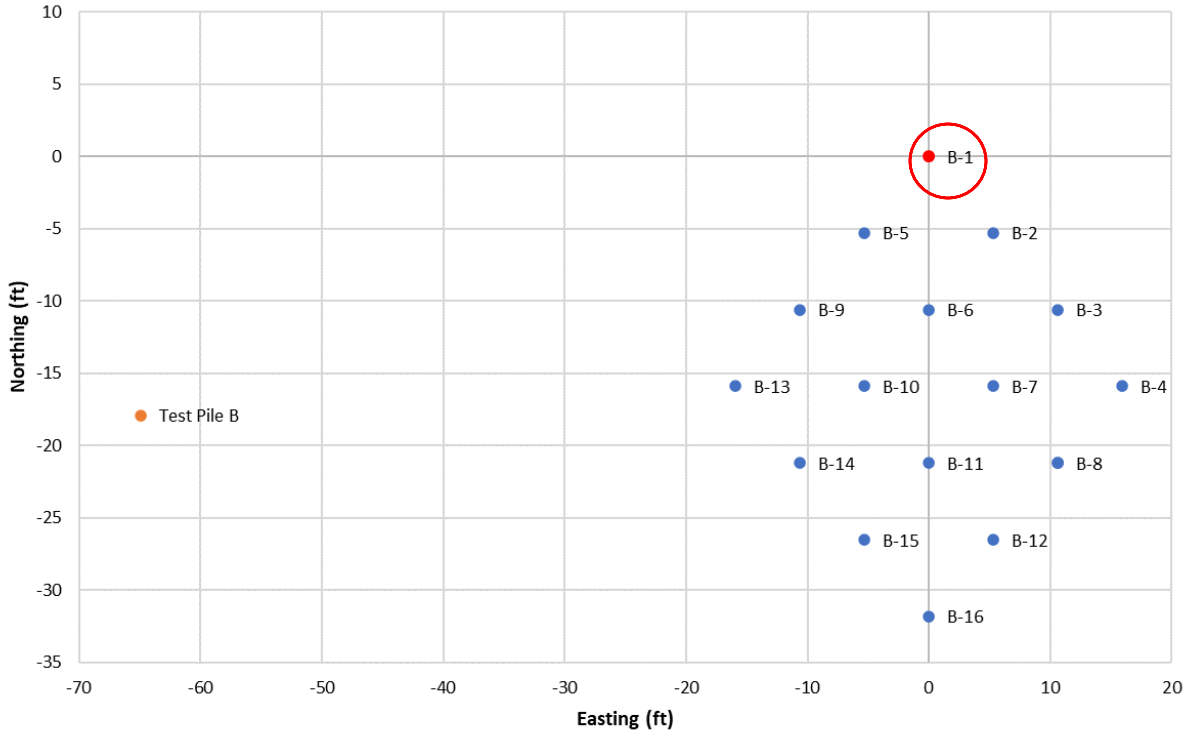


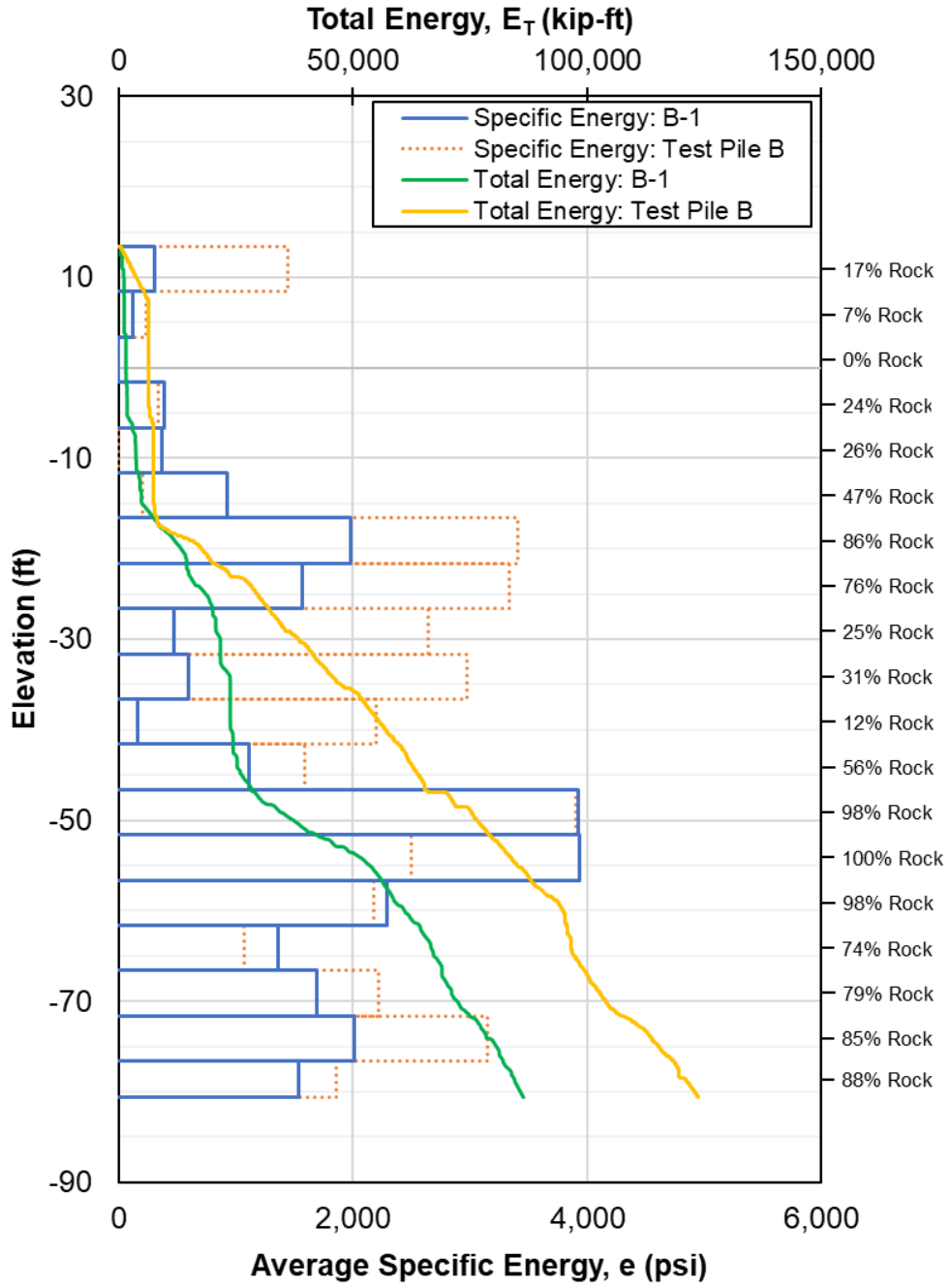


Rodgers, McVay, and Kelch (2022)

ACIP Pile MWD QA/QC
-Specific Energy & Total Energy-

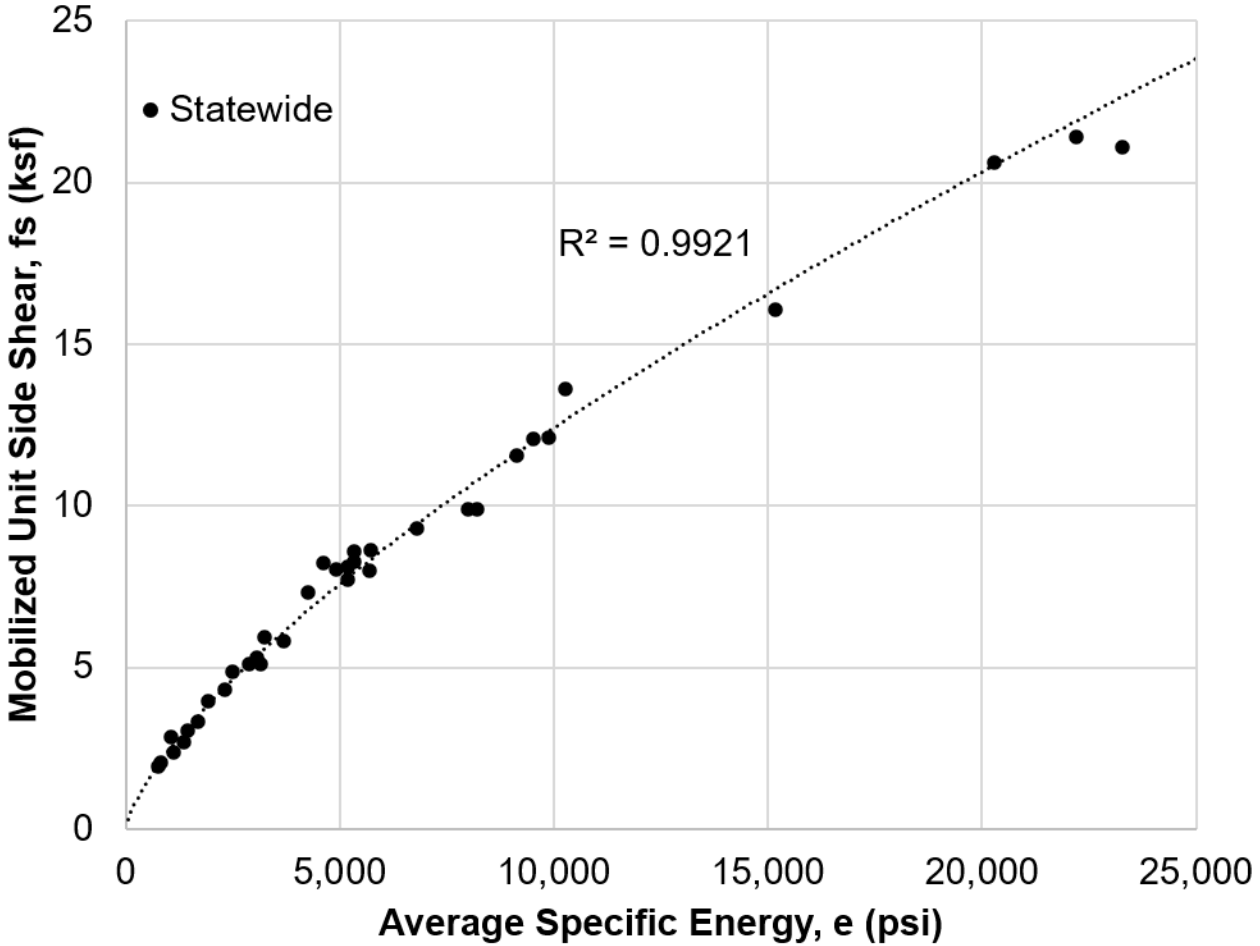
- Production pile B-1 strength profile is compared to Test Pile B strength profile
- Production pile B-1 indicates less total energy than the test pile location
  - Draws concern for the constructed pile

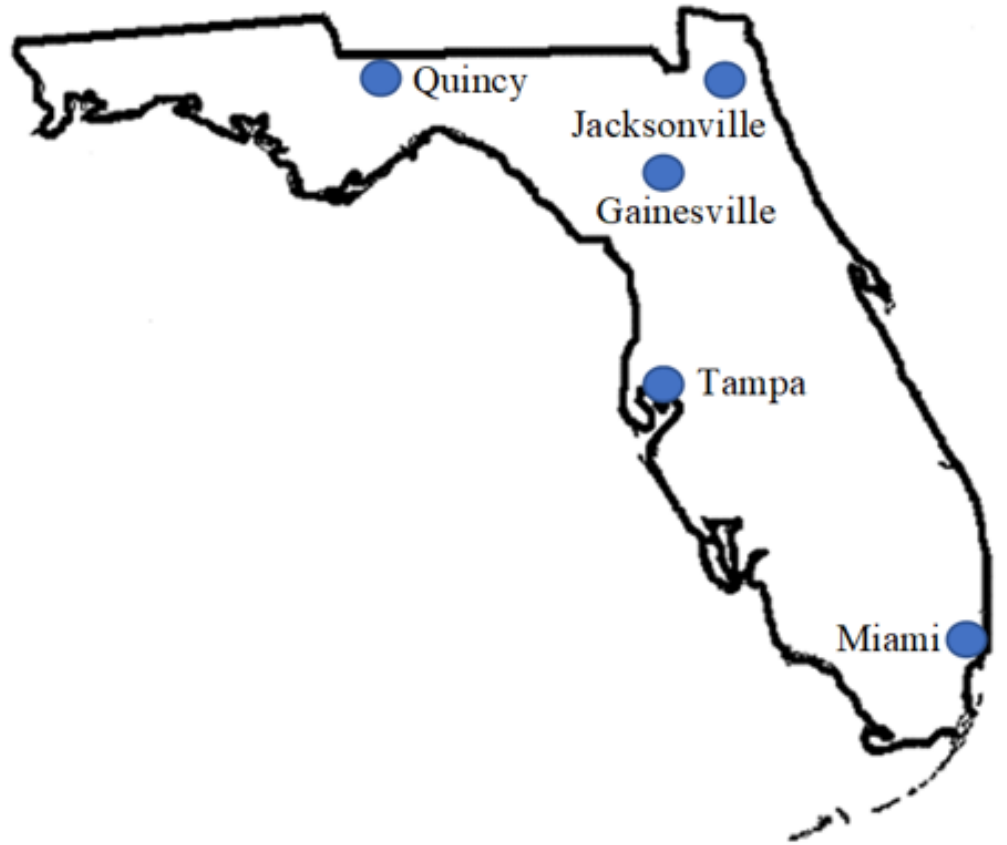




Rodgers, McVay, and Kelch (2022)

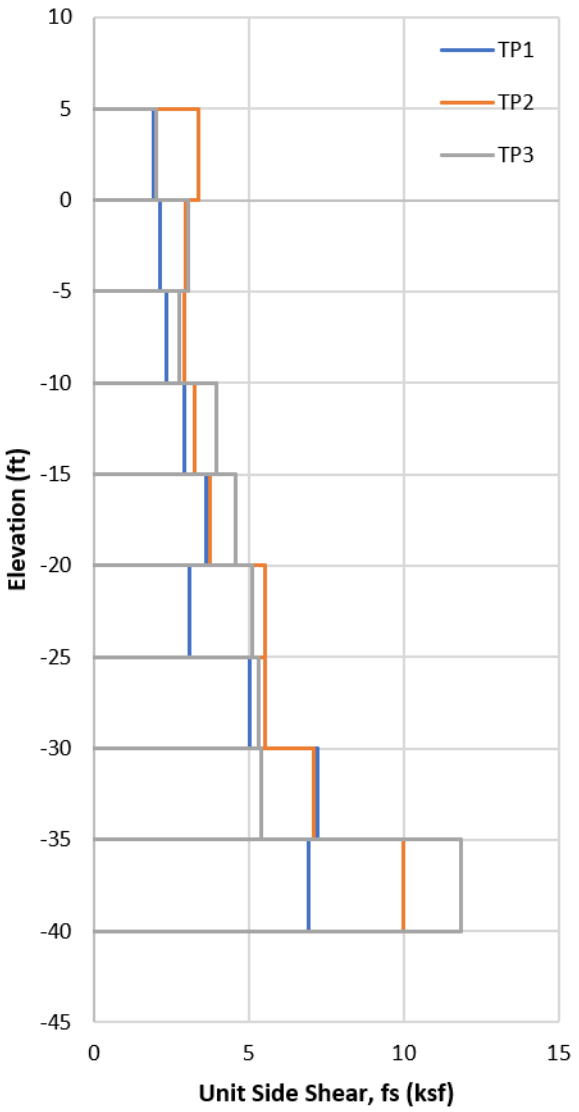
Building Correlation for Enhanced QA/QC



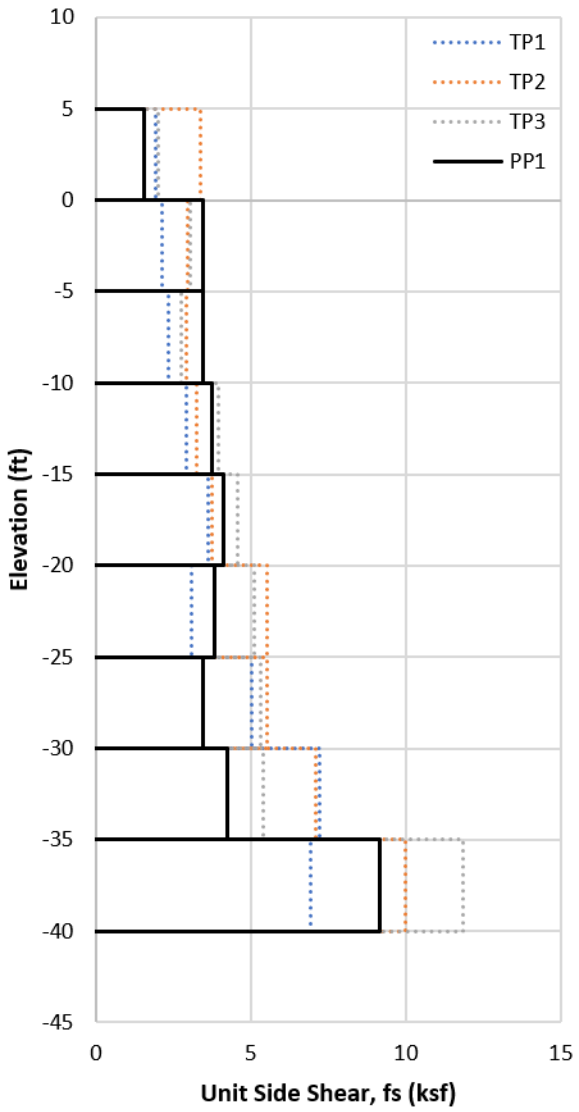


Enhanced Bored Pile QA/QC

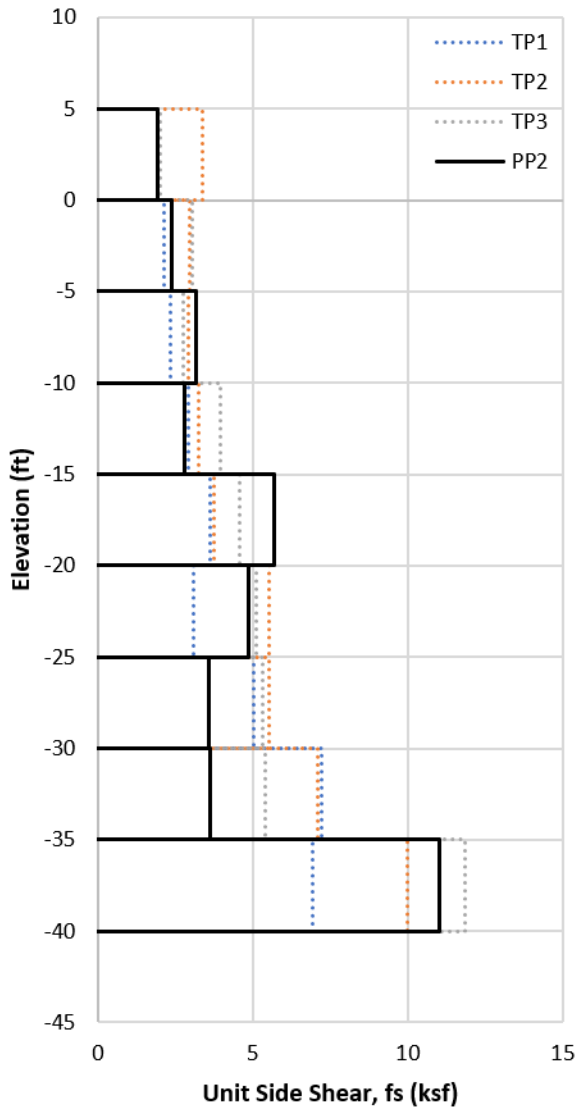
Test Piles



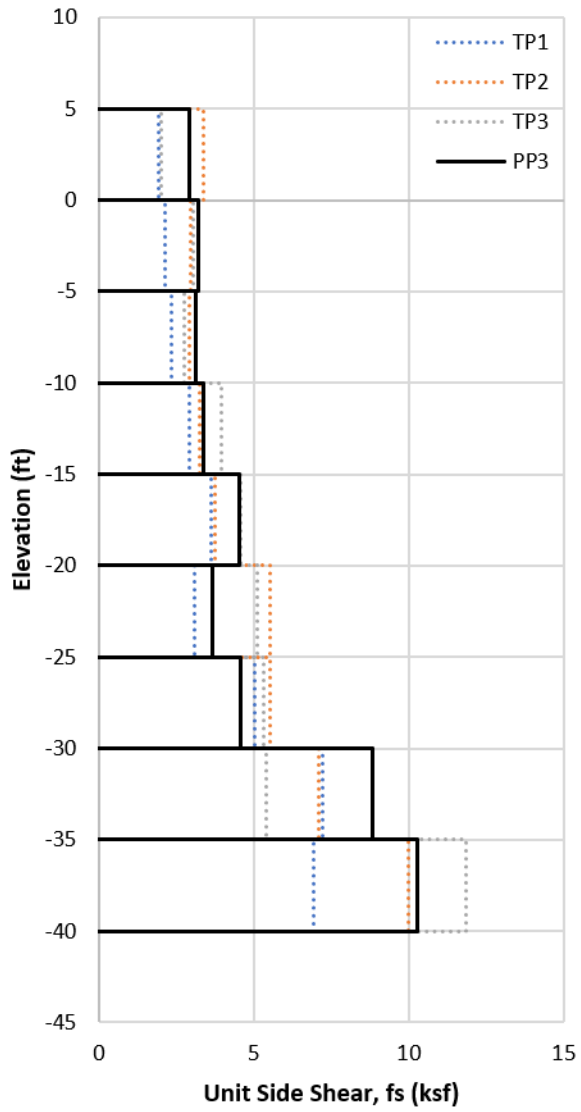
Production Pile 1



Production Pile 2

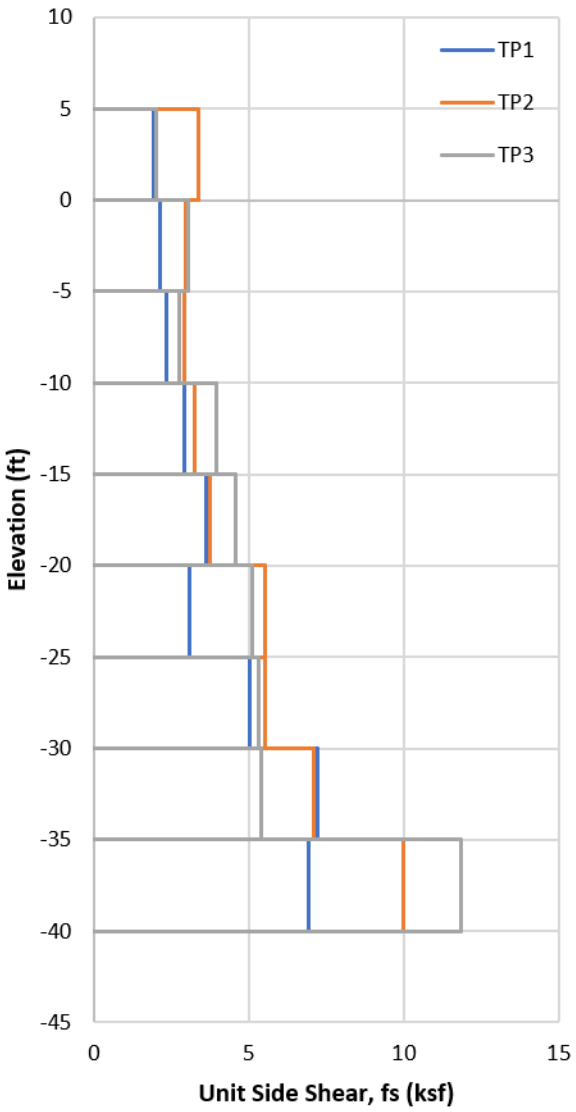


Production Pile 3

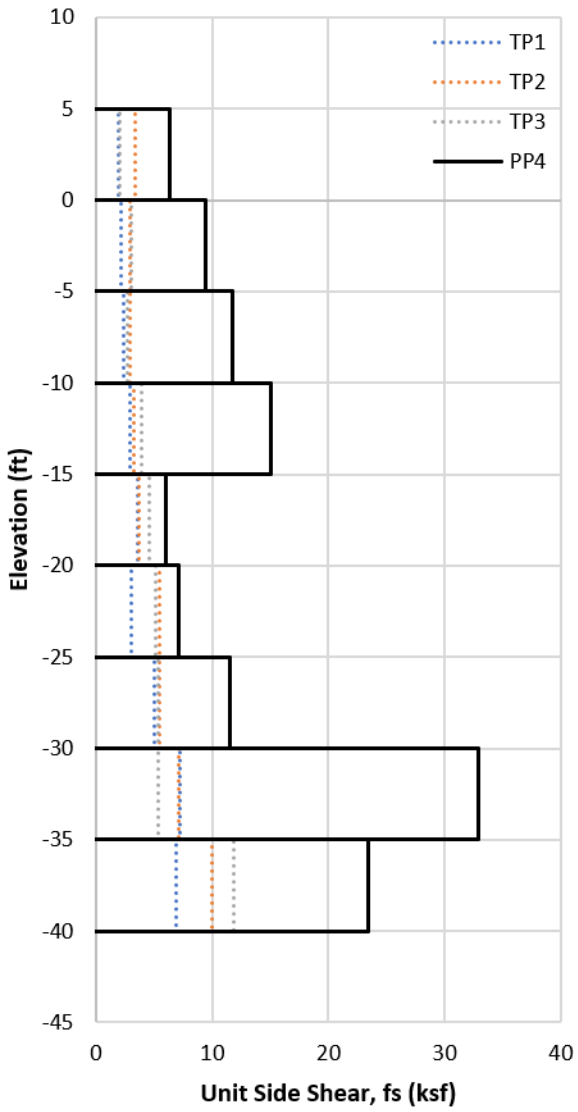


What happened?

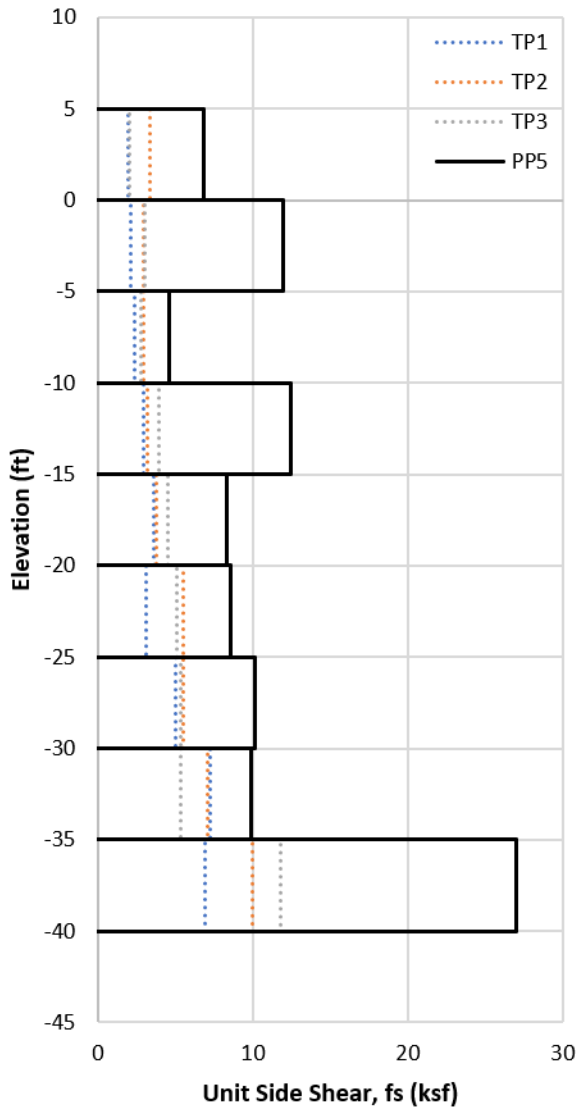
Test Piles



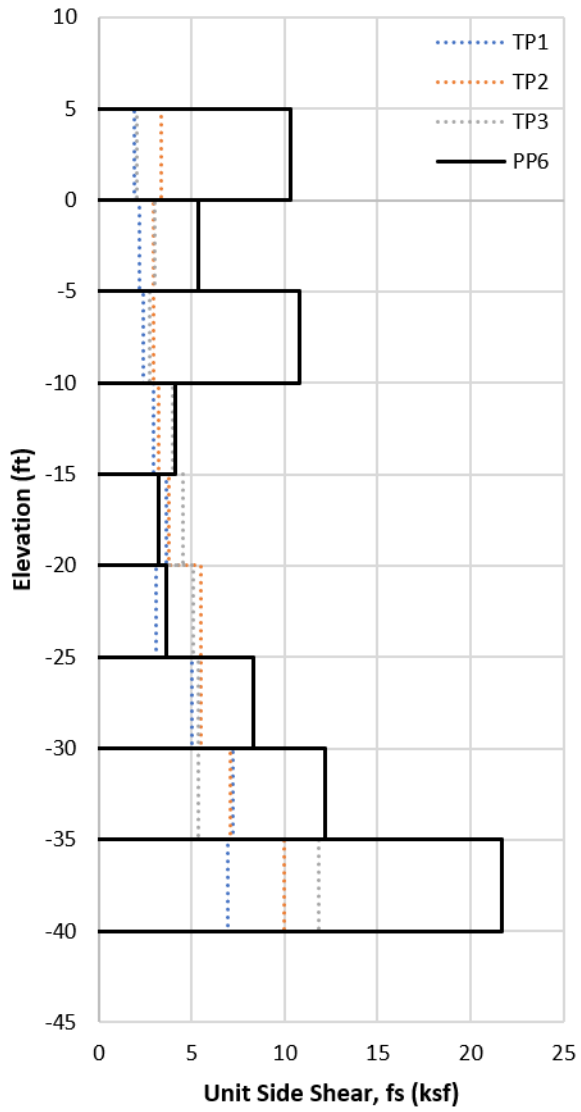
Production Pile 4



Production Pile 5

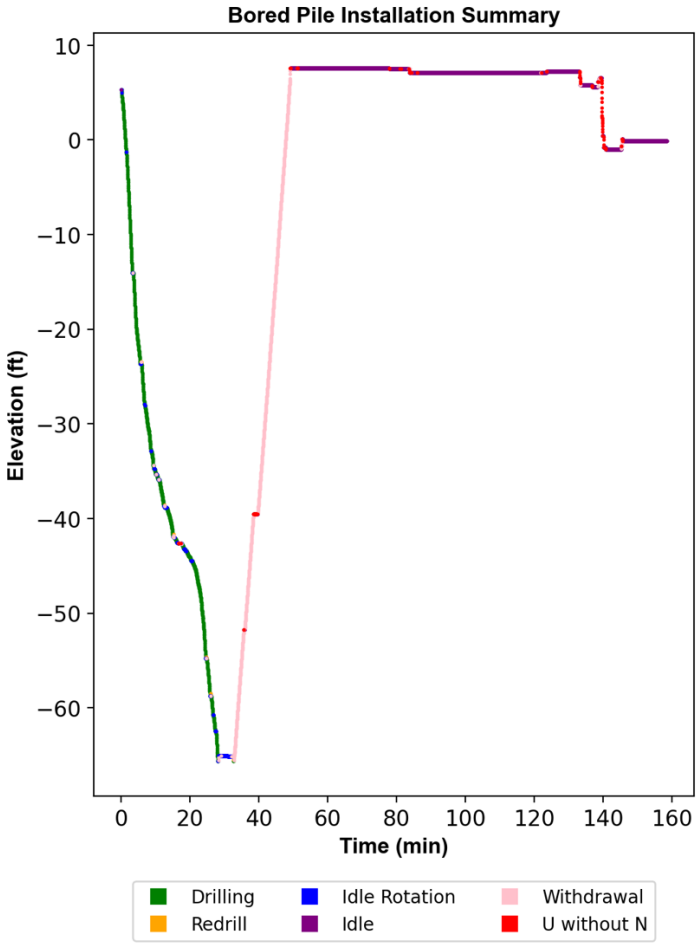


Production Pile 6

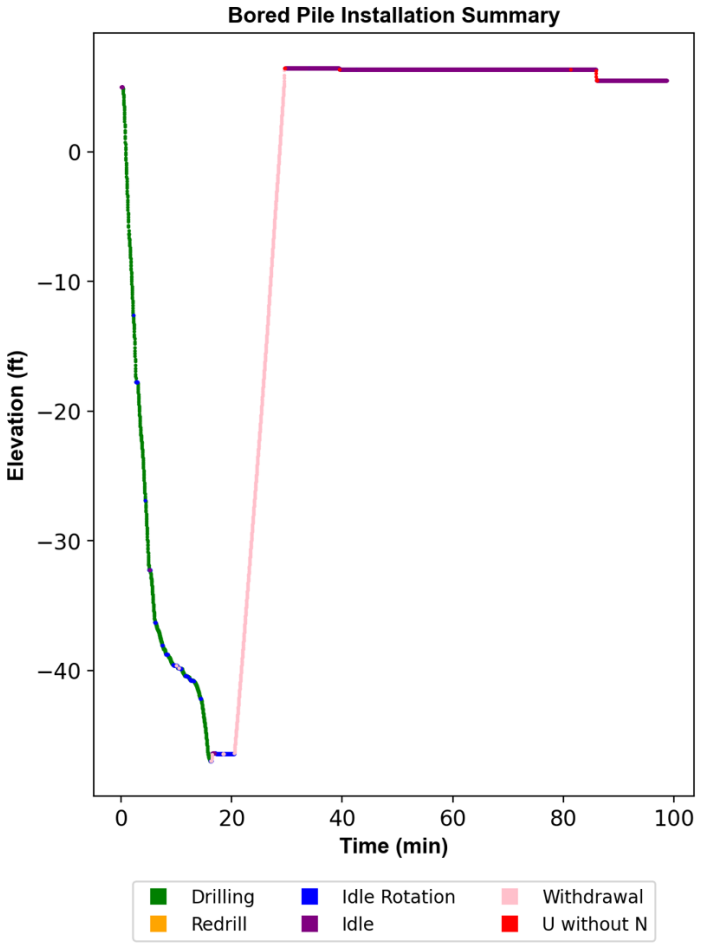


Bored Pile Installation Summaries

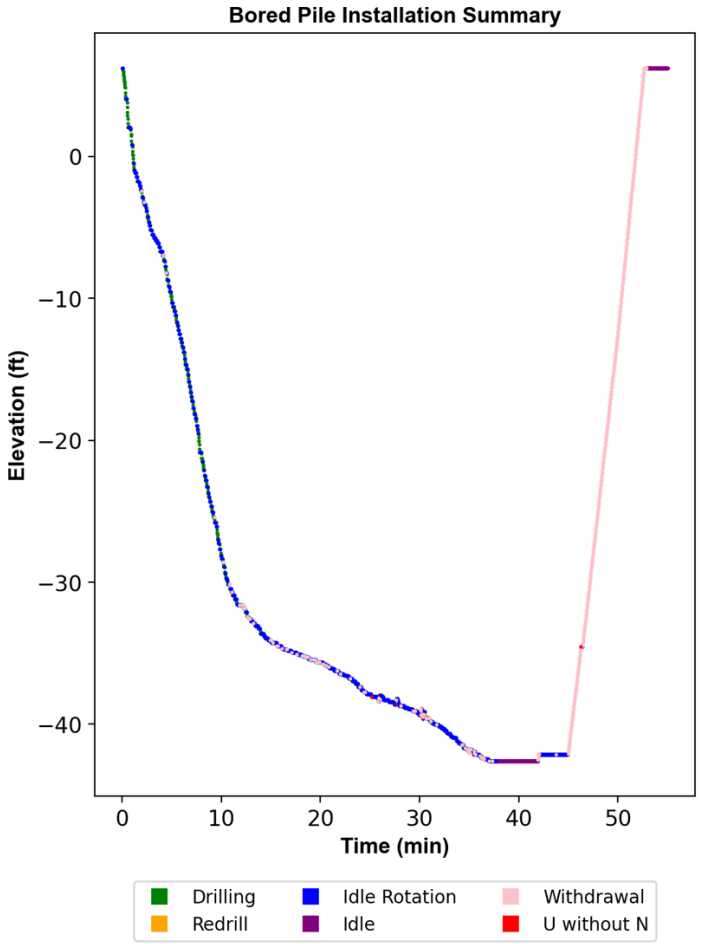
Test Pile Phase



Production Pile Phase 1

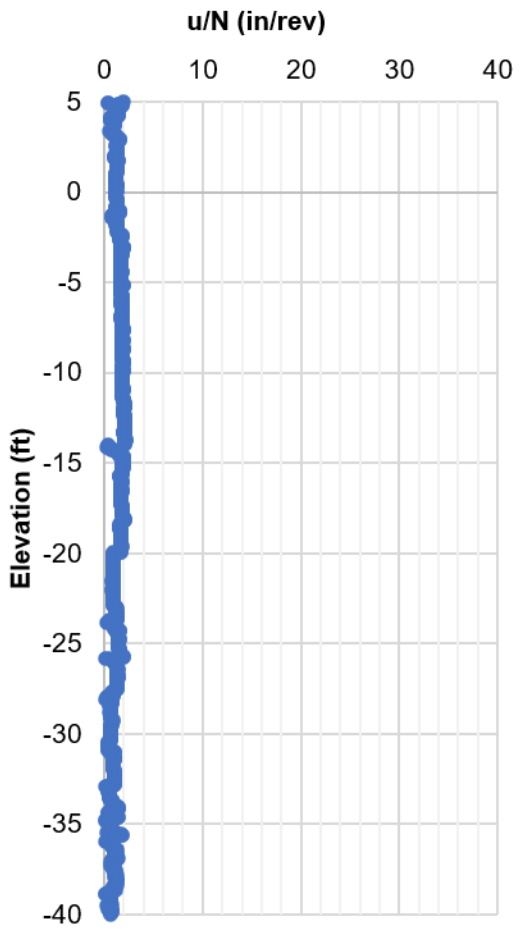


Production Pile Phase 2

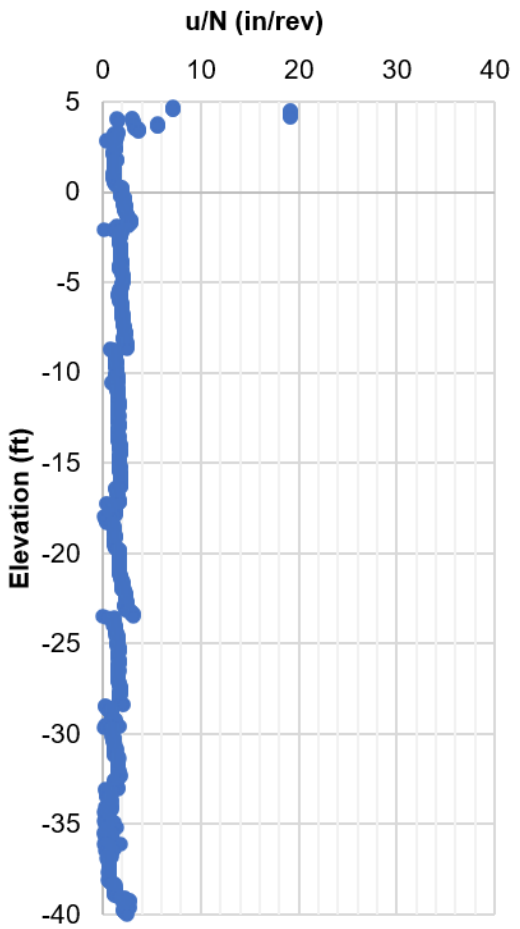


Penetration per Rotation Ratio

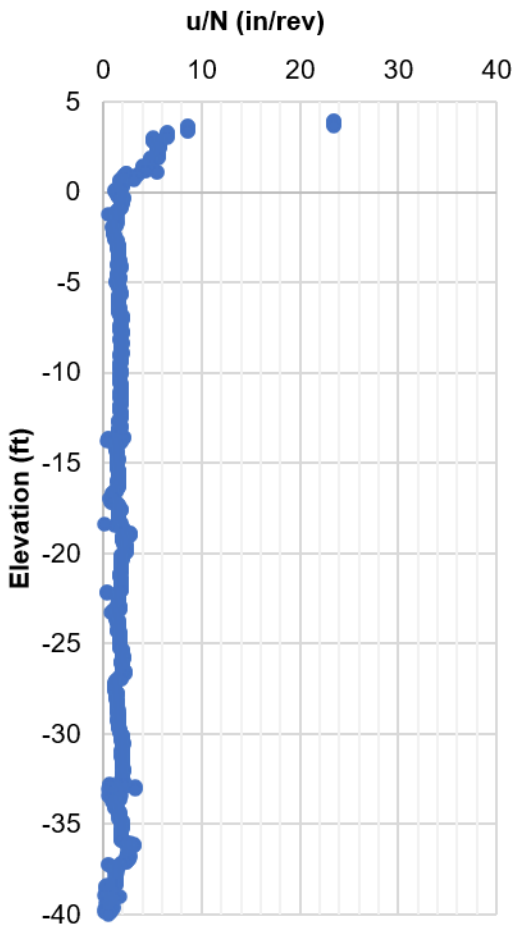
Test Pile



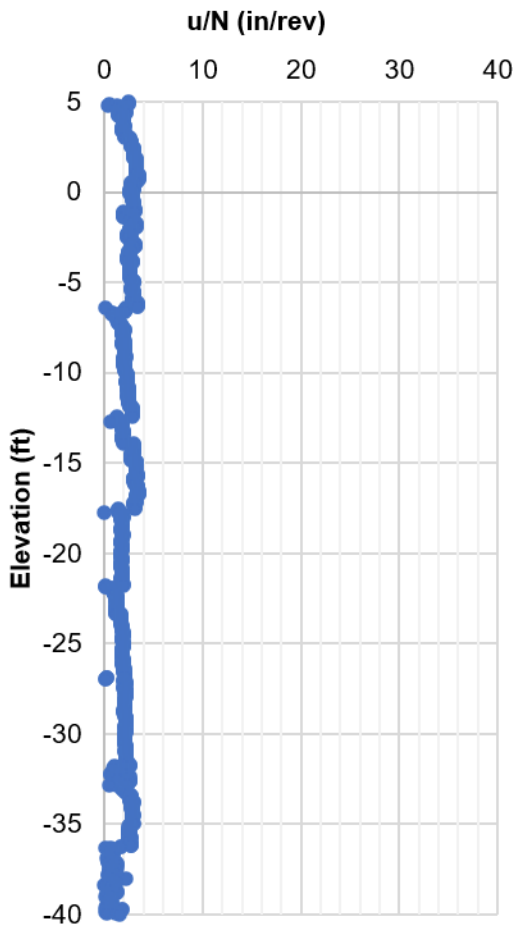
Production Pile 1



Production Pile 2

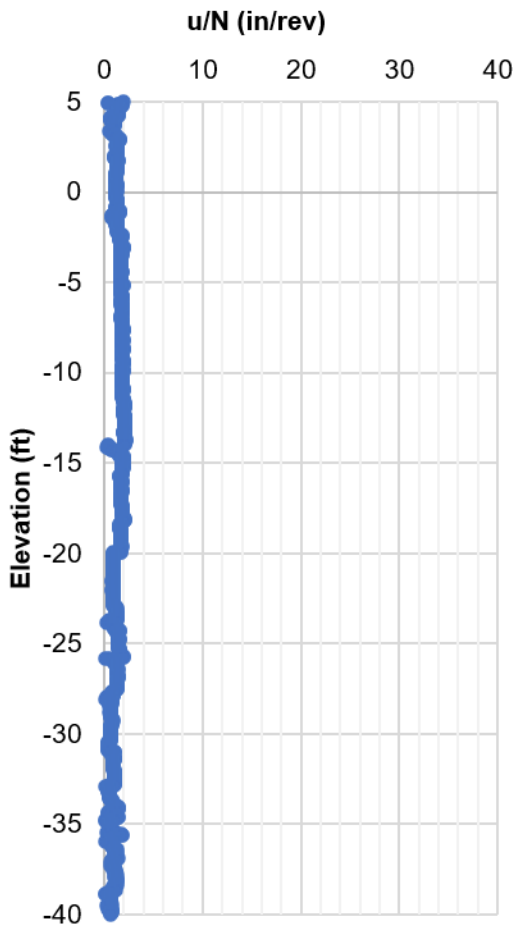


Production Pile 3

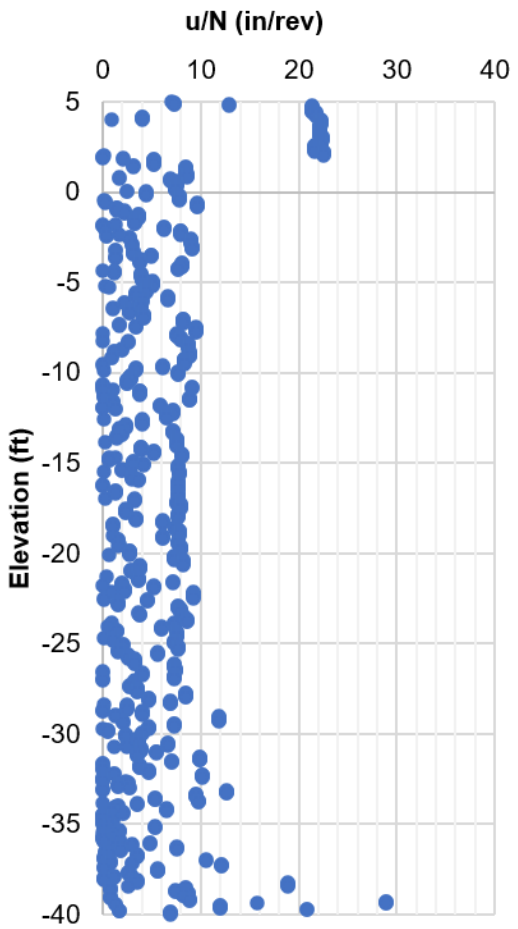


Penetration per Rotation Ratio

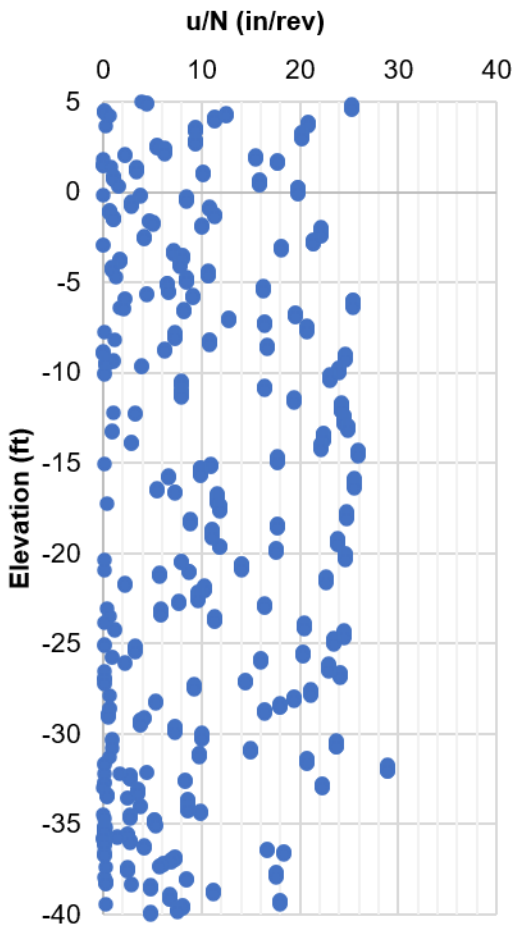
Test Pile



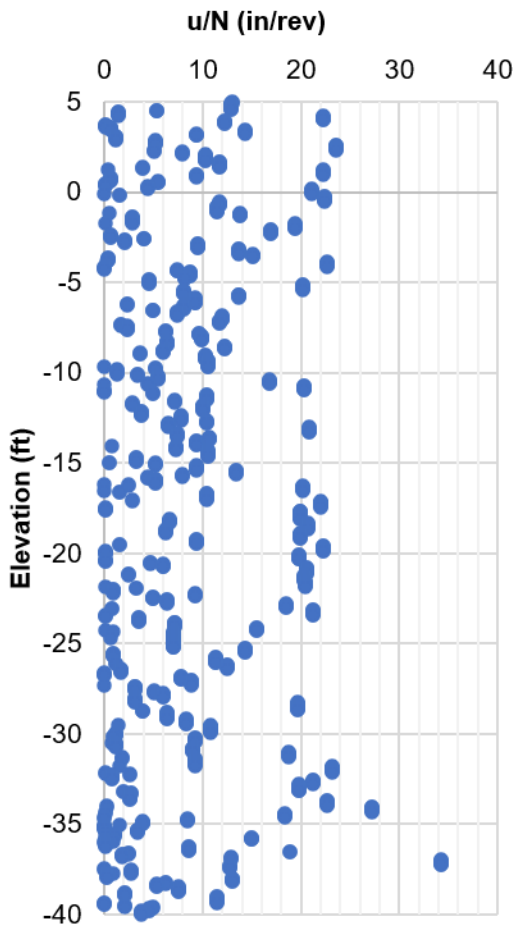
Production Pile 4



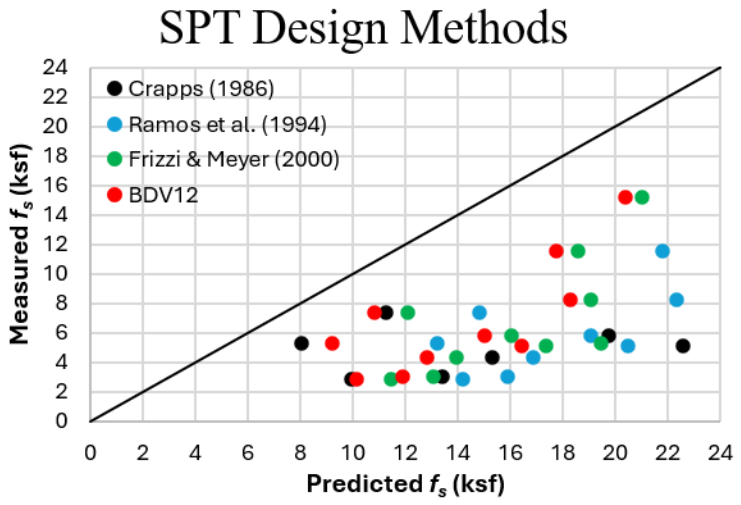
Production Pile 5

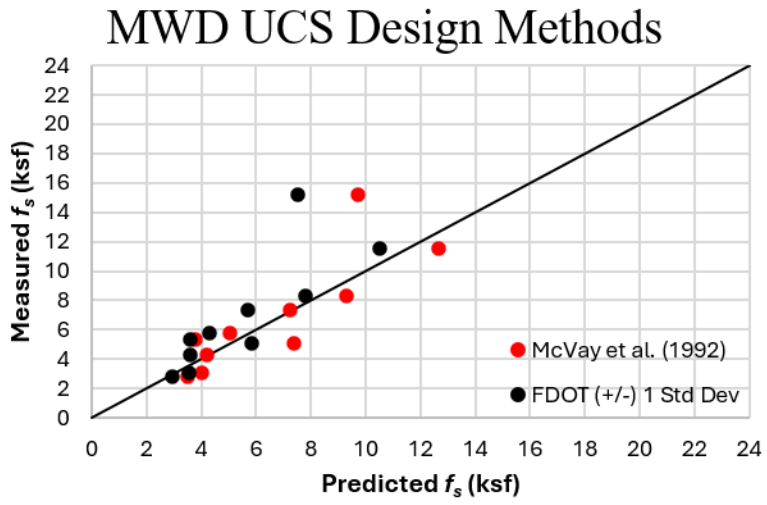


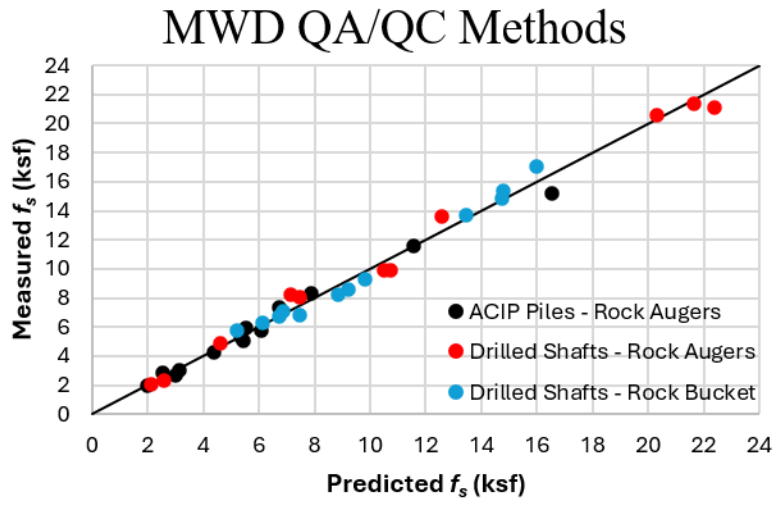
Production Pile 6

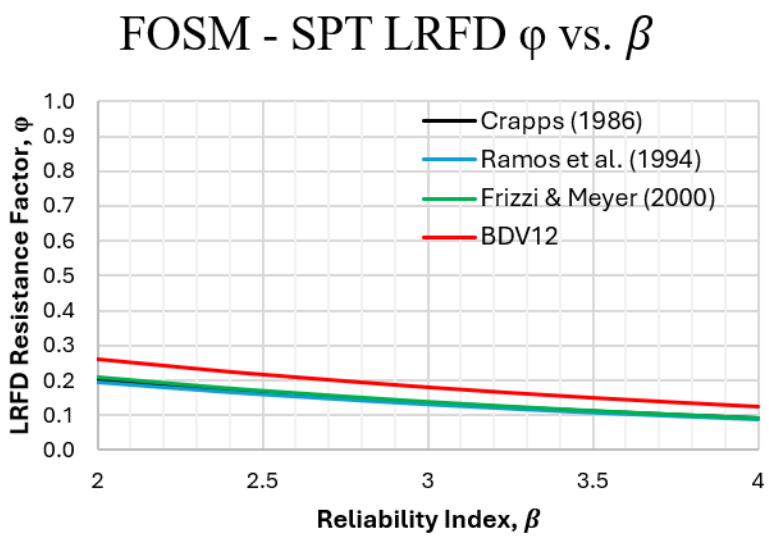


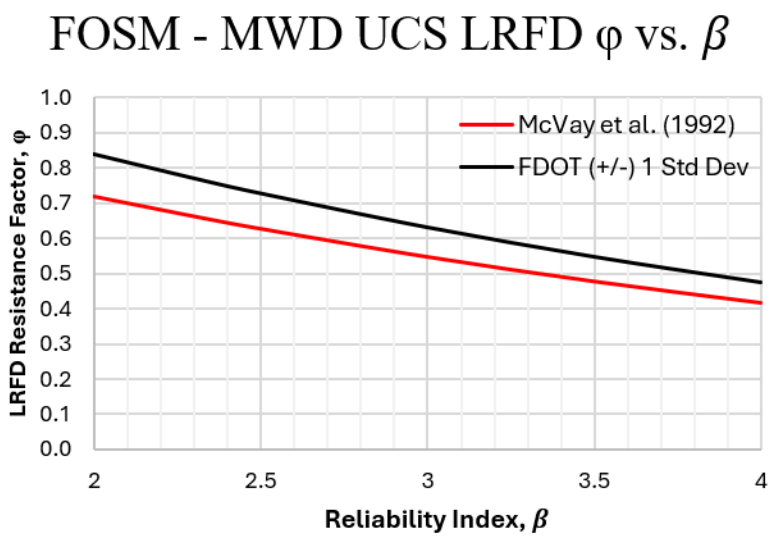
Reducing Uncertainty via MWD

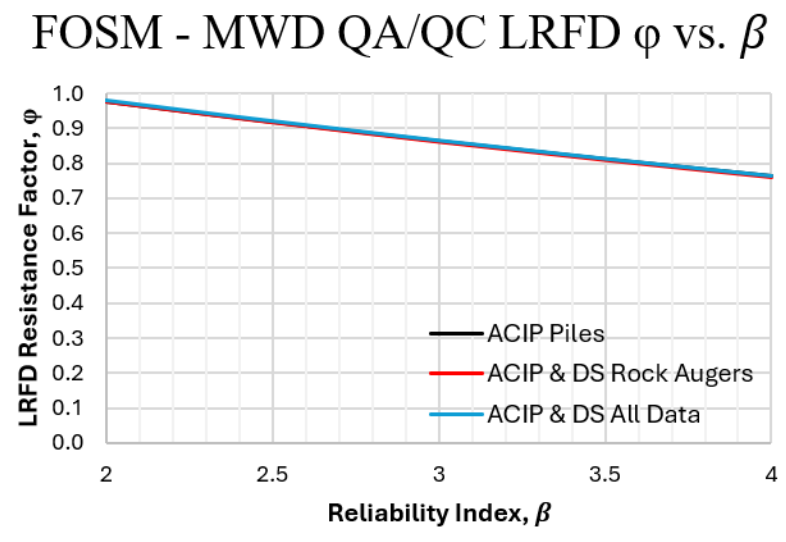













Thank you so much!