Measuring While Drilling in Florida Soils for Geotechnical Site Characterization BED31-977-03

GRIP Meeting

FDOT Project Manager:
Dino Jameson, P.E.

UF PI: Michael Rodgers, Ph.D., P.E.

Graduate Researcher:
Wyatt Kelch, Ph.D.

August 15, 2025

Project Objectives

1. Investigate the viability of developing MWD practices for in situ soil assessment in support of conventional site characterization methods
2. Investigate multiple drill bit types to determine which bit provides the best sensitivity for the delineating Florida soils and provides an efficient drilling rate
3. Identify optimal drilling parameter ranges and develop a standard drilling procedure for the new test method
4. Investigate various independent and compound drilling parameters while maintaining the optimal parameter ranges to begin building an operational index to classify soil and rock types
5. Investigate the effect of eccentric drill string rotation on in situ strength assessment
6. Develop correlations between the measured drilling response and soil and rock properties commonly used in geotechnical design

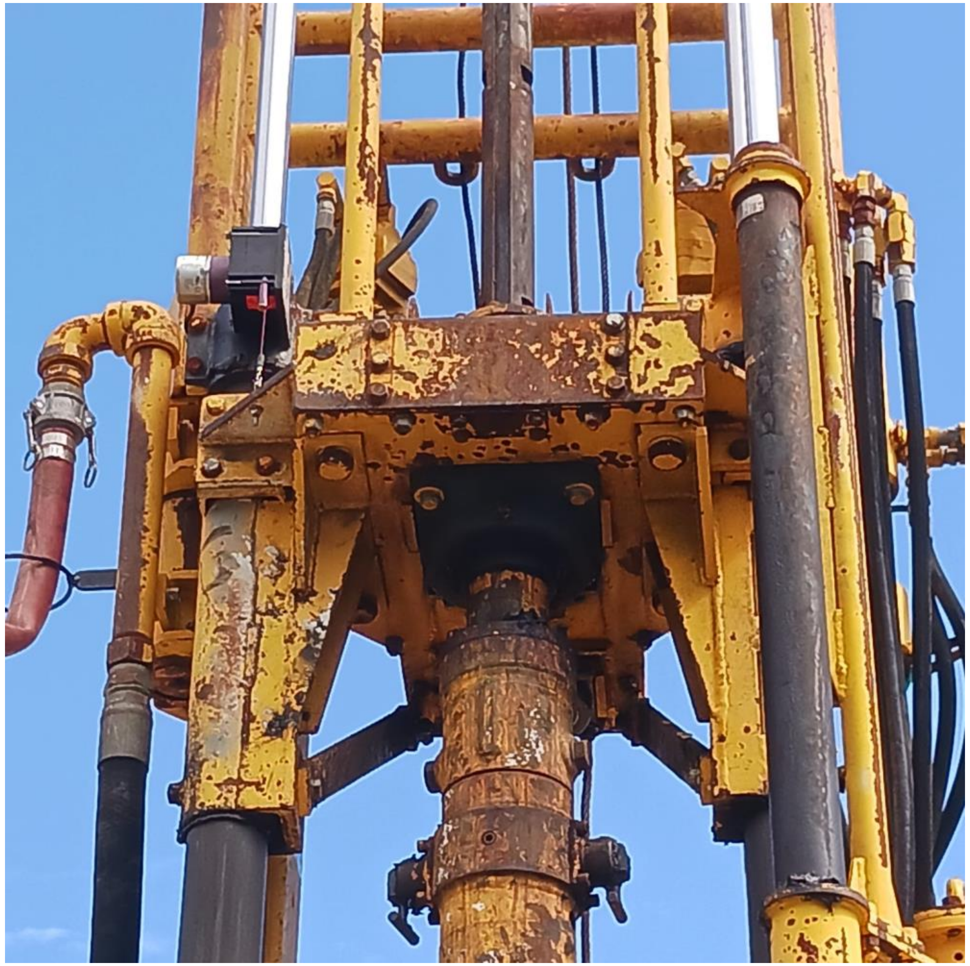
Project Tasks

- Task 1 - Drill Rig Instrumentation, Site Reconnaissance, and Preliminary Development
- Task 2 - Drill Bit Selection and Method Development
- Task 3a - Operational Index Development
- Task 3b - Eccentric Rotation Investigation at Deeper Drilling Depths
- Task 4 - Developing Correlation Between MWD and Engineering Parameters
- Tasks 5a, 5b, and 5c - Consultant Implementation of MWD for Geotechnical Site Characterization
- Task 6a - Draft Final
- Task 6b - Closeout Meeting
- Task 7 - Final Report

Task 1 – Drill Rig Instrumentation, Site Reconnaissance, and Preliminary Development

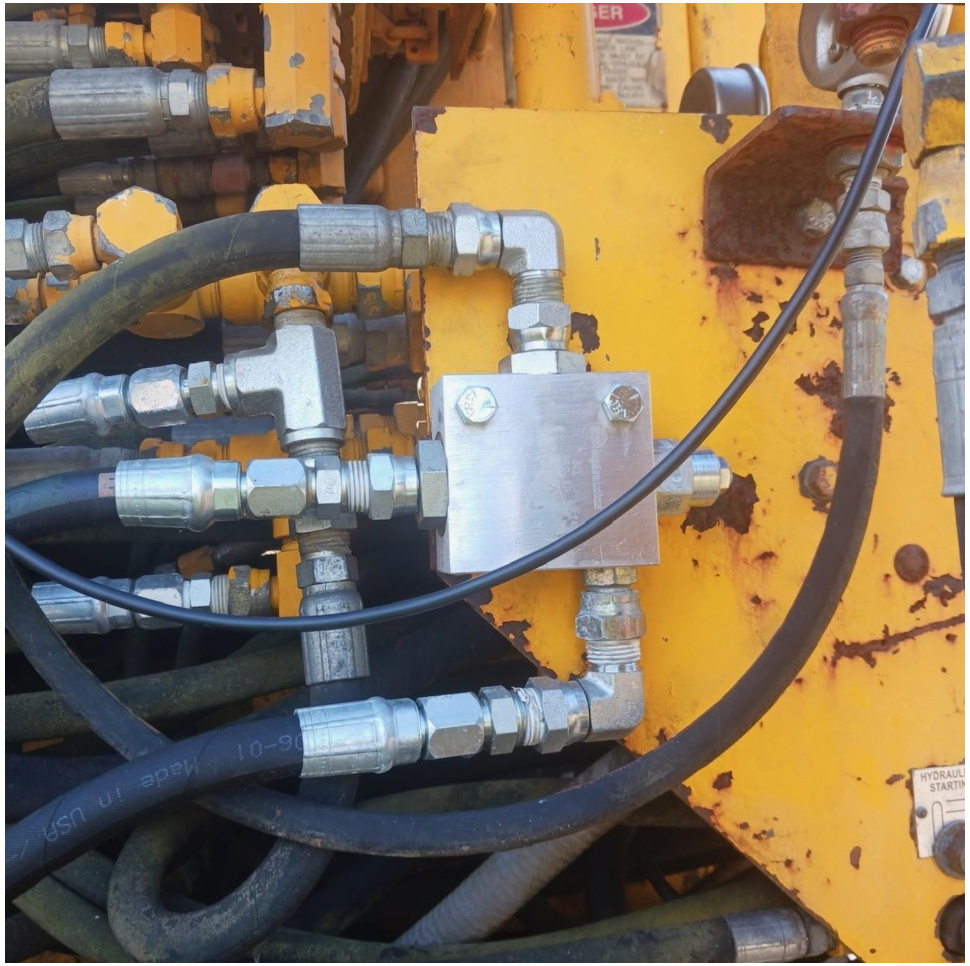
- Four Gatorock slabs were cast to assist in developing correlations between drilling parameters and qu and qt using the bit selected in Task 2
  - The slabs will also assist in determining an upper penetration rate limitation while drilling within the developed operational limits

Task 1 – Drill Rig Instrumentation - Depth Sensor

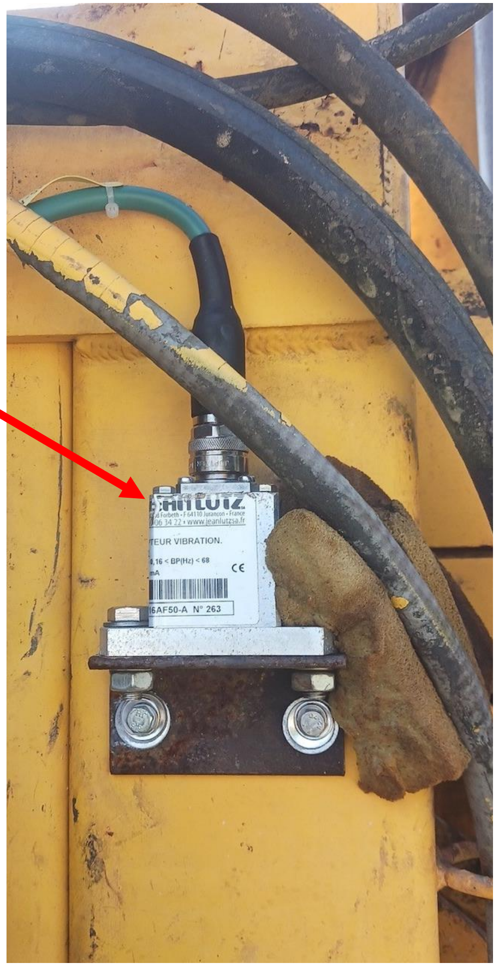


Task 1 – Drill Rig Instrumentation - RPM Sensor

Task 1 – Drill Rig Instrumentation
Hydraulic Flow Control Valve and Drill Rig Vibration Sensor

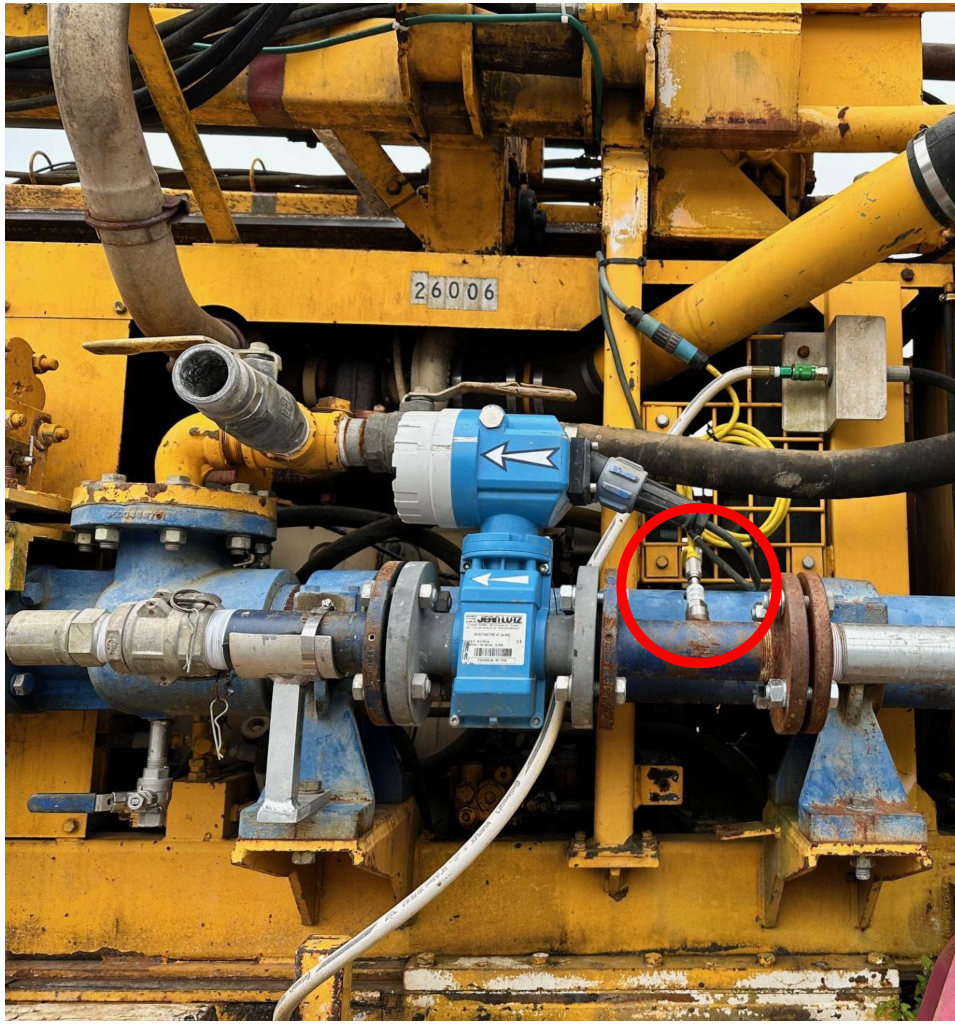


More control of penetration rate



Measure drilling vibrations on the drill rig

Task 1 – Drill Rig Instrumentation - Flow Meter & Pressure Transducer



Task 1 – Drill Rig Instrumentation

- New wireless drill rod transducer measures torque, crowd, and 3-axis vibration in the drill string
- Begins sampling drill rod data after the MWD system is powered on

<u>Old System Requirements</u>

- External computer
  - Daily shunt calibrations and logging procedures
- External base station
- Conversion module box
- Auxiliary junction box
- Additional cabling
- **Not viable for implementation**

MWD Drill Bits

- Surveys were given to FL Geotechs that do site investigation work for FDOT
- Develop method to embrace the current FL drilling practice and tooling

- Tri-cone roller bits and drag bits were identified in majority of surveys
- PDC bit is UF research recommendation
- Drill bit diameter = 2-7/8”
  - Based on survey responses

Steel Tooth Tri-cone Roller Bit

Infinity PDC Bit

3 Chevron Stepped Drag bit

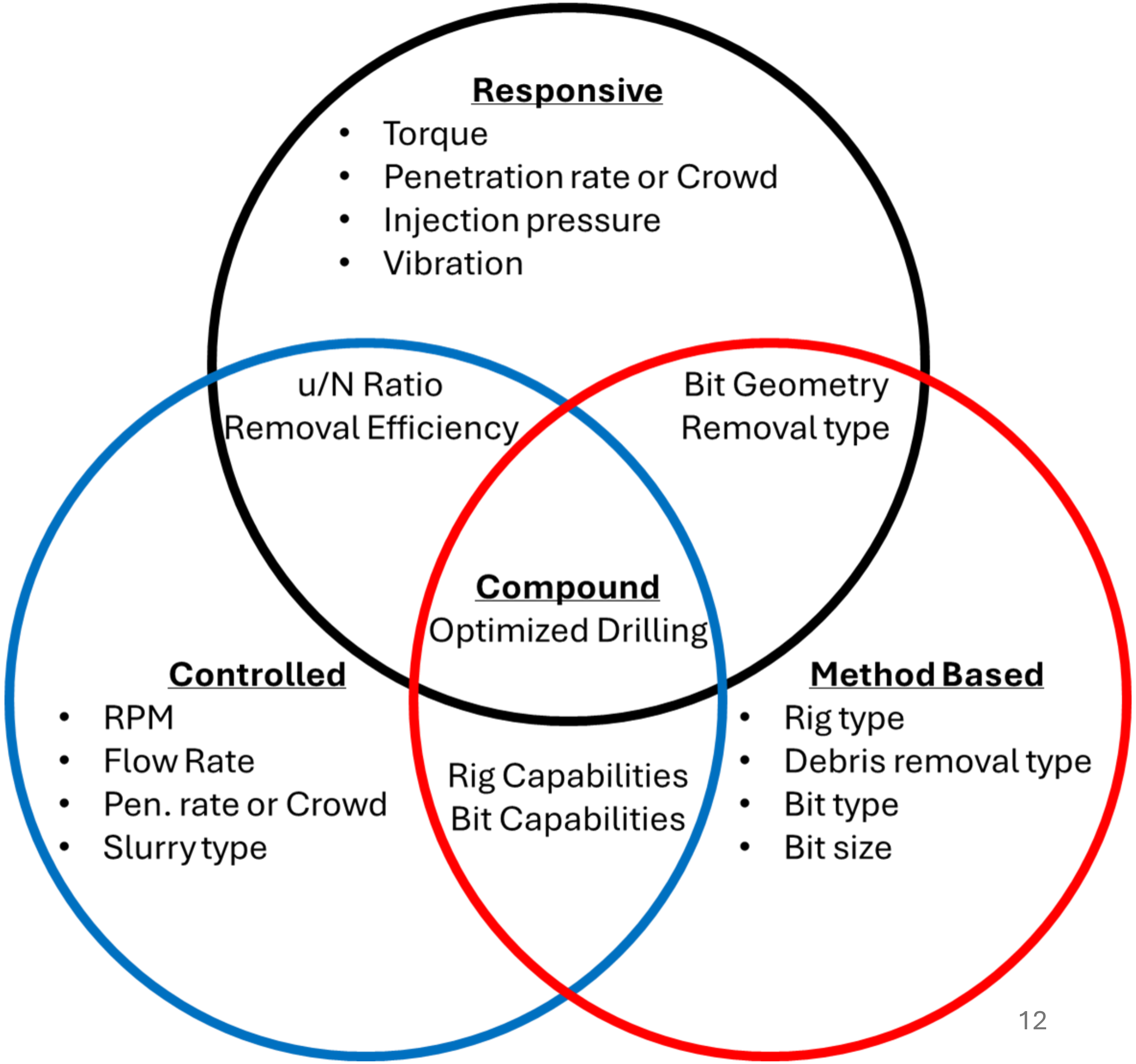
Task 2 – Drill Bit Selection and Method Development

- Which drilling tool provides…
  - Best sensitivity for the delineation of various Florida soils
  - Does not clog up in clay
  - Ideal penetration rate to ensure the method is efficient
- Optimal parameter ranges will then be dialed-in for the select drilling tool

Drilling Parameters Categories

1. **Method-based parameters**
   - Parameters that reflect the drilling application
     - Type of drill rig, type of drilling tool, drill bit diameter, method of drilled debris removal, and drill rig limitations.
2. **Controlled drilling parameters**
   - Parameters that are typically controlled by the drill rig operator
     - Penetration rate, rotational speed, inclination, drilling slurry properties, and fluid injection flow rate
3. **Responsive drilling parameters**
   - Parameters that are dependent upon method-based parameters, controlled parameters, and the strata encountered during drilling
     - **Torque**, crowd, **vibration**, and fluid injection pressure

- **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 mechanical energy **input** per unit volume of material removed during drilling

$$e = W/V = F/A + 2\pi NT/Au \quad (in \cdot lb/in^3 \ or \ psi)$$

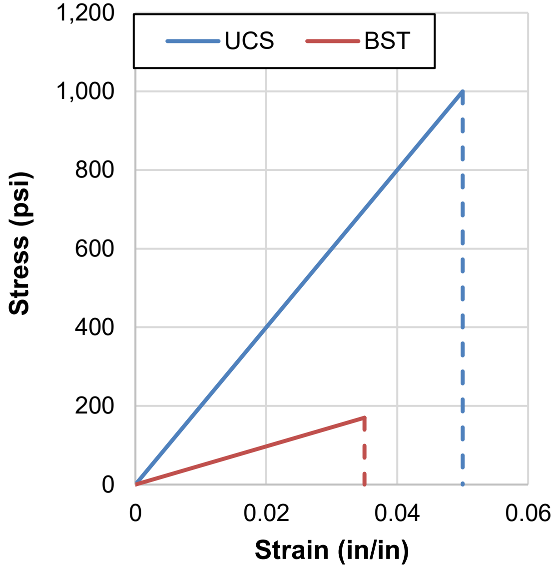
- Energy density is the mechanical energy **absorbed** elastically per unit volume of material before failure or permanent deformation

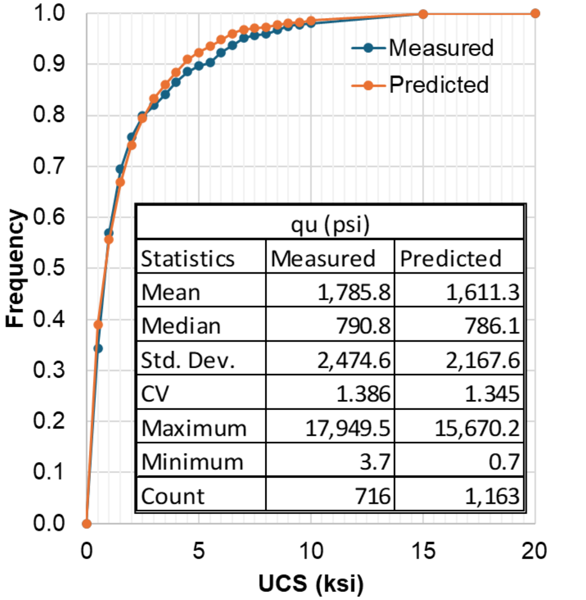
$$\text{Drilling Efficiency } (\eta) \times \text{specific energy } (e) = \text{energy density} (U)$$

$$\eta = \sum \eta_{geometry} + \eta_{u/N} + \eta_{bit\ wear} + \eta_{removal} + \eta_{ecc.} + \eta_{vib.} + \ \ldots$$

- Current goal is improving drilling efficiency (η) and inherently reducing the specific energy to closely approach the material's minimum energy density for each drilling tool
  - Controlled u/N procedures provide strain-controlled in situ loading

FDOT uses strain-controlled loading





qu (psi)		
Statistics	Measured	Predicted
Mean	1,785.8	1,611.3
Median	790.8	786.1
Std. Dev.	2,474.6	2,167.6
CV	1.386	1.345
Maximum	17,949.5	15,670.2
Minimum	3.7	0.7
Count	716	1,163

(Rodgers et al. 2019)

Phase 1 - Inefficient Drilling

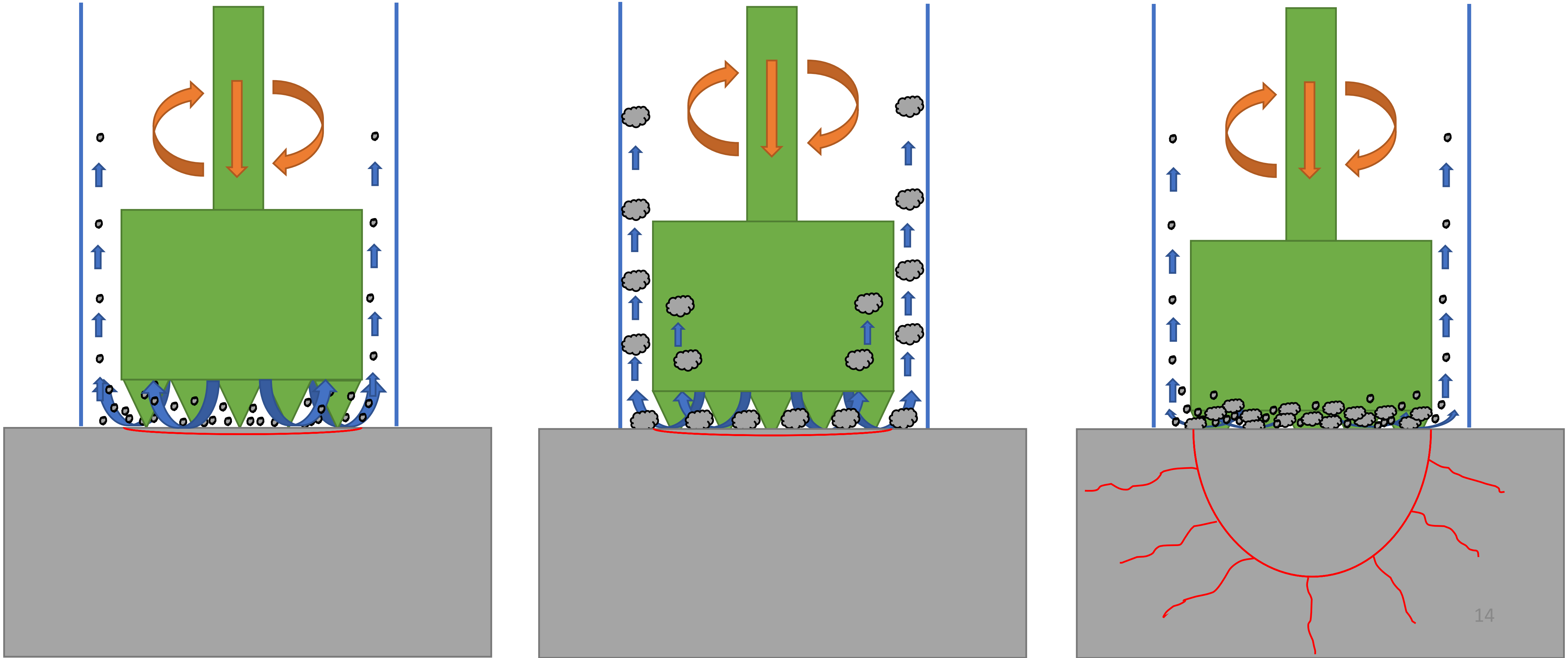
- Inefficient amount of crowd (F) applied to properly engage the drilling tool's cutting teeth
- Minimal indentation → minimal cutting action → minimal penetration per rotation (u/N)
- Majority of energy generated from baseline friction and not cutting action
- In situ strength assessment NOT viable via MWD

Phase 2 - Optimized Drilling

- Proper indentation and cutting → optimized penetration per rotation (u/N)
- Efficient removal of drilled debris → Larger soil/rock particles removed → minimal energy
- Minimal disturbance to soil/rock prior to strength assessment → Optimized core REC and quality
- In situ strength assessment viable via MWD

Phase 3 - Disturbed Drilling

- Overcrowding the bit → Increased torque
- Inefficient flushing → accumulation of drilled debris → smaller soil/rock particles removed
- Increased frictional resistance → High energy
- Increased bit wear and drill rig wear
- Disturbed soil/rock prior to strength assessment
- In situ strength assessment NOT viable via MWD



The Effects of Phase 3 Drilling

OL – Phase 2

(a)

Stall – Phase 3

(b)

MOC – Phase 3

(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)

Task 2 – Drill Bit Selection and Method Development

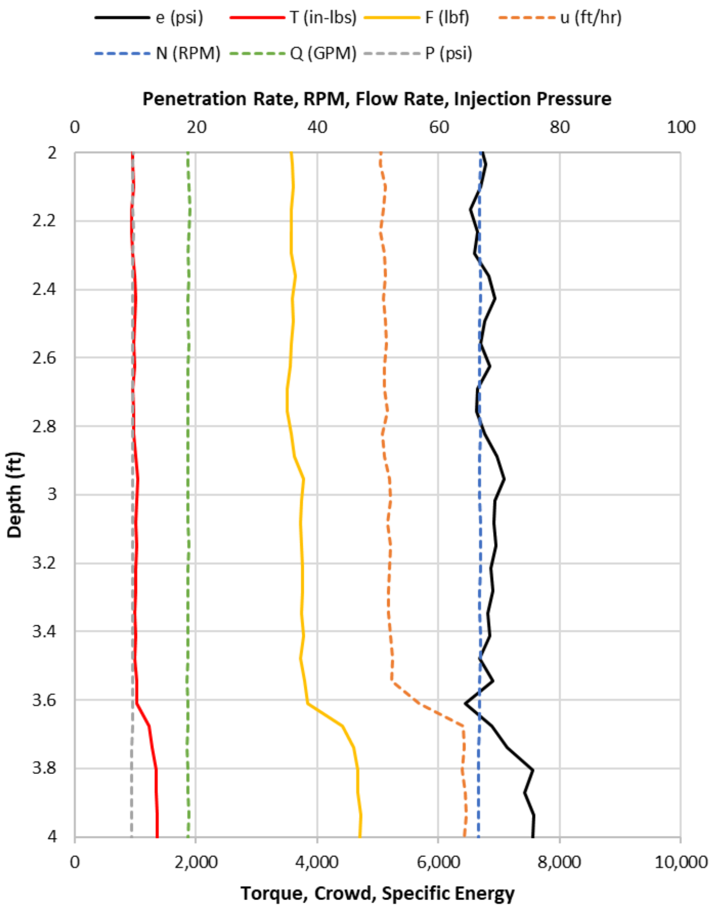
Tri-Cone Roller Bit

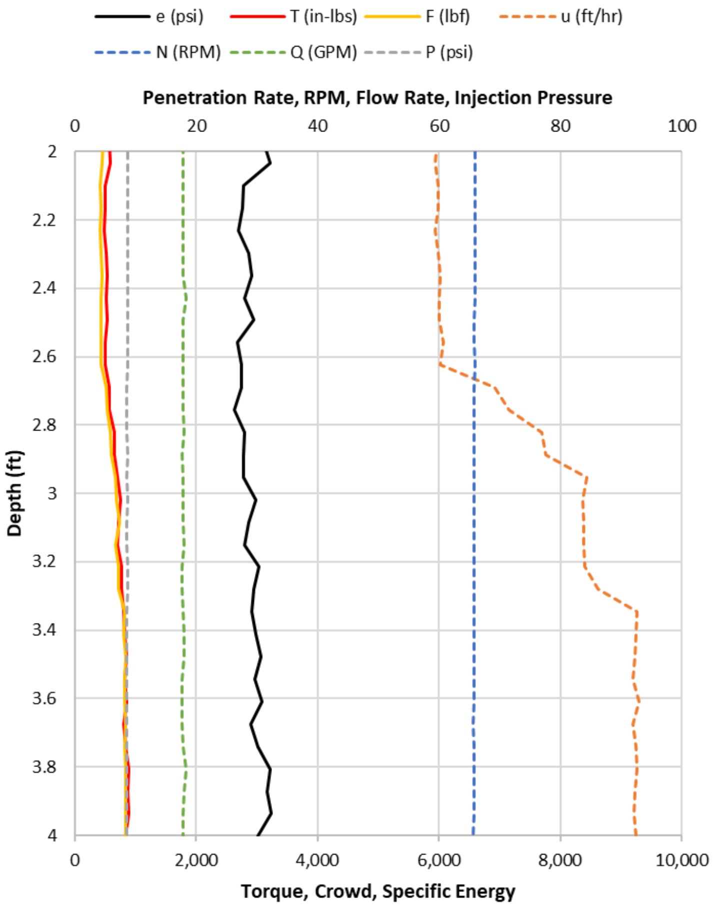
- Tri-cone SE increased w/ pen. rate increase
  - Smaller u/N range
- Requires ≈10x axial force for same penetration rate
  - Eccentric rotation
  - Less safe

PDC Bit

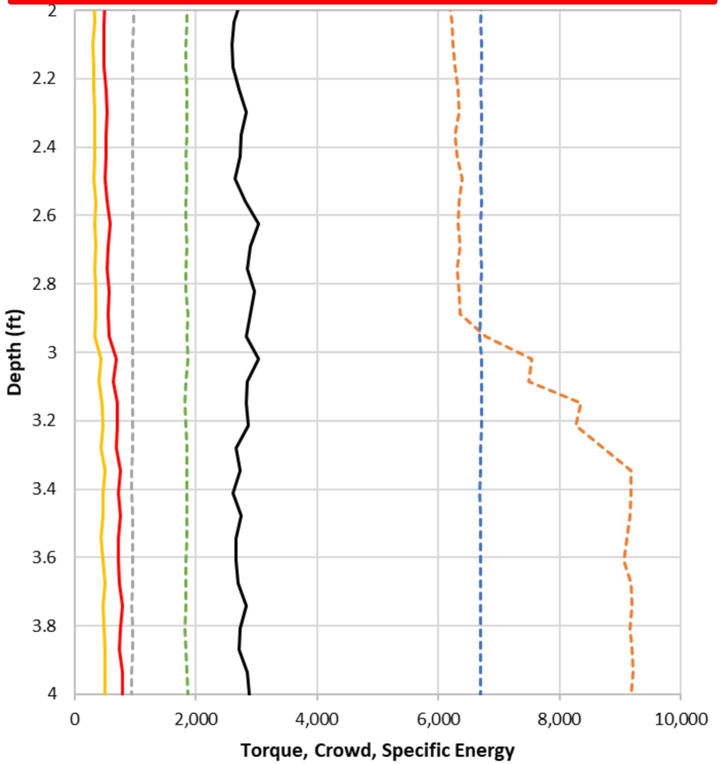
Drag bit has a superior removal mechanism in clayey soils

Drag Bit





Drag bit was chosen for its versatility in sand/clay/rock



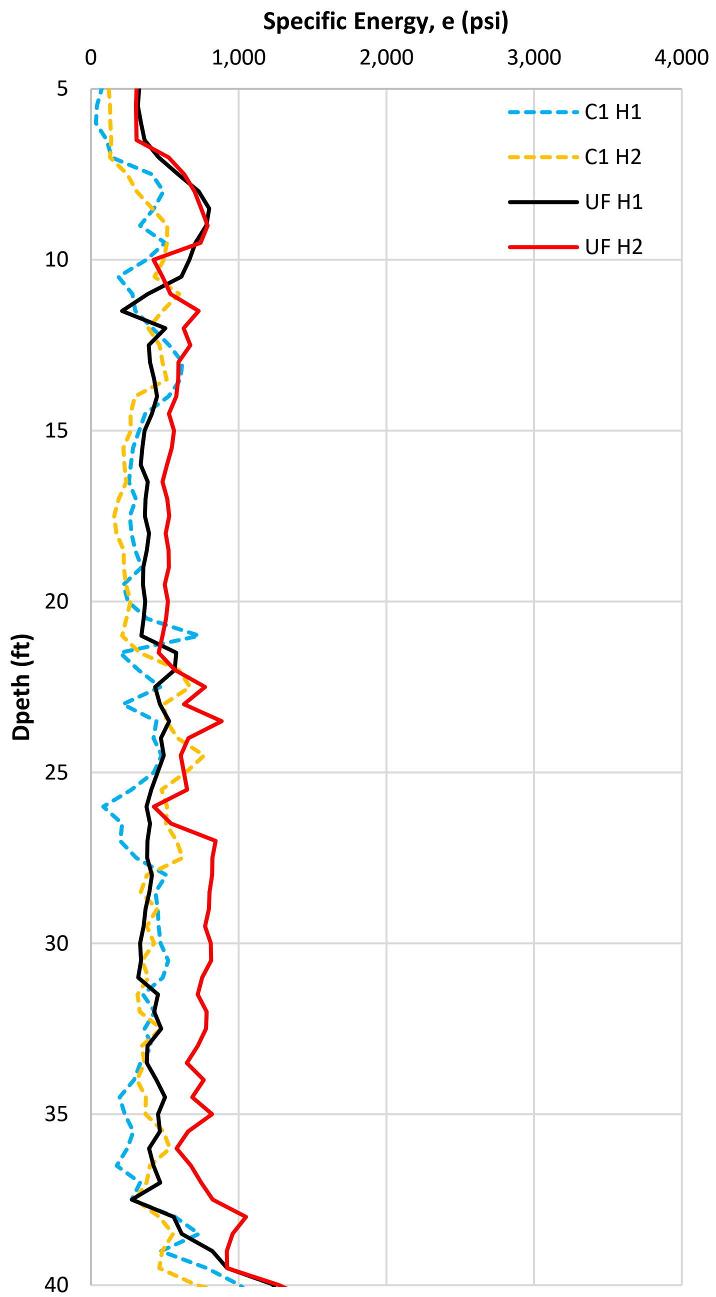
Task 2 - Method Development

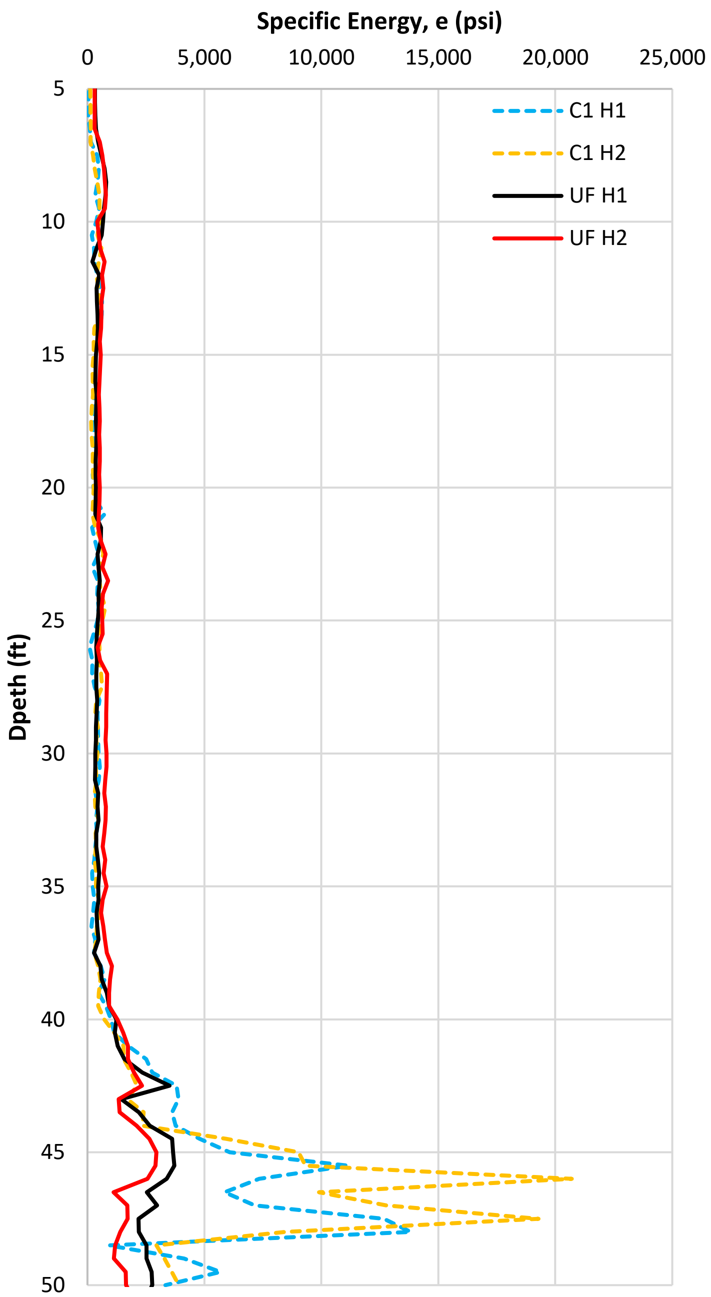
- Method development was an iterative process
  - Changing parameters to find optimal ranges for sand, clay, IGM, and rock using the same drilling tool
- Used 3 main sites during development
  - Kanapaha ⇨ Gatorock (simulated limestone and IGM) and soft clay layers
  - Trenton ⇨ Soft to medium-dense clean and slightly cohesive sands (A-3 and A-2-4)
  - CR-349 ⇨ Loose to dense silty/clayey sands and hard highly plastic clays (CH)
- Efficiently drilling highly plastic soils presented the greatest challenge
- Inspected clay cuttings and drag bit for signs of smearing or bit balling
- Dialed in optimized u/N and flow rate ranges to ensure proper cutting of clay without clogging
- Consultant 1 used optimized procedures in soil with reliable and repeatable results

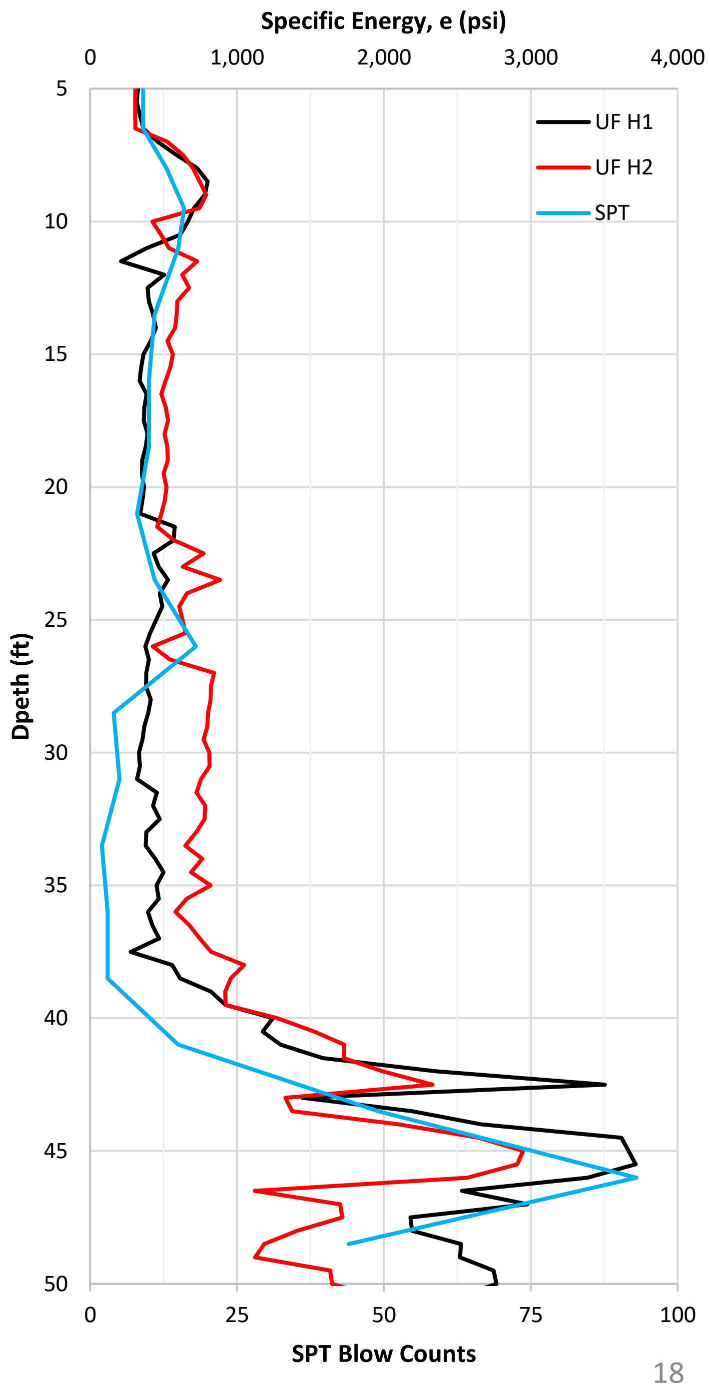
Controlled Environment

UF/FDOT Field Trials

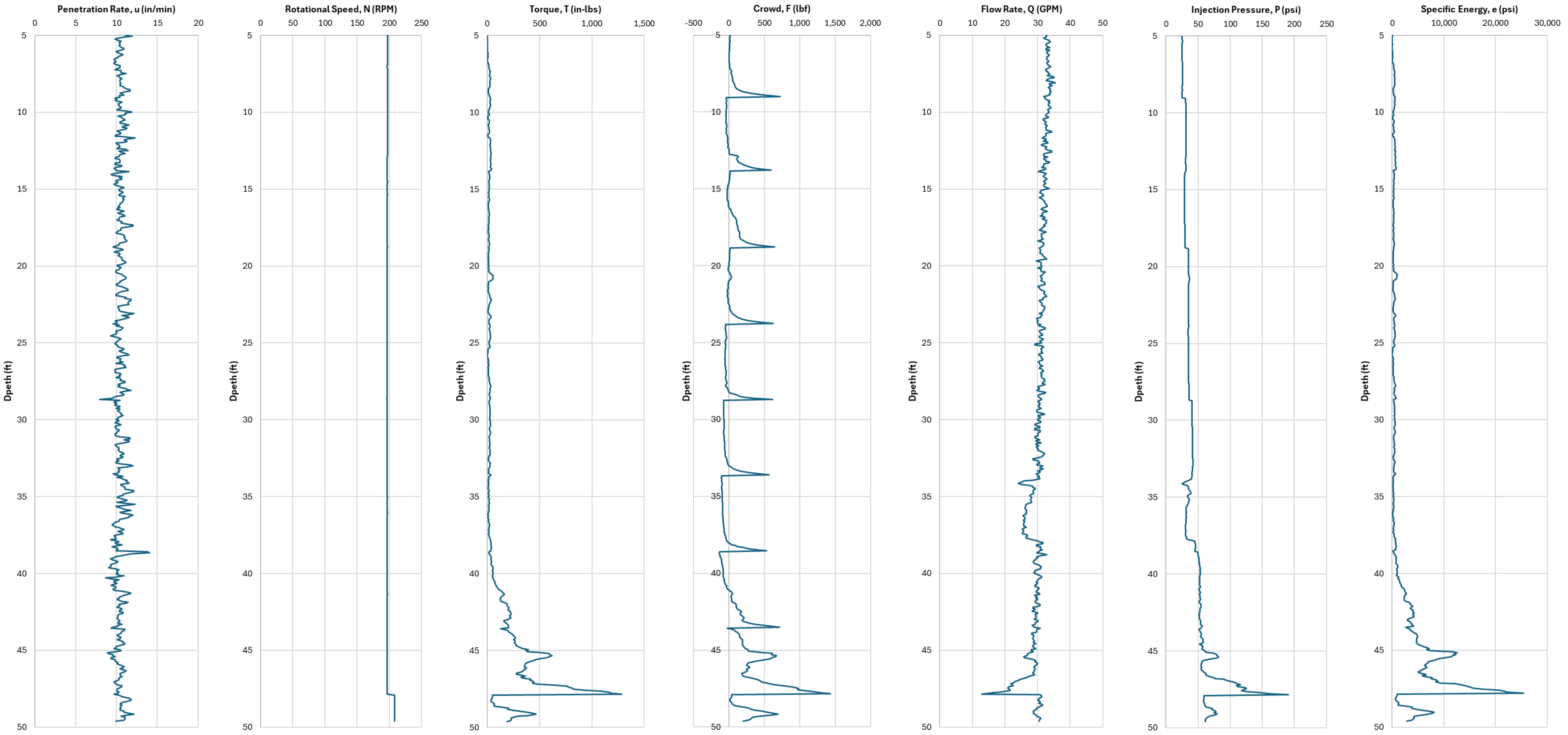
Consultant Implementation


Specific Energy, e (psi)
0
1,000
2,000
3,000
4,000
Dpeth (ft)
5
10
15
20
25
30
35
40
C1 H1
C1 H2
UF H1
UF H2


Specific Energy, e (psi)
0
5,000
10,000
15,000
20,000
25,000
Dpeth (ft)
5
10
15
20
25
30
35
40
45
50
C1 H1
C1 H2
UF H1
UF H2

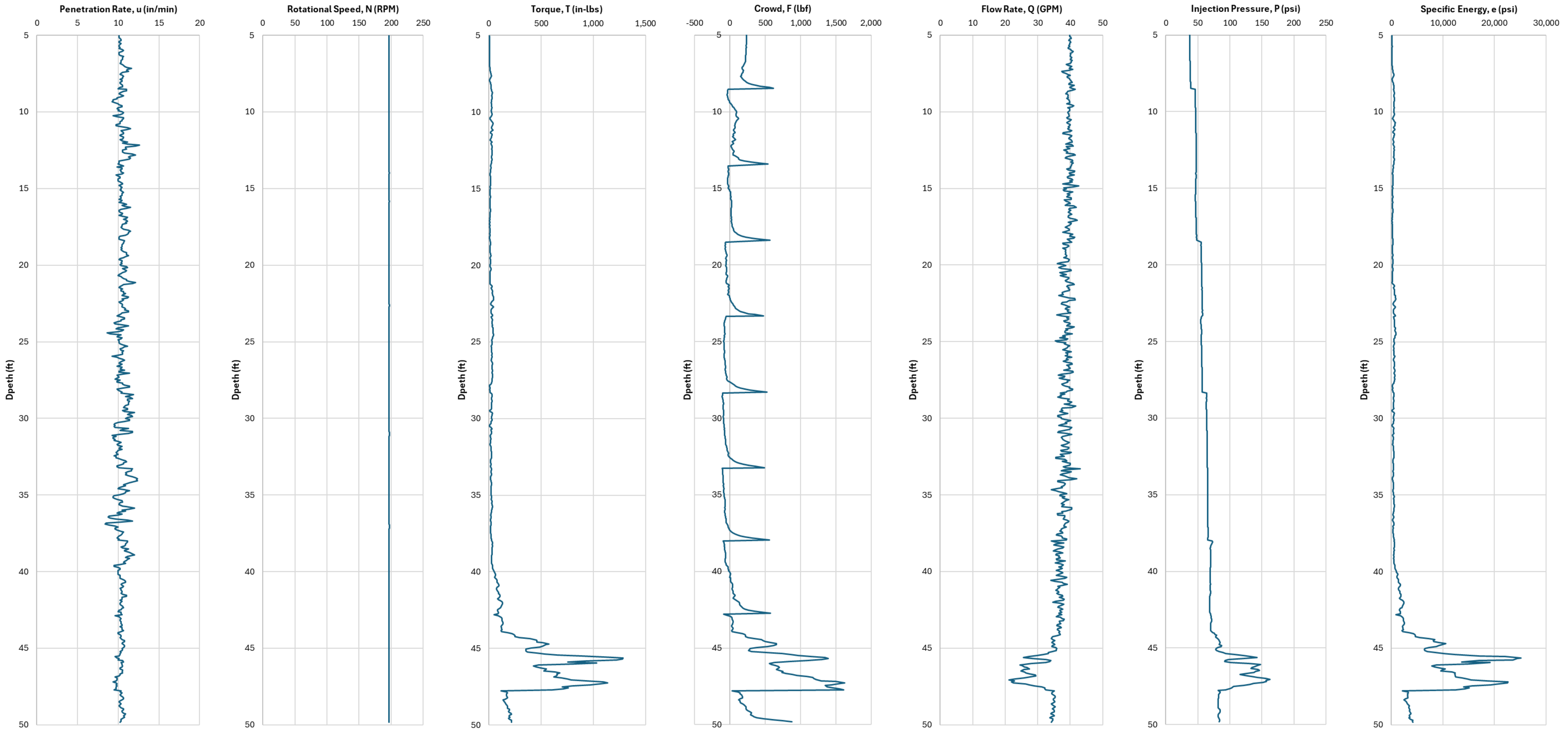

Specific Energy, e (psi)
0
1,000
2,000
3,000
4,000
Dpeth (ft)
5
10
15
20
25
30
35
40
45
50
UF H1
UF H2
SPT
0
25
50
75
100
SPT Blow Counts

C1 – H1

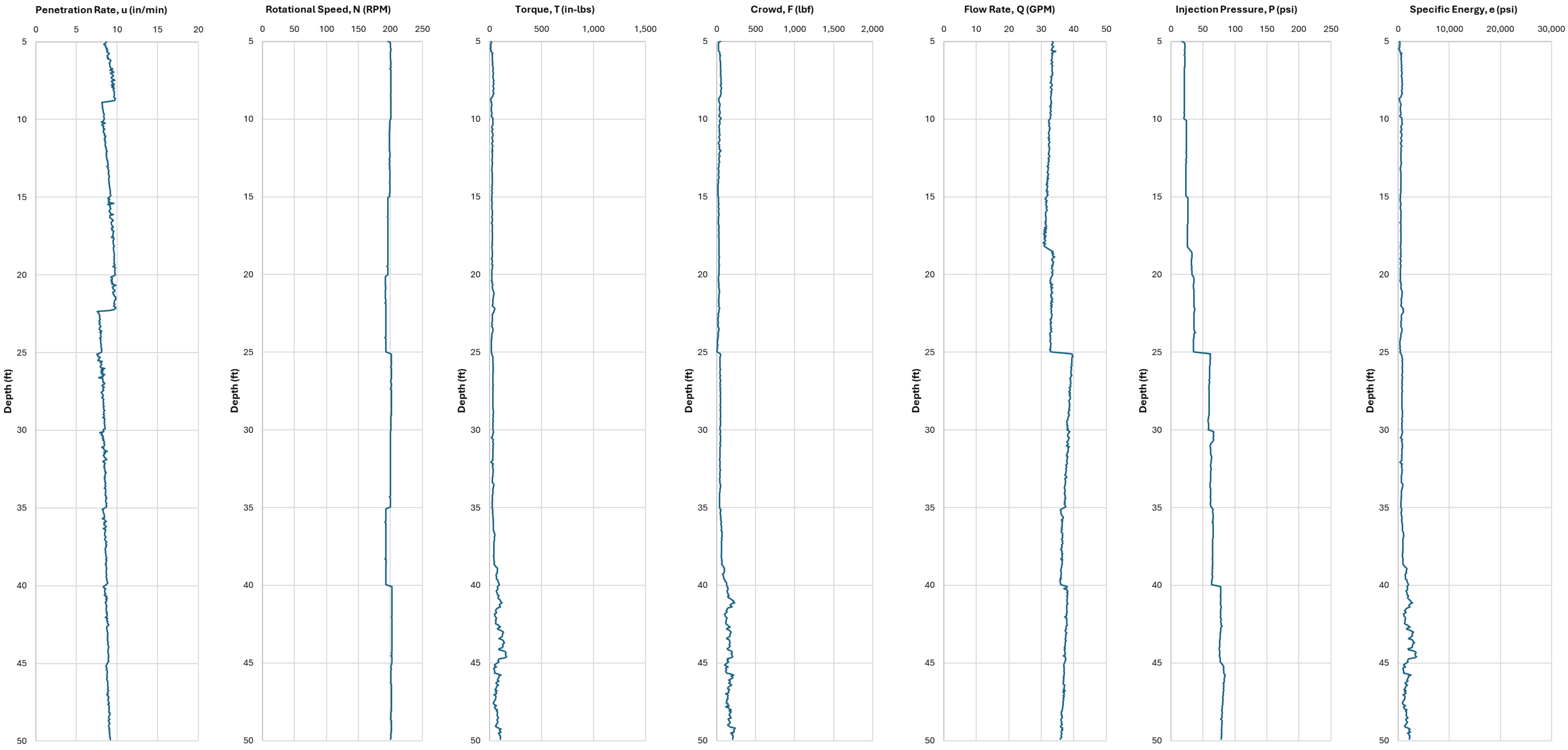


Penetration Rate, u (in/min)
Rotational Speed, N (RPM)
Torque, T (in-lbs)
Crowd, F (lbf)
Flow Rate, Q (GPM)
Injection Pressure, P (psi)
Specific Energy, e (psi)
Dpeth (ft)

C1 – H2


Penetration Rate, u (in/min)
Rotational Speed, N (RPM)
Torque, T (in-lbs)
Crowd, F (lbf)
Flow Rate, Q (GPM)
Injection Pressure, P (psi)
Specific Energy, e (psi)
Dpeth (ft)

UF – H2



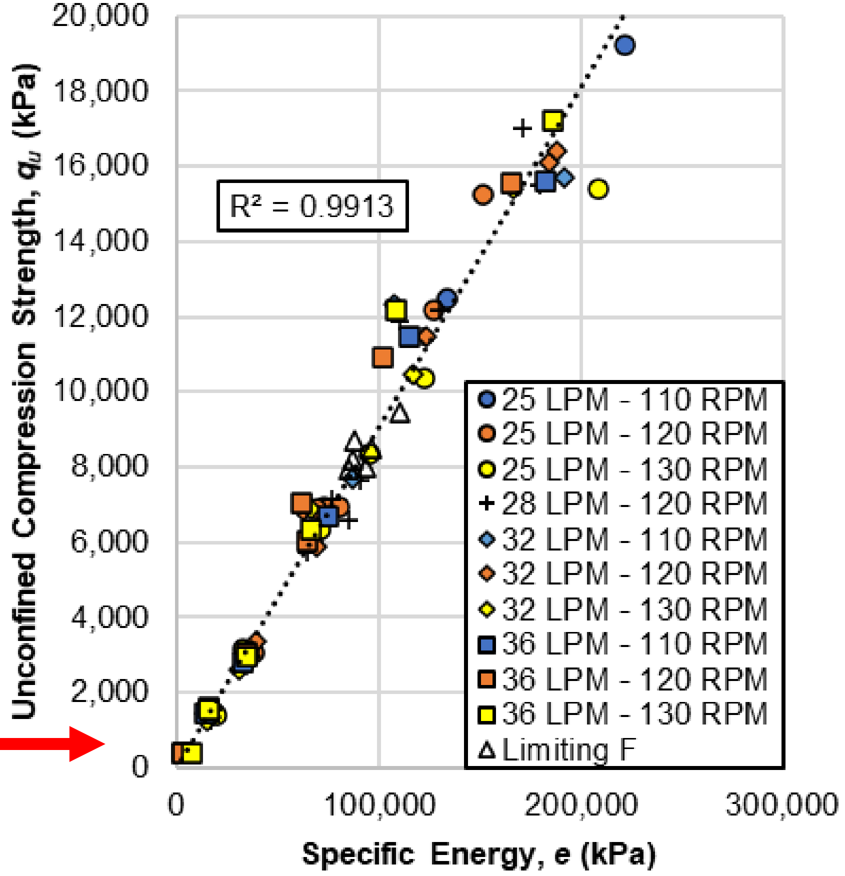
Penetration Rate, u (in/min)
0 5 10 15 20
Rotational Speed, N (RPM)
0 50 100 150 200 250
Torque, T (in-lbs)
0 500 1,000 1,500
Crowd, F (lbf)
0 500 1,000 1,500 2,000
Flow Rate, Q (GPM)
0 10 20 30 40 50
Injection Pressure, P (psi)
0 50 100 150 200 250
Specific Energy, e (psi)
0 10,000 20,000 30,000
Depth (ft)
5 10 15 20 25 30 35 40 45 50

Task 3a – Operational Index Development

- Once the optimum drilling tool has been selected for the new MWD method, an operational drilling index will be developed
- The operational drilling index will comprise multiple independent and compound drilling parameters that when considered in combination, directly identify the soil type encountered
  - Individual drilling parameters
  - Compound parameters can be generated from other parameters
  - Waveform parameters can be extracted from T, F, and 3-axis vibration
  - ML will be utilized to assist in developing the operational index

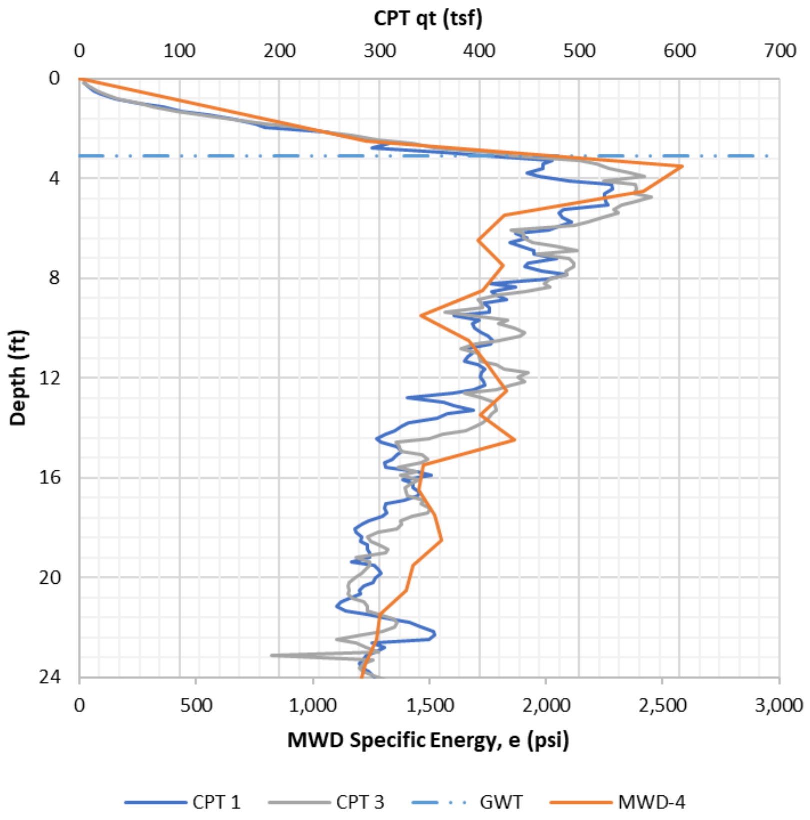
How does this work?

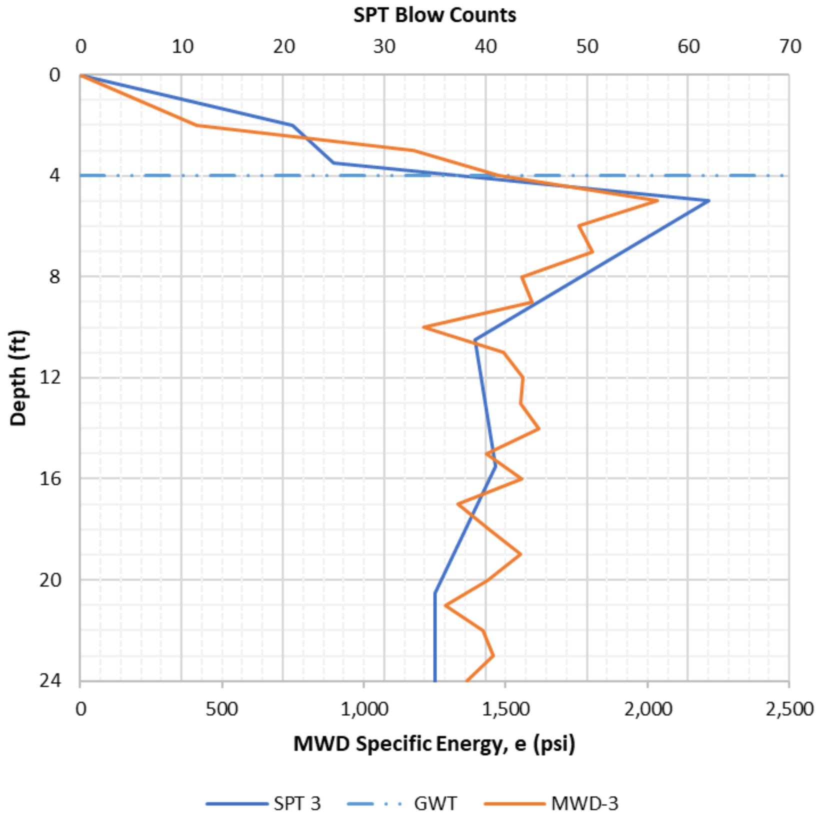
- Individual parameters will be used by drillers to maintain efficient drilling
  - Develop drilling procedures and guidelines – Task 2
  - Validates the recorded data
- Individual, compound, and waveform parameters used to identify materials
  - Operational index
- Compound parameters will be used to generate geotechnical design parameters using relationships unique to each material type
  - Specific energy vs. unconfined compression strength for coring limestone
- For soil assessment, SPT, CPT, DMT, VIP, and lab testing will be required near each MWD drilling location for development



MWD Soil Assessment

- One of the biggest challenges for developing MWD in-situ soil assessment will be relating drilling parameters to conventional soil engineering parameters commonly used in design
- We are already seeing agreement between MWD and conventional site investigation methods that are commonly used for soil characterization and design – encouraging!

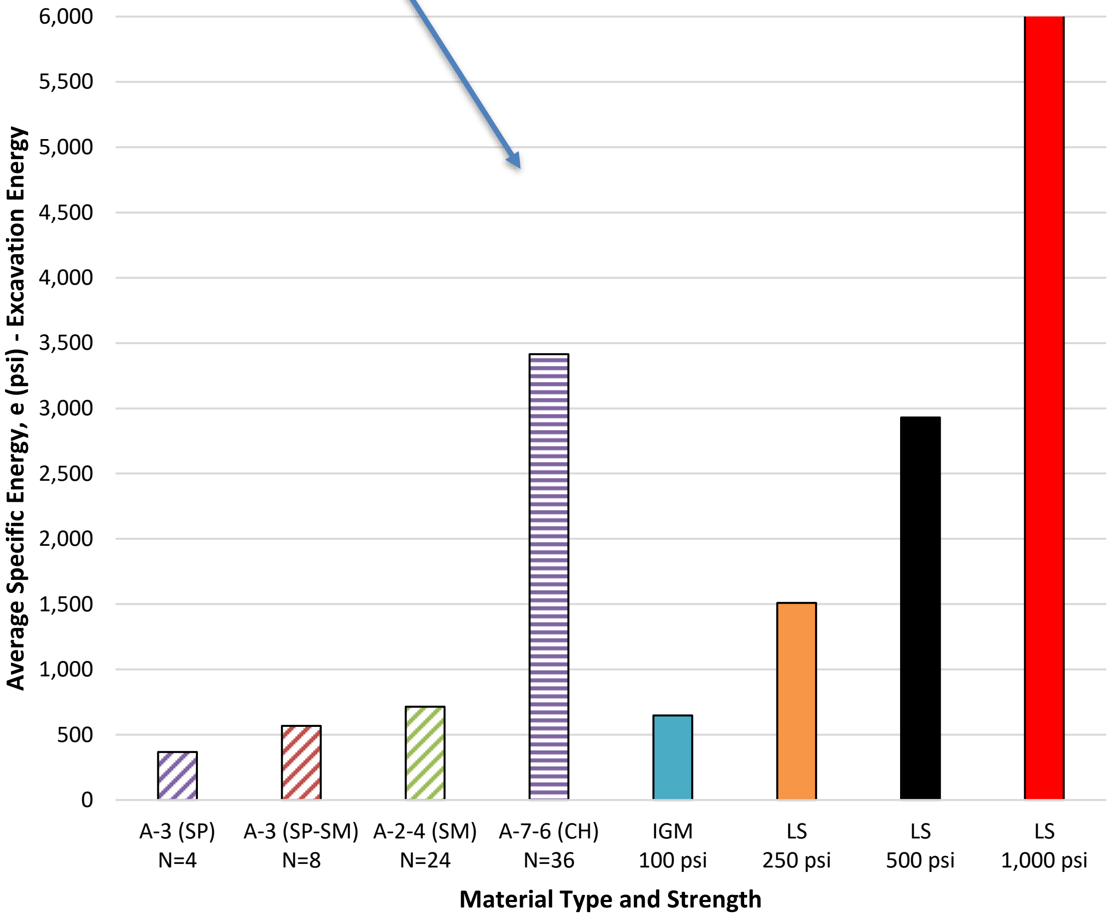




Rodgers, Horhota, and Jones (2025)

A-3 – Hard Packed Quartz Sand
Old Daytona Speedway - South Turn

Delineating Low Strength Geomaterials



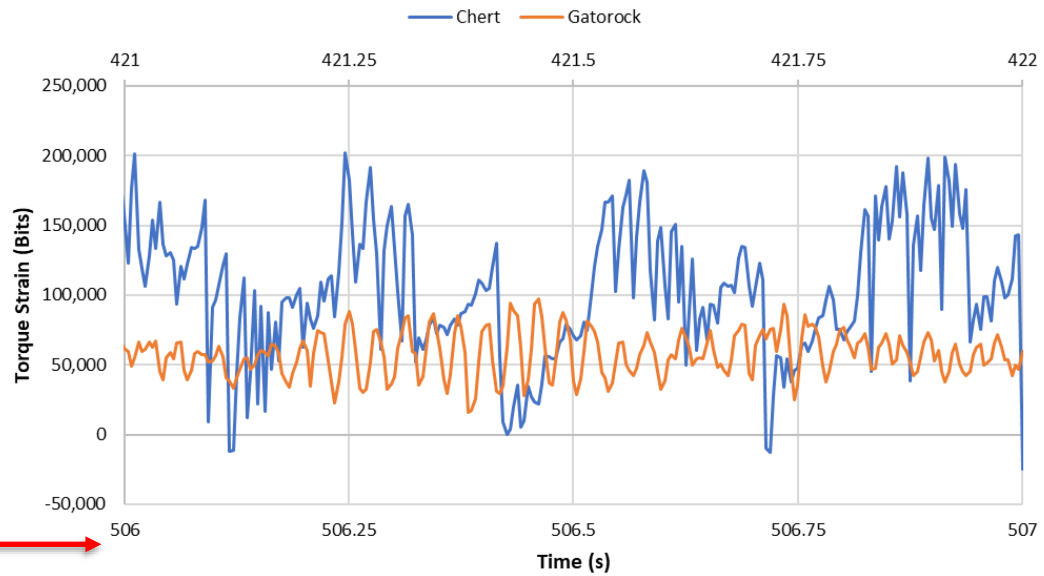
SPT N = 25,

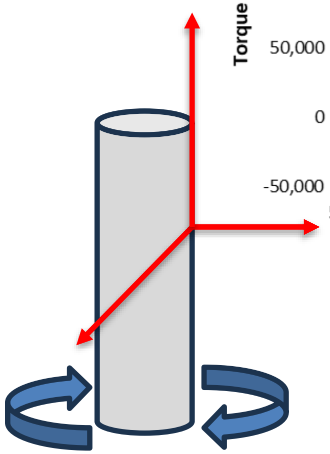
UCS = 25 to 100 psi

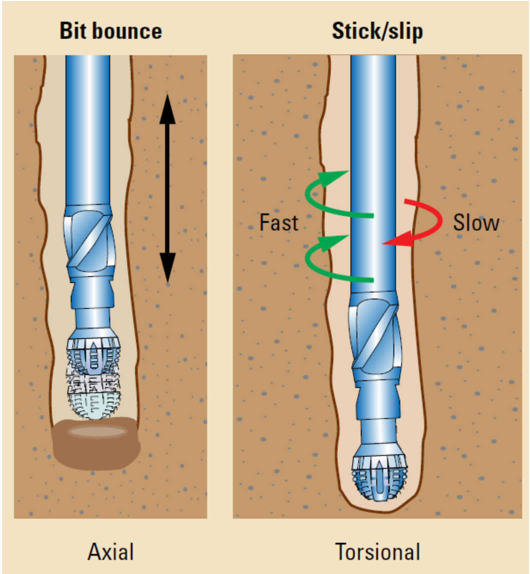
Vibrational Signatures

- Prior research indicated strain wave / vibrational signatures are unique to each geomaterial
- Developed a method to transform valuable time-referenced data to depth-referenced data
  – Required for MWD geospatial assessment
- Integrated 3-axis accelerometer into T & F sensor → 12 responsive vibration parameters
  – In total, 16 new responsive drilling parameters added
  – Allows low strength material delineation

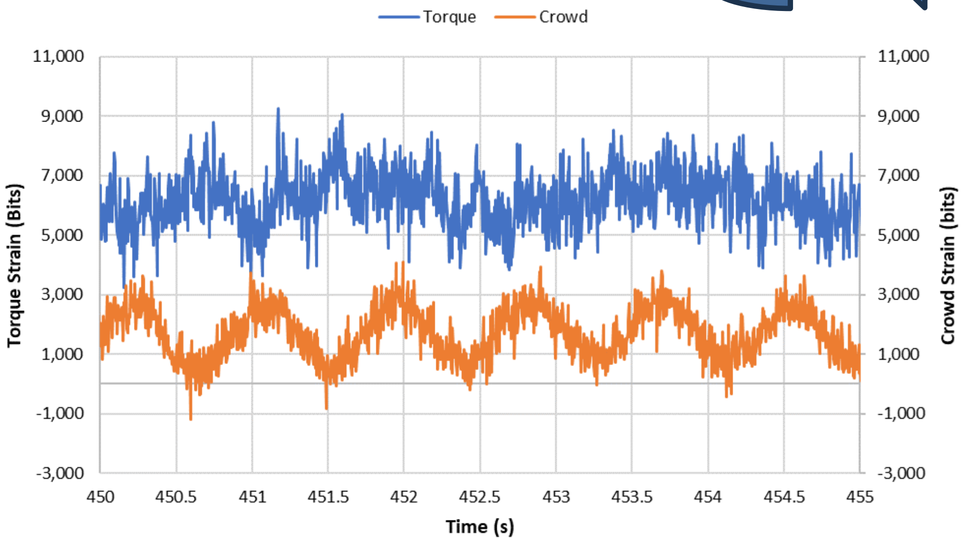
Chert vs Gatorock Strain Waves



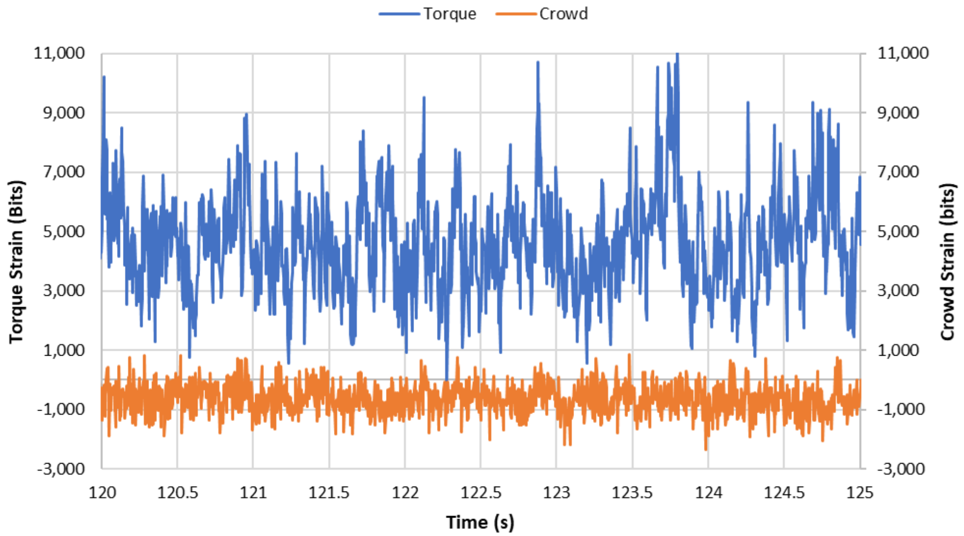




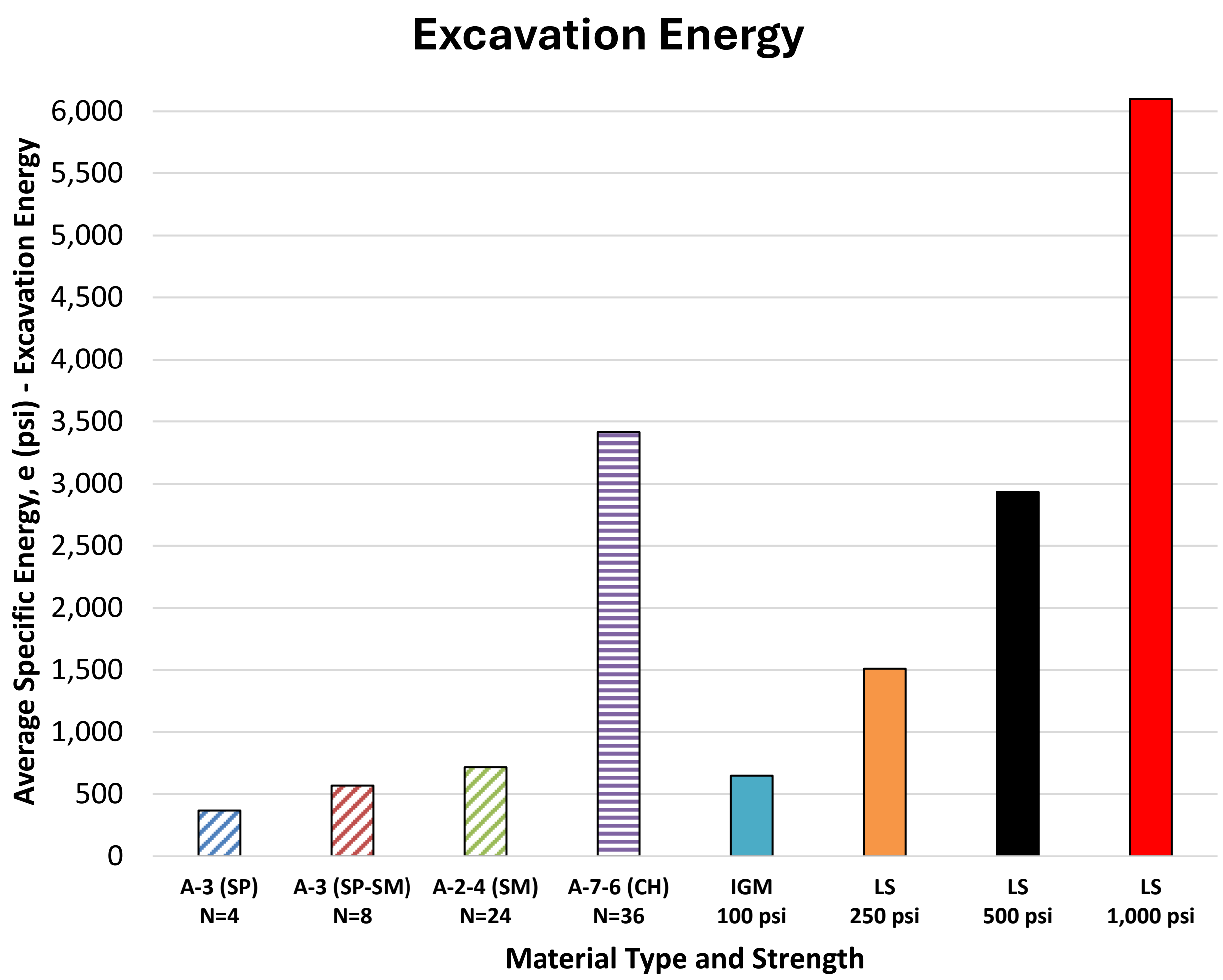
Soil Strain Waves

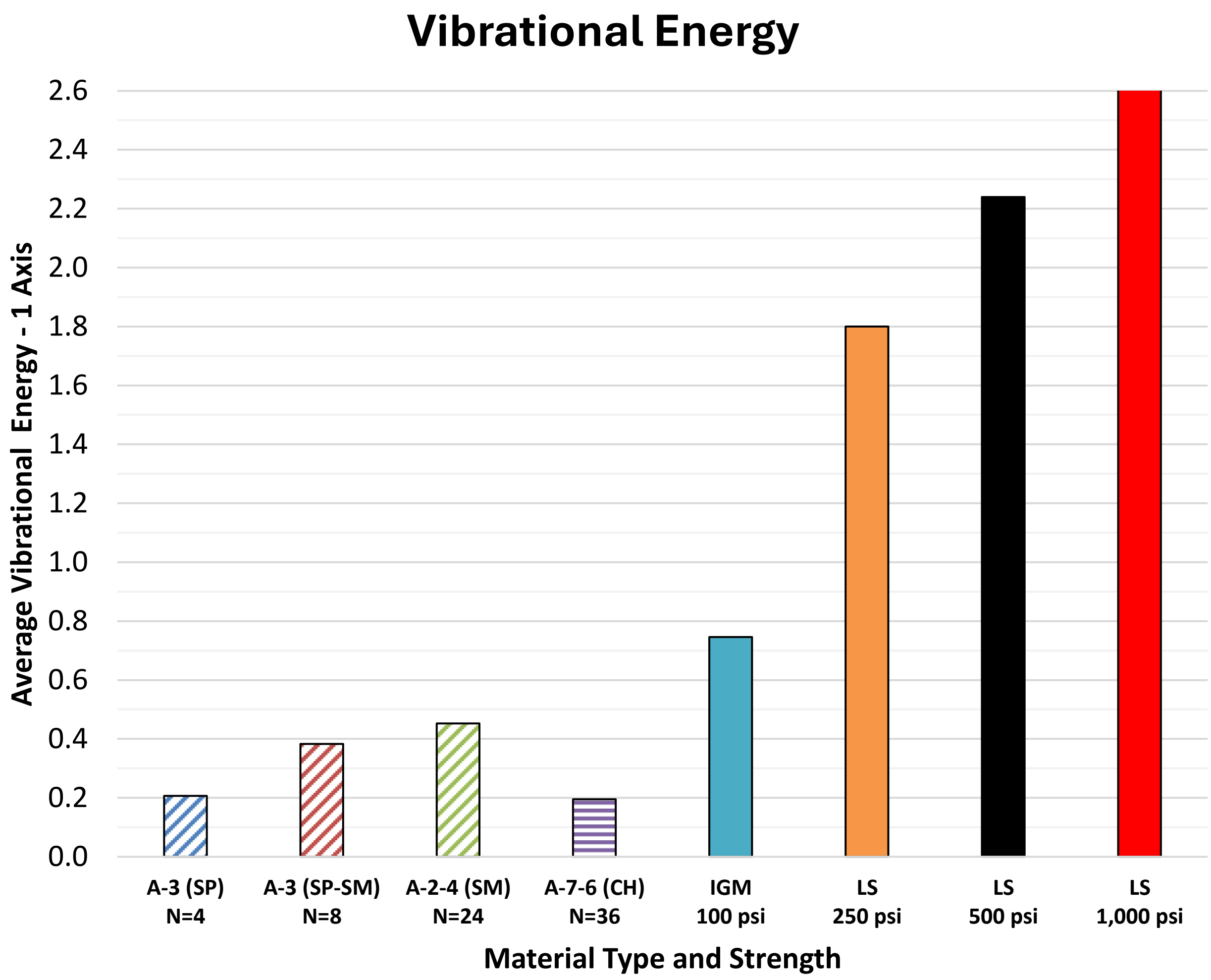


56 psi Gatorock Strain Waves



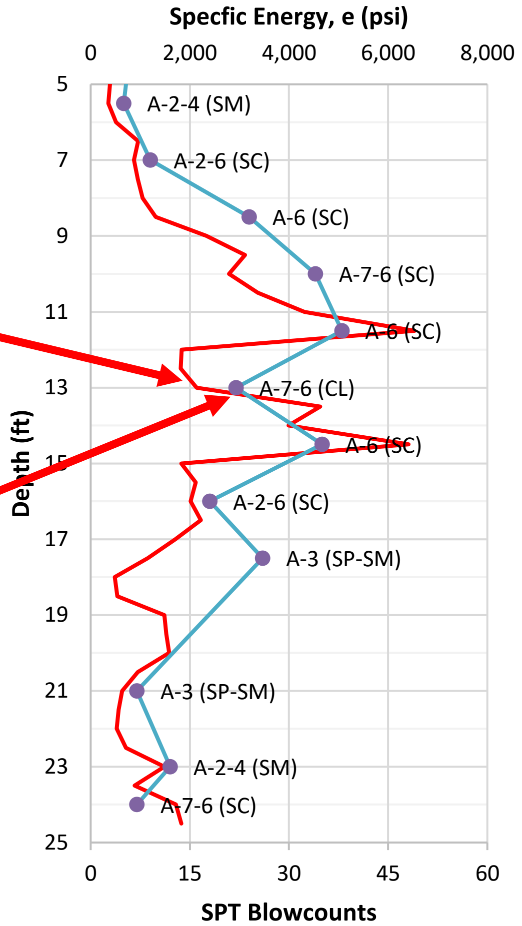
The Next Evolutionary Step of Geotechnical MWD
Drill String Vibrational Analysis

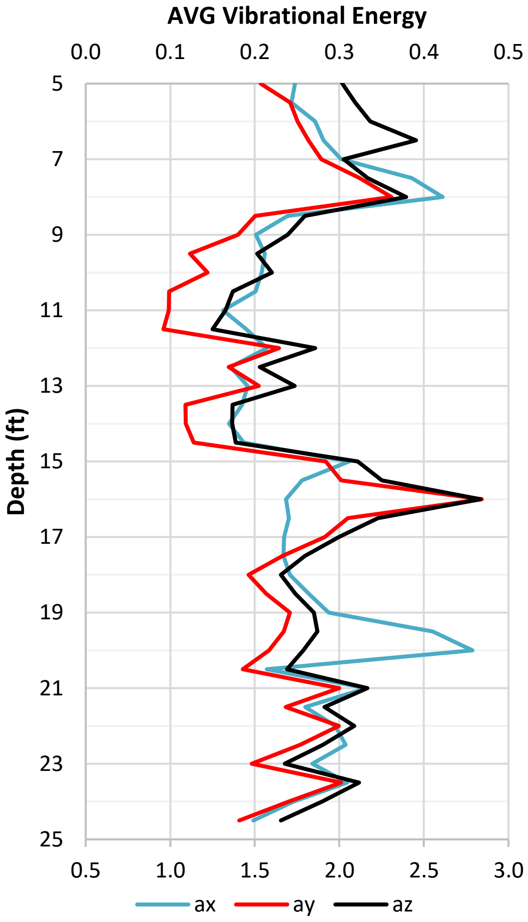


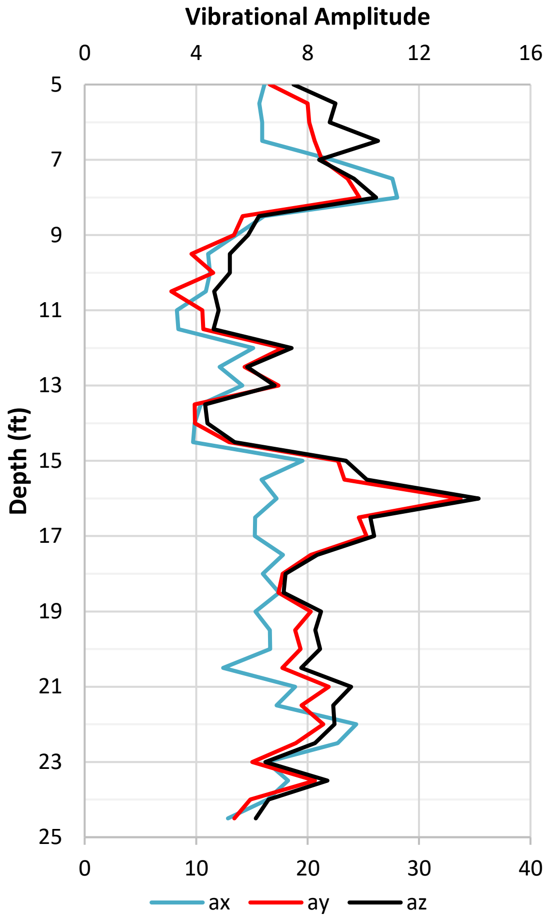


Clay eats energy quietly, sand doesn’t have much of an appetite, and rock chews loudly

Sandy Clay vs. Stiff Clay



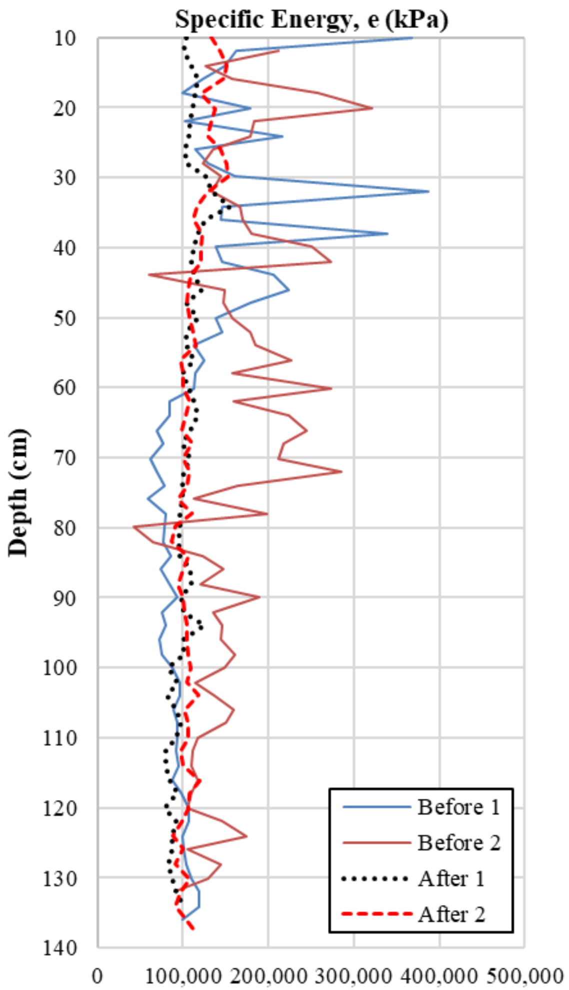


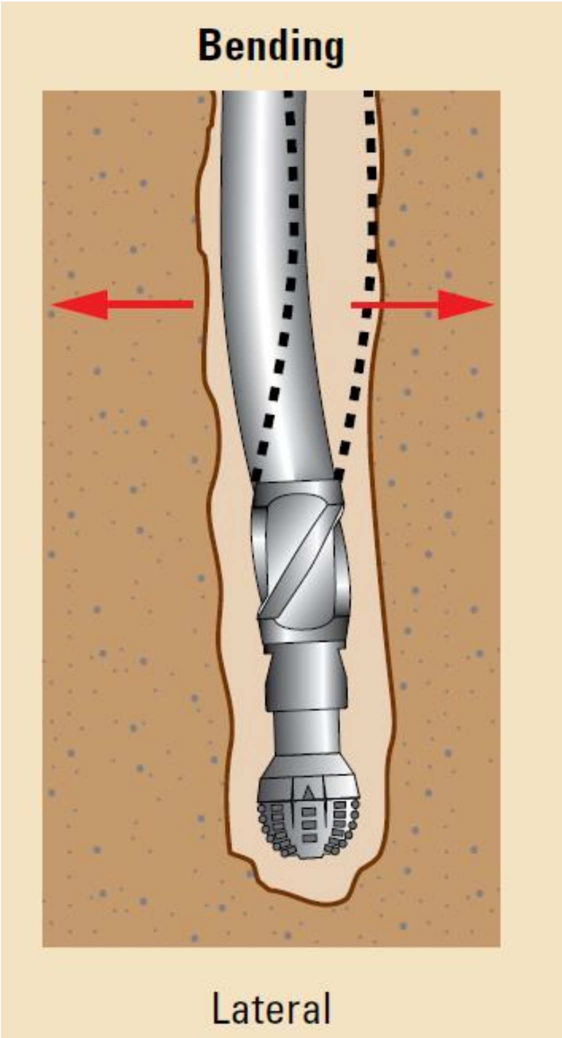


Depth (ft)	AVG Vibrational Energy	Vibrational Amplitude	Interpretation
5–7	az > ay » ax (vertical strongest, radial close)	az ≈ ay » ax	Loose/soft sand–silt lets the bit bounce (az) and wobble (ay) with little torsional stress (ax). Efficient cutting; vibration is impact-dominated, not torque-dominated
9–11	az > ay » ax (vertical slightly stronger)	az > ay » ax	Moving into stiffer, cohesive soil: vertical bounce persists while radial motion is reduced. Torsion stays quiet (ax ~ low)
12–13	az ≥ ay » ax (very close vertical & radial)	ay ≈ az » ax	Small soft/loose lens at the clay break: the bit wobbles and bounces (ay & az up) even as cutting load (specific energy) falls. Impact-dominated inefficiency (intermittent contact), not torsional.
15–17	az ≈ ay » ax (equal vertical & radial)	az ≈ ay » ax	Strong, coupled axial–radial mode (bounce/whirl) with torsion still stable. Classic looser sandier zone letting the bit move both vertically and laterally.
19–20.5	az ≈ ay » ax	az ≈ ay » ax	Torsion-dominated response: dense, interlocked fines raise steady rotational resistance without big spikes. Lateral/vertical wobble is restrained. Micro stick–slip condition, not impact bounce.

Task 3b – Eccentric Rotation Investigation at Deeper Drilling Depths

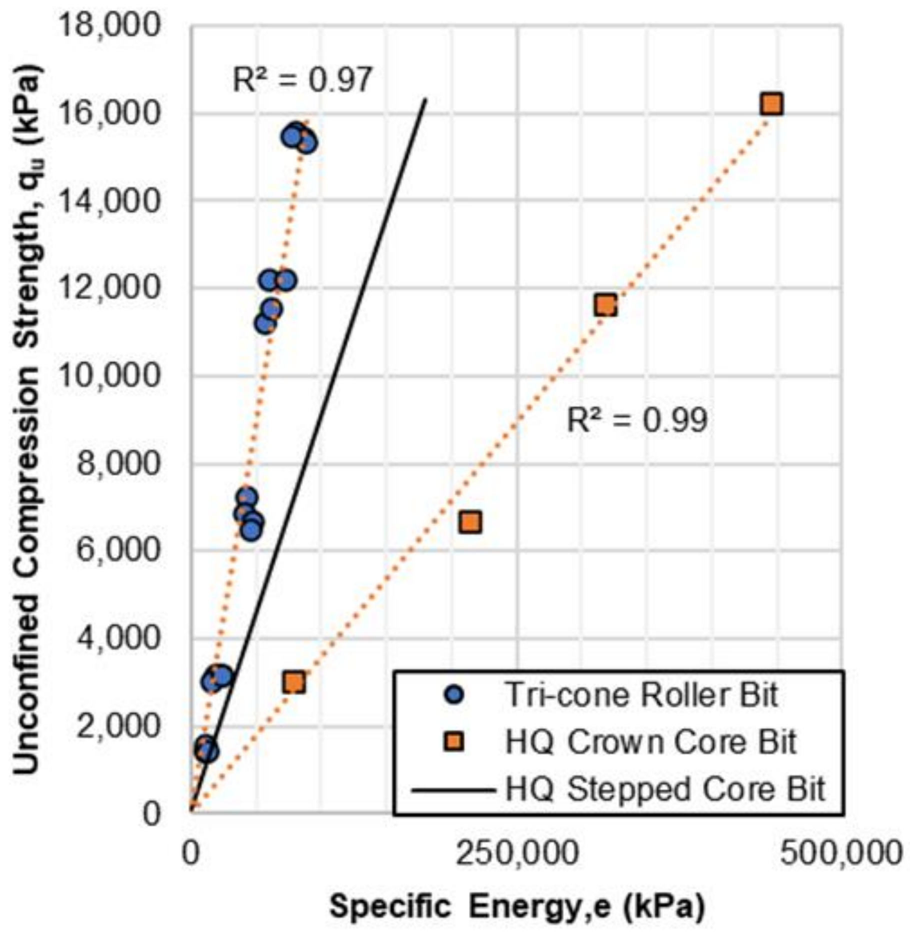
- FDOT Project BDV31-977-125 indicated eccentric rotation and excessive vibration may be induced at greater drilling depths due to the slenderness of the drill string, regardless of the rotary head's condition
- The new MWD method should be assessed based on the depth of drilling and potential effects of eccentric rotation
- If eccentric rotation becomes problematic at a certain drilling depth, this portion of the study will be used to quantify the effects
  - Waveform analysis will help identify this
- The operational limits of the drilling tool previously identified in Task 2 and further investigated in Task 3a may need to be adjusted to mitigate the effects of eccentric rotation at greater depths
- Once the investigation is complete, and the operational limits of the drilling tool have been defined, the research can then move forward to Task 4, which focuses on developing engineering parameters from MWD





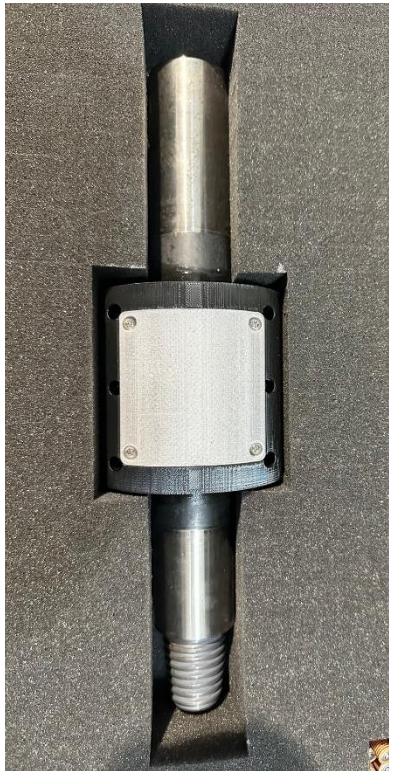
Task 4 – Developing Correlation Between MWD and Engineering Parameters

- Once the operational limits and the operational index has been developed, correlations between MWD parameters and the engineering parameters of will be investigated
- It is expected that the unique mechanical behavior and properties of various in situ soils and rock will produce a unique drilling response that will be captured by MWD
- Certain MWD parameters will be used to identify the soil and rock type encountered
  - i.e., operational index
- Certain compound drilling parameters will be used to determine the engineering parameters of the soil or rock type identified
  - e.g., specific energy
- Unique correlations will be developed between MWD compound parameters and the in situ density, internal friction angle, and undrained shear strength of soils and unconfined compression and split tension strengths of rock/IGM



Task 5 - Florida Consultant MWD

- Three FL consultants will engage in MWD site investigation
- UF research team will provide assistance and guidance
  - Instrumentation, method development, and data reduction
- UF research team will provide wireless drill rod transducers to measure mechanical torque
- 2 of 3 consultant drill rigs have been instrumented to date

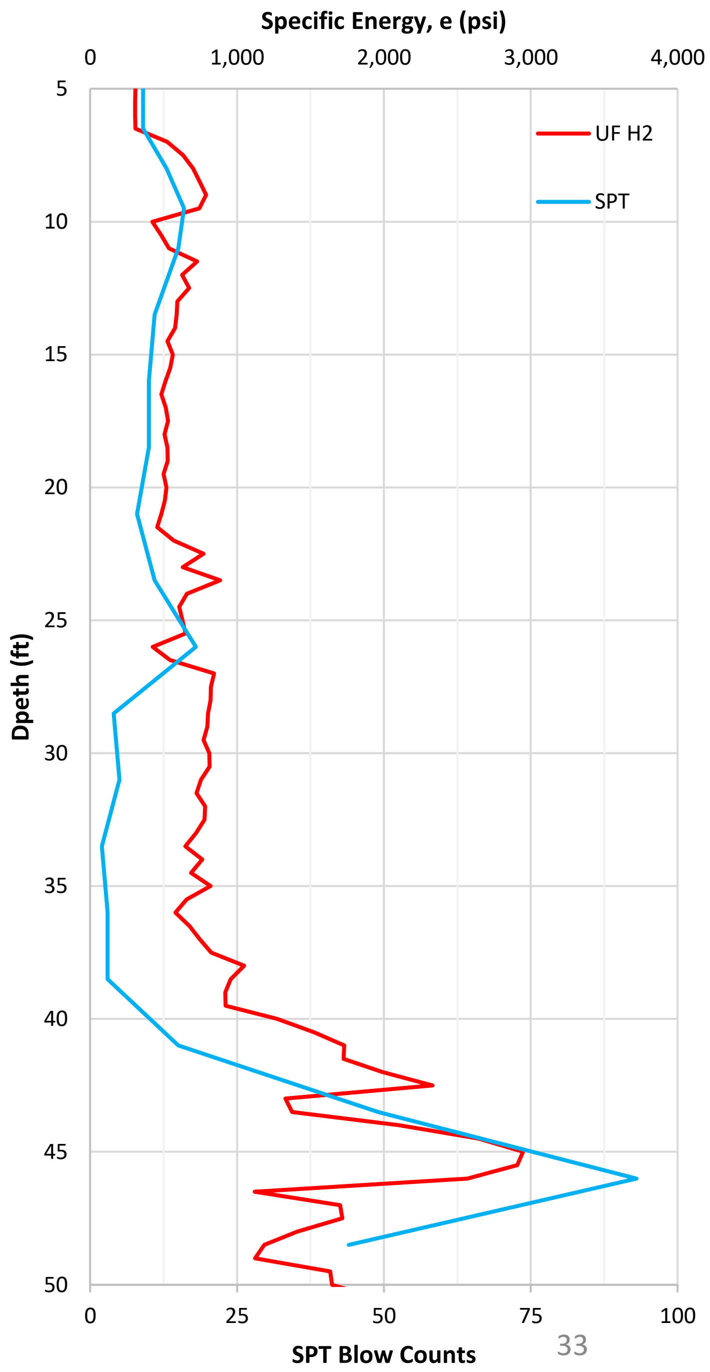


Consultant Observations – MWD Rock Coring

- Followed UF recommended MWD coring guidelines
- 85 feet of continuous rock coring REC_{avg} = 94%
  - Reduced REC when he experimented with higher RPMS
  - 1 core run had 40% REC but contained sand
- Quotes from driller:
  - "We are not coring any slower than we typically do"
  - "It seems like if rock is there and I am following the guidelines; I am going to recover every bit of it"
  - "Leads to an easier life for me"

Consultant Observations - Soils

- Compared time to complete SPT, CPT, and MWD at the same sites
  - Consultant SPT was very efficient
- Target depth of 50 feet
- SPT with 2.5 ft centers and hand augers at top
  - Full procedure ≈ 2 hours
  - Past 10 feet ≈ 1 hour 10 minutes
- MWD continuous after 5 ft of hand augers
  - Full procedure ≈ 1 hour 20 minutes
  - Past 10 feet ≈ 1 hour
- CPT continuous from top
  - Full procedure ≈ 45 minutes to 45 ft
  - CPT terminated at 45 feet due to sleeve friction
  - Could not complete sounding to desired depth



Questions?