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

GRIP Meeting

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Introduction

- The FDOT has developed and applied measuring while drilling (MWD) for the assessment of in situ rock strength for bored piles (ACIP piles and drilled shafts) and site investigation purposes (rock coring)
- The completed work has produced significant advancements in geotechnical exploration, a better understanding of Florida's highly variable geology, and improvements in deep foundation design and construction
- In situ soil classification and geo-mechanical property assessment via MWD have not been addressed by the FDOT
- This limits the use of MWD, and the many benefits associated with the new method, from being applied to numerous geotechnical applications in which the soil-structure interaction is the main focus of design

Site Investigation MWD – Geotechnical Design

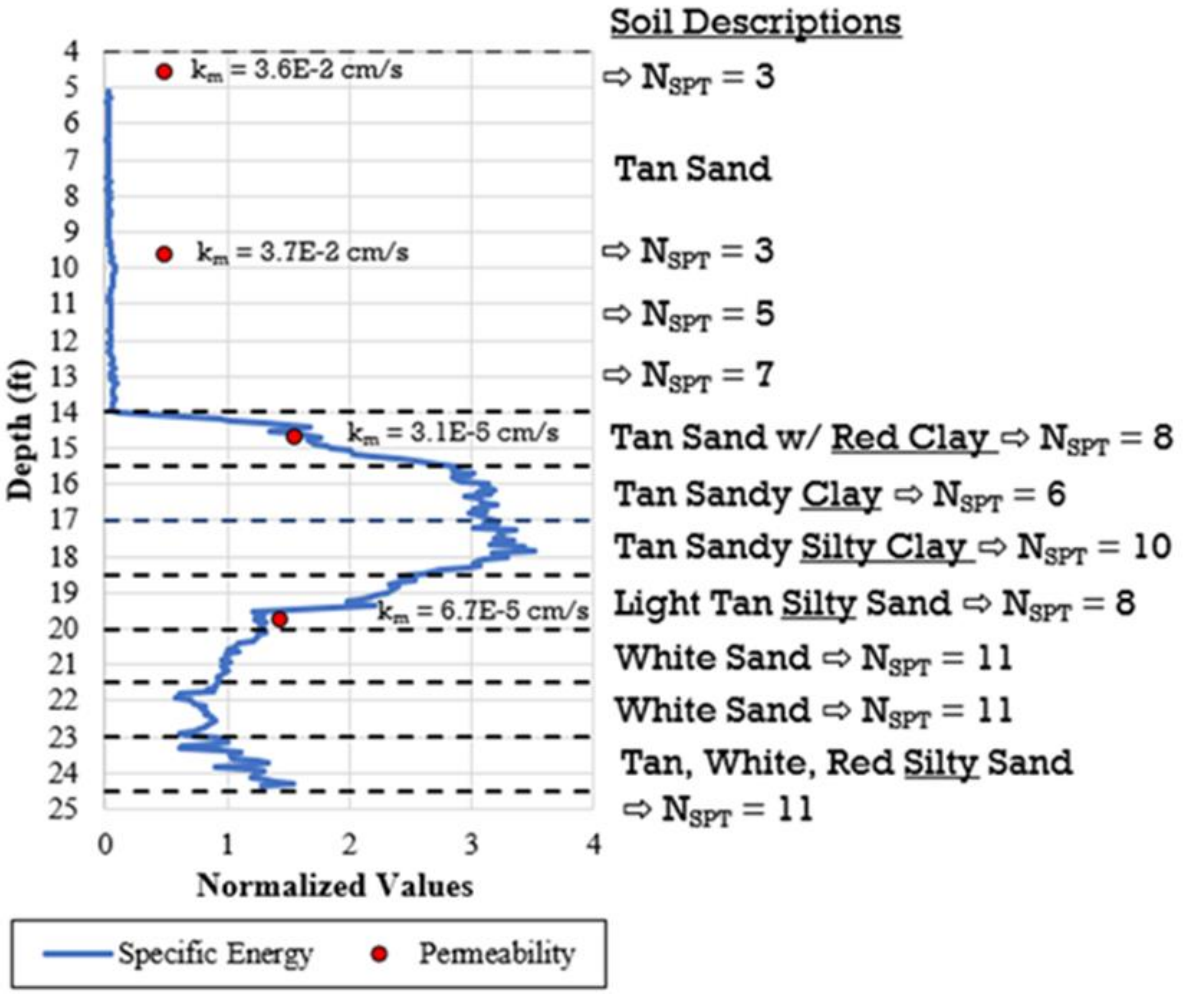
Bored Pile MWD – Construction QA/QC

Introduction

- Driven piles are used throughout the state of Florida, with the piles often driven into variable layers of soil with unique properties that provide the capacity of the foundation element
- Driven piles are often designed using Standard Penetration Test (SPT) and/or Cone Penetration Test (CPT) data
  - SPT is typically only performed every 2.5 feet for bridge structures, which produces a low-resolution profile of the strata encountered
  - CPT provides a much higher resolution profile than SPT but is vulnerable to termination when rock or stiff IGM or soil layers are encountered
- MWD is capable of producing high resolution profiling like CPT and has the ability to penetrate rock like SPT
- Therefore, developing MWD as a new method of in situ soil assessment would combine the benefits of both conventional methods and greatly improve the practice

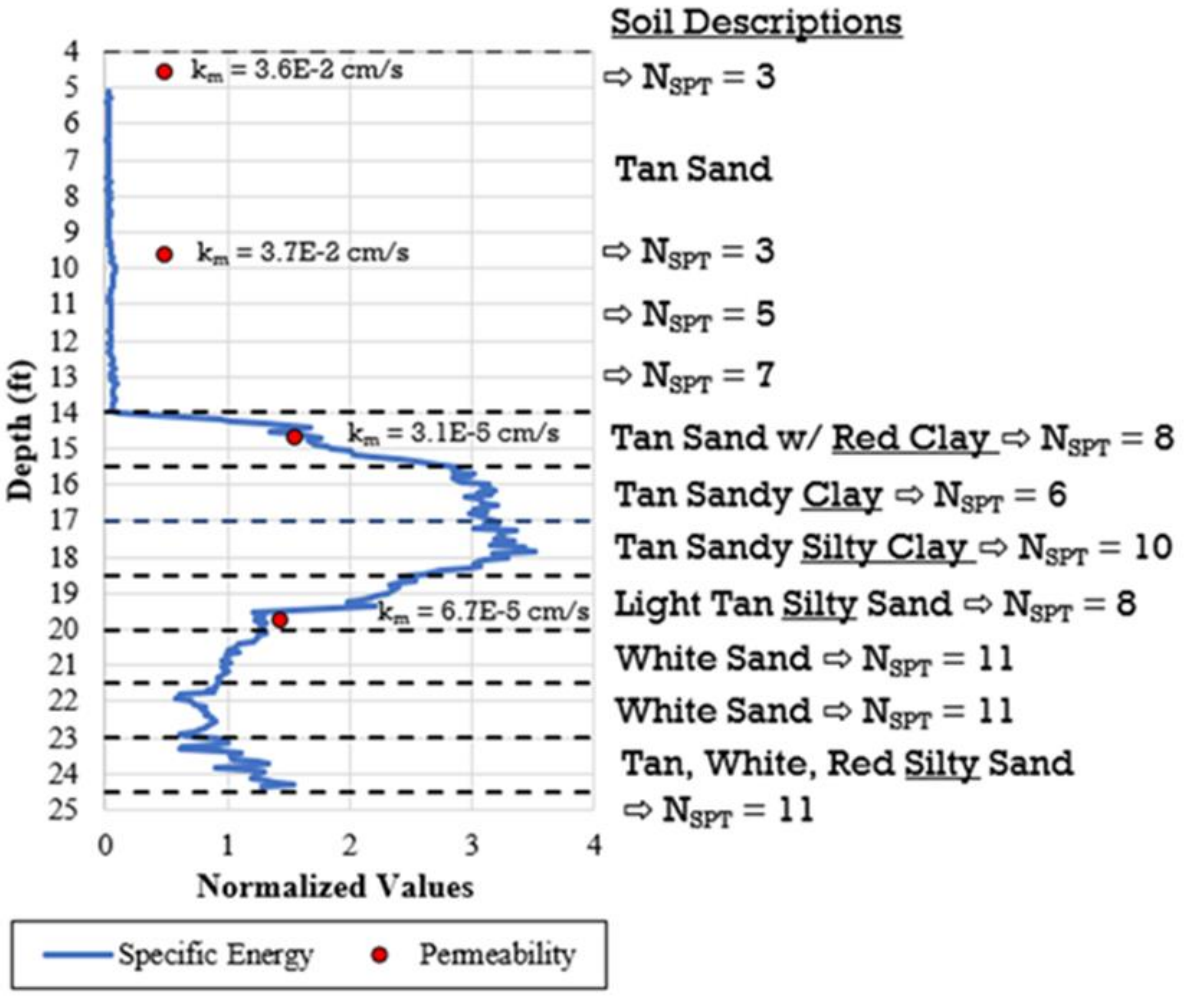
Project Background

- A brief investigation was completed during BDV31-820-006 that indicated the proposed MWD approach is promising
- The intent of the study was to investigate MWD as a quick method of identifying and assessing changes in soil layering as a potential supplement to SPT and CPT testing
- During the investigation, MWD was conducted using a tri-cone roller bit
- The monitored drilling took place from a depth of five to 25 feet,
  - 10 minutes to complete (very efficient)
- MWD results were compared
  - SPT blow counts
  - Soil descriptions
  - VIP permeability
  - Soil classifications
- MWD indicated low specific energy in cohesionless soil with low SPT blow counts
- MWD indicated increased specific energy in cohesive soil with higher SPT blow counts
- MWD injection pressure increased in lower permeable soils
  - Agreed with comparative permeability tests conducted using the VIP (FM5-614) – Not Depicted



Project Background

- MWD identified material layer changes that were consistent with the conventional methods
- The results suggested that a new quick method of soil assessment may be possible via MWD
  - MWD required far less time to characterize the soil compared to the conventional methods and lab testing
- Prior MWD investigations have shown that several individual and compound drilling parameters may be indicative of changes in soil and/or rock types
- It is believed that various soil types may be classified, and their geo-mechanical properties assessed in situ by building an operational index similar to CPT soil identification
  - The index would logically consider a variety of individual and compound drilling parameters to identify various soil types, essentially combining the benefits of SPT and CPT into one efficient method of soil assessment
- Once the operational index has been developed, independent and compound drilling parameters will be used to relate the drilling response to strength characteristics of the geomaterial encountered
  - Relating MWD parameters to soil engineering parameters to support geotechnical design



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 type provides the best sensitivity for the delineation of various 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 in order to classify and assess various soil 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 properties commonly used in the design of deep foundations

Tasks and Deliverables

- Deliverable 1 – Drill Rig Instrumentation, Site Reconnaissance, and Preliminary Development (Task 1)
- Deliverable 2 – Drill Bit Selection and Method Development (Task 2)
- Deliverable 3a - Operational Index Development (Task 3)
- Deliverable 3b - Eccentric Rotation Investigation at Deeper Drilling Depths (Task 3)
- Deliverable 4 - Developing Correlation Between MWD and Engineering Parameters (Task 4)
- Deliverable 5a - Draft Final (Task 5)
- Deliverable 5b - Closeout Meeting (Task 5)
- Deliverable 6 - Final Report (Task 6)

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

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

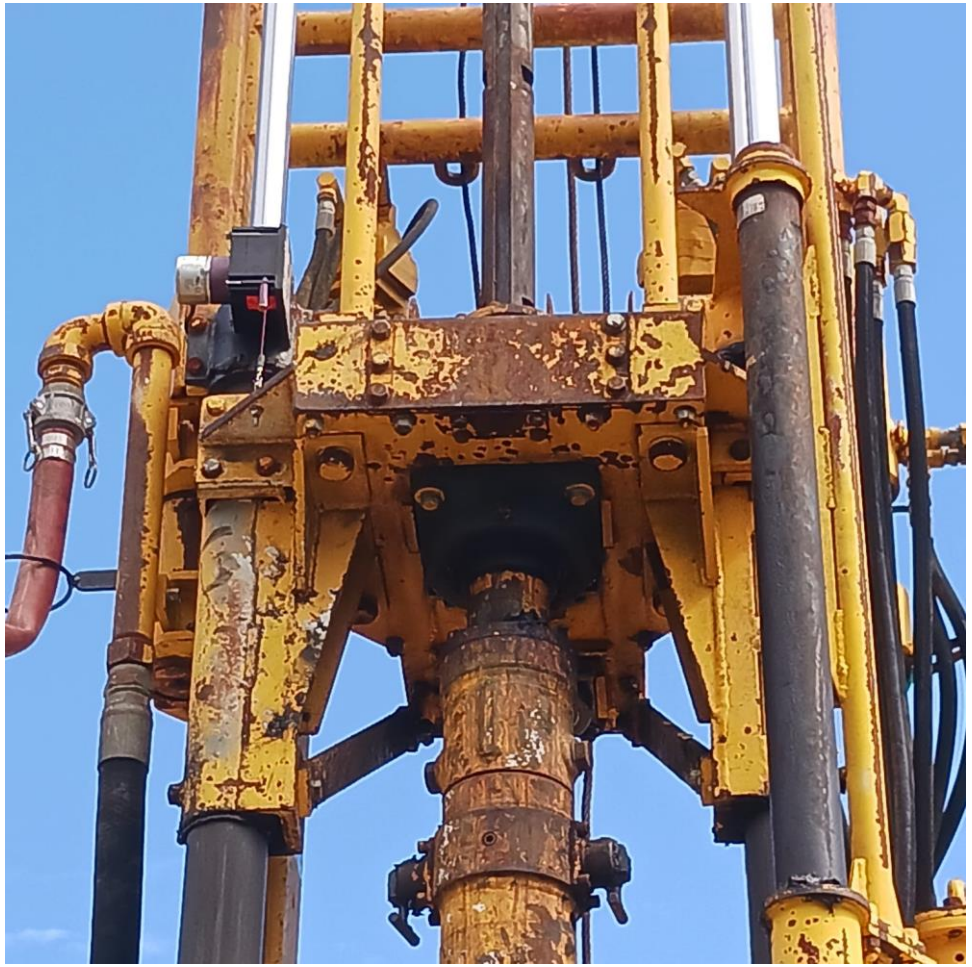
- Tri-cone roller bits and drag bits were identified in majority of surveys
  - Drag bit depicted was chosen for versatility in sand/clay/rock
- PDC bit is UF research recommendation
- Drill bit diameter = 2-7/8”
  - Based on survey responses

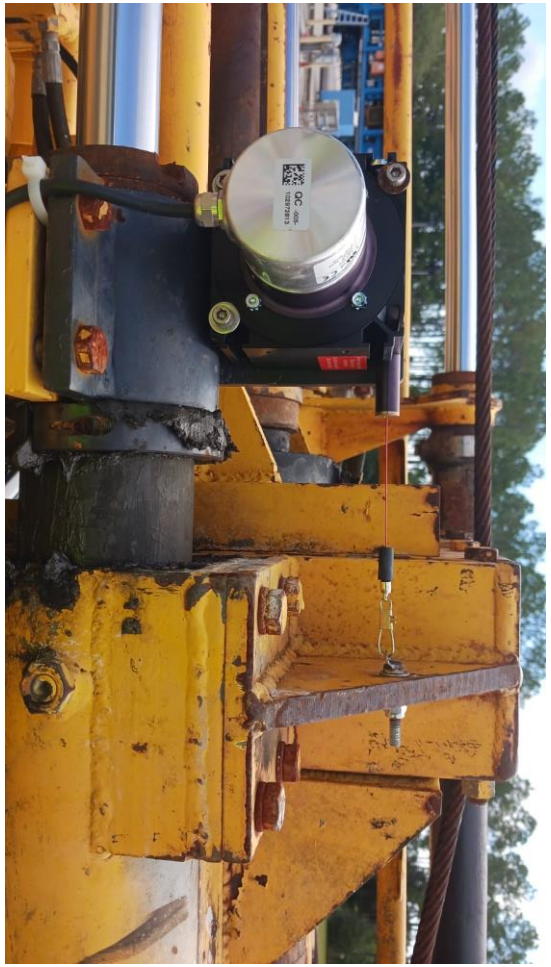
Steel Tooth Tri-cone Roller Bit

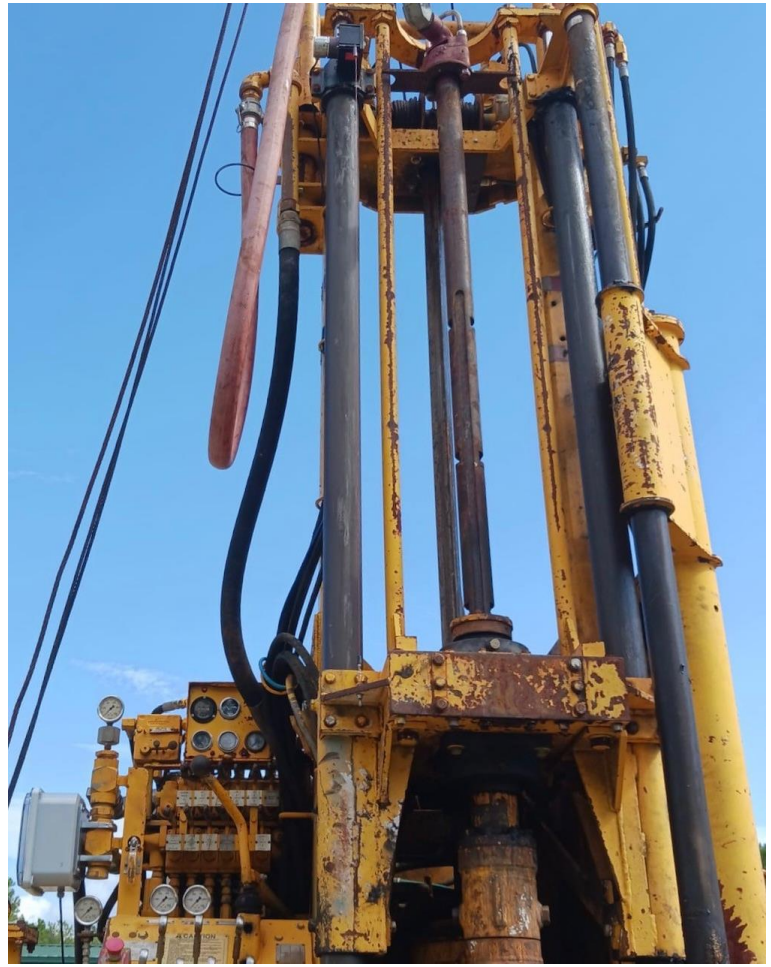
Infinity PDC Bit

3 Chevron Stepped Drag bit

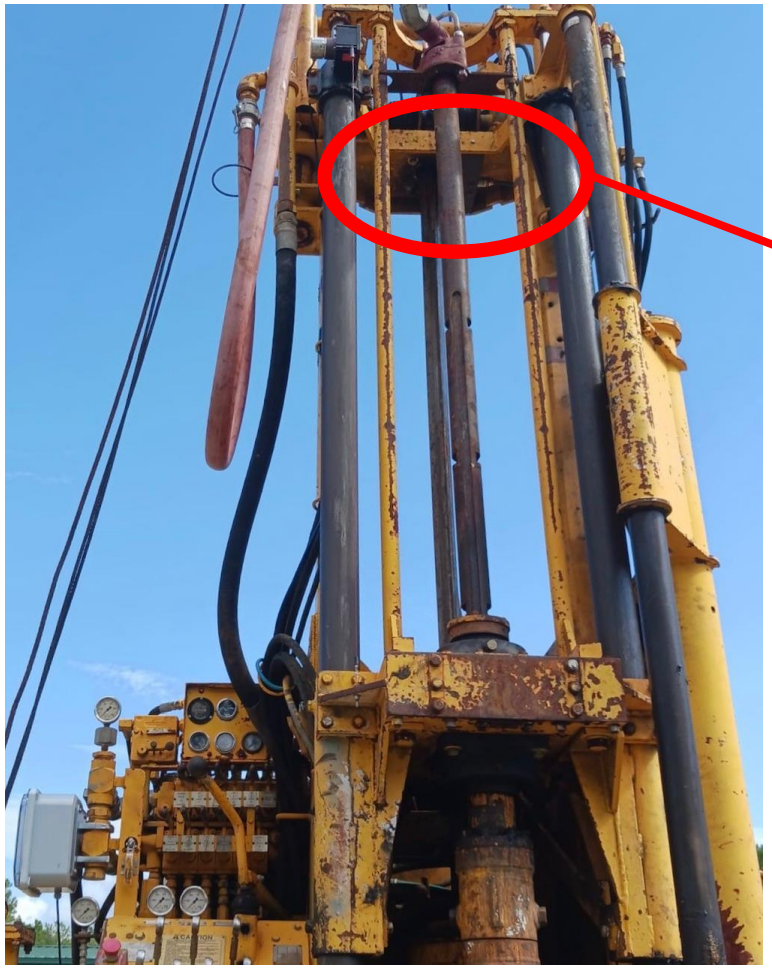
Task 1 – Drill Rig Instrumentation
Depth Sensor





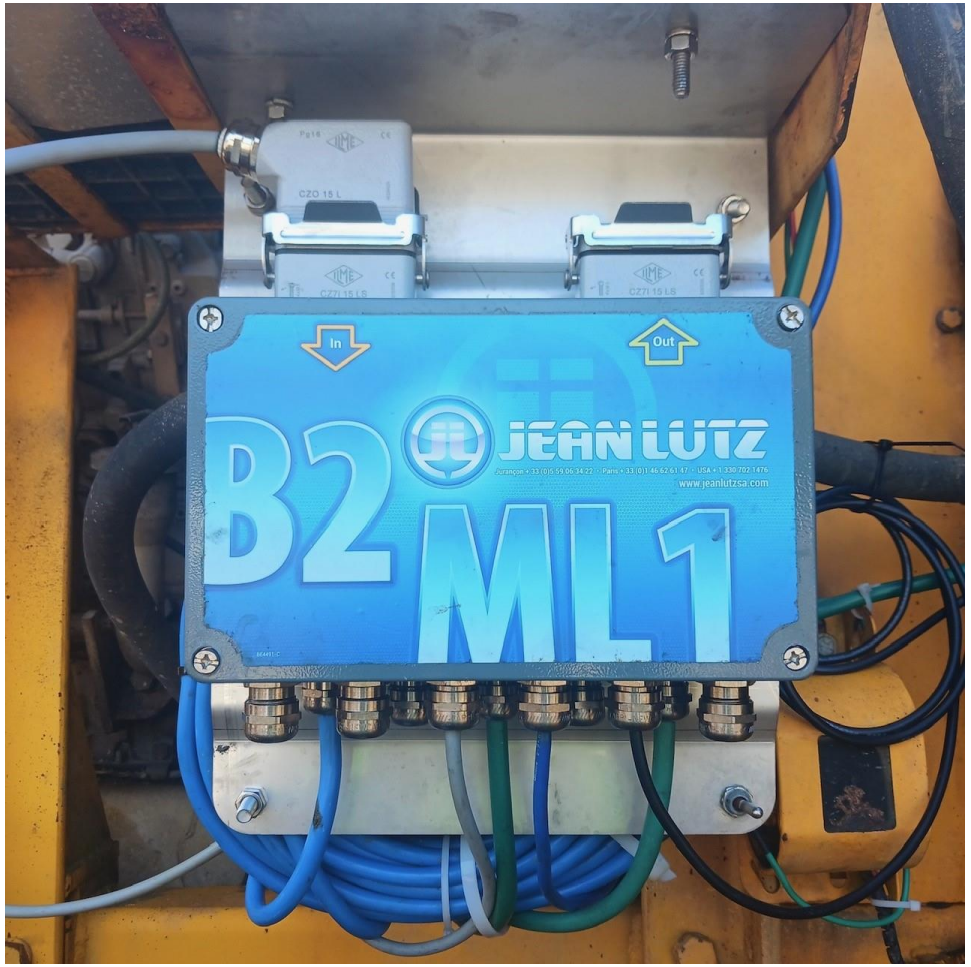


Task 1 – Drill Rig Instrumentation
Rotational Speed Sensor

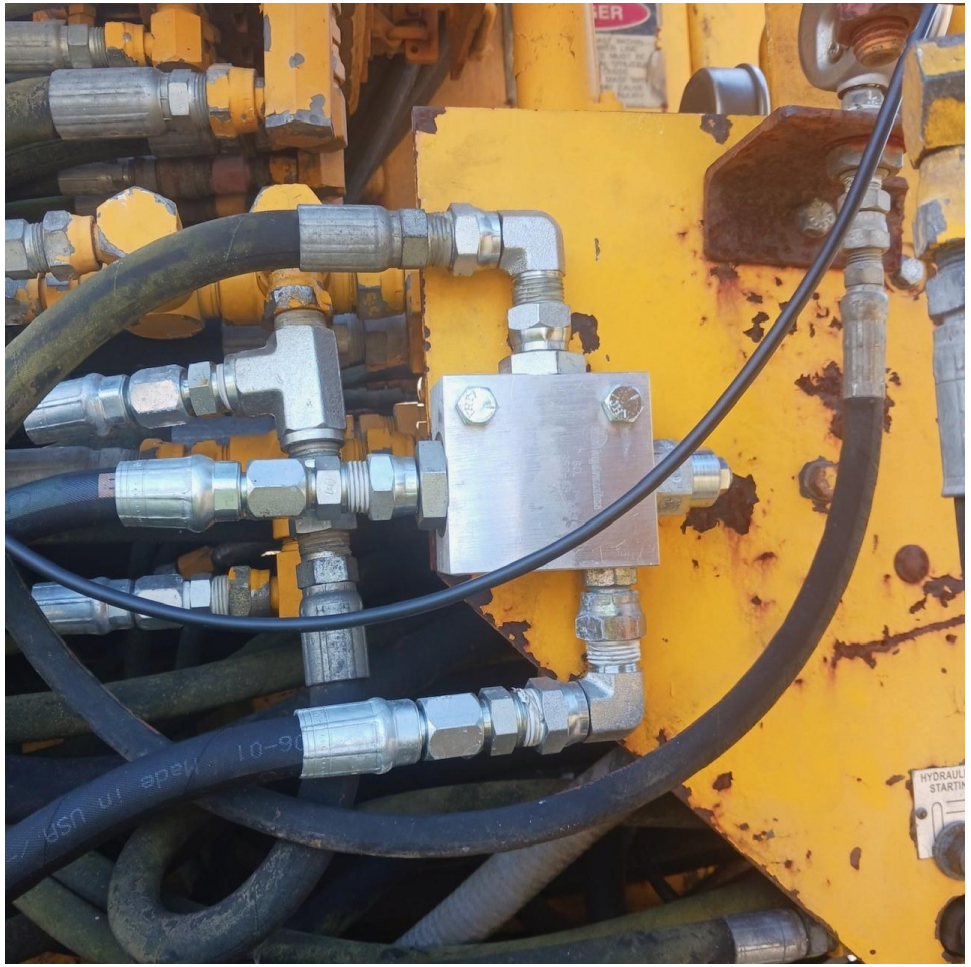


Task 1 – Drill Rig Instrumentation
Flow Meter

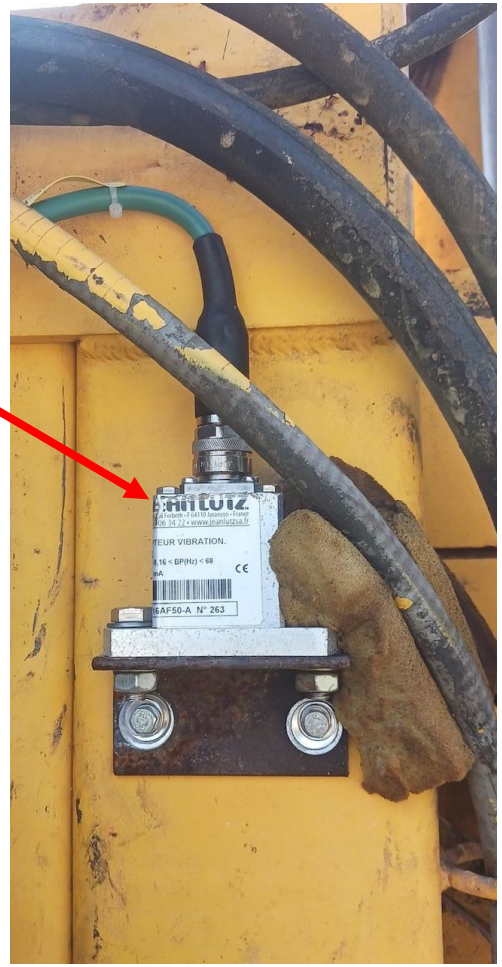
Task 1 – Drill Rig Instrumentation
Junction Box and DAQ Module



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



More control of penetration rate



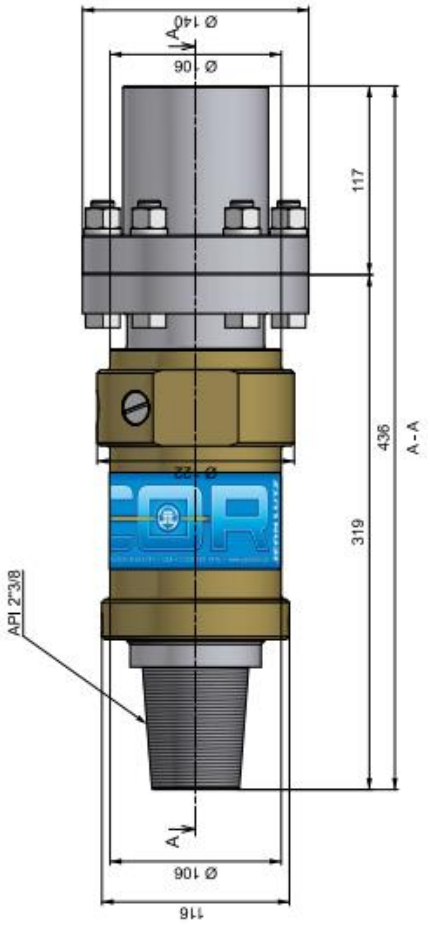
Measure drilling vibrations on the drill rig

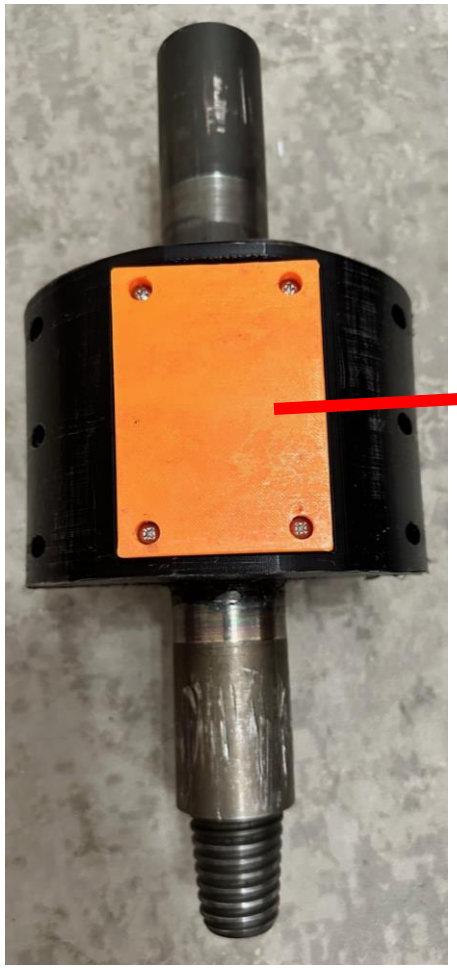
Task 1 – Drill Rig Instrumentation
Weather Protected SBC Enclosure

IP68 SBC enclosure for acquiring wireless data

Begins sampling drill rod data after the MWD system is powered on

Task 1 – Drill Rig Instrumentation
Wireless Drill Rod Transducer



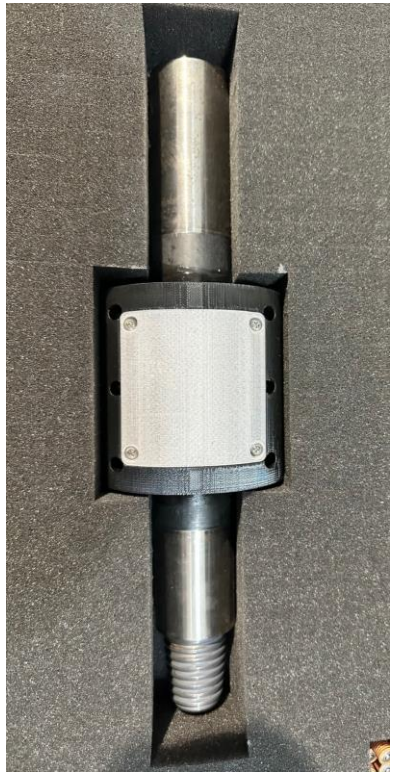


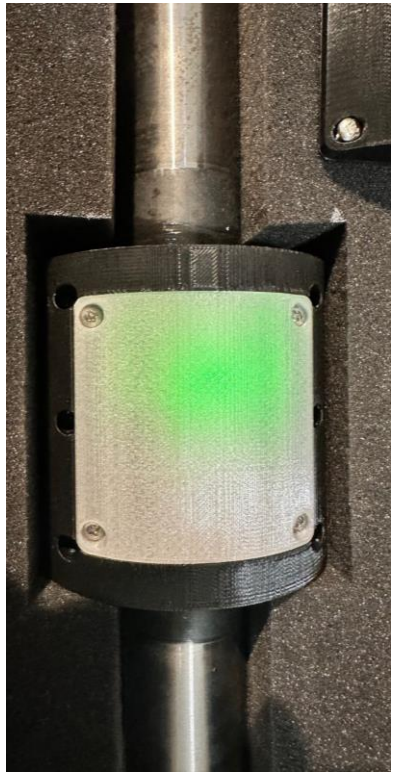
New wireless drill rod transducer can measure torque, crowd, and 3-axis vibration in the drill string

-Project Amendment-
Florida Consultant MWD

- Three FL consultants will engage in MWD site investigation
- UF research team will provide assistance and guidance

Wireless AWJ rod transducer to measure mechanical torque

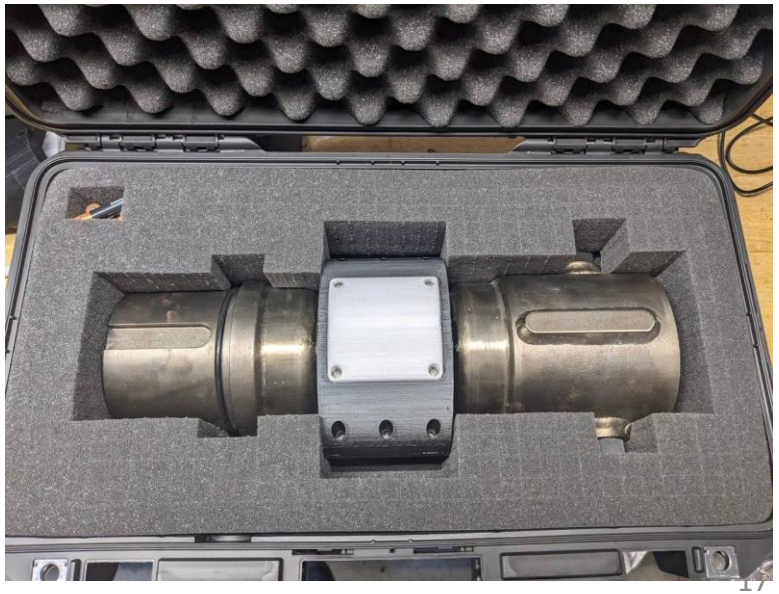




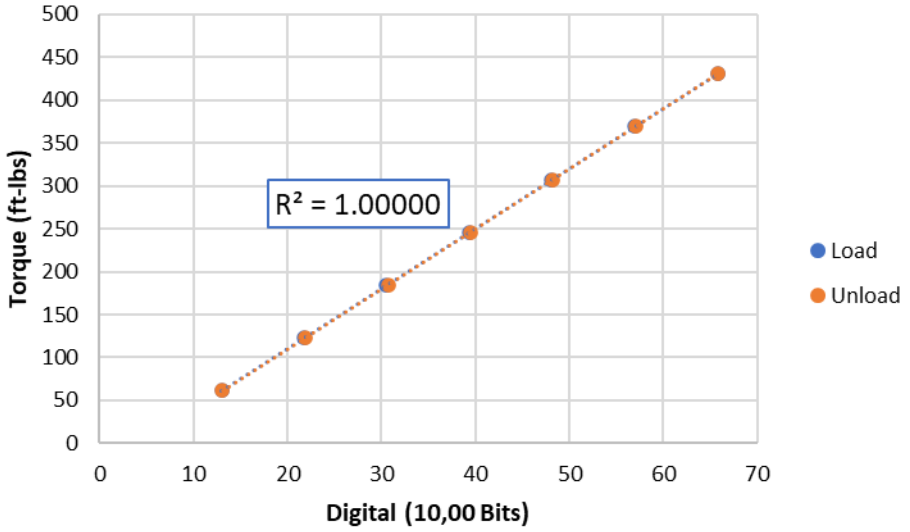
Powered by 3 AAA Batteries for 80+ hours of MWD at 256 Hz sampling

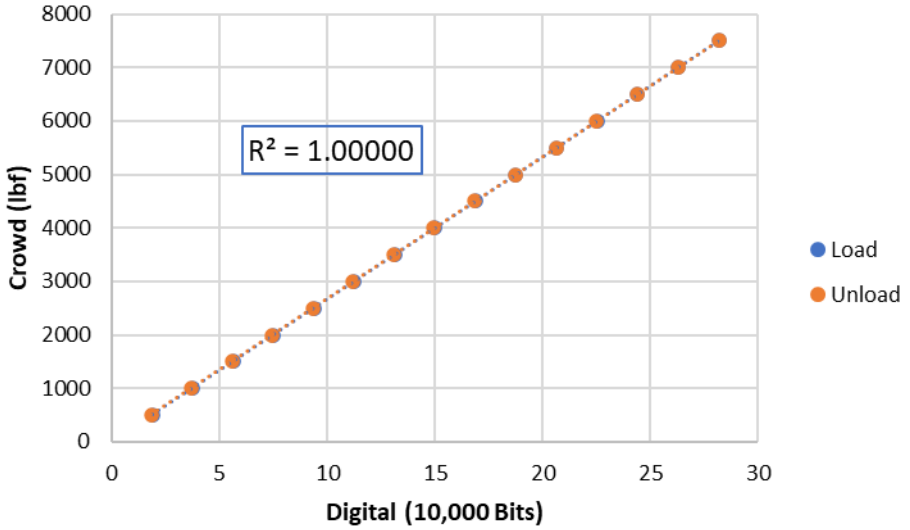
NWJ Rods

HSA Subs

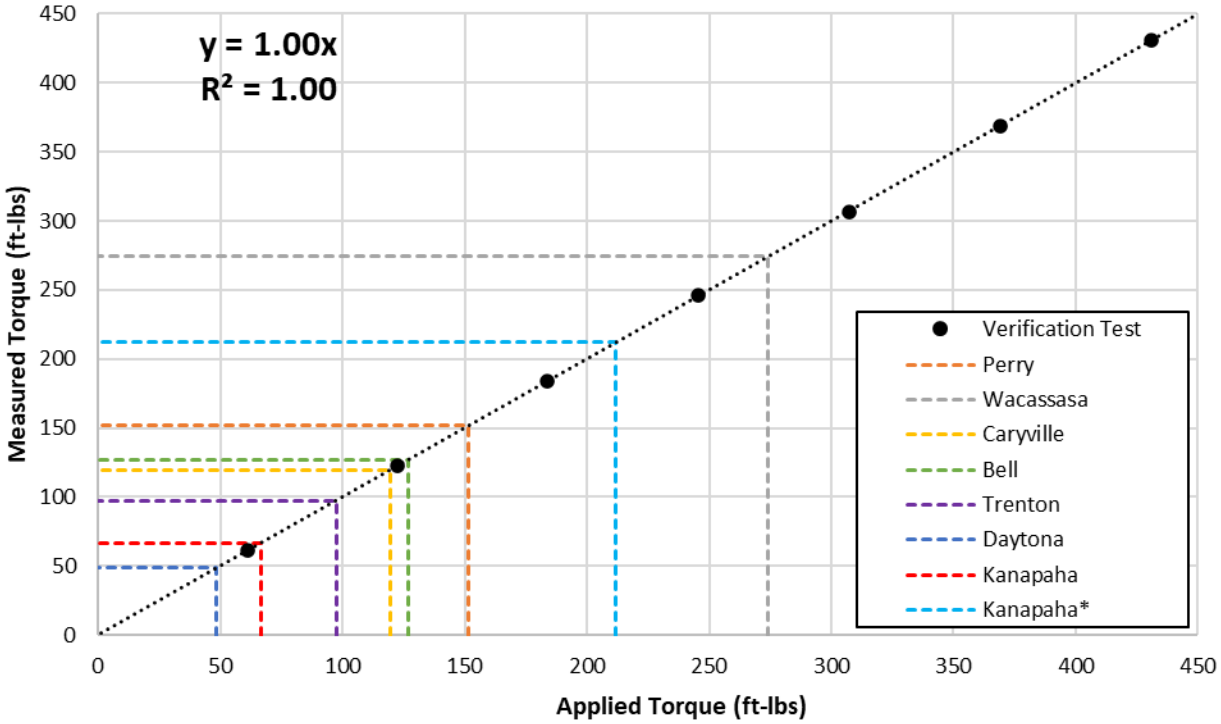


Task 1 – Drill Rig Instrumentation
Wireless Drill Rod Transducer





Torque (ft-lbs)		% Error
Applied	Measured	
61.2	61.5	0.59%
122.5	123.0	0.43%
184.0	184.3	0.16%
245.6	245.9	0.11%
307.3	306.9	-0.14%
369.1	368.8	-0.10%
431.0	430.6	-0.10%
	Average =	0.14%

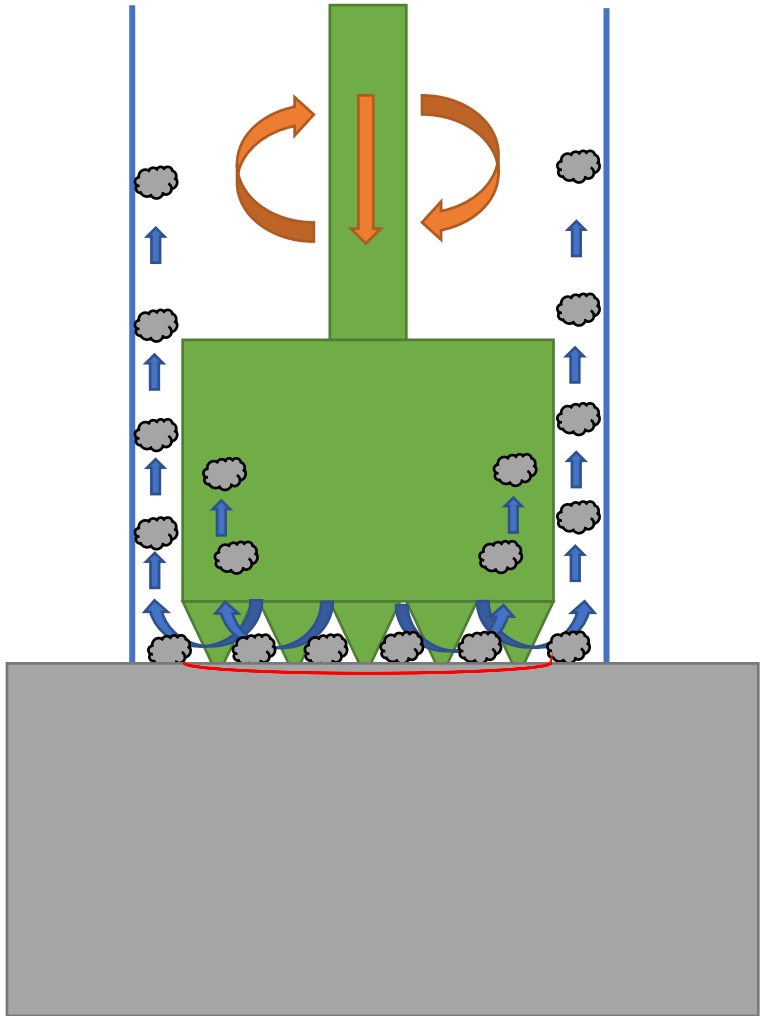


Task 2 – Drill Bit Selection and Method Development

- One of the main components of the project will be determining which drilling tool provides the best sensitivity for the delineation of various Florida soil types as well as an ideal rate of penetration to ensure the method is efficient
- This will require investigating three potential drilling tools: a tri-cone roller bit, a PDC bit, and a stepped drag bit
  - Each of these drilling tools are commonly used to advance boreholes during SPT and rock coring procedures
- Survey results from BDV31-820-006 and manufacturer recommendations will provide the initial drilling parameter ranges implemented during drilling for this investigation
- Optimal parameter ranges will then be dialed-in and identified for each drilling tool
- Once the optimal parameter ranges are identified, the drilling results will be analyzed, and a recommended drill bit will be selected for further development

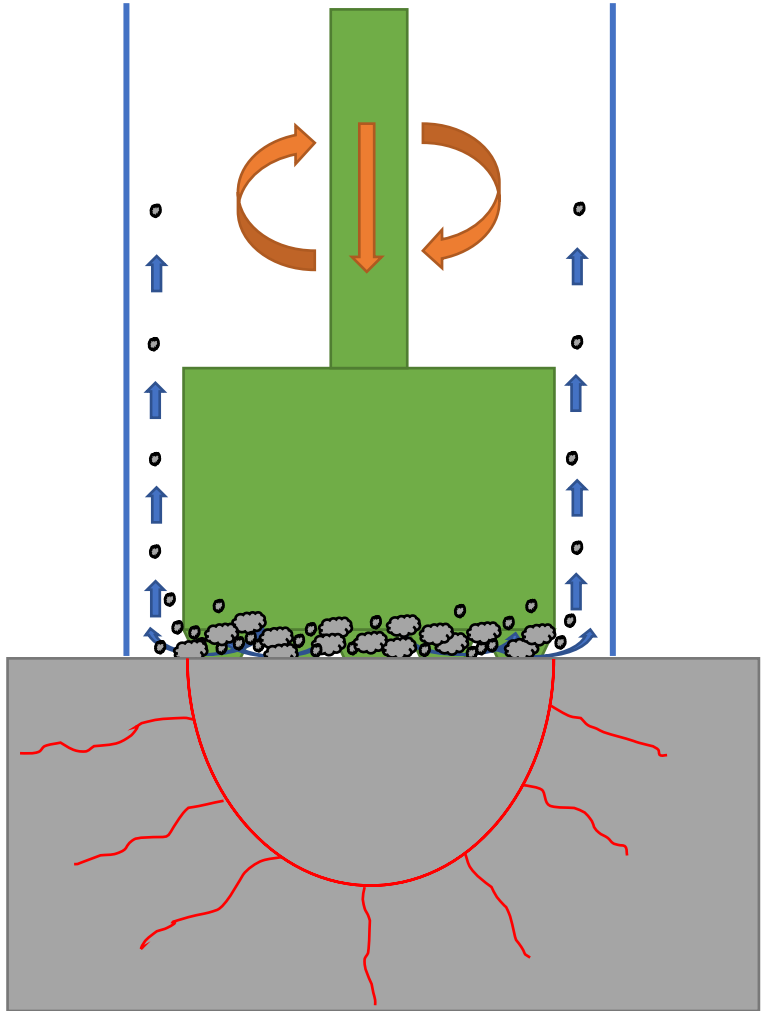
Optimized Drilling

- Proper indentation and cutting → optimized penetration per rotation
- 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 RQD
- In situ strength assessment viable via MWD



Drilling Disturbance

- 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

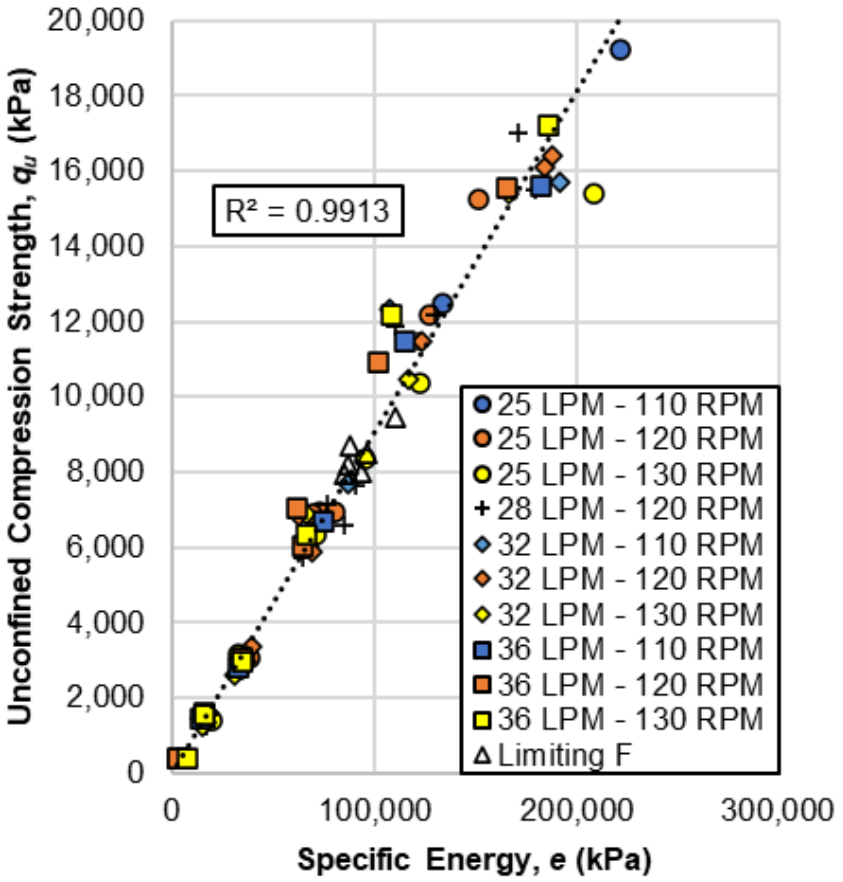


Optimized

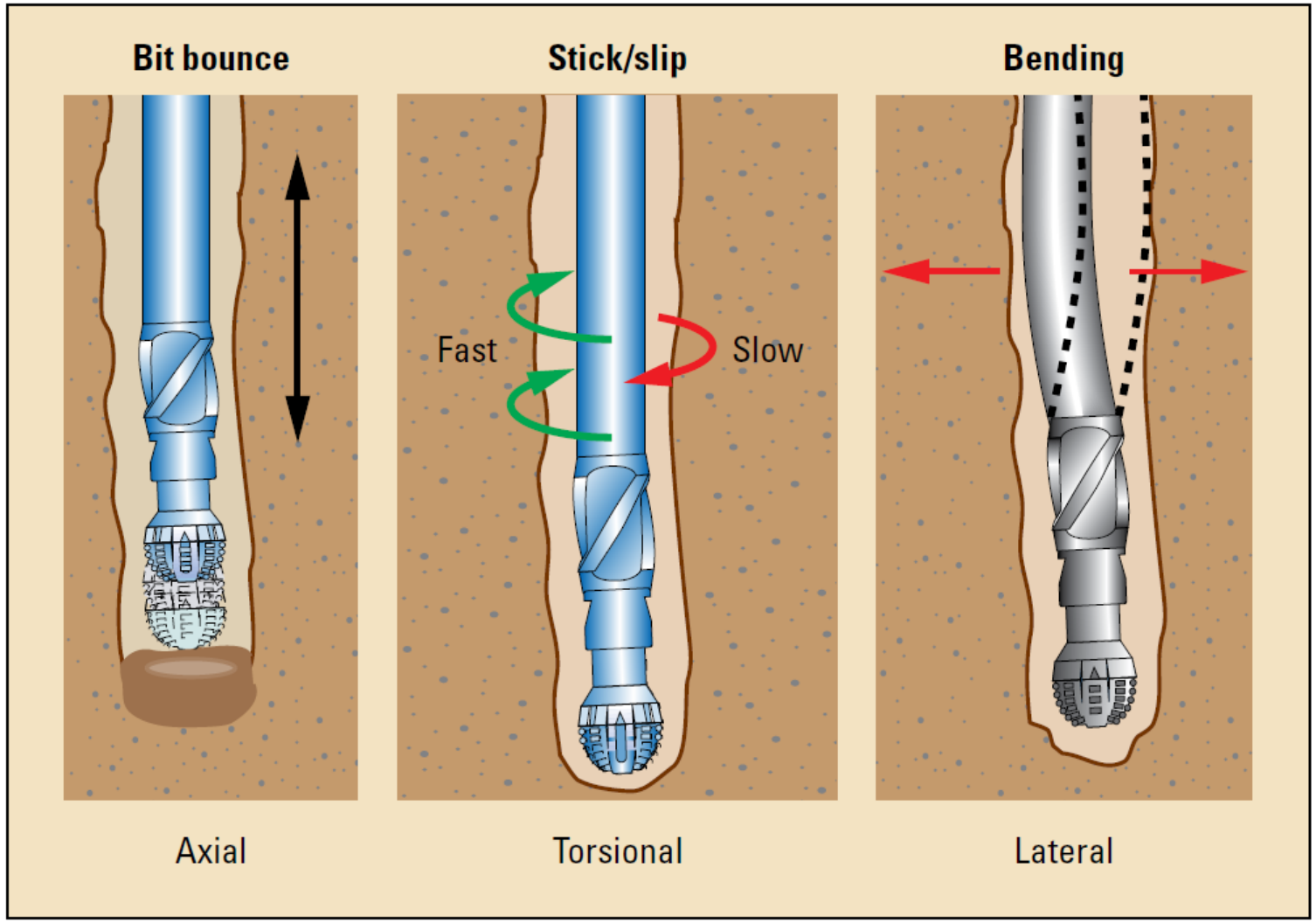
Disturbed

Task 3a – Operational Index Development

- Once the optimum drilling tool has been selected for the new MWD method, additional drilling locations identified in Task 1 will be required to further develop the operational drilling index
- The operational drilling index will comprise multiple independent and compound drilling parameters that when considered in combination, directly identify the soil type encountered
  - 18 individual drilling parameters will be measured with the new system
  - 7 waveform parameters can be extracted from T, F, and 3-axis vibration for an additional 35 parameters generated from the wireless transducer
  - Numerous compound parameters can be generated from individual parameters
  - ML will be utilized to assist in developing the operational index
- Specific energy likely will be used to assess the strength of each soil/rock type identified by the operational index
  - Additional compound parameters commonly used to assess drilling resistance will also be considered
- During this portion of the study SPT, CPT, DMT, VIP, and lab testing will be required in close proximity to each MWD drilling location

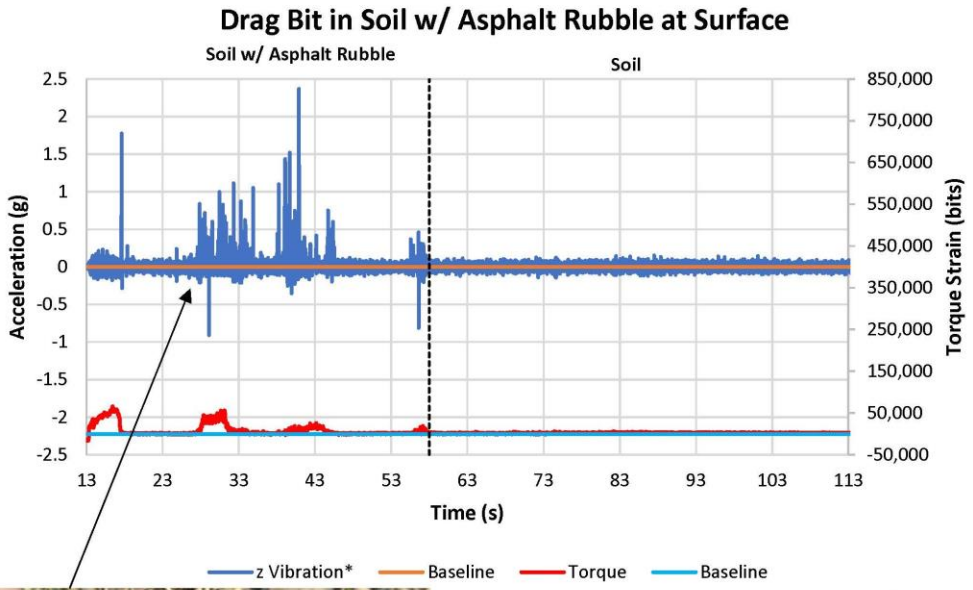


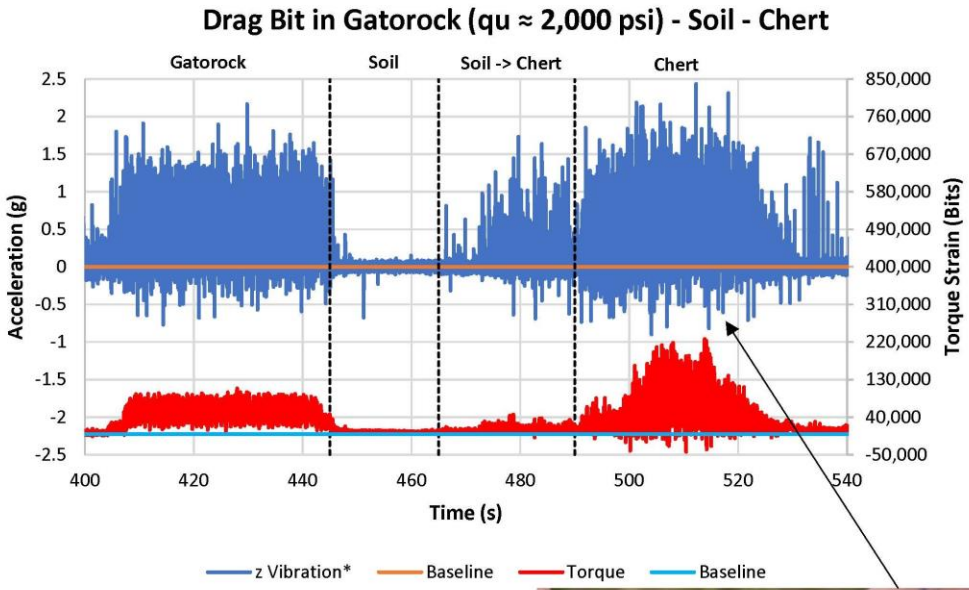
Drilling Vibration Types

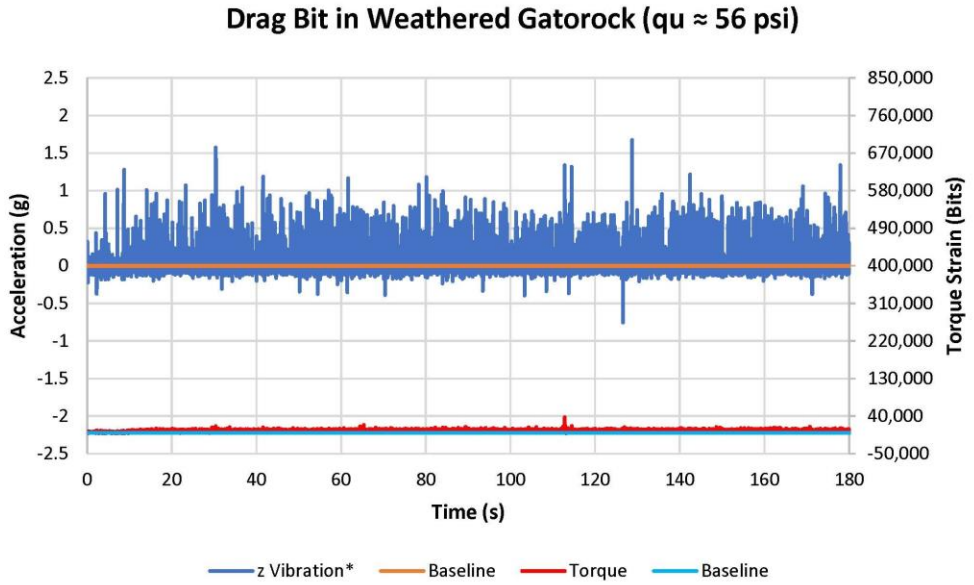


Schlumberger (2010)

Drilling Vibration and Torque Telemetry

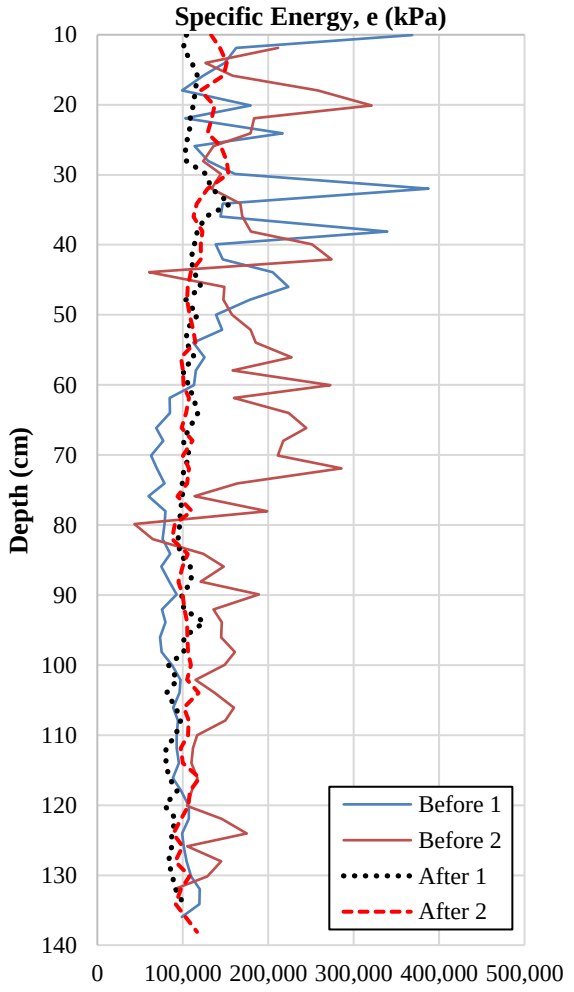


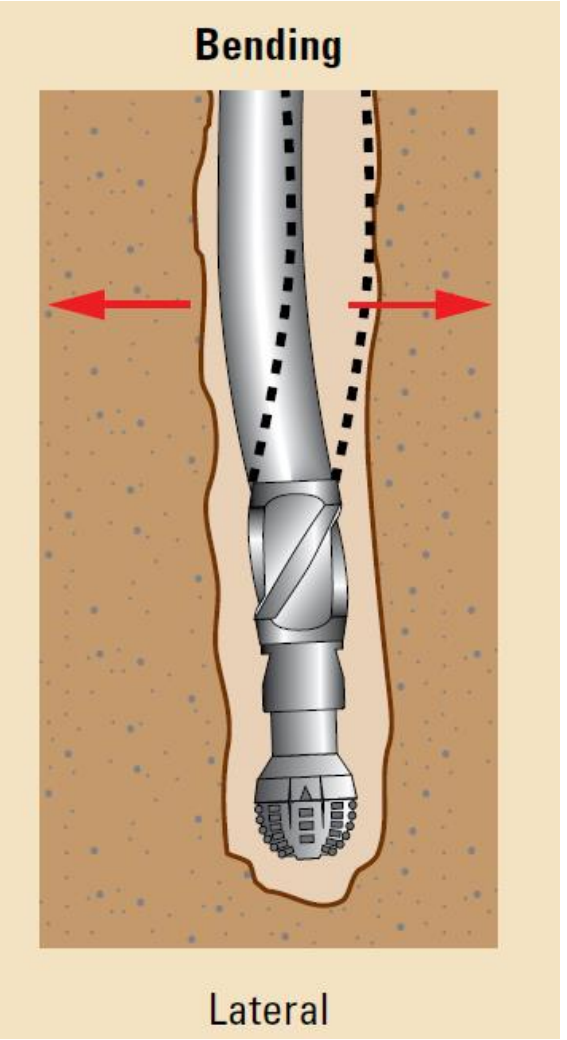




Task 3b – Eccentric Rotation Investigation at Deeper Drilling Depths

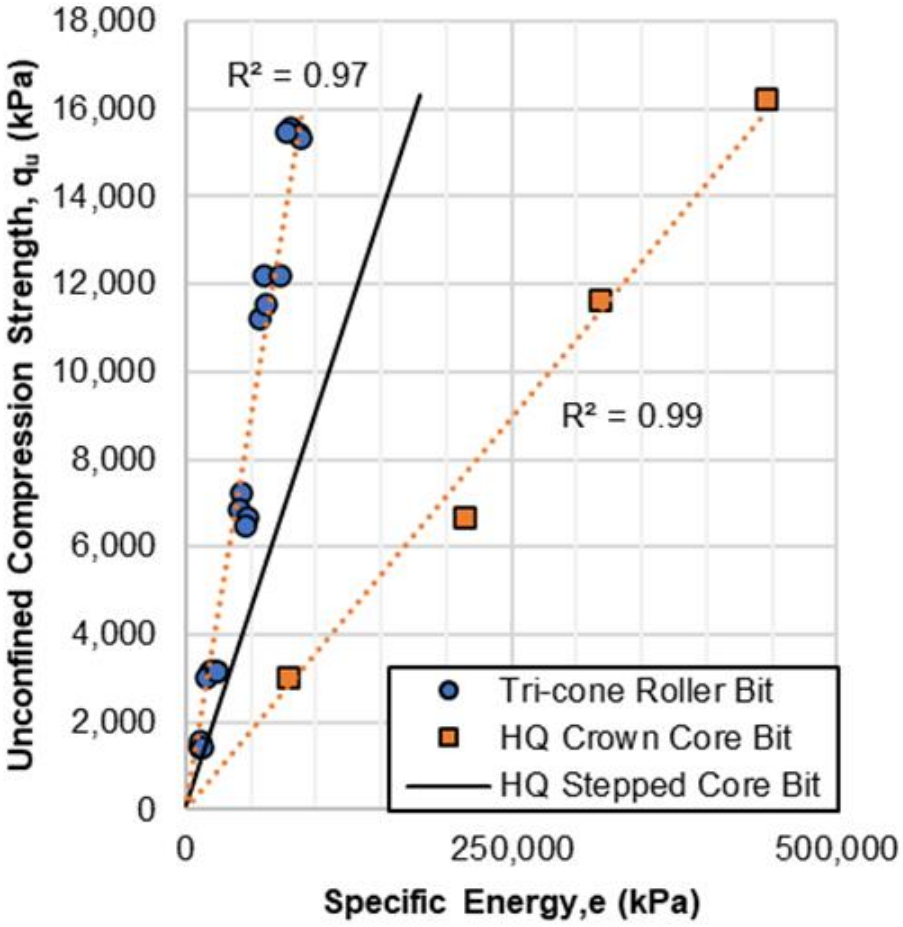
- FDOT Project BDV31-977-125 indicated eccentric rotation and excessive vibration may be induced at greater drilling depths due to the slenderness of the drill string, regardless of the rotary head's condition
- The new MWD method should be assessed based on the depth of drilling and potential effects 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





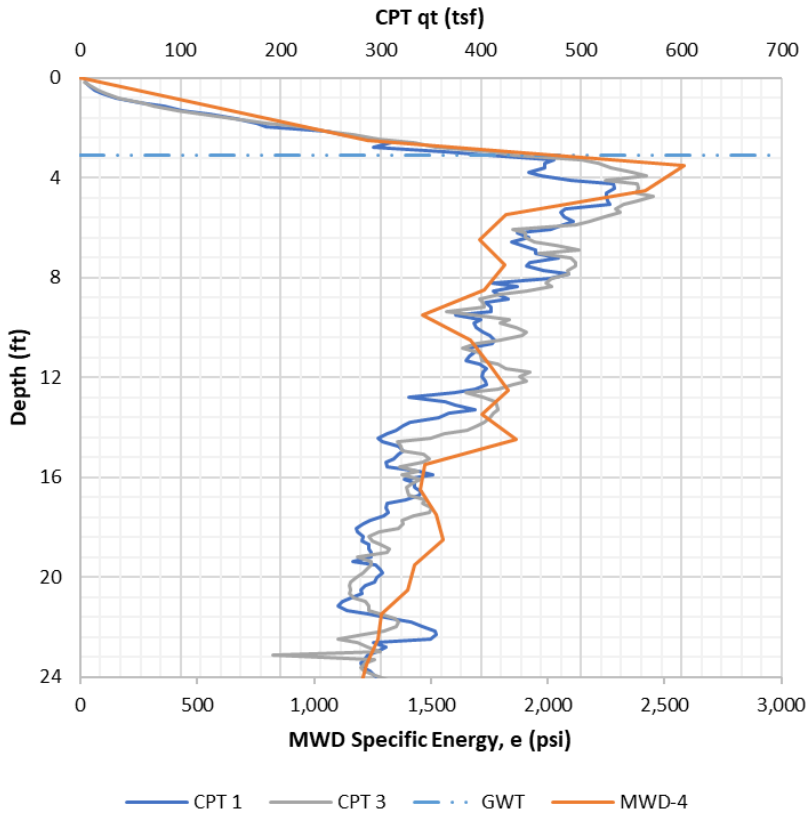
Task 4 – Developing Correlation Between MWD and Engineering Parameters

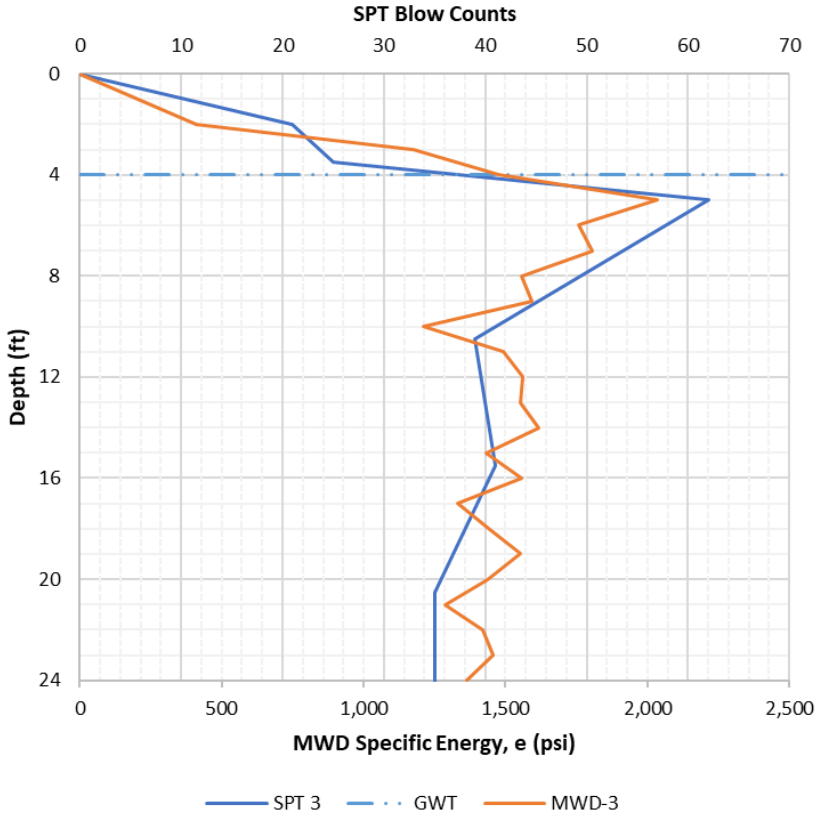
- Once the operational limits and the operational index has been developed, correlations between MWD parameters and the engineering parameters of will be investigated
- It is expected that the unique mechanical behavior and properties of various in situ soils and rock will produce a unique drilling response 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



MWD Compared to Conventional Methods

- 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 (2024)

Questions?