Assessment of Drilled Shaft Capacity and QA/QC from Measuring While Drilling BED31-977-09

GRIP Meeting

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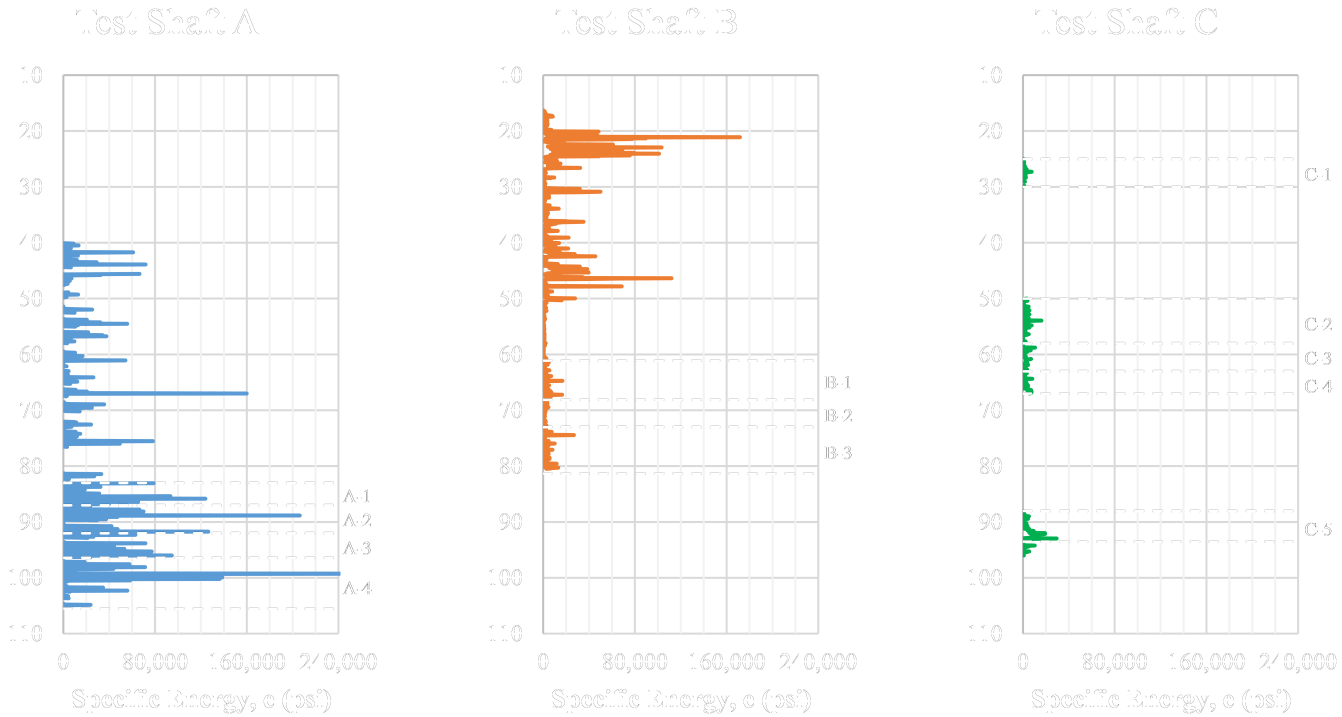
August 12, 2022

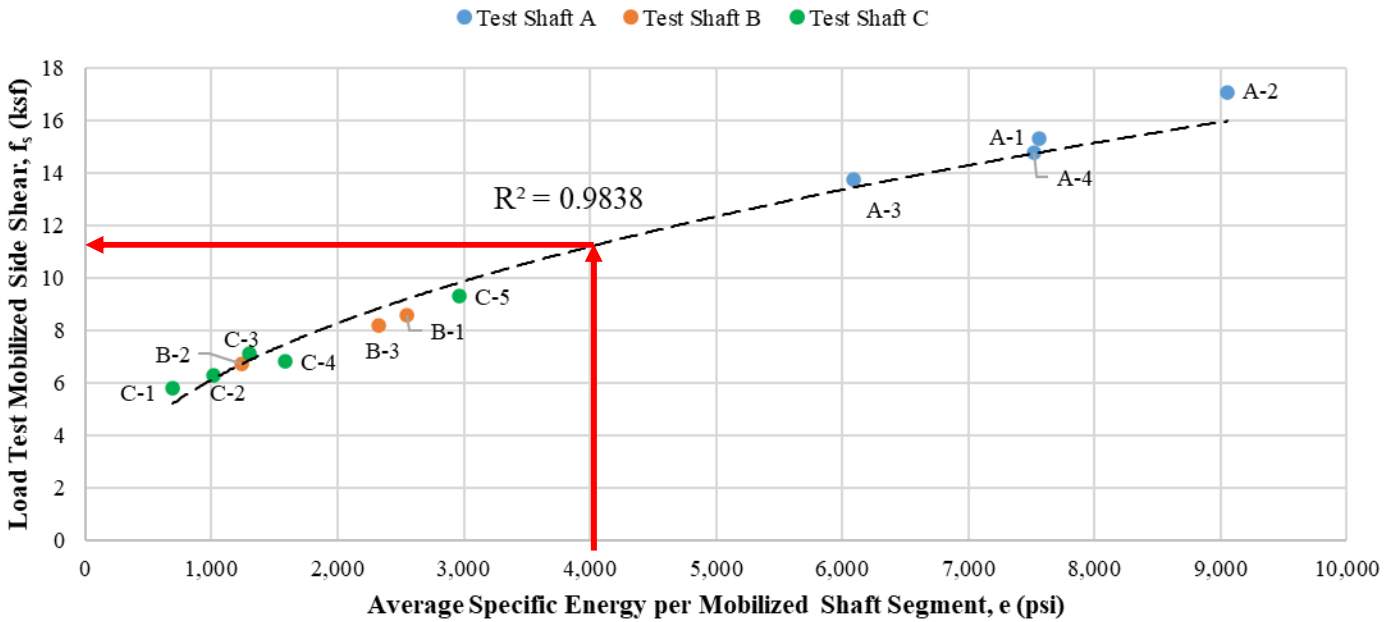
Florida Geotechnical Design Challenges

- In Florida, our bored piles (drilled shafts and ACIP piles) that support larger structures often rely on a competent length of rock socket to develop the necessary axial capacity required to satisfy the engineering design
- As described by Graham et al. (2013), the subsurface stratigraphy of Florida sites underlain by weathered limestone formations can be highly variable with respect to material layer thicknesses and strengths, even over short horizontal distances. These conditions present a challenging environment for the design of drilled foundations in terms of axial performance
- Graham et al. (2013) identified the following contributing factors:
  - Due to the variability in subsurface conditions, it is not always possible to anticipate stratigraphy based on borings even a short distance away, and sometimes even across the footprint of a single foundation unit
  - Highly weathered material is not well suited for typical investigation methods designed for soil or rock
    - SPT borings, CPT soundings, and rock coring – “none of these tests are fully capable of defining the in-situ strengths for design in weathered limestone”
  - It is a challenge to assign material properties to a seemingly erratic stratigraphy that will produce meaningful correlations to the load testing data
  - “Rigorous QA/QC required, and the designer must remain engaged during construction”
- The FDOT has turned to measuring while drilling (MWD) to improve Bored Pile QA/QC

Drilled Shaft MWD

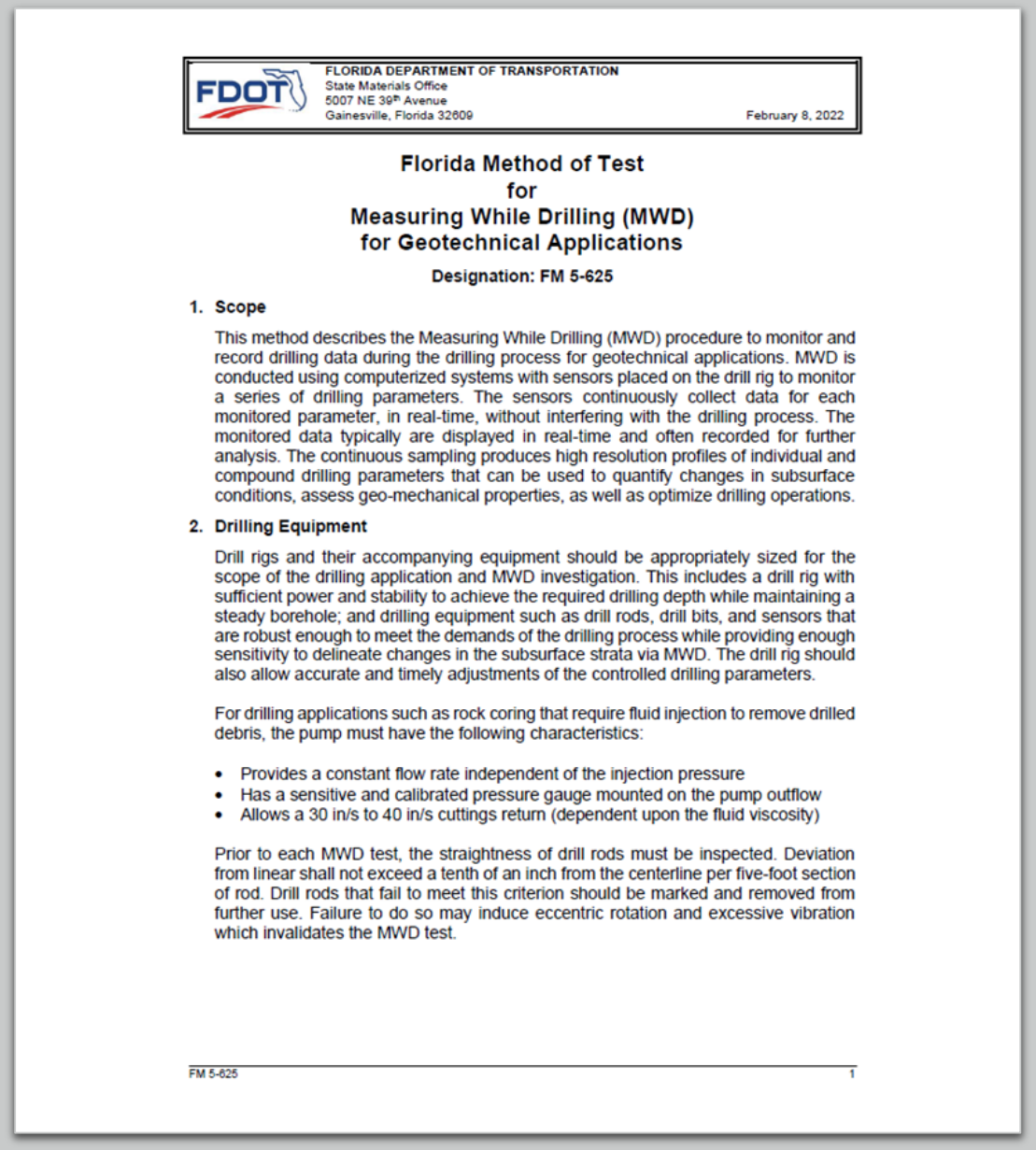
- Specific energy recorded in layers of rock at a Florida bridge site
  - Avg. distance between shafts ≈ 700 yds
  - "Seemingly erratic stratigraphy"
- This site was the focus of the Graham et al. (2013) paper
  - "Challenging to produce meaningful correlations to load tests"
- MWD is allowing us to produce a meaningful correlation with load test data that can be translated to untested production shafts via MWD
  - Eliminates spatial uncertainty concerns that arise from Florida's high degree of subsurface variability
    - MWD allows us to assess the subsurface conditions within the footprint of each production shaft location at full-scale
  - Increases the value of load tests when coupled with MWD





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
- Based on the prior work completed, a new FDOT test method was developed, "Measuring While Drilling (MWD) for Geotechnical Applications", designated FM 5-625



FLORIDA DEPARTMENT OF TRANSPORTATION
State Materials Office
5007 NE 39th Avenue
Gainesville, Florida 32609
February 8, 2022

Florida Method of Test
for
Measuring While Drilling (MWD)
for Geotechnical Applications

Designation: FM 5-625

1. **Scope**

This method describes the Measuring While Drilling (MWD) procedure to monitor and record drilling data during the drilling process for geotechnical applications. MWD is conducted using computerized systems with sensors placed on the drill rig to monitor a series of drilling parameters. The sensors continuously collect data for each monitored parameter, in real-time, without interfering with the drilling process. The monitored data typically are displayed in real-time and often recorded for further analysis. The continuous sampling produces high resolution profiles of individual and compound drilling parameters that can be used to quantify changes in subsurface conditions, assess geo-mechanical properties, as well as optimize drilling operations.

2. **Drilling Equipment**

Drill rigs and their accompanying equipment should be appropriately sized for the scope of the drilling application and MWD investigation. This includes a drill rig with sufficient power and stability to achieve the required drilling depth while maintaining a steady borehole; and drilling equipment such as drill rods, drill bits, and sensors that are robust enough to meet the demands of the drilling process while providing enough sensitivity to delineate changes in the subsurface strata via MWD. The drill rig should also allow accurate and timely adjustments of the controlled drilling parameters.

For drilling applications such as rock coring that require fluid injection to remove drilled debris, the pump must have the following characteristics:

- Provides a constant flow rate independent of the injection pressure
- Has a sensitive and calibrated pressure gauge mounted on the pump outflow
- Allows a 30 in/s to 40 in/s cuttings return (dependent upon the fluid viscosity)

Prior to each MWD test, the straightness of drill rods must be inspected. Deviation from linear shall not exceed a tenth of an inch from the centerline per five-foot section of rod. Drill rods that fail to meet this criterion should be marked and removed from further use. Failure to do so may induce eccentric rotation and excessive vibration which invalidates the MWD test.

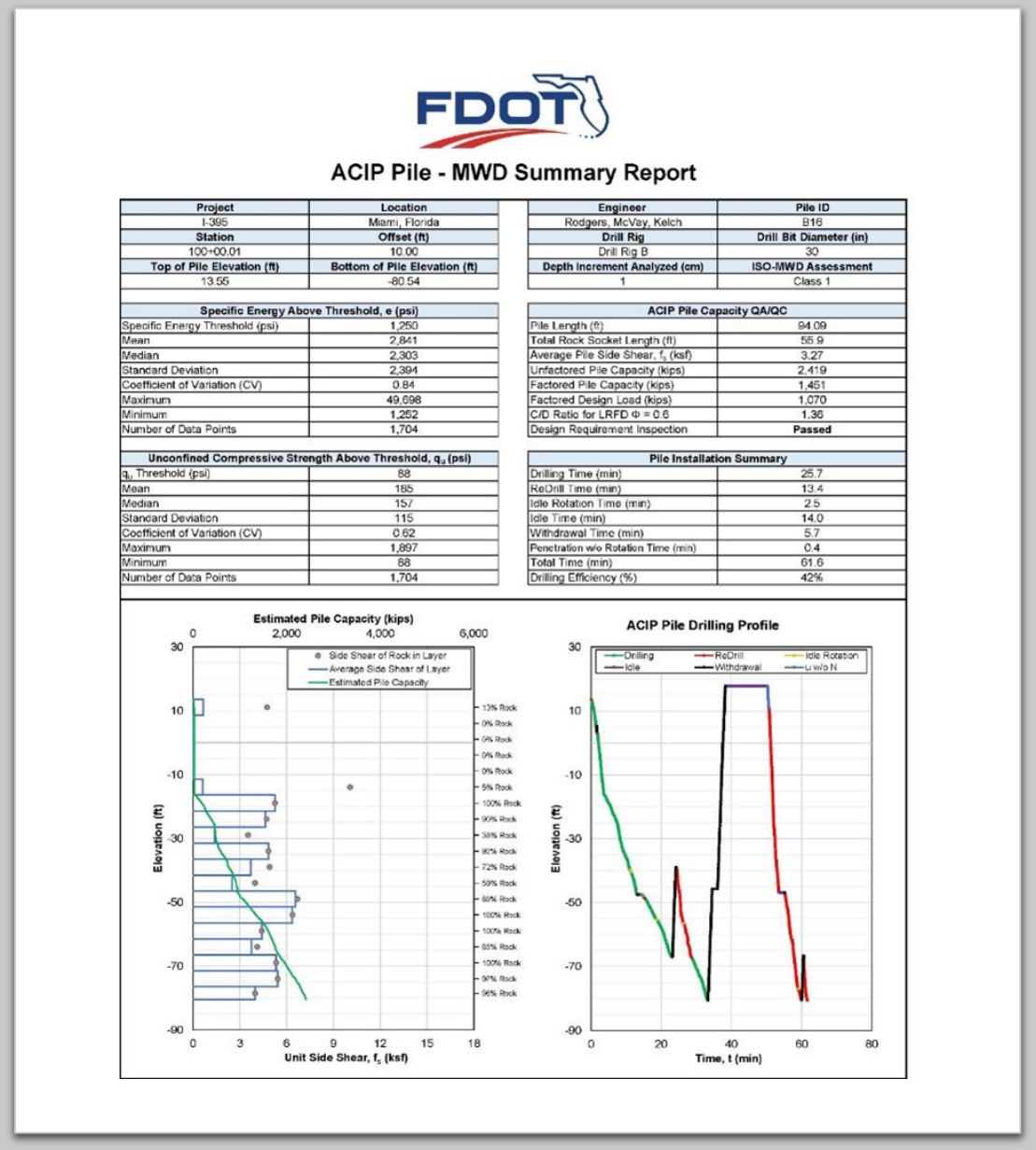
FM 5-625 1

Introduction

- The new method provides an overview of the general MWD approach, gives guidance for developing MWD guidelines and procedures, and details the format in which MWD data should be reported
- However, with multiple variations of data recording and reporting generated from the various commercial and on-board drill rig monitoring systems used during drilled shaft installations, further investigation is required to develop a universal format of analysis for all Florida bored pile QA/QC applications

Project Background

- Recently the FDOT investigated the use of MWD for Auger Cast Piles (ACP) to provide QA/QC during pile installations in Miami-Dade
  - BDV31-977-125
- During the effort, a new analysis tool was developed to transform time-referenced data collected from AME to depth-referenced data that is compatible for strength assessment
- For ACPs, a time-referenced data format collected from AME is most commonly used in Florida, and the ACP analysis tool was developed specifically to accommodate the data format



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ACIP Pile - MWD Summary Report

Project	Location	Engineer	Pile ID
I-395	Miami, Florida	Rodgers, McVay, Kelch	B16
Station	**Offset (ft)**	**Drill Rig**	**Drill Bit Diameter (in)**
100+00.01	10.00	Drill Rig B	30
Top of Pile Elevation (ft)	**Bottom of Pile Elevation (ft)**	**Depth Increment Analyzed (cm)**	**ISO-MWD Assessment**
13.55	-80.54	1	Class 1

Specific Energy Above Threshold, e (psi)	
Specific Energy Threshold (psi)	1,250
Mean	2,841
Median	2,303
Standard Deviation	2,394
Coefficient of Variation (CV)	0.84
Maximum	49,698
Minimum	1,252
Number of Data Points	1,704

ACIP Pile Capacity QA/QC	
Pile Length (ft)	94.09
Total Rock Socket Length (ft)	55.9
Average Pile Side Shear, f_s (ksf)	3.27
Unfactored Pile Capacity (kips)	2,419
Factored Pile Capacity (kips)	1,451
Factored Design Load (kips)	1,070
C/D Ratio for LRFD $\Phi = 0.6$	1.36
Design Requirement Inspection	**Passed**

Unconfined Compressive Strength Above Threshold, q_u (psi)	
q_u Threshold (psi)	88
Mean	185
Median	157
Standard Deviation	115
Coefficient of Variation (CV)	0.62
Maximum	1,897
Minimum	88
Number of Data Points	1,704

Pile Installation Summary	
Drilling Time (min)	25.7
ReDrill Time (min)	13.4
Idle Rotation Time (min)	2.5
Idle Time (min)	14.0
Withdrawal Time (min)	5.7
Penetration w/o Rotation Time (min)	0.4
Total Time (min)	61.6
Drilling Efficiency (%)	42%

Project Background

- However, for drilled shaft MWD, some systems produce time-referenced data, some systems produce depth-referenced data, and some systems can produce both data formats
- Consequently, a new analysis tool should be developed for drilled shafts to accommodate the possible variations in raw data recording and reporting
- This will provide the FDOT with a reliable method of drilled shaft QA/QC analysis similar to ACPs, regardless of the monitoring system used
- This would also allow potential contractors to utilize a variety of MWD systems instead of solely relying on systems that can produce depth-referenced data, which is a current constraint for full drilled shaft MWD implementation
- On-site and remote monitoring should be also explored to improve the quality control portion of the of the QA/QC tool
  - Providing real time strength assessments that can be viewed by all stakeholders

Project Objectives

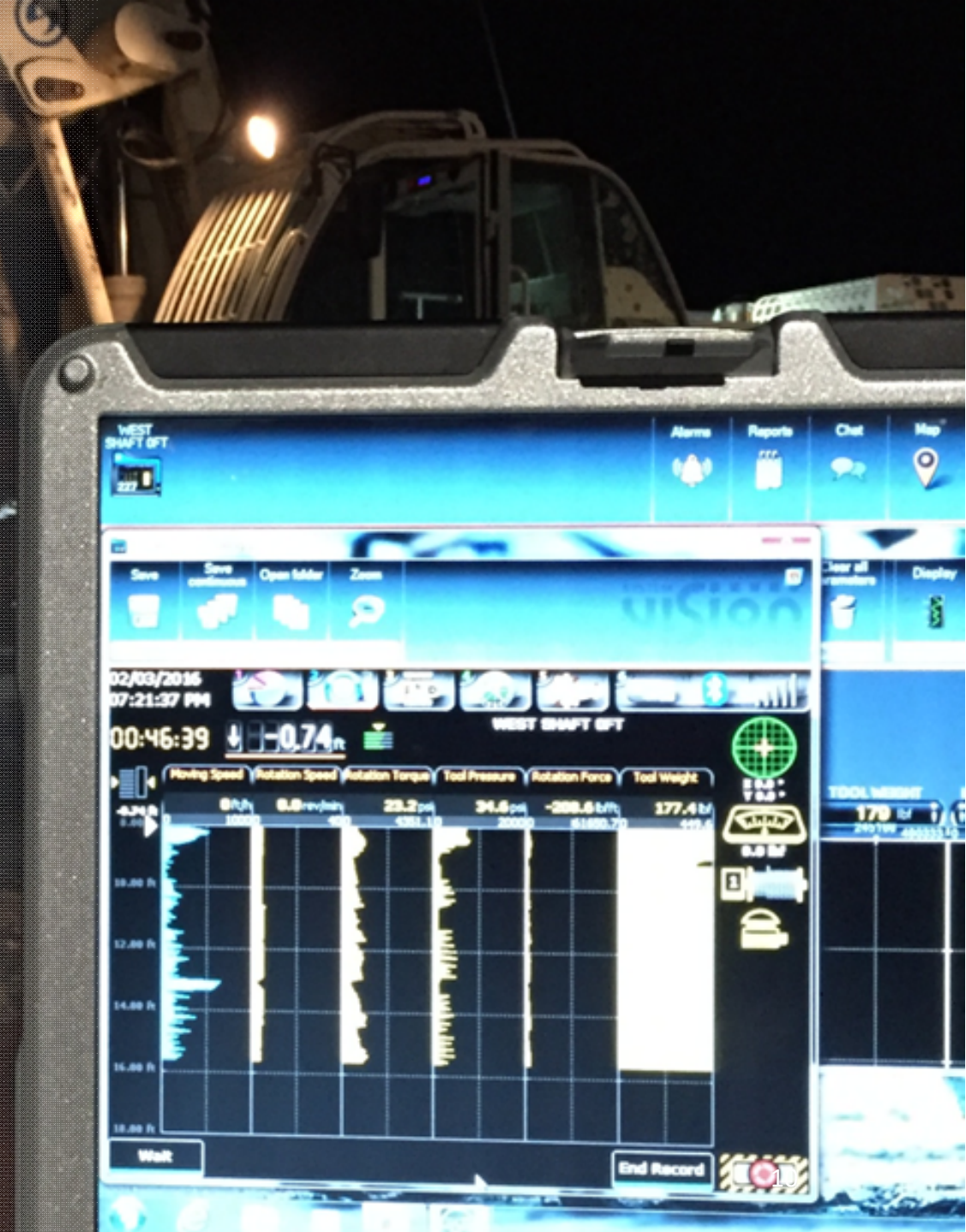
1. Using FDOT MWD criteria (FM 5-625), develop a versatile data analysis tool that will be used to provide drilled shaft MWD QA/QC
2. Conduct a feasibility study to identify the requirements of providing on-site and remote monitoring capabilities to enhance the QA/QC method
3. Monitor at least one load tested shaft and three production shafts at three independent sites to develop correlations for QA/QC purposes
4. Provide a QA/QC report for all shafts monitored during the research
5. Compare test results with previously derived correlations

Tasks and Deliverables

- Deliverable 1 – Establish drilled shaft MWD data reduction criteria and procedures (Task 1)
- Deliverable 2 – On-site and remote monitoring implementation feasibility study (Task 2)
- Deliverable 3 – MWD specific energy vs. drilled shaft side shear correlation (Task 3)
- Deliverable 4 – MWD correlation validation for drilled shaft QA/QC (Task 4)
- Deliverable 5a - Draft Final (Task 5)
- Deliverable 5b - Closeout Meeting (Task 5)
- Deliverable 6 - Final Report (Task 6)

Task 1 – Establish Drilled Shaft MWD Data Reduction Criteria and Procedures for QA

- Task 1 will be comprised of two subtasks, (1a) developing specification language and (1b) developing a new versatile data analysis tool for drilled shaft QA/QC purposes
- This will provide the department the necessary specification language to convey proper MWD requirements to the contractor during bidding, or prior to construction, and the necessary data analysis tool to process and evaluate the raw MWD data received from the contractor to provide quality assurance (QA)

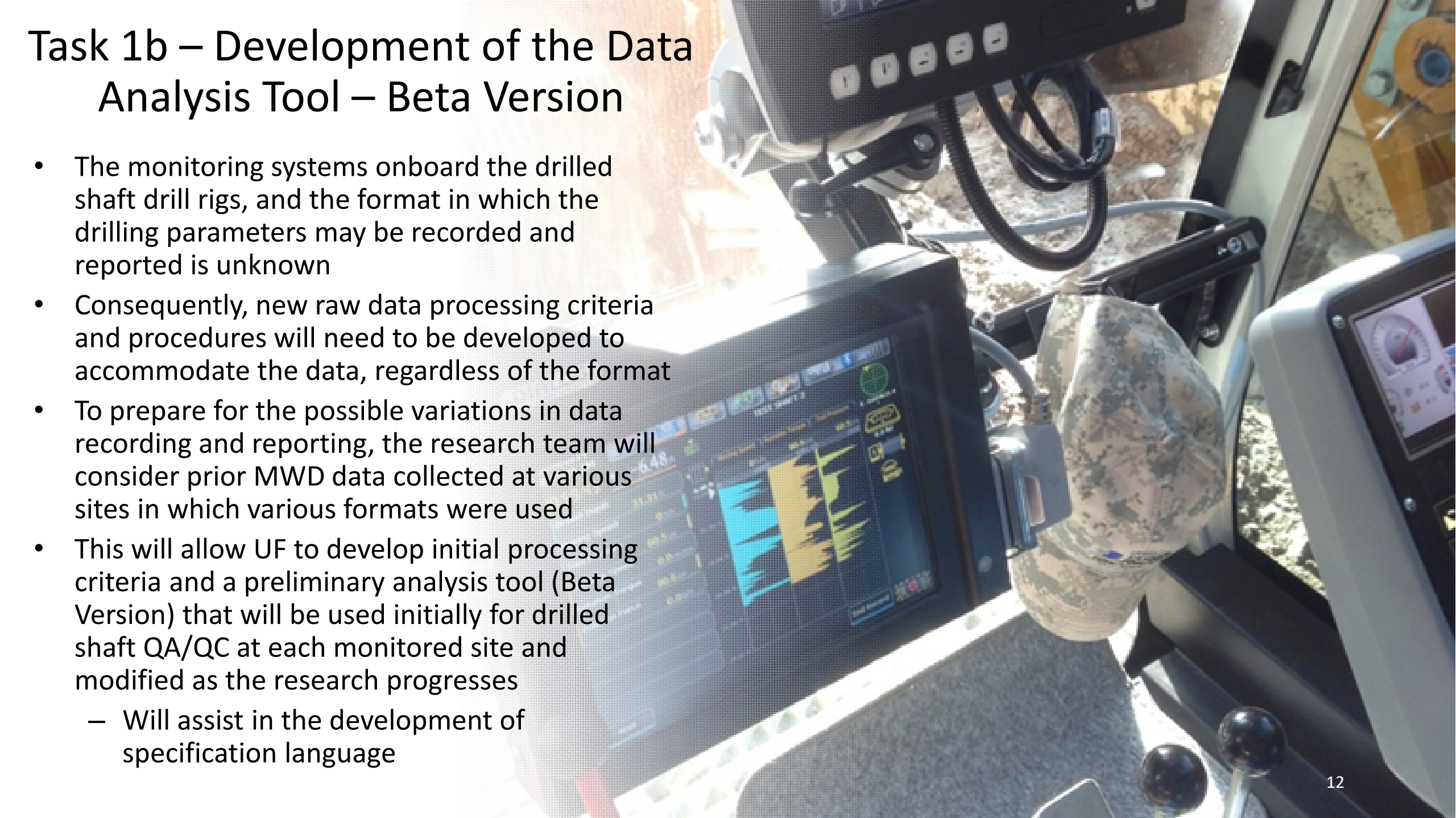


Task 1a – Development of Specification Language

- Identify MWD systems that are currently available
  - On-board drill rig systems and commercially available systems
- Based on the findings, develop specification language that includes data recording and data formatting requirements for contractor supplied MWD raw data that will allow the FDOT to perform the drilled shaft QA procedure
- Specification language will detail construction specification requirements for the contractor
  - Ensures each drill rig used has the appropriate monitoring equipment installed and calibrated, prior to the start of work, with the required data logging capabilities to supply the FDOT with the necessary electronic records for drilled shaft MWD QA.

Task 1b – Development of the Data Analysis Tool – Beta Version

- The monitoring systems onboard the drilled shaft drill rigs, and the format in which the drilling parameters may be recorded and reported is unknown
- Consequently, new raw data processing criteria and procedures will need to be developed to accommodate the data, regardless of the format
- To prepare for the possible variations in data recording and reporting, the research team will consider prior MWD data collected at various sites in which various formats were used
- This will allow UF to develop initial processing criteria and a preliminary analysis tool (Beta Version) that will be used initially for drilled shaft QA/QC at each monitored site and modified as the research progresses
  - Will assist in the development of specification language



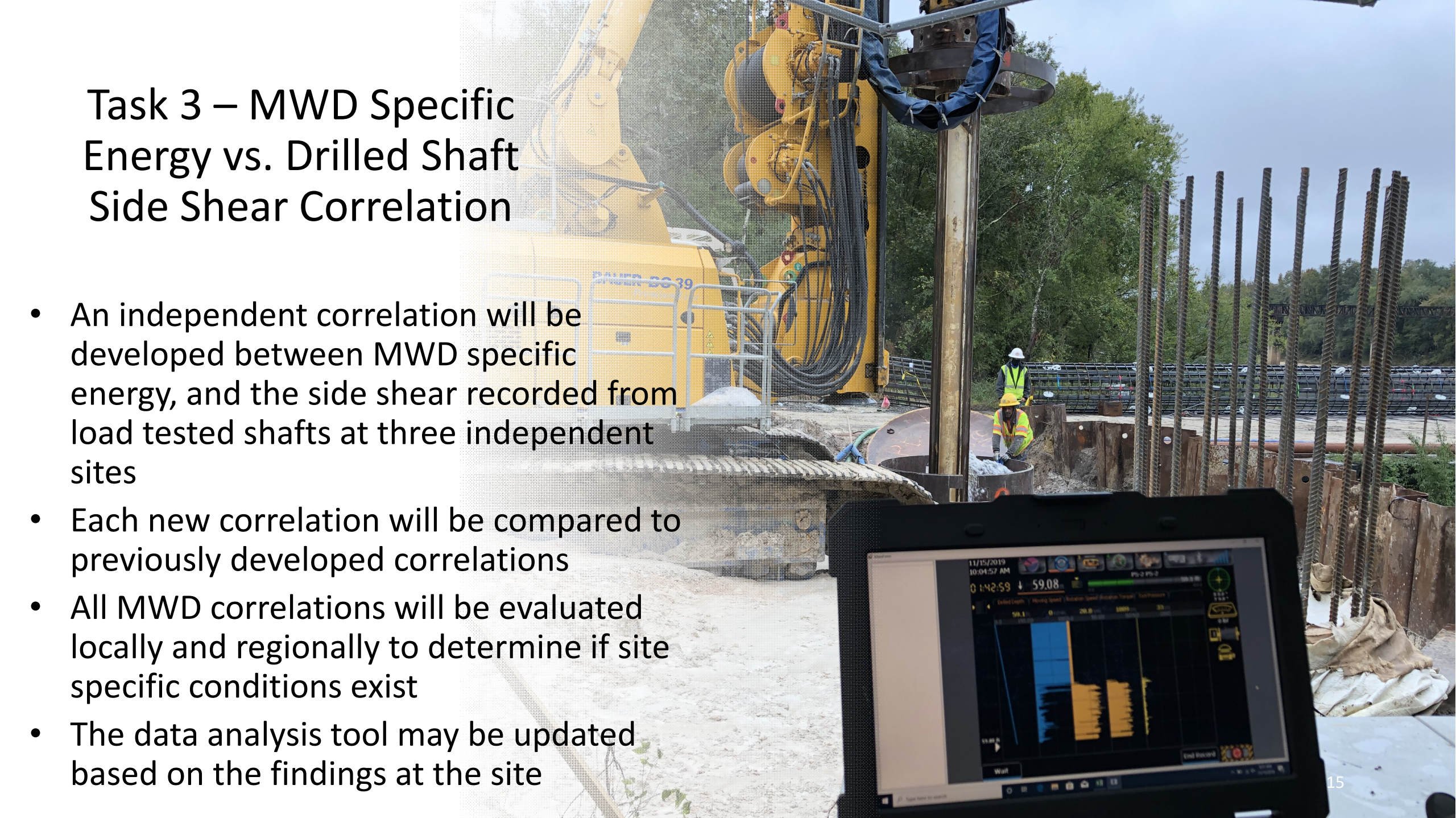
Task 2 – Real Time, On-site and Remote QC Monitoring Implementation Feasibility Study

- The proposed data analysis tool will greatly improve drilled shaft QA/QC as the quality and lengths of rock sockets can be verified through specific energy obtained from MWD
- When MWD-load test correlations can be established for a site or region, the QA portion of the procedure is improved by allowing the shaft's axial capacity to be estimated to ensure it meets design criteria, directly
- However, the quality control (QC) portion of the procedure could be further improved by providing real-time measurements of specific energy, total energy, and side shear axial shaft capacity during the drilling process

Task 2 – Real Time, On-site and Remote QC Monitoring Implementation Feasibility Study

- Therefore, a feasibility study will be conducted that reports on the anticipated requirements to provide the enhanced version of MWD QA/QC with real-time specific energy and shaft capacity estimates in addition to real-time measurements of the drilling parameters
- UF will continue to inquire about the monitoring capabilities and data recording and reporting formats that are provided by a number of drill rig manufacturers and MWD instrumentation vendors
- This will allow UF researchers to further identify universal commonality between each of the MWD systems and establish criteria for on-site and remote monitoring to provide the enhanced version of the QA/QC method

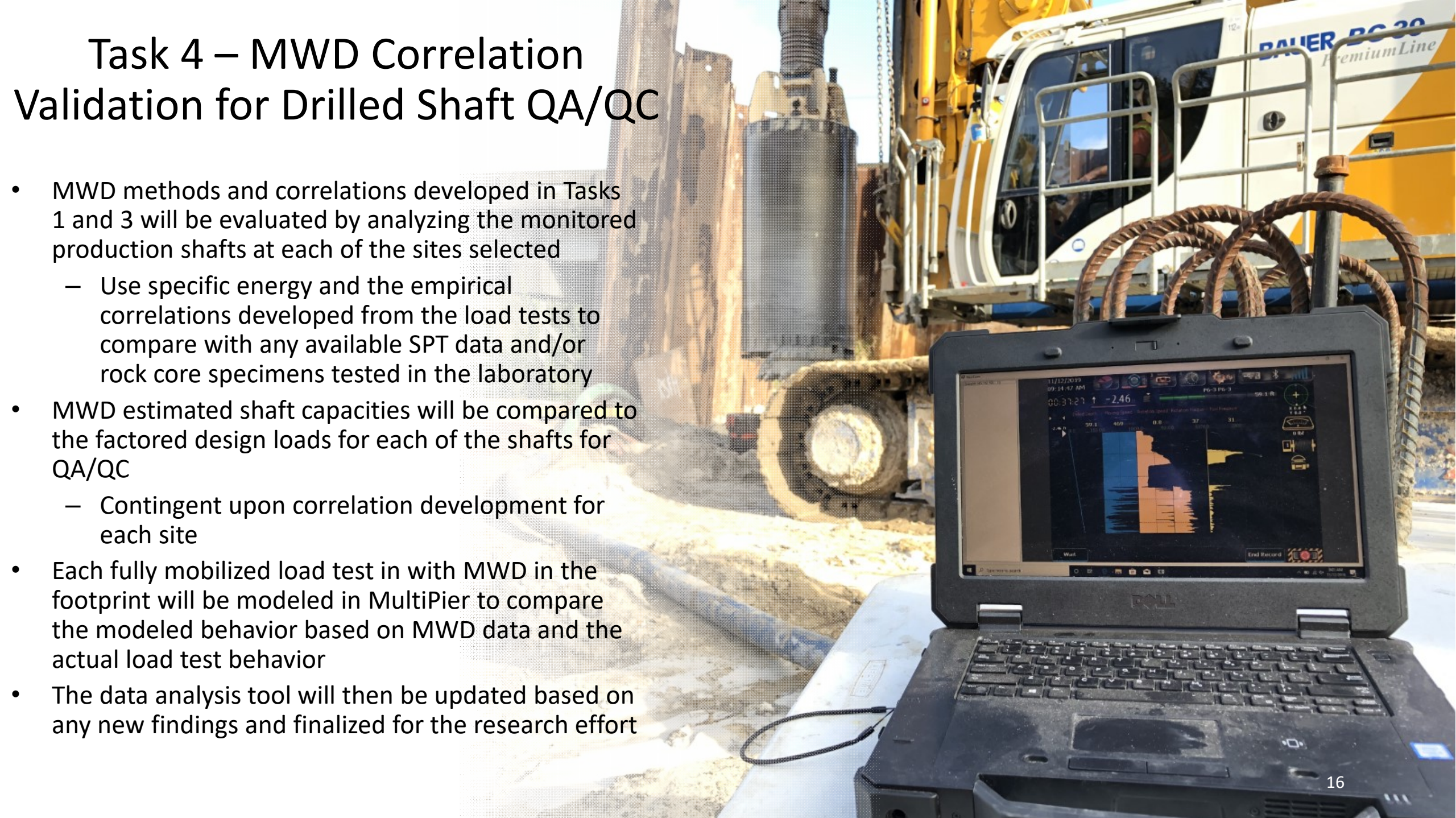
Task 3 – MWD Specific Energy vs. Drilled Shaft Side Shear Correlation



- An independent correlation will be developed between MWD specific energy, and the side shear recorded from load tested shafts at three independent sites
- Each new correlation will be compared to previously developed correlations
- All MWD correlations will be evaluated locally and regionally to determine if site specific conditions exist
- The data analysis tool may be updated based on the findings at the site

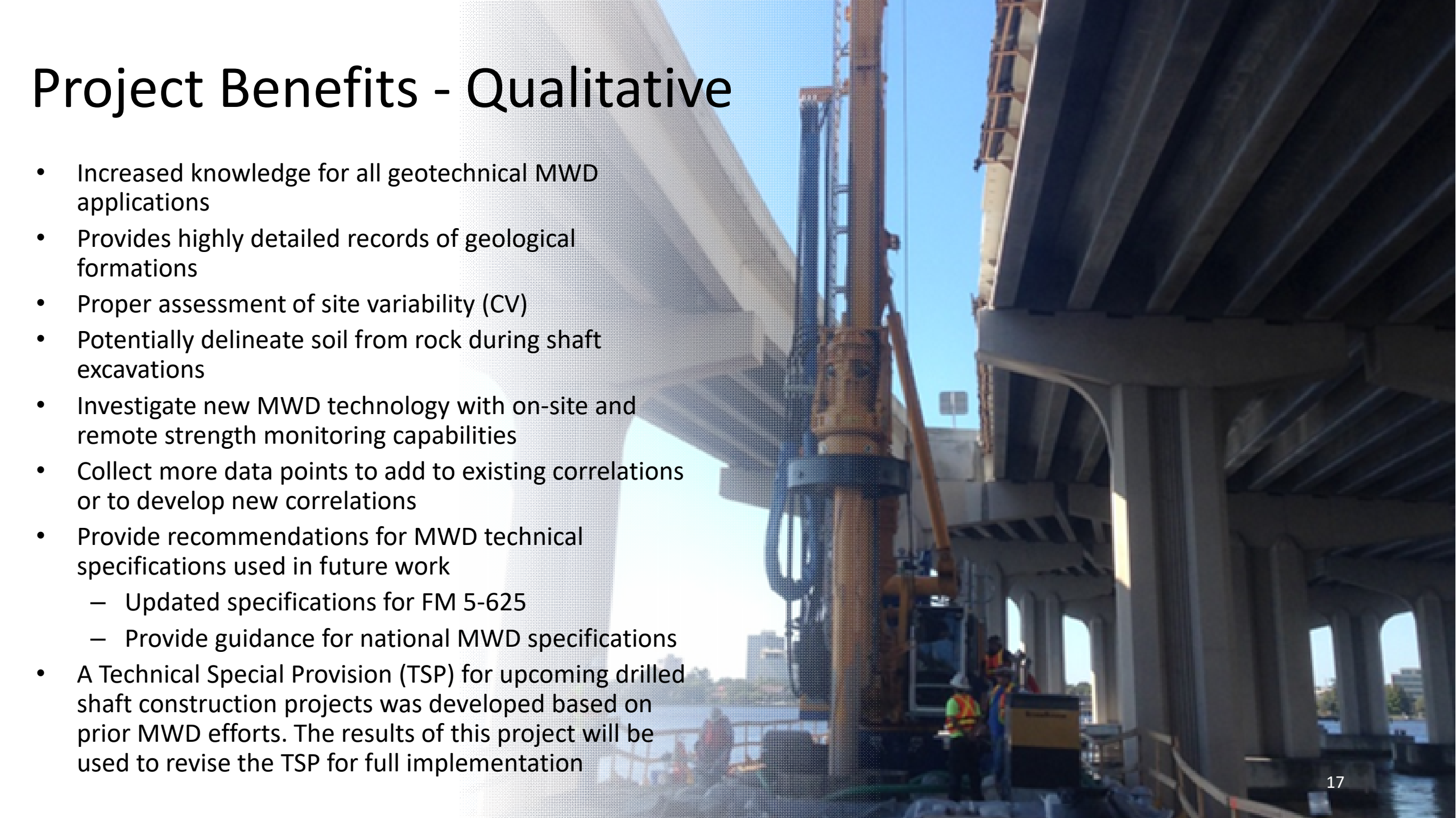
Task 4 – MWD Correlation Validation for Drilled Shaft QA/QC

- MWD methods and correlations developed in Tasks 1 and 3 will be evaluated by analyzing the monitored production shafts at each of the sites selected
  - Use specific energy and the empirical correlations developed from the load tests to compare with any available SPT data and/or rock core specimens tested in the laboratory
- MWD estimated shaft capacities will be compared to the factored design loads for each of the shafts for QA/QC
  - Contingent upon correlation development for each site
- Each fully mobilized load test in with MWD in the footprint will be modeled in MultiPier to compare the modeled behavior based on MWD data and the actual load test behavior
- The data analysis tool will then be updated based on any new findings and finalized for the research effort



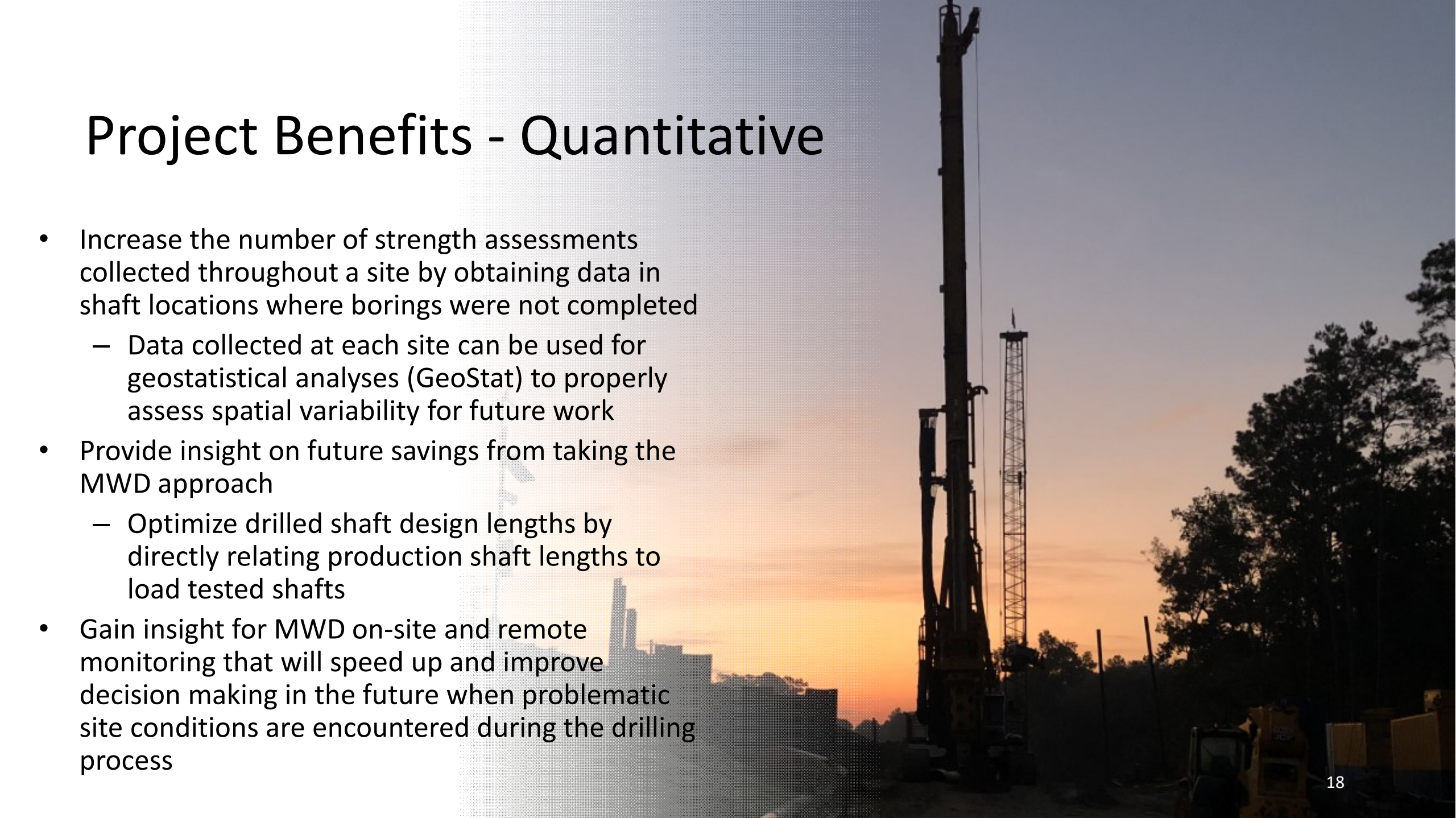
Project Benefits - Qualitative

- Increased knowledge for all geotechnical MWD applications
- Provides highly detailed records of geological formations
- Proper assessment of site variability (CV)
- Potentially delineate soil from rock during shaft excavations
- Investigate new MWD technology with on-site and remote strength monitoring capabilities
- Collect more data points to add to existing correlations or to develop new correlations
- Provide recommendations for MWD technical specifications used in future work
  - Updated specifications for FM 5-625
  - Provide guidance for national MWD specifications
- A Technical Special Provision (TSP) for upcoming drilled shaft construction projects was developed based on prior MWD efforts. The results of this project will be used to revise the TSP for full implementation



Project Benefits - Quantitative

- Increase the number of strength assessments collected throughout a site by obtaining data in shaft locations where borings were not completed
  - Data collected at each site can be used for geostatistical analyses (GeoStat) to properly assess spatial variability for future work
- Provide insight on future savings from taking the MWD approach
  - Optimize drilled shaft design lengths by directly relating production shaft lengths to load tested shafts
- Gain insight for MWD on-site and remote monitoring that will speed up and improve decision making in the future when problematic site conditions are encountered during the drilling process



Project Timeline

Deliverable # / Description of Deliverable as provided in the scope (included associated task #)	Anticipated Date of Deliverable Submittal (month/year)	TO BE COMPLETED BY RESEARCH CENTER (performance monitoring)
Kick-off Teleconference	(07/2022)	
Deliverable (1): Establish Drilled Shaft MWD Data Reduction Criteria and Procedures. (Task 1)	(12/2022)	
Deliverable (2): On-site and Remote Monitoring Implementation Feasibility Study. (Task 2)	(06/2023)	
Deliverable (3): MWD Specific Energy vs. Drilled Shaft Side Shear Correlation. (Task 3)	(12/2023)	
Deliverable (4): MWD Correlation Validation for Drilled Shaft QA/QC. (Task 4)	(02/2024)	
Deliverable (5a): Draft Final Report. (Task 5)	(03/2024)	
Deliverable (5b): Closeout Teleconference. (Task 5)	(05/2024)	
Deliverable (6): Final Report. (Task 6)	(06/2024)	

Questions?

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