Implementation of Geo-Statistical Deep Foundation Software

FDOT GRIP - Segment 1 - No. 10 - August 11, 2022

FDOT Project	BDV31 977-143
Project Manager	Rodrigo Herrera, PE
Institution	University of Florida
PI	Michael Davidson, PhD, PE
Co-PI	Michael Rodgers, PhD, PE
Co-PI	Gary Consolazio, PhD

Bridge Software Institute

Outline

- Introduction and background
- Project objective
- Project tasks
- Recent progress
- Summary

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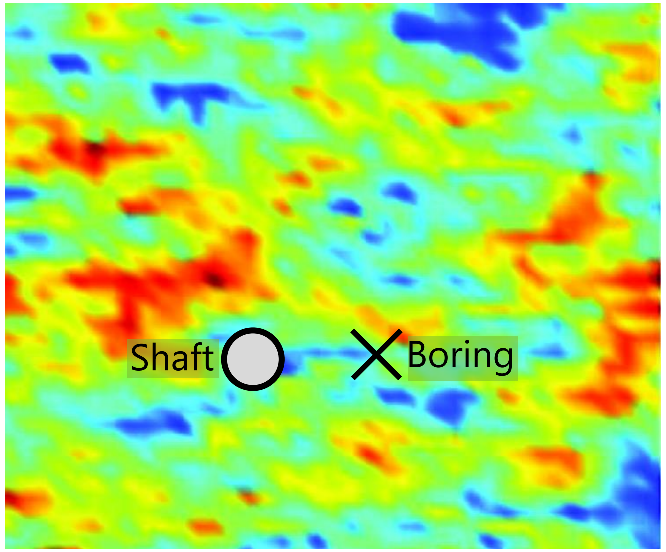
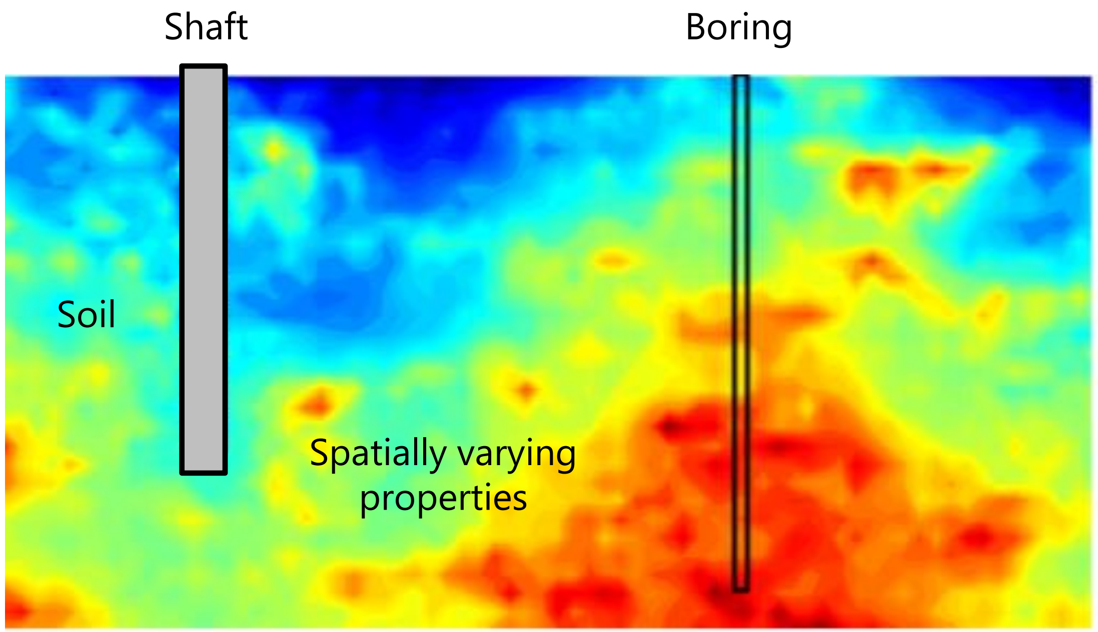
Introduction

- Spatial variability
  - Horizontal
  - Vertical



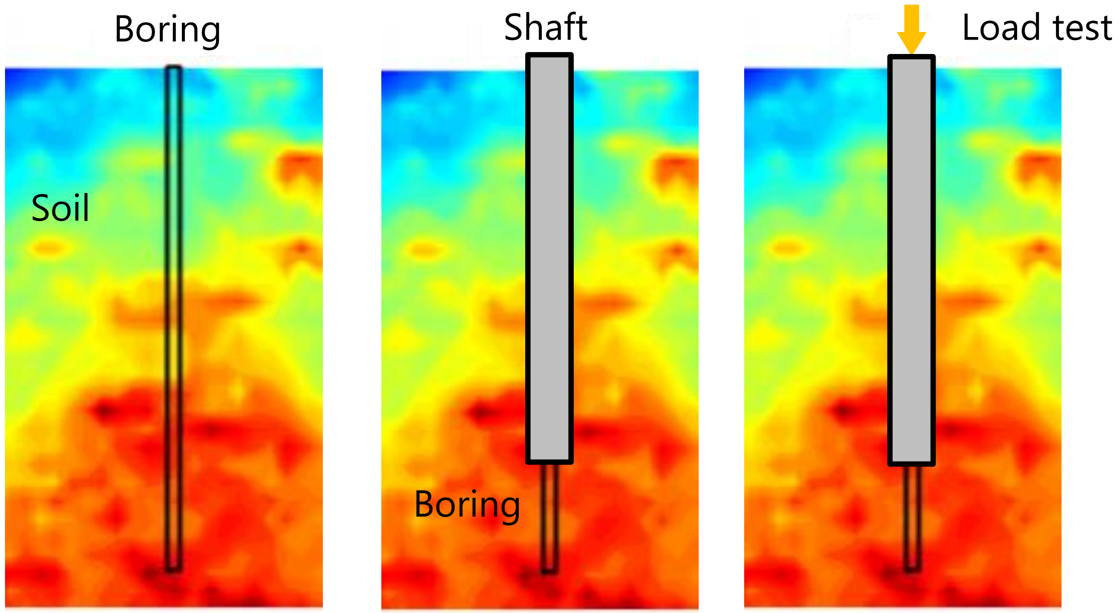
Plan view, illustrative
(contour image from Zhu and Zang 2013)



Elevation view, illustrative
(contour image from McVay et al. 2012)

Introduction

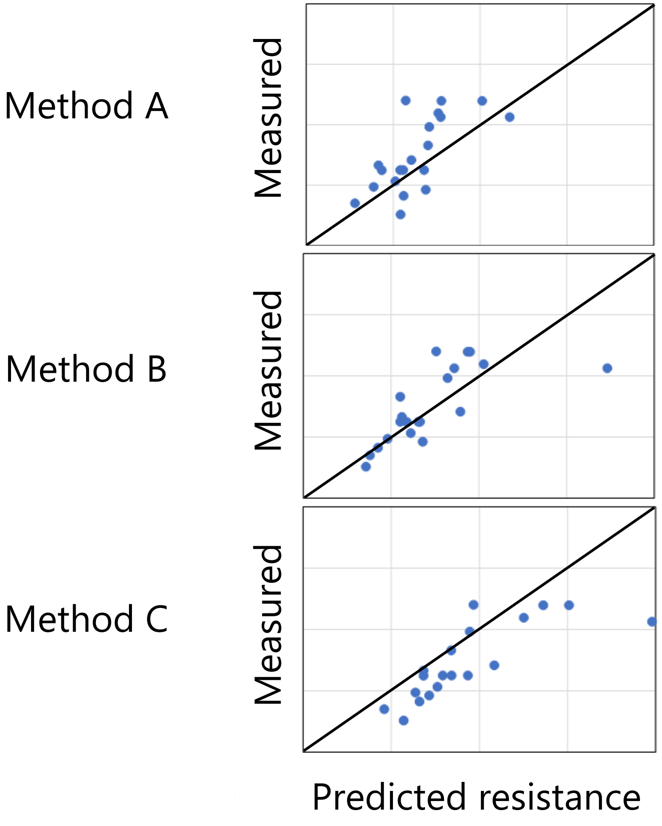
- Method error
  - Due to underlying assumptions in empirical methods
  - Correlation of measurement to unit resistance

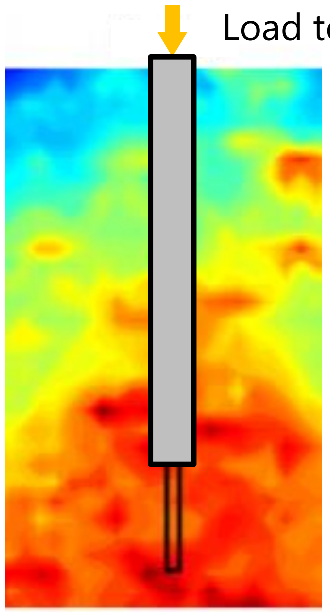


Example: boring in footprint of shaft

Introduction

- Method error
  - Increases uncertainty in computed capacities

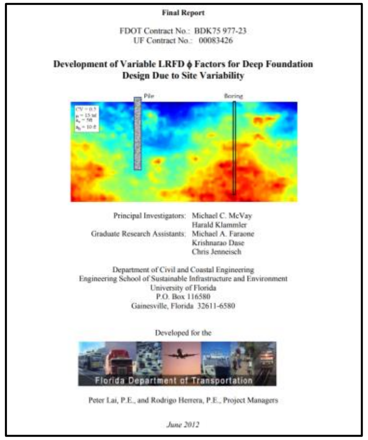




Example: boring in footprint of shaft

Background

- FDOT BDK 977-23 and FDOT BDV31 977-108
  - Formulated geostatistical methodologies
  - Compiled method error data
  - Developed prototype and then design tools


Final Report

FDOT Contract No.: BDK75 977-23
UF Contract No.: 00083426

Development of Variable LRFD ϕ Factors for Deep Foundation Design Due to Site Variability

Principal Investigators: Michael C. McVay, Harald Klammler
Graduate Research Assistants: Michael A. Faraone, Krishnarao Dase, Chris Jenneisch

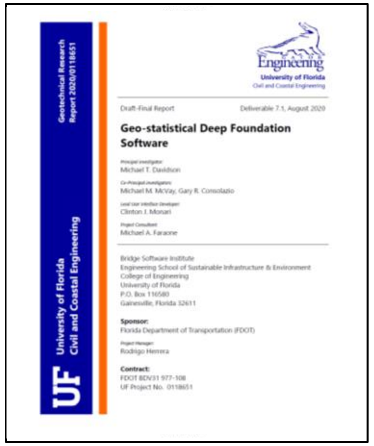
Department of Civil and Coastal Engineering
Engineering School of Sustainable Infrastructure and Environment
University of Florida
P.O. Box 116580
Gainesville, Florida 32611-6580

Developed for the
Florida Department of Transportation

Peter Lai, P.E., and Rodrigo Herrera, P.E., Project Managers

June 2012

FDOT BDK75 977-23 final report


Geotechnical Research Report 2020/0118651

University of Florida Civil and Coastal Engineering

UF

Engineering
University of Florida
Civil and Coastal Engineering

Draft-Final Report Deliverable 7.1, August 2020

Geo-statistical Deep Foundation Software

Michael T. Davidson
Michael M. McVay, Gary R. Consolazio
Clinton J. Monari
Michael A. Faraone

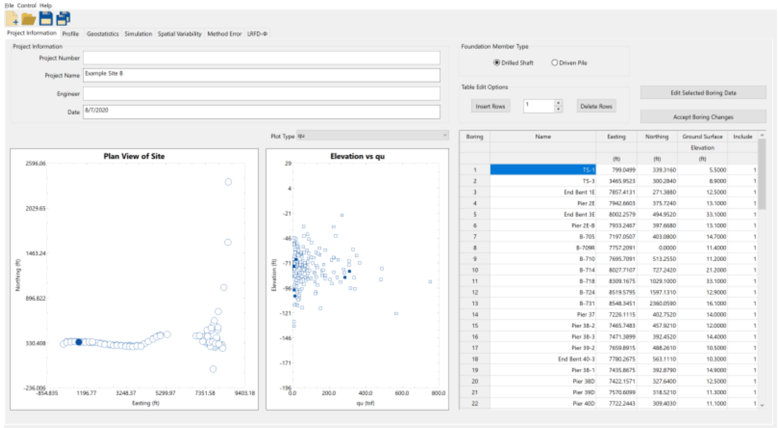
Bridge Software Institute
Engineering School of Sustainable Infrastructure & Environment
College of Engineering
University of Florida
P.O. Box 116580
Gainesville, Florida 32611

Sponsor:
Florida Department of Transportation (FDOT)

Rodrigo Herrera

Contract:
FDOT BDV31 977-108
UF Project No. 0118651

FDOT BDV31 977-108 final report



GeoStat design tool

Outline

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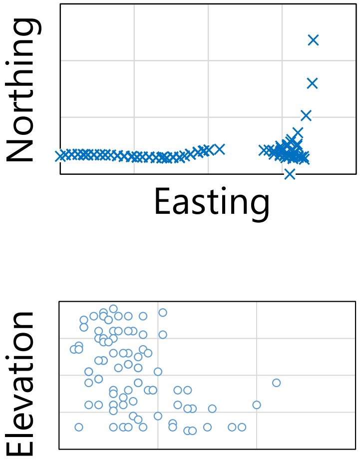
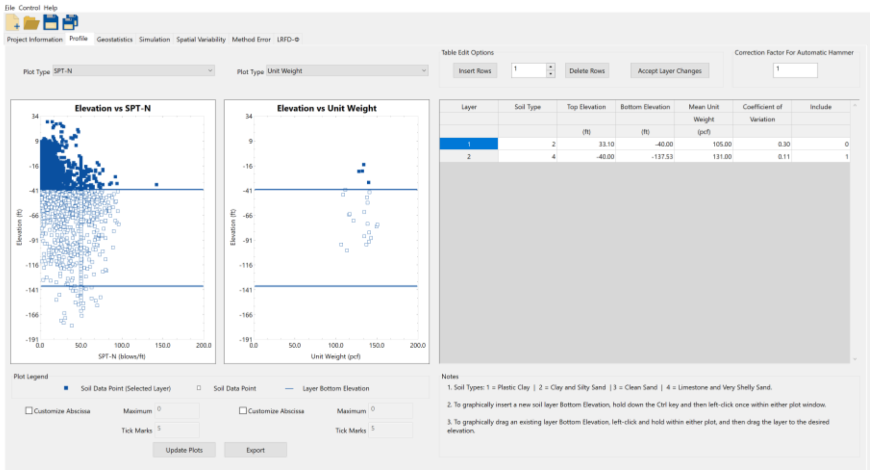
Objective

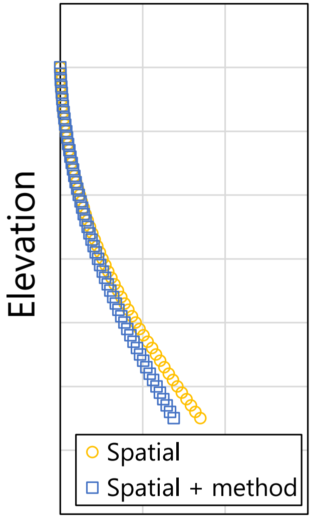
- Implement updates to geostatistical design tool
  - Leverage previous FDOT research
  - Compute axial design capacities of piles and shafts
  - Reflect spatial variability and uncertainty



Site measurements within layer



Illustrative layer definitions in GeoStat



Computed resistance

Objective

- Quantitative benefits:
  - How much variability is present in computed pile/shaft axial capacity?
  - How much uncertainty is introduced by empirical method?
  - Are geological zones present?
- Qualitative benefits:
  - Within a zone/site, what are representative layer definitions?
  - Do additional site data need to be gathered?

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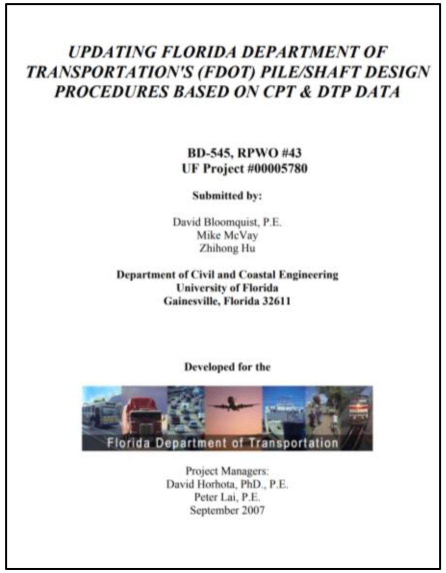
Project tasks

- Task 1: Incorporate analysis of CPT data
  - Read-write of key variables
  - Generation of variograms
  - Population of analysis files for simulation
  - Identify method error regressions
  - Software manual documentation
  - Deliverable: report



UPDATING FLORIDA DEPARTMENT OF TRANSPORTATION'S (FDOT) PILE/SHAFT DESIGN PROCEDURES BASED ON CPT & DTP DATA

BD-545, RPWO #43
UF Project #00005780

Submitted by:

David Bloomquist, P.E.
Mike McVay
Zhihong Hu

Department of Civil and Coastal Engineering
University of Florida
Gainesville, Florida 32611

Developed for the

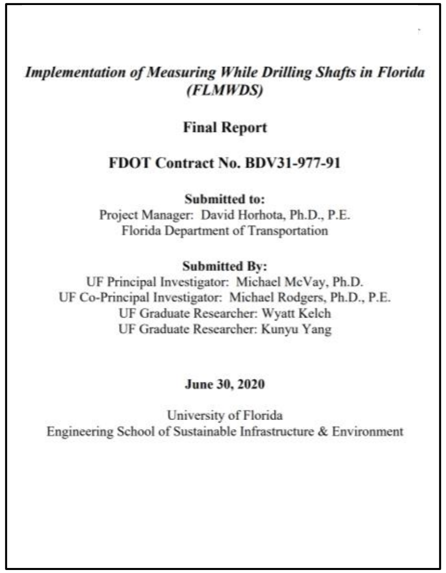
Florida Department of Transportation

Project Managers:
David Horhota, PhD., P.E.
Peter Lai, P.E.
September 2007

FDOT BD-545, RPWO #43 final report

Project tasks

- Task 2: Incorporate analysis of results from Measuring While Drilling (MWD)
  - Read-write of key variables
  - Generation of variograms
  - Population of analysis files for simulation
  - Identify method error regressions
  - Software manual documentation
  - Deliverable: report



Implementation of Measuring While Drilling Shafts in Florida (FLMWDS)

Final Report

FDOT Contract No. BDV31-977-91

Submitted to:
Project Manager: David Horhota, Ph.D., P.E.
Florida Department of Transportation

Submitted By:
UF Principal Investigator: Michael McVay, Ph.D.
UF Co-Principal Investigator: Michael Rodgers, Ph.D., P.E.
UF Graduate Researcher: Wyatt Kelch
UF Graduate Researcher: Kunyu Yang

June 30, 2020

University of Florida
Engineering School of Sustainable Infrastructure & Environment

FDOT BDV31-977-31 final report

Project tasks

- Task 3: Conduct quality assurance (QA) testing
  - Develop test input sets
    - CPT
    - MWD
  - Add data validation checks
  - Ensure integrity of data writes to simulation files
  - Deliverables
    - Report
    - Beta version of software with CPT and MWD capabilities

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Project tasks

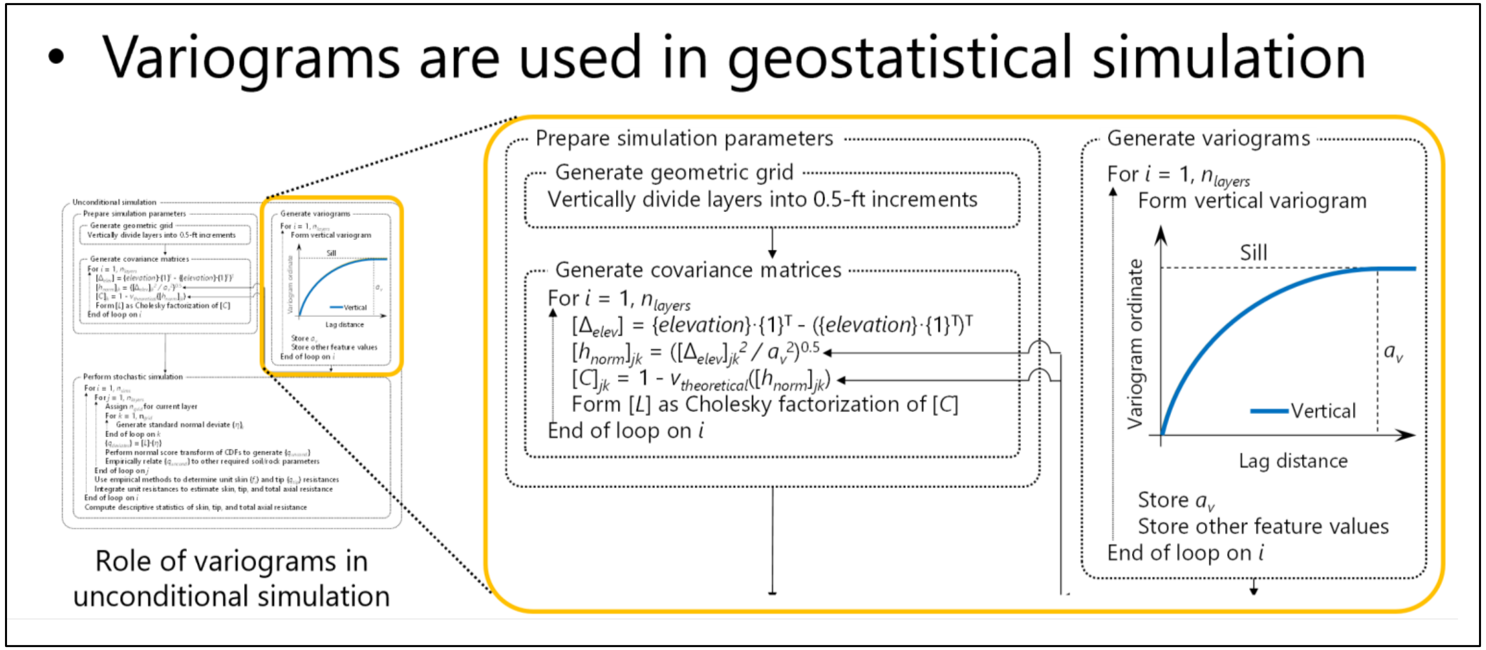
- Task 4: Investigate methodology for effective radius
  - Assess GeoStat capabilities to aid engineers in producing estimates of zonal radii
    - Focus on effective radius of test shaft data
    - Applicability of LRFD resistance factors
  - If identified as feasible:
    - Obtain site data from Project Manager
    - Build up illustration case
    - Add feature to visualize radius on plan-view plot within program
  - Document if not feasible

Project tasks

- Task 5: Technology transfer
  - Leverage sample projects in FDOT BDV31-97-108
  - Web-based
  - Delivered to FDOT district engineers
  - Two sessions
    - Theoretical basis and driven pile sample project (2 hrs)
    - Drilled shaft sample project and Q&A (2 hrs)

Project tasks

- Deliverable 5: Technology transfer materials
  - Zip-file package
    - Slides
    - Models



Illustrative technology transfer content for variogram generation

Project tasks

- Task 6: Draft final and closeout teleconference
  - Deliverable 6.1: draft final report
  - Deliverable 6.2: Closeout teleconference
- Task 7: Final report
  - Deliverable 7: Submission of final report

Outline

- Introduction and background
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Working timeline

- Total duration: 18 months
  - Task 1 (Deliverable 1: Nov. 2021) **Deliverable Approved**
  - Task 2 (Deliverable 2: Mar. 2022) **Deliverable Approved**
  - Task 3 (Deliverable 3.1: Jun. 2022) **Deliverable Approved**
  - Task 3 (Deliverable 3.2: Jun. 2022) **Deliverable Submitted**
  - Task 4 (Deliverable 4: Aug. 2022) **In progress**
  - Task 5 (Deliverable 5: Sept. 2022)
  - Task 6 (Deliverable 6.1: Oct. 2022)
  - Task 6 (Deliverable 6.2: Dec. 2022)
  - Task 7 (Deliverable 7: Jan. 2023)

Recent progress

- Task 1: Incorporate analysis of CPT data
  - Key parameters
    - Tip resistance
    - Sleeve friction
    - Friction ratio
  - UF method, Schmertmann, LCPC
  - Method error
    - FDOT BD-545, RPWO #43 final report, Tables in Ch. 4
    - Approach from Faraone et al. (2021)


UPDATING FLORIDA DEPARTMENT OF TRANSPORTATION'S (FDOT) PILE/SHAFT DESIGN PROCEDURES BASED ON CPT & DTP DATA

BD-545, RPWO #43
UF Project #00005780

Submitted by:

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Developed for the

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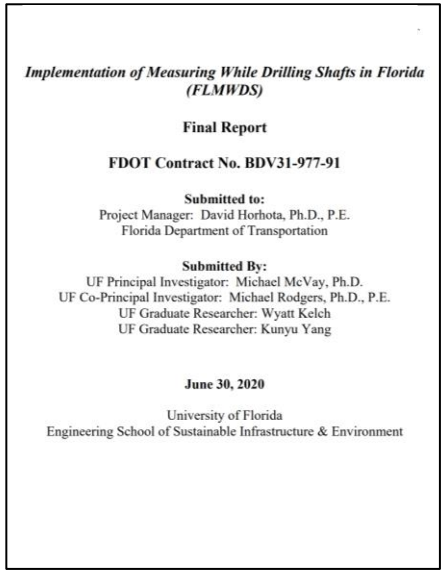
Project Managers:
David Horhota, PhD., P.E.
Peter Lai, P.E.
September 2007

FDOT BD-545, RPWO #43 final report

Recent progress

- Task 2: Incorporate analysis of MWD data
  - Drilled shafts in limestone
  - Key parameters
    - Specific energy, *e*
    - MWD estimates for rock properties such as q_u
      - McVay and Rodgers (2020)
      - Rodgers et al. (2018)
  - Method error
    - Strong correlation to side shear (McVay and Rodgers 2020)
    - Site-specific



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June 30, 2020

University of Florida
Engineering School of Sustainable Infrastructure & Environment

FDOT BDV31-977-31 final report

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Recent progress: geostatistical analysis (MWD)

Preparatory steps for stochastic simulation using MWD data

Given: profiles and location data of specific energy; candidate drilled shaft properties; range of shaft embedment lengths; presence of limestone layer(s)

Select empirical calculation method

MWD (Rodgers et al. 2018)

Define soil/rock layers

Inspect profiles of MWD Parameters

Measured values of specific energy and MWD estimates of rock parameters

Assign layer properties

Decide upon number of layers
For each layer:
- Assign top and bottom elevations
- Assign layer type

End of loop on layers

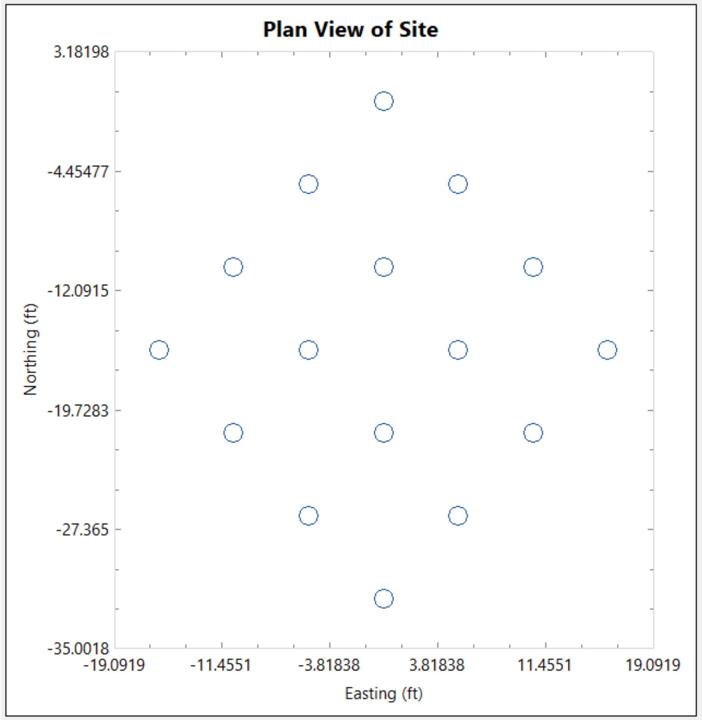
Generate variograms

For each limestone layer:
- Use guidance in Chs. 2, 4, and 5 of the GeoStat Technical Manual to form variograms based on available pairs of (calculated) unconfined compressive strength

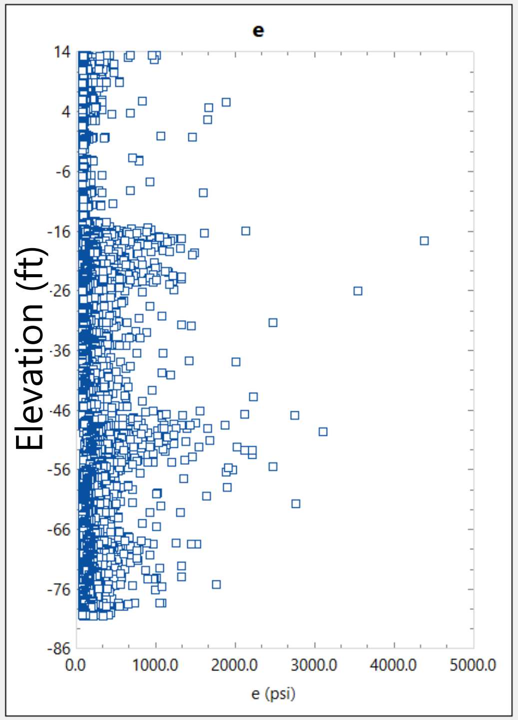
End of loop on layers

Formation of layer variograms using MWD site data

Illustrative model file of MWD site data:

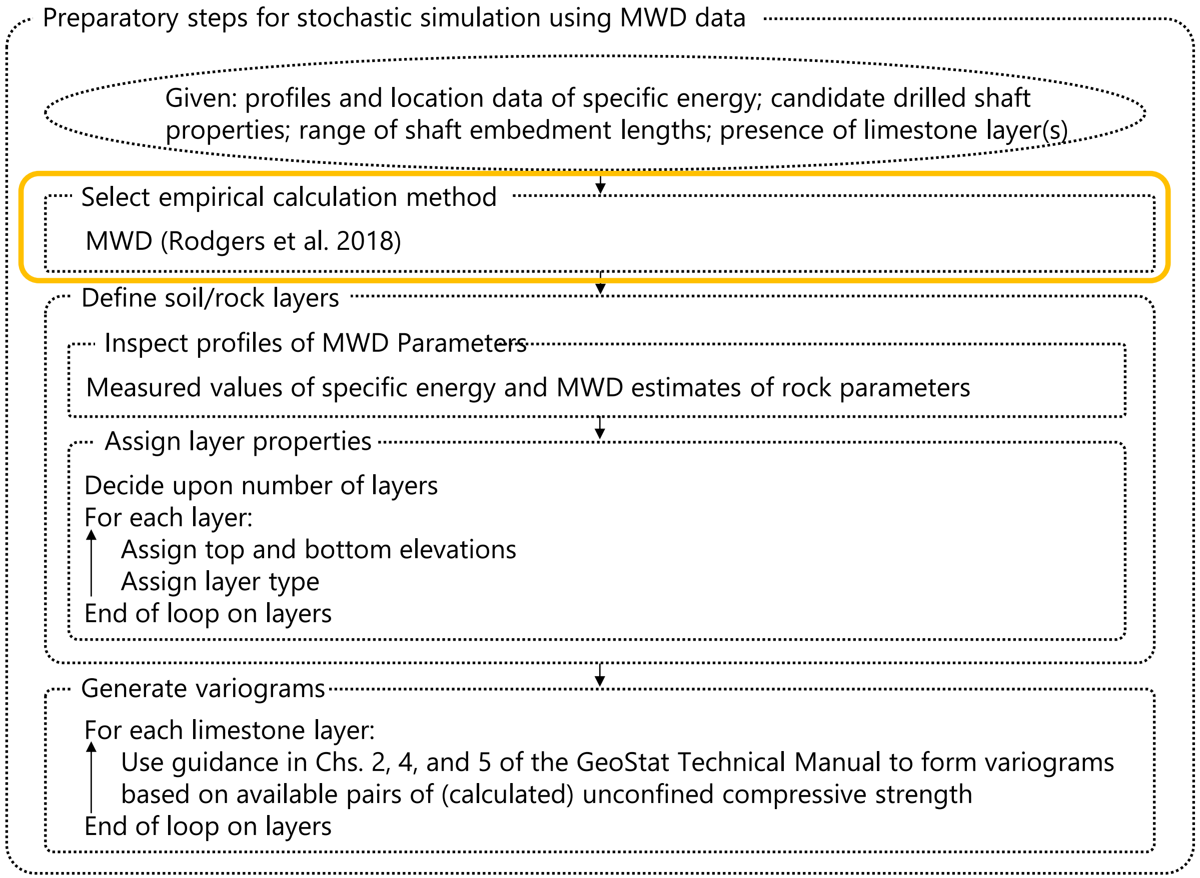


Plan view of MWD borings



Specific energy, e (psi)

Recent progress: geostatistical analysis (MWD)



Formation of layer variograms using MWD site data

- For Florida limestone (Rodgers et al. 2018):

$$e = 0.0066 \cdot {q_u}^2 + 13.68 \cdot q_u$$

- Invert to produce MWD estimate, q_{u_MWD}:

$$q_{u\_MWD} = \frac{-13.7 + \sqrt{13.7^2 - 4 \cdot 0.0066 \cdot (-e)}}{2 \cdot 0.0066}$$

- MWD estimate, q_{t_MWD}, (McVay and Rodgers 2020):

$$q_{t\_MWD} = 0.436 \cdot {q_{u\_MWD}}^{0.825}$$

Note: all units in psi

Recent progress: geostatistical analysis (MWD)

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End of loop on layers

Formation of layer variograms using MWD site data

Simulate REC_{MWD} values

Prepare length intervals

Given an elevation profile of measured values of e
From top to bottom, divide profile into n_{int} intervals
  Assign 5-ft lengths to intervals 1…n_{int}-1
  Assign remaining length (≤5 ft) to interval n_{int}

Estimate REC_{MWD} value within each interval

For i = 1, n_{int}
  Determine n_e: number of e values within interval
  Initialize n_{accept} to zero
  For j = 1, n_e
    If $e_j \geq e_{threshold}$
      $n_{accept} = n_{accept} + 1$
  End of loop on j
  $REC_{MWD} = n_{accept}/n_e$
End of loop on i

MWD estimate of REC_{MWD}

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Recent progress: geostatistical analysis (MWD)

Preparatory steps for stochastic simulation using MWD data

Given: profiles and location data of specific energy; candidate drilled shaft properties; range of shaft embedment lengths; presence of limestone layer(s)

Select empirical calculation method

MWD (Rodgers et al. 2018)

Define soil/rock layers

Inspect profiles of MWD Parameters

Measured values of specific energy and MWD estimates of rock parameters

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End of loop on layers

Generate variograms

For each limestone layer:
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End of loop on layers

Formation of layer variograms using MWD site data

Simulate RQD_{MWD} values

Prepare length intervals

Given an elevation profile of measured values of e
From top to bottom, divide profile into n_{int} intervals
  Assign 5-ft lengths to intervals 1…n_{int}-1
  Assign remaining length (≤5 ft) to interval n_{int}

Estimate RQD_{MWD} value within each interval

For i = 1, n_{int}
  Determine n_e: number of e values within interval
  Initialize L_{int} to length of i^{th} interval
  Initialize L_{sub} and L_{RQD_MWD} to zero
  For j = 1, n_e
    If $e_j \geq e_{threshold}$
      Mark j^{th} entry as above threshold
  End of loop on j
  For j = 2, n_e
    If entry j was marked as above threshold
      $L_{sub} = L_{sub} + z_j - z_{j-1}$
    Else
      If $L_{sub} \geq L_{threshold}$
        $L_{RQD\_MWD} = L_{RQD\_MWD} + L_{sub}$
      L_{sub} = 0 ft
  End of loop on j
  $RQD_{MWD} = L_{RQD\_MWD}/L_{int}$
End of loop on i

MWD estimate of RQD_{MWD}

Recent progress: geostatistical analysis (MWD)

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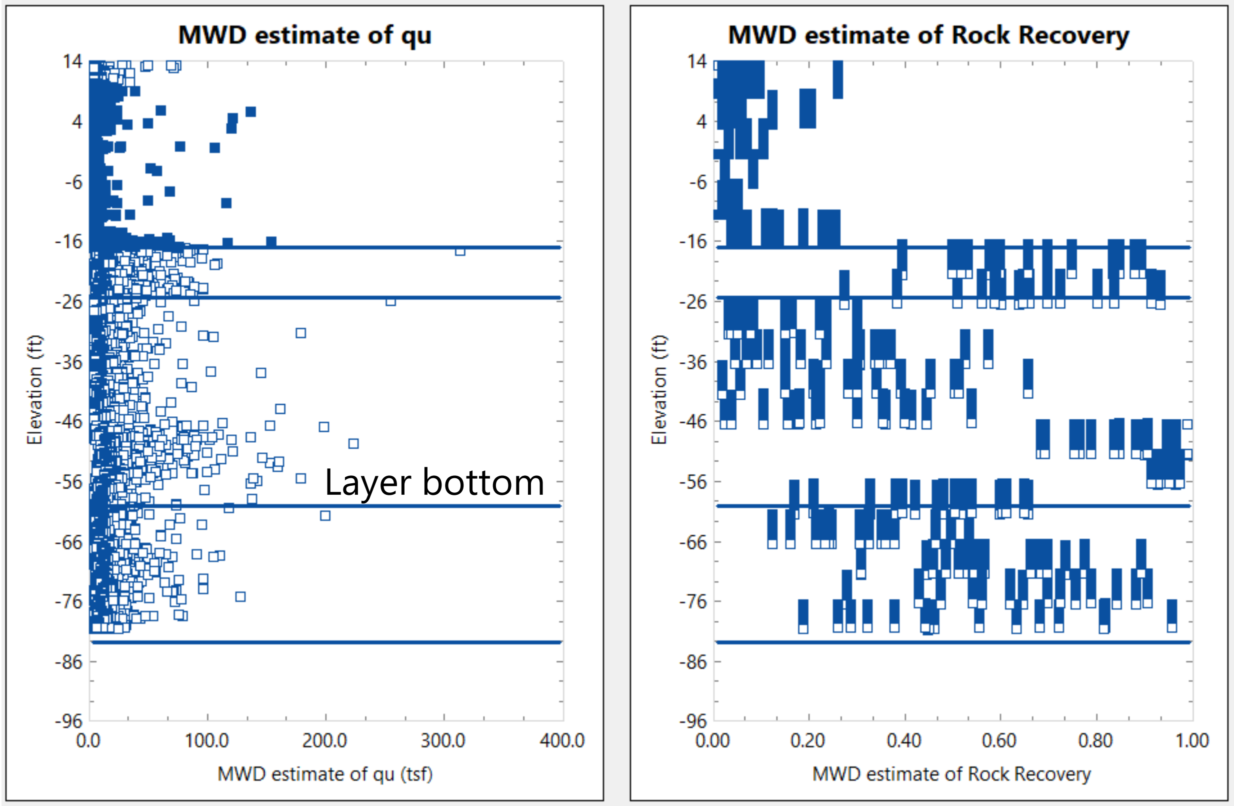
Formation of layer variograms using MWD site data



Illustrative layer definitions

Recent progress: geostatistical analysis (MWD)

Preparatory steps for stochastic simulation using MWD data

Given: profiles and location data of specific energy; candidate drilled shaft properties; range of shaft embedment lengths; presence of limestone layer(s)

↓

Select empirical calculation method

MWD (Rodgers et al. 2018)

↓

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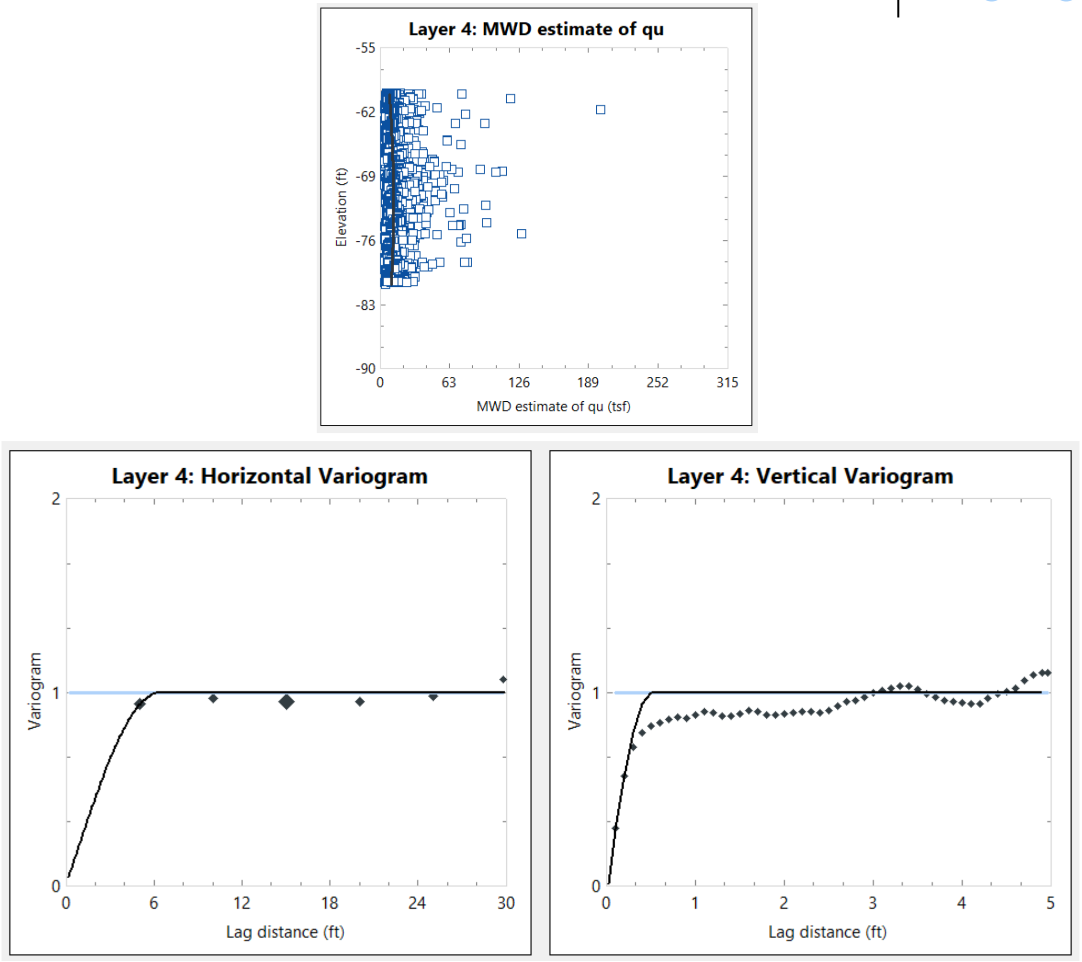
Formation of layer variograms using MWD site data



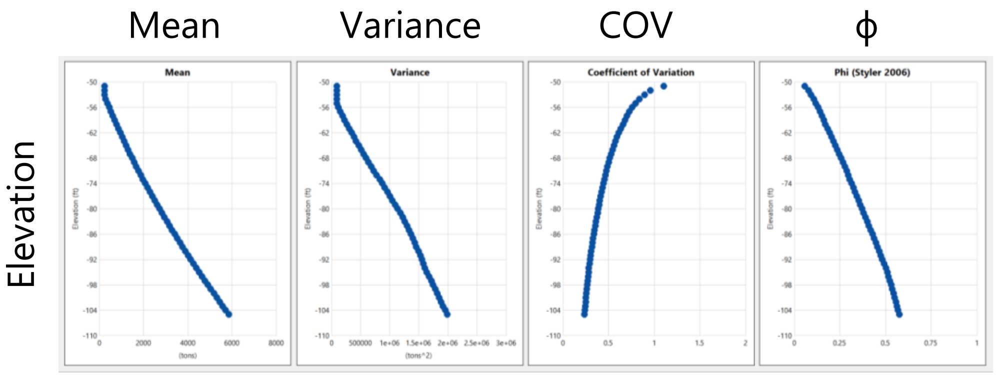
Illustrative variograms formed using q_{u_MWD}

Recent progress: geostatistical analysis (MWD)

- Stochastic simulation using MWD site data
  - Leverage geostatistical approaches for drilled shafts in limestone
    - FDOT BDK 977-23
    - FDOT BDV31 977-108
  - Simulate numerous profiles of limestone parameters, including:
    - q_u
    - q_t
    - *recovery*

Recent progress: geostatistical analysis (MWD)

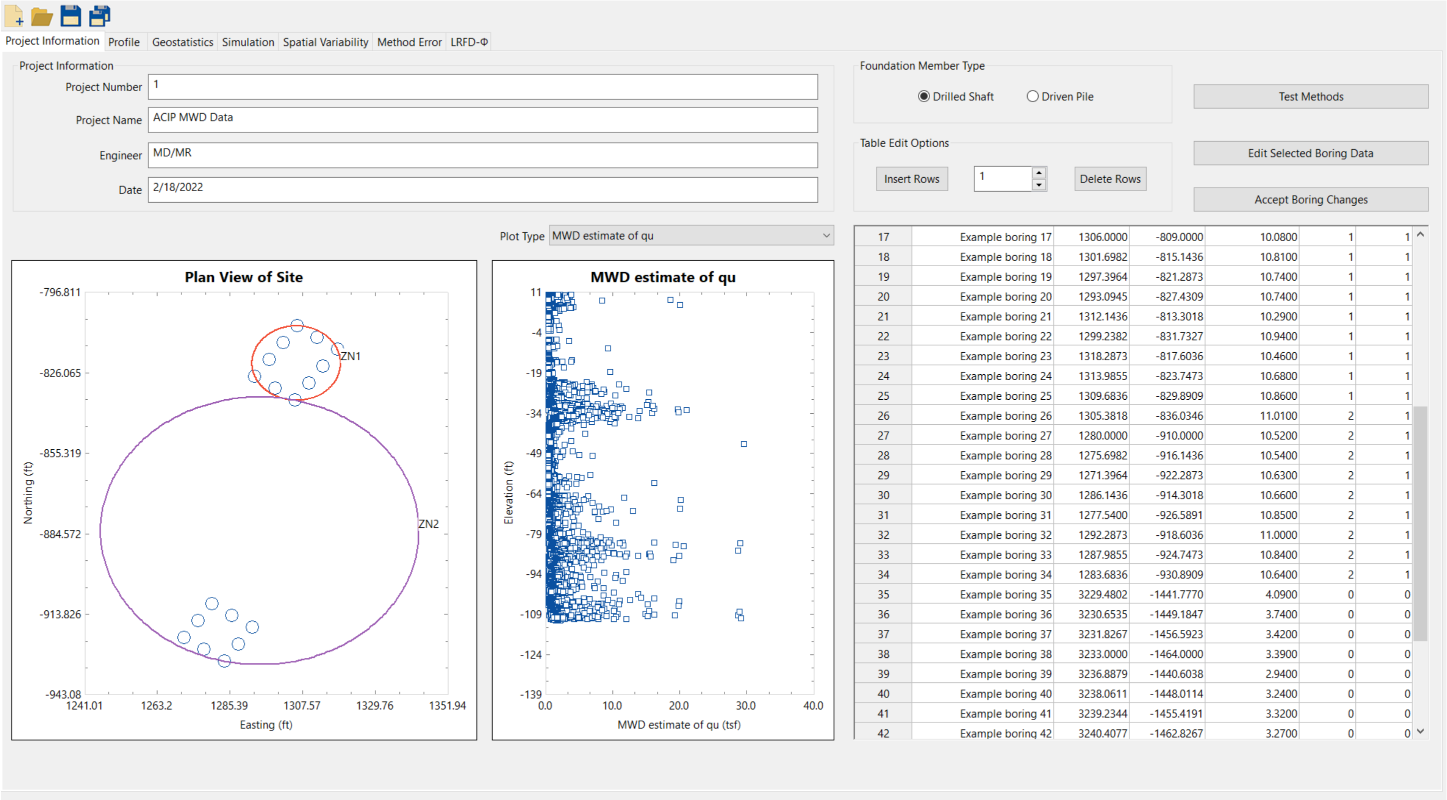
- Stochastic simulation using MWD site data (cont'd):
  - Calculate unit side friction (f_s) using McVay et al. (1992)
    - $f_s = 0.5 \cdot \sqrt{q_u \cdot q_t} \cdot recovery$
  - Integrate over candidate lengths of embedment for each profile
    - Produces collection of axial resistance profiles
  - Calculate resistance and variability
    - Mean
    - Variance
    - COV
    - Resistance factor (ϕ)
      - First-order second-moment (FOSM), Styler (2006)
      - First order reliability method (FORM), NCHRP 507



Profiles of axial resistance data

Ongoing progress

- Task 4: Zonal radii
  - Visualization



Visualization of geological zones (shown for illustration only)

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Summary

- Benefits of using geostatistical design tool
  - Gauge sufficiency of available geotechnical site investigation data
  - More representative layer definitions
  - Prevent mixing data from different geological zones in axial resistance calculations
  - Compute axial resistance and associated variability/uncertainty
  - Calculate location-specific resistance factors (use must be approved by Owner)
- New methodologies for geostatistical analysis in development
  - CPT
  - MWD
  - Assess ability to estimate zonal radius
    - Feature for zone assignment and visualization
- Technology transfer
  - Promotes use by FDOT engineers

Thank you

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Engineering School of Sustainable Infrastructure & Environment