Development and Implementation of the Vertical Insitu Permeameter

GMEC Conference

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State Materials Office

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Introduction

• Measuring hydraulic conductivity in soil can be challenging
• Grain size, grain orientation, density, degree of saturation, and soil type all affect hydraulic conductivity
• Soil disturbance will alter results
• Many methods available to measure hydraulic conductivity
  – Includes both laboratory and field methods
Introduction

• Laboratory methods – concerns with sample disturbance during extraction and transport

• Field methods typically have less disturbance – offers better insight of insitu conditions

• Field testing is often preferred
  – Traditional field testing includes cased and uncased borehole methods
  – Disturbance is still a concern during drilling that can lead to variability of results

• Traditional field testing can be expensive and time consuming
  – Opportunity for efficiencies
Drive Point Probes

- Small-diameter probes with tapered conical tips similar to a CPT probe
- Water is injected horizontally into the soil through injection screens
- Designed to be advanced into the soil:
  - hydraulic rams supplemented with vehicle weight
  - high-frequency percussion hammers
- Advantages compared to traditional borehole methods:
  - Simplified testing procedure
  - Faster setup and testing times
  - Less soil disturbance
  - More information for permeability variations (k vs depth)
Problems with Drive Point Probes

Disturbances caused alongside the probe as a result of channeling, smearing, or siltation:

• Channeling - commonly results from injecting water during probe advancement
• Smearing - clay layers encountered during advancement and the highly-plastic soil cakes the injection screens
• Siltation - high fines soils with lower plasticity in a liquid state enter the probe through the injection screens
Problems with Drive Point Probes

• Channeling can be resolved through procedural modifications

• Smearing and siltation are a result of the soil type encountered
  – Minimizing effects is dependent upon the probe’s design
  – Smearing and siltation can either partially or fully clog the injection screens
    • Leads to inaccurate measures of hydraulic conductivity since equations assume full flow conditions
Project History

VAHIP = Vertical and Horizontal Insitu Permeameter

Original (2004) VAHIP showing:
(A) vertical testing position
(B) horizontal testing position

Third generation:
“Smear Proof” VAHIP

Evolution of the VAHIP showing the 2005-2007 second generation model:
(A) horizontal flow position
(B) vertical flow position
VAHIP and VIP

VAHIP

VIP

VIP = Vertical Insitu Permeameter
Project History

• VAHIP
  – Difficult operation
  – Development of VIP

• VIP = Vertical Insitu Permeameter
  – Vertical flow of water
  – Measures only vertical permeability?
  – Improvement compared to existing insitu test methods
    • Allows testing at several depths using SPT rig
Background

- Vertical Insitu Permeameter (VIP) developed by UF researchers
  - Includes an inner rod/outer casing design with a retractable tip that produces a circular injection surface
  - Retractable tip injects flow in the vertical direction
- Does not utilize a well screen with horizontal injection
- Channeling effects are eliminated by VIP design
- Smearing and/or siltation effects are minimized by the VIP’s design
  - Probe is closed off from debris intrusion during advancement
- Vertical injection eliminates misleading results caused by the well screen positioned between two different soil layers
VIP Project Objectives

• Implement a simple field procedure for measuring hydraulic conductivity
• Develop simple and theoretically consistent equations for VIP data interpretation
• Conduct field testing at multiple sites for validation
• Perform an empirical data analysis comparing data with independent field test results
Modifications to Original VIP

Based on preliminary testing:

– Tapered friction sleeve and AWJ connection adapter
  • Keep soil from building up between connections
– Enlarged set-screw on friction sleeve
  • More resistance to torque
– Removed internal pin
  • Locking mechanism
– Added O-ring to inner rod
  • Internal resistance keeps outer casing in place during probe advancement
– Revised twist-to-open design
  • Pull to open; push to close and advance
Modified VIP Probe Design

A. Probe head
B. Inner rod
C. Main chamber
D. Connector
E. Friction reducer
F. AWJ adaptor connection
Field Permeability Test Formulas (Hvorslev, 1951)

FDOT Soils and Foundations Handbook
Figure 15

Hvorslev Case C: flush bottom in uniform soil

Falling (Variable) Head Procedure

Shape Factor (F):
Currently, $F = 3D$
Range of 2.5D to 3.1D from literature
VIP Hydraulic Conductivity Equation

\[ k_m = \frac{\pi d^2}{4F(t_f - t_i)} \ln \frac{H_i}{H_f} \]

Based on falling head test:
• \( k_m \) = mean hydraulic conductivity (cm/sec) = \((k_h k_v)^{1/2}\)
• \( d \) = diameter of the falling head tank (cm)
• \( F \) = shape factor (cm) = 3\( D \)
• \( D \) = VIP circular injection port diameter (cm) = 1.905 cm
• \( t_i \) = initial test time (sec)
• \( t_f \) = final test time (sec)
• \( H_i \) = initial water level in falling head tank (cm)
• \( H_f \) = final water level in falling head tank (cm)
Summary of VIP Testing Procedure

• Push probe to test depth
• Attach AWJ connection to the top of the drill string
• Connect the falling head vessel hose to the AWJ connection
  – Introduces water to probe
• Lift the drill string up to open the probe for testing
  – Introduces water to soil
• Perform testing
  – Saturate soil if needed
• Push the drill string down to close the probe
  – Probe is flushed during closing
• Remove the hose and AWJ connection
• Add an AWJ rod and push to the next test depth
VIP Field Testing

- Chalk lines to track vertical lift
- Drill rig slip ring holding probe in open position
- AWJ connection
- Chalk lines to track vertical lift
Measuring Flow

• During testing the time is recorded
• The falling head vessel is marked for change of head (ΔH) over a specified time increment (Δt)
  – Dry erase marker is used
• $k_m$ is calculated for each $\Delta H/\Delta t$ reading
• An average $k_m$ is then calculated from each individual $\Delta H/\Delta t$ reading
Field Testing with Modified VIP

• During the original project, performed 104 VIP tests:
  – 4 different sites
  – 72 depths ranging from 4 to 15 feet
  – Hydraulic conductivities ranging from $1 \times 10^{-5}$ to $1 \times 10^{-2}$ cm/s

• Test Locations
  1. Jacksonville
  2. Hawthorne
  3. Lady Lake
  4. Panama City
Site 1 (Jacksonville)

• Uncased constant head tests previously conducted
• Additional cased constant head tests performed by FDOT
• Fine to slightly silty fine sand (A-3)
• VIP results in good agreement with conventional methods
  – Agreement w/ soil type

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<th>Location</th>
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<th>VIP</th>
<th>Conventional</th>
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Site 2 (Hawthorne)

- Cased falling head tests previously conducted
- Additional cased constant head tests performed by FDOT
- Three main soil types encountered
  - A-2-4, A-2-6, and A-3
  - A-6 and A-7 soil also encountered
- VIP results in good agreement with conventional methods
  - Agreement w/ soil type

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<td></td>
<td>1.7</td>
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Comparison of VIP and Borehole Permeability Results

\[ y = 1.25x^{1.05} \]

\[ R^2 = 0.82 \]
VIP Probe Testing Observations

- VIP measurements were in good agreement with results obtained from various conventional methods
  - Cased constant head
  - Cased falling head
  - Uncased constant head
- VIP required less test time than conventional methods
  - Improves efficiency and more data can be collected
  - Easier to determine k vs depth
- Based on findings, Florida Test Method (FM 5-614) was developed for the equipment and procedure
- Additional testing recommended to validate the success of the preliminary trials
FM 5-614

• Standard Test Method for Determination of Mean Permeability In the Field Using the Vertical Insitu Permeameter (VIP)
  – Procedure
  – Equipment Checklist
  – Data Sheet
  – Calculations
  – Shop Drawings

• Available on State Materials Office website (FSTMs)
<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Air Pressure</th>
<th>Recording Increment</th>
<th>Total Length of Test</th>
<th>Flush Time</th>
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<tbody>
<tr>
<td>Coarse Sand</td>
<td>10 – 20 psi</td>
<td>30 sec</td>
<td>5 min</td>
<td>10 sec</td>
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<td>Fine Sand</td>
<td>15 – 25 psi</td>
<td>30 sec – 1 min</td>
<td>5 – 10 min</td>
<td>10 – 30 sec</td>
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<tr>
<td>Silty Sand</td>
<td>20 – 30 psi</td>
<td>30 sec – 1 min</td>
<td>5 – 10 min</td>
<td>10 – 30 sec</td>
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<td>Sandy Silt</td>
<td>25 – 35 psi</td>
<td>1 – 5 min</td>
<td>10 – 50 min</td>
<td>10 – 30 sec</td>
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<tr>
<td>Clay</td>
<td>30 – 50 psi</td>
<td>5 – 10 min</td>
<td>50 min</td>
<td>30 sec – 1 min</td>
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</table>

*Numbers in this table are general approximations and will vary based on actual soil type and field conditions. Proper discretion should be used when selecting values. Initial saturation can be used to estimate appropriate values for the air pressure and time increments. Water tank is rated for 90 psi.
1.) Probe Head
2.) Inner Rod
3.) Main Chamber
4.) Connector
5.) Friction Reducer
6.) AWJ Connection
Implementation Project Objectives

- The primary objective of the current project is to implement VIP testing throughout Florida
  - Validation testing
  - Introduce the test method to each FDOT district
    - On-site training provided by UF research team
- Additional locations will be tested
  - 2 test sites per district including Turnpike
- More variable soil and field conditions are expected to be encountered (statewide)
  - Provide a better understanding of the probe’s capabilities and constraints
Implementation Project Objectives

• Investigate and update VIP probe design provided in FM 5-614
  – More robust internal design for percussive driving
  – Simplify design for easier assembly and disassembly
• Fabricate 8 probes and falling head vessels
  – Distribute to each district
• Develop an instructional video
  – VIP training using updated test method
  – Refresher training since video will be available on web
Updating Probe Design for FM 5-614

• Current probe design in FM 5-614 was investigated and being updated
  – Working with machinist to ensure design accuracy and fabrication repeatability

• More robust design recommended by users from prior testing observations
  – Need for percussive advancement into denser soils
  – Allows the probe to be advanced without predrilling which requires more time and may cause soil disturbance

• Two steel prototypes have been fabricated and tested
New VIP - Prototype 1

- Similar to original probe design
  - 7 individual pieces
- More robust threading
  - Percussive advancement
- Increased wall thickness
- Increased stroke length to 2”
  - Easier to track the required lift to open the probe tip (before 1-5/8”)
- Investigated smaller diameter friction reducer
- Increased length of the connector to ¾”
  - Fit wrench for easier disassembly
- Added O-ring to seal upper chamber when testing
  - Ensure water only exits the tip
Smaller Friction Reducer

• Friction reducer creates an annular space between the soil and AWJ rods during advancement
  – Reduces friction at soil-AWJ rod interface when lifting rods to open probe for testing
  – Larger diameter ensures probe remains stationary for testing

• Will a smaller diameter friction reducer decrease resistance during direct push advancement?

• Performed push tests while monitoring force on AWJ rods
  – Two diameters investigated (2.25” and 2”)

Smaller friction reducer 2” diam.

Original VIP  VIP Prototype 1
Push Tests in Soil

SMO - 1
Dia. = 2.25”
Dia. = 2.00”

SMO - 2
Dia. = 2.25”
Dia. = 2.00”

Trenton
Dia. = 2.25”
Dia. = 2.00”
Push Tests – Encountered Rock

- At Kanapaha soft weathered limestone was encountered during advancement
- Probe survived being pushed through limestone twice (not recommended)
- Encouraging result for new robust design
- Results were not included for push test analysis
Push Test Analysis

• Obtained an average measured resistance at 3 test sites (soil only)
• Average decrease in push resistance not significant
• Increased resistance lifting the AWJ rods to open the probe for testing
• Original diameter was selected for final design
  – OD = 2.25”
Prototype 1 Observations

Advantages with Prototype 1

• Robust design allowed percussive advancement
  – Tested after probe could no longer be directly pushed
• Reduction in assembly time compared to original probe
  – Less time threading
  – No set screws (3 in original)
• Easier to ensure open position
  – 2” total lift
  – Flow introduced at 1.5” lift
• Provided higher upper permeability limit

Problems with Prototype 1

• Three exterior and two interior threaded connections
  – Lengthens assembly time
• Difficulties fabricating a concentric connector piece
  – Effects probe mechanics
• Difficulties fabricating proper internal alignment with seven pieces and five threaded connections
• External unthreading noticed during preliminary testing when AWJ rods were added
  – Lack of set screws
New VIP - Prototype 2

- **Simplified probe design**
  - 4 pieces
  - Combined Prototype 1 pieces:
    - Probe head and main chamber
    - Connector and friction reducer
    - AWJ adaptor connection and AWJ adaptor

- **One interior and one exterior threaded connection**
  - Reverse threading used on exterior connection
    - Eliminates unthreading when adding AWJ rods without using set screws

- **Includes Prototype 1 features:**
  - Robust threading
  - Increased wall thickness
  - 2” stroke length
  - Upper chamber O-ring
Prototype Comparison

Prototype 2 Advantages:

• Same robust design with only four pieces and two threaded connections
  – Compared to seven pieces and five threaded connections

• Less assembly time
  – Less than 30 seconds

• Easier to fabricate concentric probe pieces
  – Ensure proper internal alignment

• 20% reduction in fabrication cost

• External unthreading eliminated by reversed external threaded connection

• Prototype 2 selected for final design
  – Design model to be delivered to districts
Prototype 2 – Simplified Assembly

1.) Arrange parts A - D
2.) Slide C onto B

3.) Slide D into C and thread onto B (CW)
4.) Thread A onto C (CCW)
**Probe Mechanics**

**Closed Position - No Flow**

- Water enters probe
- 2 O-rings seal the bottom chamber so no water exits the probe tip in closed position.

**Open Position - Flow**

- Lift 2 inches
- O-ring seals upper chamber so water only exits through the probe tip in open position.
- Probe tip retracted
- Water exits probe
New Falling Head Vessel Design

• Each district will receive a falling head vessel to accompany the VIP probe
  – Used to measure flow
• Aluminum plates used instead of steel (original)
  – Reduced weight for onsite transport
• Greater wall thickness in falling head vessel
  – More robust design
• More robust tripod stand
• All individual pieces are removable/replaceable
  – Individual pieces can be replaced easily if damaged
Test Site 1 (Trenton)

- VIP and cased constant head (CCH) tests performed at 3 depths - 5’, 10’, 15’
- Change of soil type at 15’
  - A-3 (SP) → A-2-4 (SM)
    - < 5% at 5’ and 10’
    - 20% passing No. 200 at 15’
  - Nearby boring indicated sand w/ clay at 15’
- VIP and CCH both indicated changes in hydraulic conductivity ($k_m$) at 15’
  - $1 \times 10^{-2}$ cm/s → $1 \times 10^{-5}$ cm/s
Test Site 2 (Trenton)

- Similar soils at each depth
  - A-3 (SP) at 5’, 10’, and 15’
- Push test indicated soil density increasing with depth
  - Based on measured axial force
- VIP and CCH tests both indicated $k_m$ decreasing with increasing soil density
VIP Calibration

• After each probe is constructed, ensure the probes and accompanying equipment function properly before distribution

• Develop a standard calibration procedure
  – O-ring compression check
  – Determine permeability limits of the probe

• The previous shape factor (F) will be evaluated
  – Currently, F = 3D
  – Based on literature, ranges from 2.5D to 3.1D
O-ring Compression Check

• Three separate checks:
  – Watertight seal in lower chamber when probe is in closed position for advancement
    • Water level in falling head vessel stabilizes after testing
  – Watertight seal in upper chamber when probe is in open position for testing
    • Ensures water only exits the flow port in the tip of the probe
  – Properly opens for testing at shallow depths and in less dense soils
    • Probe needs to provide watertight seal at depths up to 30 feet while functioning properly in soil with low density
Standard Procedure to Check O-ring Compression

• Insitu tests were performed in low density (low SPT-N) soil
  – Probe opened and closed properly in soil with SPT N = WR to 3
• Developed quick O-ring compression checks:
  1) When dry, probe will remain closed/open under own weight
    – Can be opened or closed by hand with some resistance
  2) When wet, probe will open/close slowly under own weight
    – Opens and closes with minimal resistance
Permeability Limits

• Tests performed in which the probe was left to drain freely in air
  – Determines upper permeability limit
• Upper permeability was increased with new VIP design compared to original VIP design
  – $k_{\text{max}} = 1.0 \times 10^{-1} \text{ cm/s} > k_{\text{max}} = 7.5 \times 10^{-2} \text{ cm/s}$
• Lower permeability limit will be determined after all testing is complete
  – Lowest permeability recorded with new VIP design is $k_m = 9.5 \times 10^{-6} \text{ cm/s}$
    • Lowest permeability recorded with any VIP probe
Preliminary Testing Observations

• New VIP probe design provides consistent readings in similar soil types
• Readings agree with soil classification
  – VIP clearly indicates changes in soil types versus depth
• VIP compared well with cased constant head (CCH) tests performed at the same locations
  – VIP appears to provide less variable results
  – Soil disturbance from CCH predrilling could introduce more variability in results
• Probe functionality with new design has been improved compared to old design
• PTFE (Teflon or plumber’s) tape should be used on threaded connections to ensure watertight seal
  – Driller’s copper grease also used on drill rod joints
FM 5-614 Instructional Video

• An instructional video will be developed and available on the internet
• Will be developed after calibration standards have been finalized and some field testing has taken place with the new probe design and equipment
• The video will serve as a companion to the instructions provided in the updated version of FM 5-614
Project Benefits

• VIP testing increases the amount of data obtained during a standard site investigation
  – Allows more data to be collected at multiple depths
  – Reduces test times
  – More accurate results due to less disturbance

• Current project intended to implement FM 5-614
  – Validate testing procedure
  – Add calibration procedure
  – Each district will be provided with the equipment
  – Develop training materials
…and now for the advertisement…
GRIP 2019

• Where: State Materials Office, Gainesville

• When: August 15 & 16, 2019

• Videoconference feeds to several district offices throughout the state
# GRIP 2019

**Thursday, August 15**

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:45 – 9:00</td>
<td>Welcome</td>
<td>Rodrigo Herrera &amp; Dave Horhota</td>
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<tr>
<td>9:00 – 9:45</td>
<td><strong>Bearing Capacity Factors for Shallow Foundations Subject to Combined Lateral and Axial Loading</strong></td>
<td>Dr. Scott Wasman</td>
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<tr>
<td>9:45 – 10:15</td>
<td><strong>Sinkhole Detection with 3-D Full Elastic Seismic Waveform Tomography</strong></td>
<td>Dr. Khiem Tran</td>
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<tr>
<td>10:15 – 10:45</td>
<td><strong>Implementation of Down-Hole Geophysical Testing for Rock Sockets</strong></td>
<td>Dr. Dennis Hiltunen</td>
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<tr>
<td>10:45 – 11:30</td>
<td><strong>Measuring While Drilling (MWD) for Florida Site Investigations</strong></td>
<td>Drs. Mike Rodgers &amp; Michael McVay</td>
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<tr>
<td>11:30 – 12:00</td>
<td><strong>Implementation of Measuring While Drilling Shafts in Florida</strong></td>
<td>Drs. Mike Rodgers &amp; Michael McVay</td>
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<td>12:00 – 1:00</td>
<td><strong>Lunch Break</strong></td>
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<tr>
<td>1:00 – 1:45</td>
<td><strong>LRFD Factors for Tip Grouted Drilled Shafts</strong></td>
<td>Dr. Gray Mullins</td>
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<tr>
<td>1:45 – 2:15</td>
<td><strong>Design Phase Evaluations of High Pile Rebound Soils with an Emphasis on SPT Testing</strong></td>
<td>Dr. Paul Cosentino</td>
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<tr>
<td>2:15 – 2:45</td>
<td><strong>Quantifying Pile Rebound with Deflection Measuring Systems Best Suited for Florida Soils</strong></td>
<td>Dr. Paul Cosentino</td>
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<td>2:45 – 3:00</td>
<td><strong>Field Investigation of Downdrag on Concrete Piles in Sandy Soil (pending approved scope of services)</strong></td>
<td>Dr. Gray Mullins</td>
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<tr>
<td>3:00 – 3:15</td>
<td><strong>Break</strong></td>
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<tr>
<td>3:15 – 3:45</td>
<td><strong>Development of an Improved Vertical and Horizontal In-situ Permeameter (VAHIP)</strong></td>
<td>Dr. Ana Mohseni</td>
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<tr>
<td>3:45 – 4:15</td>
<td><strong>Field Implementation of the Vertical In-situ Permeameter (VIP)</strong></td>
<td>Dr. Mike Rodgers</td>
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<td>4:15 – 4:45</td>
<td><strong>Development of GS-DEEP software</strong></td>
<td>Dr. Michael Davidson</td>
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<tr>
<td>4:45 – 5:00</td>
<td><strong>Performance Testing of GRS Test Piers Constructed with Florida Aggregates – Axial Load Deformation Relationships (pending approved scope of services)</strong></td>
<td>Dr. Scott Wasman</td>
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<tr>
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<td><em>Strength Envelopes for Florida Rock and Intermediate Geomaterials</em></td>
<td>Drs. Michael McVay &amp; Xiaoyu Song</td>
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<tr>
<td>9:15 – 9:30</td>
<td><em>Field Load Testing of Florida Limestone (pending approved scope of services)</em></td>
<td>Dr. Michael McVay</td>
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<tr>
<td>9:30 – 10:00</td>
<td><em>Determining Bearing Resistance of Cantilever Sheet Piles</em></td>
<td>Drs. Xiaoyu Song &amp; Amirata Taghavi</td>
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<tr>
<td>10:00 – 10:15</td>
<td><em>In-service Assessment of Road Sinkholes with 2D Ambient Noise Tomography (pending approved scope of services)</em></td>
<td>Dr. Khiem Tran</td>
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<td><em>Prediction Model of Vibration-Induced Settlement Due to Pile Driving</em></td>
<td>Drs. Boo Nam &amp; Luis Monsalve</td>
</tr>
<tr>
<td>11:00 – 11:30</td>
<td><em>Estimating Soil Pressure against Unyielding Surfaces</em></td>
<td>Dr. Mike Rodgers</td>
</tr>
<tr>
<td>11:30 – 12:00</td>
<td><em>Comparison of SPT N-value with Alternative Field Test Methods in Determining Moduli for Settlement Predictions</em></td>
<td>Drs. Manoj Chopra &amp; Luis Monsalve</td>
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<td>12:00 – 12:30</td>
<td><em>Development of Statistical Models to Predict Compressibility of Florida’s Soils</em></td>
<td>Dr. Boo Nam</td>
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Questions?