Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

Field Implementation of the Vertical In situ Permeameter (VIP) BDV31-977-88

FDOT GRIP Meeting

Project Manager: David Horhota, Ph.D., P.E.

UF PI: Michael Rodgers, Ph.D., P.E.
UF Co-PI: Ana Mohseni, Ph.D.

August 15, 2019

POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

Topics Covered

- Introduction
- Background
- Objectives
- Calibration and preliminary testing analysis
- Project Benefits

Introduction

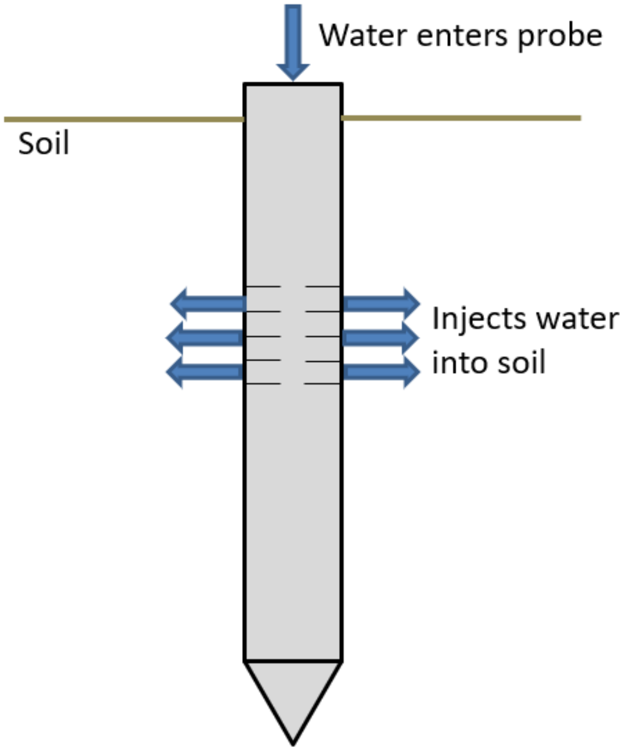
- Measuring hydraulic conductivity in soil can be challenging
- Grain size, grain orientation, density, degree of saturation, and soil type all effect hydraulic conductivity
- Soil disturbance can lead to skewed results
- Several methods have been developed to measure hydraulic conductivity
  - Includes laboratory and field methods

Introduction

- Laboratory methods are often questionable
  - Inherent sample disturbance induced during extraction and transport
- Field methods induce less disturbance
  - Provides better insight for in situ conditions
- Field testing is often preferred
  - Traditional field testing includes cased and uncased borehole methods
  - Disturbance is still induced during drilling to test depth
    - Creates more variability in hydraulic conductivity measurements
- Traditional field testing is more expensive and time consuming
  - Makes the approach less ideal

Drive Point Probes

- Small-diameter probes with tapered conical tips similar to CPT probe
- Water is injected horizontally into the soil through injection screens
- Designed to be pushed into the soil
  - hydraulic rams supplemented with vehicle weight
  - high-frequency percussion hammers
- Advantages compared to traditional borehole methods
  - Simplified testing procedures
  - Faster setup and testing times
  - Less soil disturbance
  - More detailed information for permeability variations



Problems with Drive Point Probes

- Disturbances may be created alongside the probe as a result of channeling, smearing, or siltation.
- Channeling
  - Result from injecting water during probe advancement
- Smearing
  - Fat clay layer is encountered during advancement and the highly-plastic, cohesive soil cakes the injection screen
- Siltation
  - Cohesive 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
  - Not injecting flow during advancement
- Smearing and siltation are a result of the soil type encountered and mitigating these effects is largely dependent upon the probe's design.
  - Smearing and siltation either partially or fully clog injection screens
    - Leads to inaccurate measures of hydraulic conductivity
    - Developed equations for measuring hydraulic conductivity assume a full flow condition (i.e., screens are not clogged)

Background

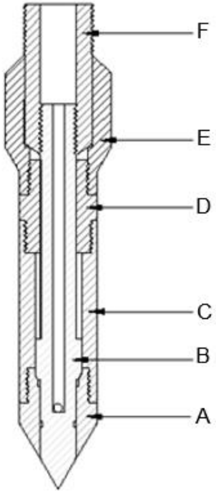
- Recently UF and FDOT developed a new permeability probe, the Vertical In situ Permeameter (VIP)
  - Includes an inner rod/outer casing design with a retractable tip that produces a circular injection surface
  - Retractable tip injects flow in the vertical direction
- Does not utilize a well screen with horizontal injection
  - Typical drive point probe flow injection
- Channeling effects are eliminated by VIP design
  - No fluid injection necessary during advancement
- Smearing and/or siltation effects are minimized by the VIP's unique 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.

Original VIP Probe Design

A. Probe head
B. Inner rod
C. Main chamber
D. Connector
E. Friction reducer
F. AWJ adaptor connection

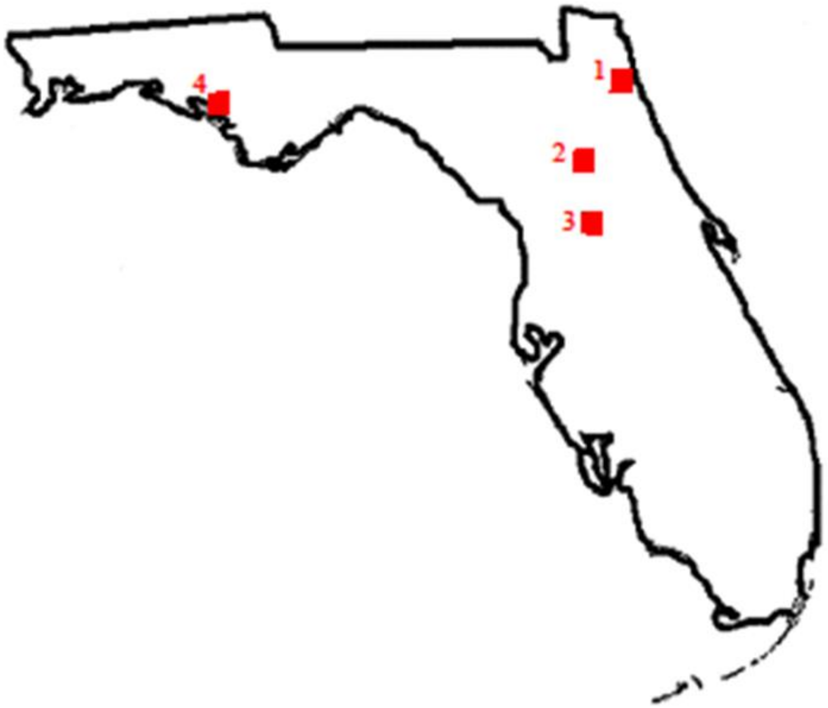
*AWJ adaptor depicted

**3 set screws not depicted



Prior Testing with Original VIP

- During the previous investigation, 104 VIP tests were performed
  - 4 different sites
  - 72 depths ranging from 4 to 15 feet
  - Hydraulic conductivities ranging from $1x10^{-5}$ to $1x10^{-2}$ cm/s
- Test Locations
  1. Jacksonville
  2. Hawthorne
  3. Lady Lake
  4. Panama City



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 requires far less test time than conventional methods
  - Greatly improves efficiency
  - More data can be collected with less effort
- Based on the success, a new Florida Method of Test was developed for the probe
  - FM 5-614
- Additional testing is recommended to validate the success of the preliminary trials

Research Primary Objectives

- The primary objective of the current research effort is to implement VIP testing throughout Florida
  - Validation testing
  - Introduce the new test method to each FDOT district
    - On-site training provided by UF research team
- 8 locations will be tested
  - 7 FDOT districts and along the turnpike
  - 2 sites per location
- Variable soil and field conditions will be encountered
  - Provide a better understanding of the probe's capabilities and constraints

Research Secondary 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 amongst the FDOT districts
- Develop an instructional video
  - VIP training purposes
  - Promote the newly developed test method

Updating Probe Design for FM 5-614

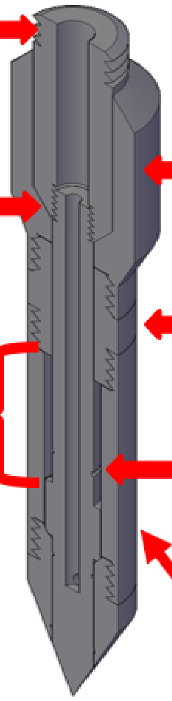
- Current probe design provided in FM 5-614 was investigated and currently being updated
  - Working alongside machine shop to ensure design accuracy and fabrication repeatability

- More robust design recommended by FDOT field specialists based on prior testing observations
  - Needed 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 were fabricated and tested based on FDOT field specialists' recommendations

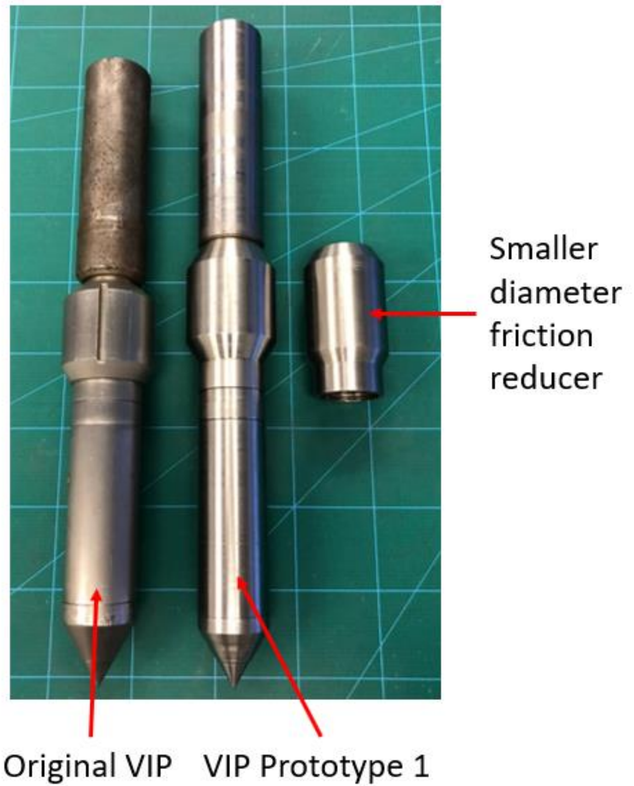
New VIP - Prototype 1

- Similar to original probe design
  - 7 individual pieces
    - AWJ adaptor not pictured
- More robust threading
  - Percussive advancement
- Increased wall thickness
- Increased stroke length to 2”
  - Easier to track the required lift to open the probe tip
- 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
  - Water only exits through the tip



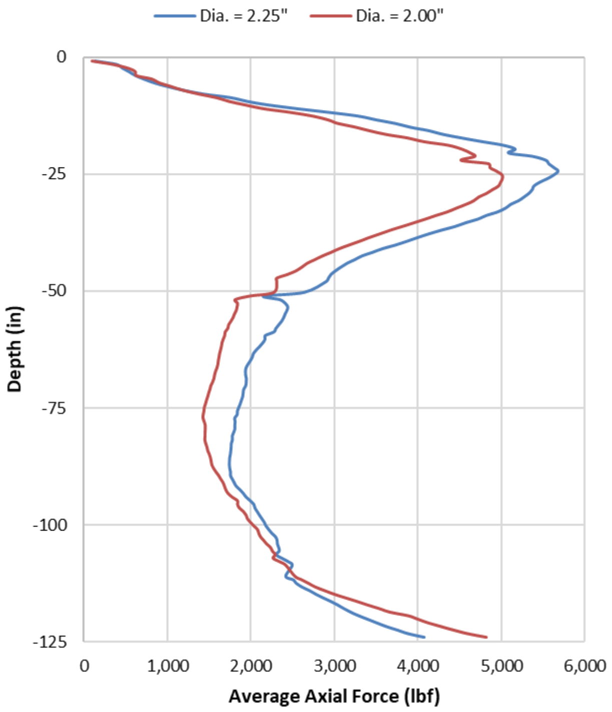
Investigated Smaller Friction Reducer

- 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 monitored push tests using an instrumented AWJ rod
  - Two diameters investigated
  - Three different locations



Push Test Analysis

- Generated the average measured resistance from locations where only soil was encountered
  - 2 locations at the SMO
  - Trenton location
- Average decrease in push resistance was not significant
  - Increased push resistance measured at various depths in all tested locations
- Increased resistance lifting the AWJ rods to open the probe for testing
  - Benefit < Cost
- Original diameter was selected for final design
  - OD = 2.25”



Prototype 1 Observations

Advantages with Prototype 1

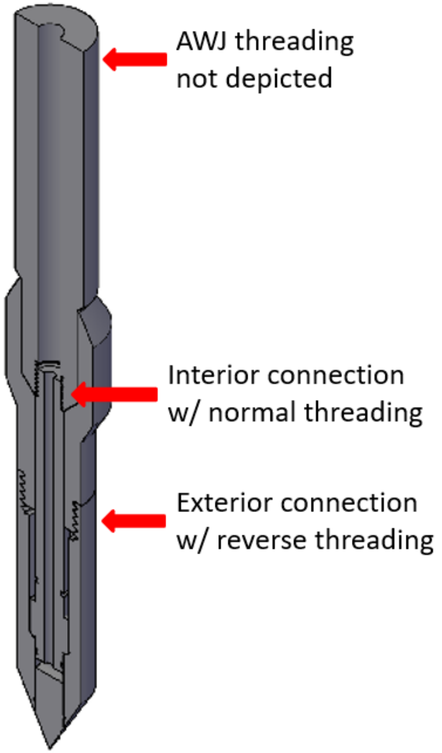
- Robust design allows percussive advancement
  - Tested after probe could no longer be directly pushed
- Reduction in assembly time compared to original probe
  - Less time threading
  - No set screws (3 in original)
- Easier to ensure open position
  - 2" total lift
  - Flow introduced at 1.5" lift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

Problems with Prototype 1

- Three exterior and two interior threaded connections
  - Assembly still time consuming
- Difficulties fabricating a concentric connector piece
  - Effects probe mechanics
- Difficulties fabricating proper internal alignment with seven pieces and numerous 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 individual 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 attributes:
  - Robust threading
  - Increased wall thickness
  - 2” stroke length
  - Upper chamber O-ring



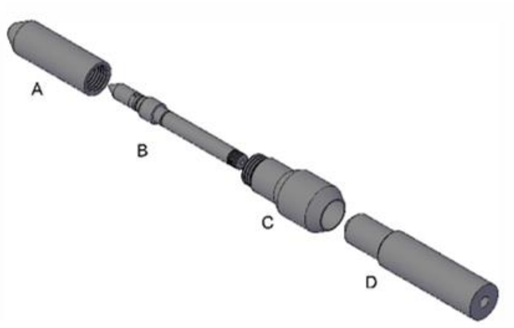
Prototype Comparison

Prototype 2 Advantages

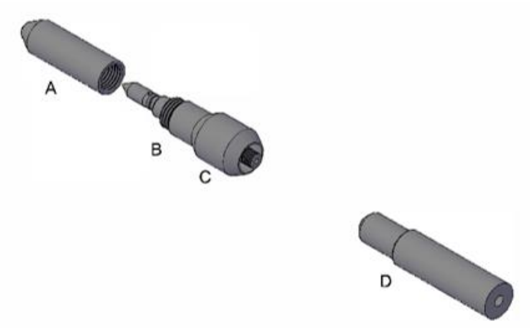
- Same robust design with only four pieces and two threaded connections
  - Compared to seven pieces with five threaded connections
- Assembly is less time consuming
  - Less than 30 seconds
- Easier to fabricate concentric probe pieces
- Easier to fabricate proper internal alignment
- 20% reduction in fabrication cost
- External unthreading eliminated by reversed external threaded connection
- Prototype 2 selected for final design

Prototype 2 – Simplified Assembly

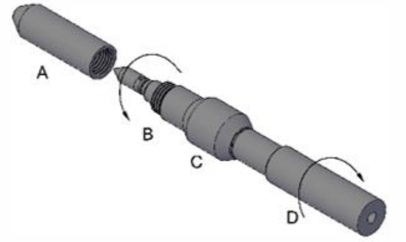
1.) Arrange parts A - D



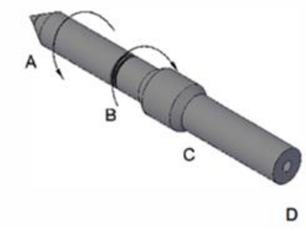
2.) Slide C onto B



3.) Slide D into C and thread onto B (CW)

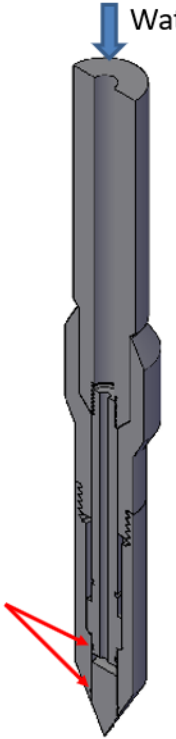


4.) Thread A onto C (CCW)

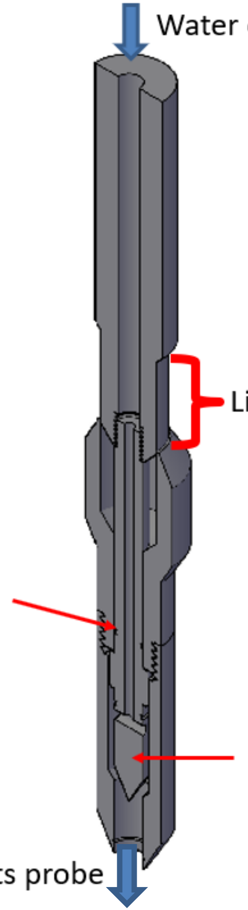


Probe Mechanics

Closed Position - No Flow



Open Position - Flow



New Falling Head Vessel Design

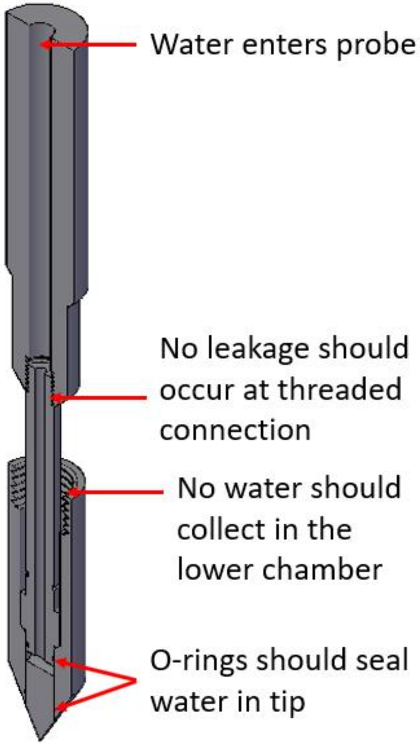
- Each FDOT district will receive a falling head vessel to accompany the VIP probe
  - Used to measure flow
- Aluminum plates used instead of steel (original)
  - Reduced weight for onsite transport
- Greater wall thickness in falling head vessel
  - More robust design
- More robust tripod stand
- All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

VIP Calibration

- After each probe is constructed, calibration will take place to ensure the probes and accompanying equipment function properly before distribution
- Requires a standard calibration procedure to be developed
  - Check O-ring compression
  - Determine permeability limits of the probe
- The previously developed shape factor (F) will also be investigated
  - Currently, F = 3D
  - Could range from 2.5D to 3.1D based on the literature

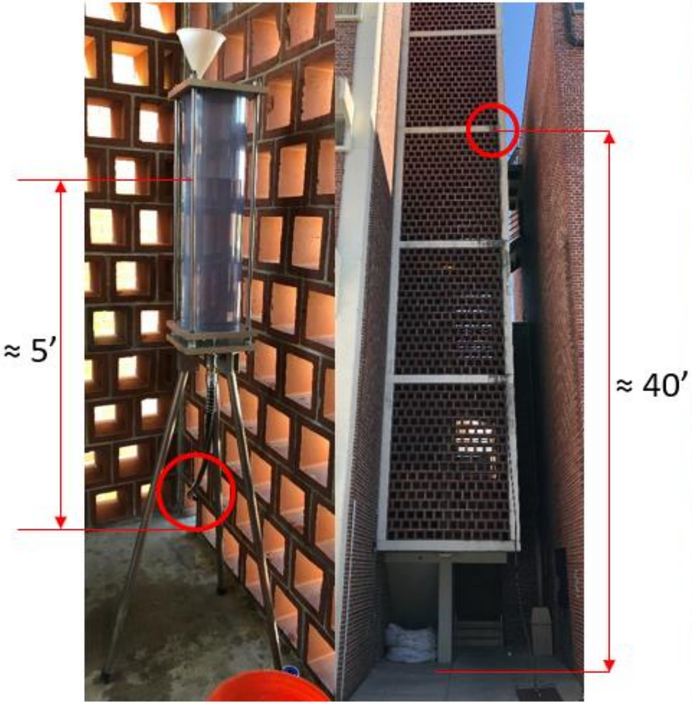
O-ring Watertight Seal Testing

- Friction reducer is removed
  - Can observe internal components for leakage
- Water is introduced to probe at various elevation heads
- Investigated locations for leakage
  - O-ring seals near tip
    - Ensures water is contained until the probe tip is retracted to inject water for testing
  - Internal threaded connection
    - Ensures water only exits through the inner rod flow ports

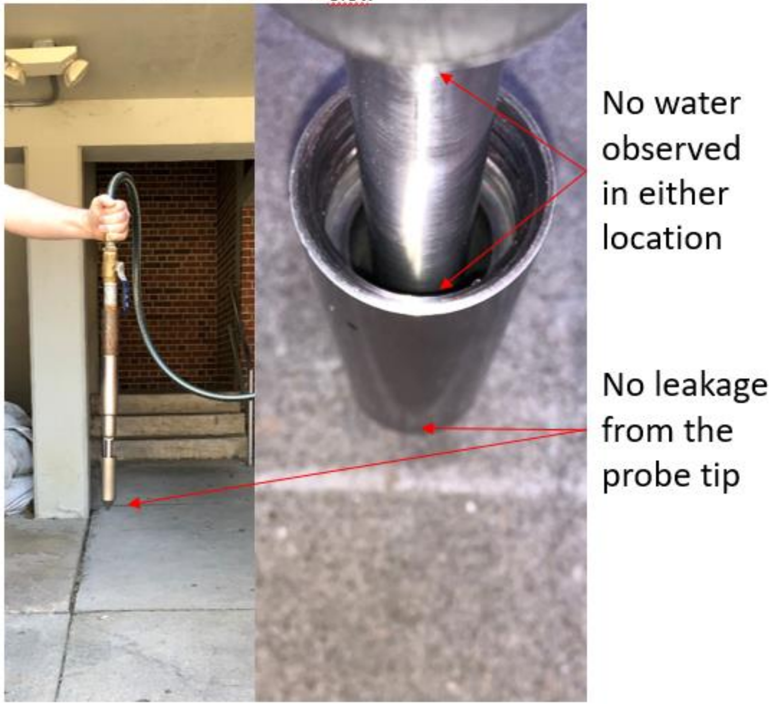


Watertight Seal Controlled Testing

Falling head vessel placed on the fifth floor of stairwell



Probe inspected for leakage at ground level ($\Delta H_{elev.} \approx 45$ feet)



Watertight Seal Testing Analysis

- Tested at 45 feet of head in controlled setting
  - Maximum estimated field test depth = 25 feet
  - Factor of safety ≈ 2 based on controlled testing
- PTFE (plumbers) tape recommended at threaded connections
  - PTFE tape is commonly used to prevent leaks in threaded pipe connections containing water under pressure
  - Some leakage observed without PTFE tape
  - No leakage observed when PTFE tape was applied at the inner rod threaded connection (internal connection)
- No leakage observed at probe tip O-ring locations
  - Confirming O-ring seal at the tip confirms upper O-ring seal
    - Same O-ring seal is provided in both locations
  - Ensures water only exits through flow ports during testing
  - Provides more accurate measurements of hydraulic conductivity

Permeability Limits

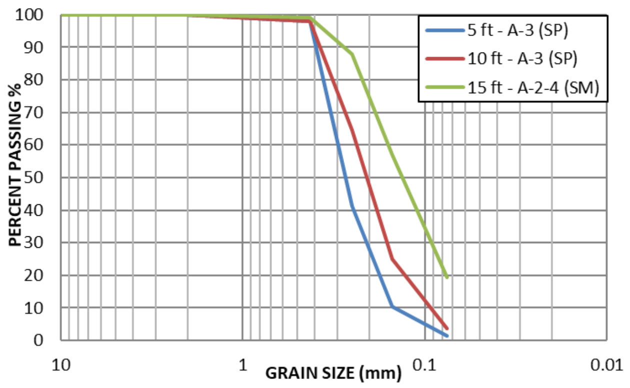
- Tests were performed in which the probe was left to drain freely into the air
  - Determines upper permeability limit
  - Procedure provided in FM 5-614
- Upper permeability was increased with new VIP design compared to original VIP design
  - $k_{max} = 1.07 \times 10^{-1}$ cm/s > $k_{max} = 7.48 \times 10^{-2}$ cm/s
- Lower permeability limit will be determined after all testing is complete
  - Lowest permeability recorded to date with new VIP design is $k_m = 9.48 \times 10^{-6}$ cm/s
    - Lowest permeability recorded with any VIP probe

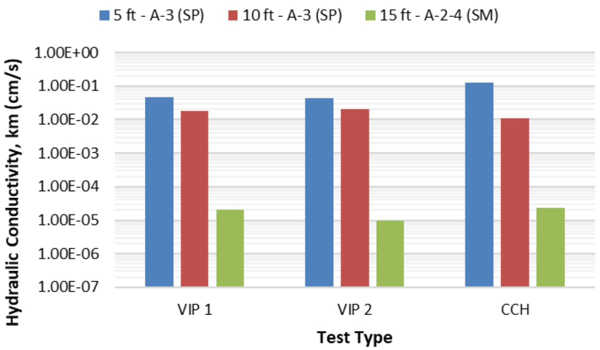
VIP Field Testing

- Field testing will be conducted at 16 different sites throughout Florida
  - 7 FDOT districts and along the turnpike (2 sites/location)
- Additional testing will also be conducted at each site
  - Comparative conventional testing
    - Cased and uncased borehole methods
  - Soil classification
  - VIP push tests to quantify soil density effects on hydraulic conductivity
- Data will be reduced and analyzed after each site is completed
- Upon completion of all sites, a final analysis will be conducted, and conclusions will be drawn
  - Cost comparisons to conventional methods
  - Commentary on any regional/geological variability effects

Trenton, Florida – Test Location 1

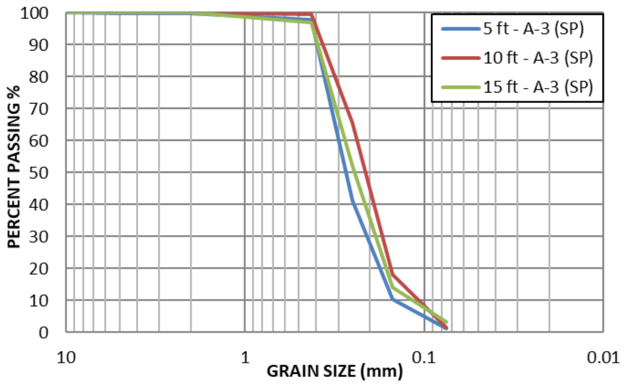
- VIP and cased constant head (CCH) test performed at 3 depths
  - Depths = 5’, 10’, 15’
- Sieve Analysis indicated changing soil type at 15’
  - A-3 (SP) → A-2-4 (SM)
  - 20% passing No. 200 at 15’
    - < 5% at 5’ and 10’
  - Nearby boring indicated sand with red clay at 15’
- VIP and CCH both indicated changes in hydraulic conductivity (k_m) at 15’
  - $1x10^{-2}$ cm/s → $1x10^{-5}$ cm/s

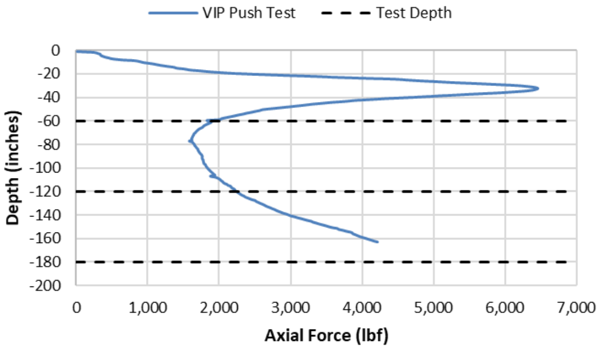


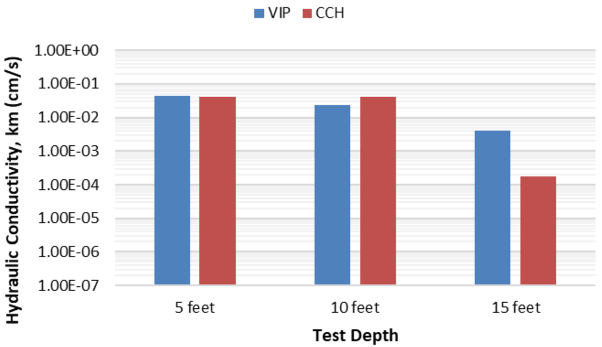


Trenton, Florida – Test Location 2

- Same soil type 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







Preliminary Testing Observations

- New VIP probe design provides very consistent readings in the same soil type
- Readings agree with soil classification
  - VIP clearly indicates changes in soil type and drainage conditions
- VIP compared well with cased constant head (CCH) tests performed at the same locations
  - VIP provides less variable readings in same soil type
  - Soil disturbance from CCH predrilling likely creates more variability in hydraulic conductivity readings
- Probe functionality with new design is much improved compared to old design
- PTFE (plumbers) tape should be placed on both threaded connections to ensure watertight seal

FM 5-614 Instructional Video

- An instructional video will be developed and made readily available on the internet
  - e.g., YouTube
- Will be developed after calibration standards have been established and some field testing has taken place with the new probe design and equipment
  - Allow research team to identify/resolve any issues before the video is made public
- The video will serve as a companion to the instructions provided in FM 5-614

Project Benefits

- VIP testing will provide a significant increase in the amount of data obtained during a standard site investigation
  - VIP allows more data to be collected at multiple depths with reduced test times
  - More data is collected with less effort
- Lead to a reduction in future costs for obtaining accurate hydraulic conductivity data
- Current research effort will validate and promote the use of the FDOT's newly developed Florida Method of Test (FM 5-614)
  - Each district will be provided with the needed equipment and training to implement VIP testing

Herbert Wertheim College of Engineering

UNIVERSITY of FLORIDA

POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE