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

FDOT GRIP Meeting

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Project Background

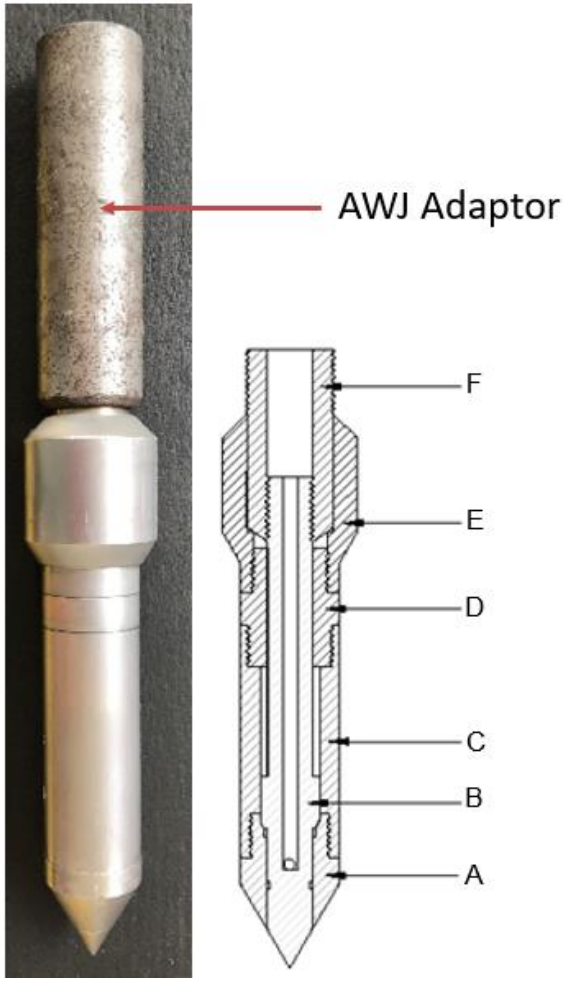
- Recently UF and FDOT developed a new permeability probe, the Vertical In situ Permeameter (VIP)
  - Includes an inner rod/outer casing design with a retractable tip that produces a circular injection surface
  - Retractable tip injects flow in the vertical direction
- Does not utilize a well screen 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



Original VIP Probe 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

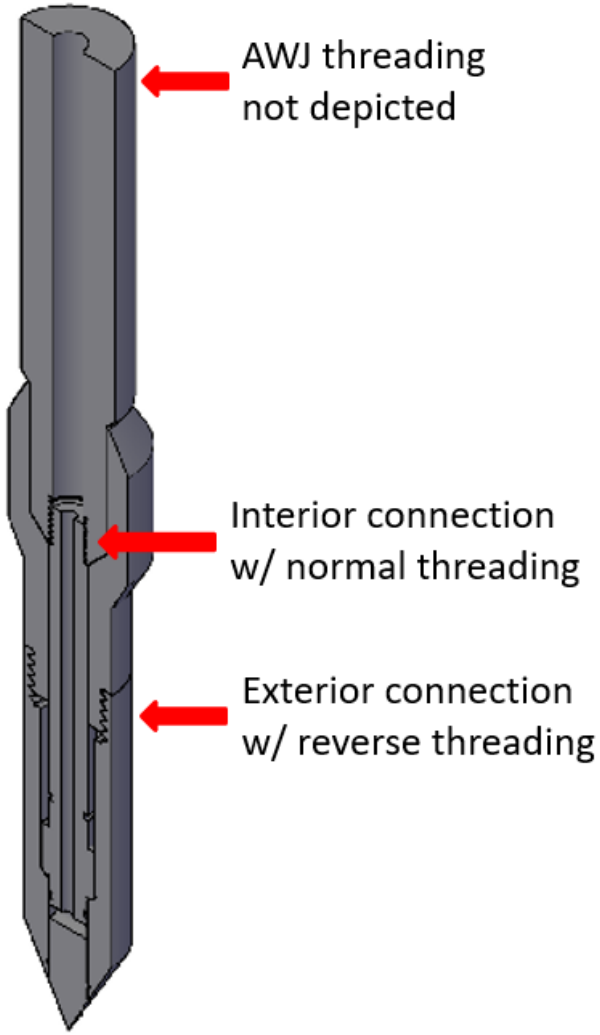
- The primary objective of the current research effort is to implement VIP testing throughout Florida
  - Validation testing
  - Introduce the new test method to each FDOT district
    - On-site training provided by UF research team
- 8 locations will be tested
  - 7 FDOT districts and along the turnpike
- 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

New VIP Design

- Simplified probe design
  - 4 individual probe components
  - Combined original VIP probe components:
    - 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
- Additional attributes:
  - Robust threading
  - Increased wall thickness
  - 2” stroke length
  - Upper chamber O-ring ensures water only flows through injection port at probe tip
  - Assembly in less than 30 seconds
  - Easier to fabricate concentric probe pieces
  - Easier to fabricate proper internal alignment
  - 20% reduction in fabrication cost



VIP Testing Equipment

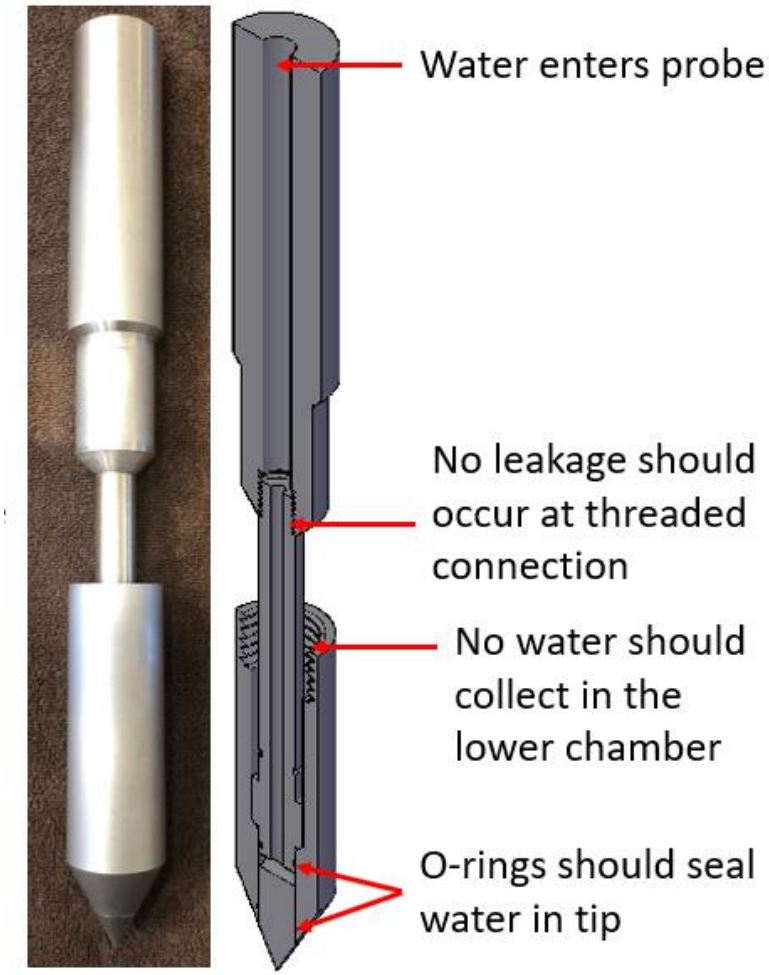
- Each district received:
  - VIP Probe
  - Falling Head Vessel
  - AWJ attachment
- On-site training was provided within each FDOT district
  - D4 and D6 were combined
- YouTube VIP instructional video now available online

VIP Calibration

- Calibration was completed to ensure the probes and accompanying equipment function properly before distribution
- Required a standard calibration procedure to be developed
  - Check O-ring compression
  - Determine permeability limits of the probe
- The previously developed shape factor (F) was investigated
  - F = 3D found to be appropriate shape factor for new VIP

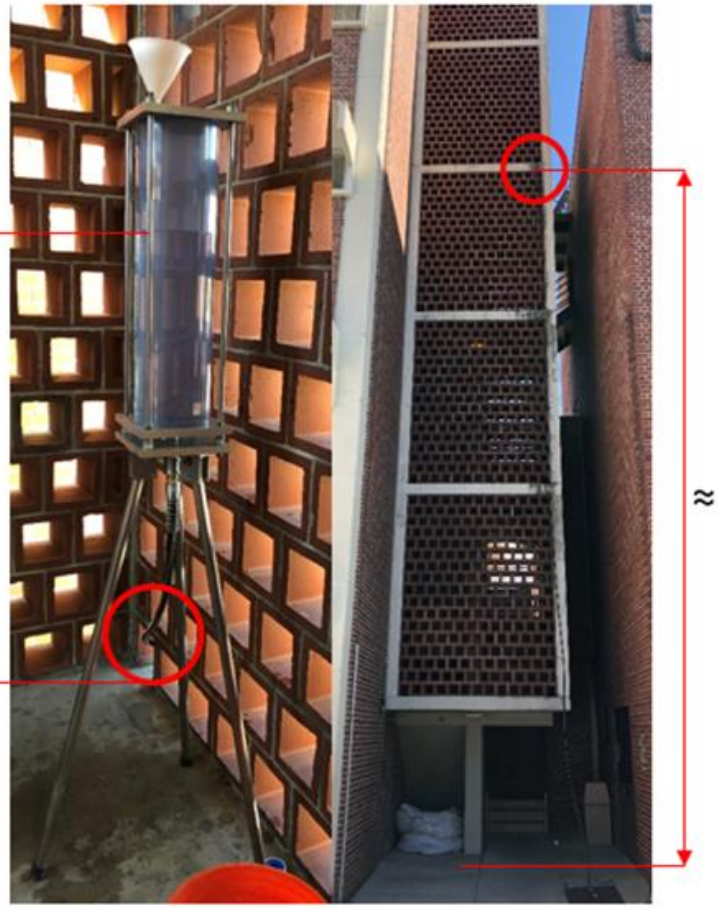
O-ring Watertight Seal Testing

- 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

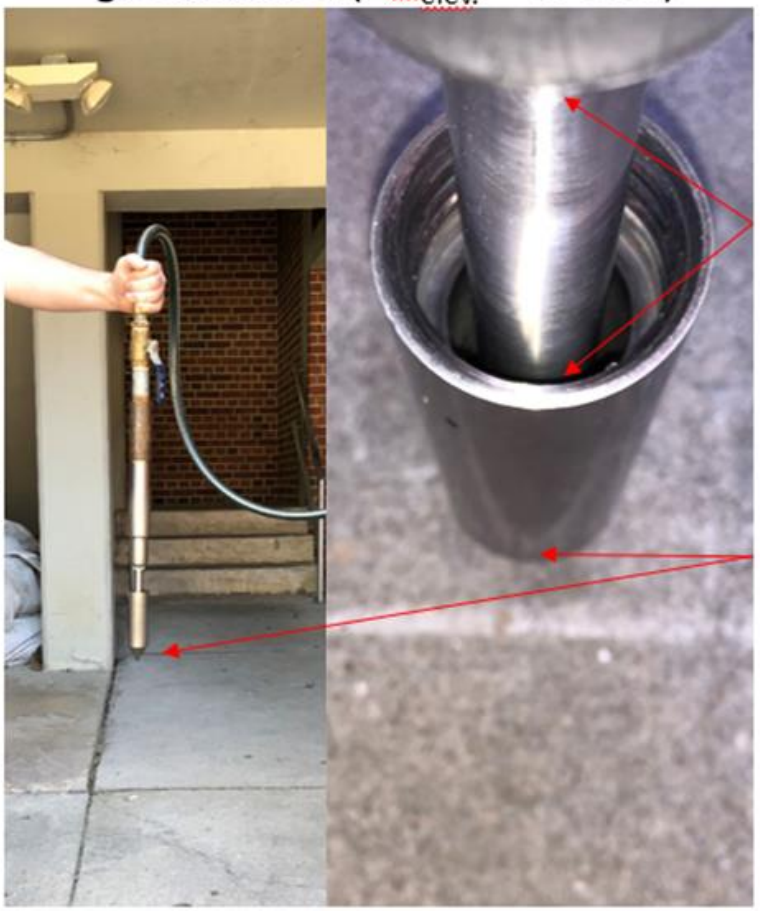


Watertight Seal Controlled Testing

Falling head vessel placed on the fifth floor of stairwell



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



No water observed in either location

No leakage from the probe tip

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)

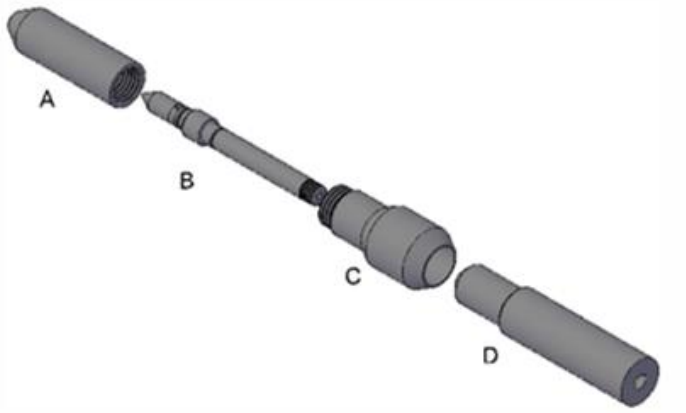
- No leakage observed at probe tip O-ring locations
  - Confirming O-ring seal at the tip confirms upper O-ring seal
    - Same O-ring seal is provided in both locations
  - Ensures water only exits through flow ports during testing
  - Provides more accurate measurements of hydraulic conductivity

Updated Test Method - FM 5-614

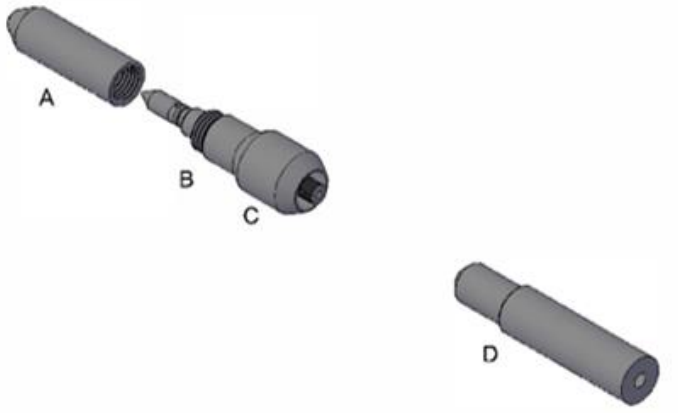
- Test method was updated to reflect new probe design
- Improved procedures with more detail
- Incorporated feedback from consultants and FDOT engineers
- CAD plans are provided for probe and falling head vessel
  - Anyone can fabricate a new VIP probe
  - Probe cost ≈ $2,000
  - Falling Head Vessel Cost ≈ $1,500

Probe Assembly

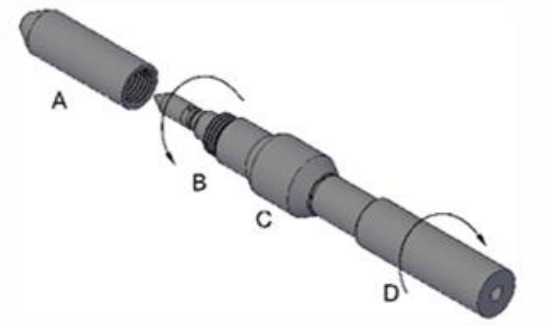
1.) Arrange parts A - D



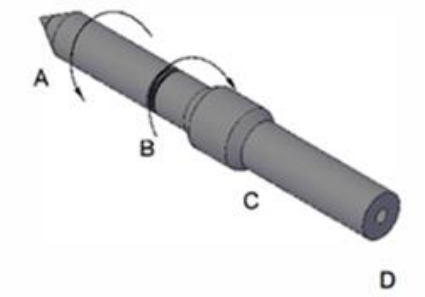
2.) Slide C onto B



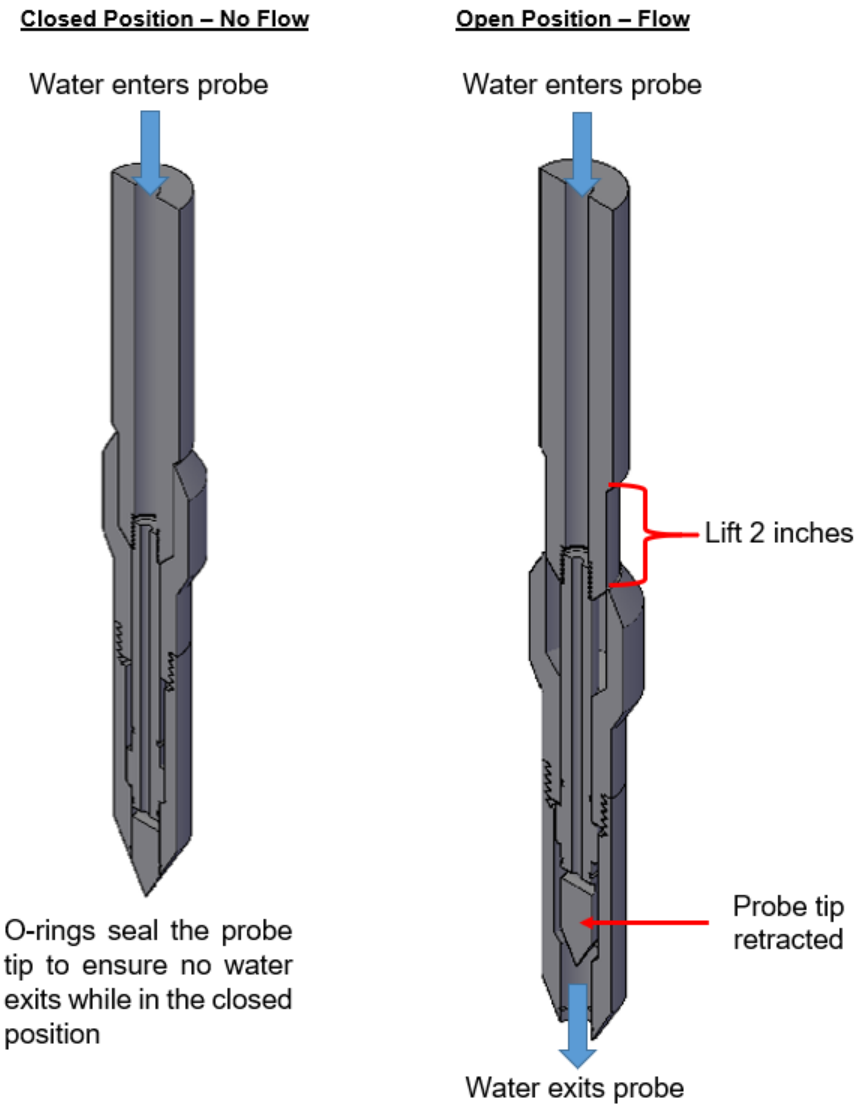
3.) Slide D into C and thread onto B (CW)



4.) Thread A onto C (CCW)



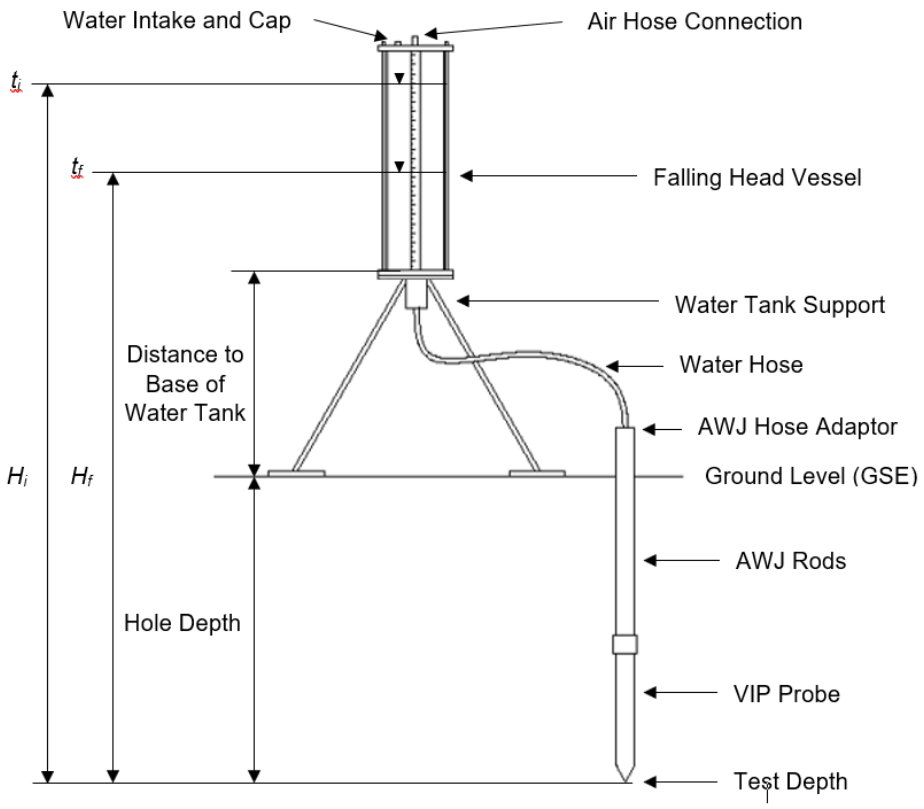
Probe Mechanics



VIP Mean Permeability Calculations

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

- k_m = mean permeability (L/T)
- d = piezometer (water tank) inner diameter (L)
- D = vertical flow port diameter (L) = 0.75-in = 1.905-cm
- F = Hvorslev (Case C) shape factor = 3D (L) = 5.715-cm
- t_i, t_f = initial and final time of test, respectively (T)
- H_i, H_f = initial and final water head, respectively (L)



Updated Test Recommendations

Supplemental Information

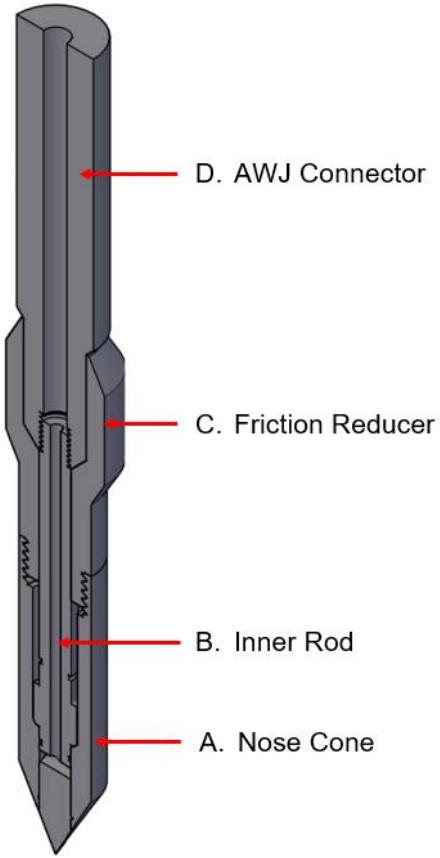
Testing Times Based on Soil Type and Flushing Recommendations*.

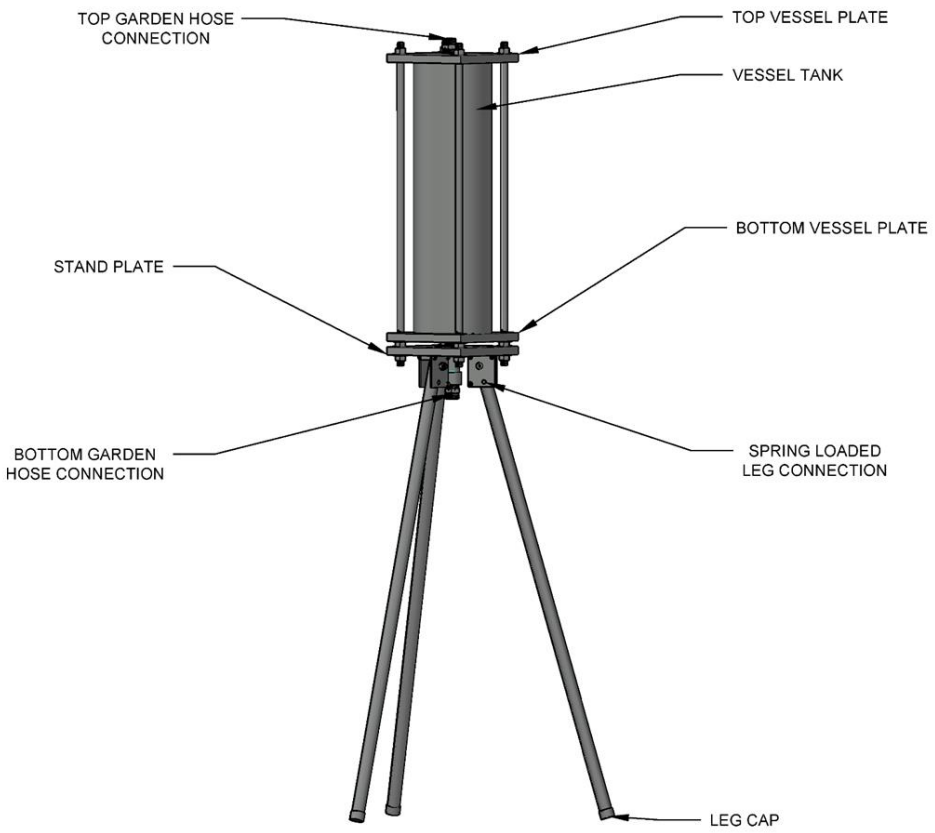
Testing Recommendations (Estimate during saturation)			**Flushing Recommendations** (If needed, typically not required)	
Soil Type	**Recording Increment**	**Total Length of Test**	**Air Pressure**	**Flush Time**
Coarse Sand	15 – 30 sec	3 – 5 min	10 – 20 psi	10 sec
Fine Sand	30 sec – 1 min	5 – 10 min	15 – 25 psi	10 – 30 sec
Silty Sand	30 sec – 1 min	5 – 10 min	20 – 30 psi	10 – 30 sec
Sandy Silt	1 – 5 min	10 – 50 min	25 – 35 psi	10 – 30 sec
Clay	5 – 15 min	45 - 60 min	30 – 45 psi	30 sec – 1 min

Updated CAD Drawings

Probe Layout

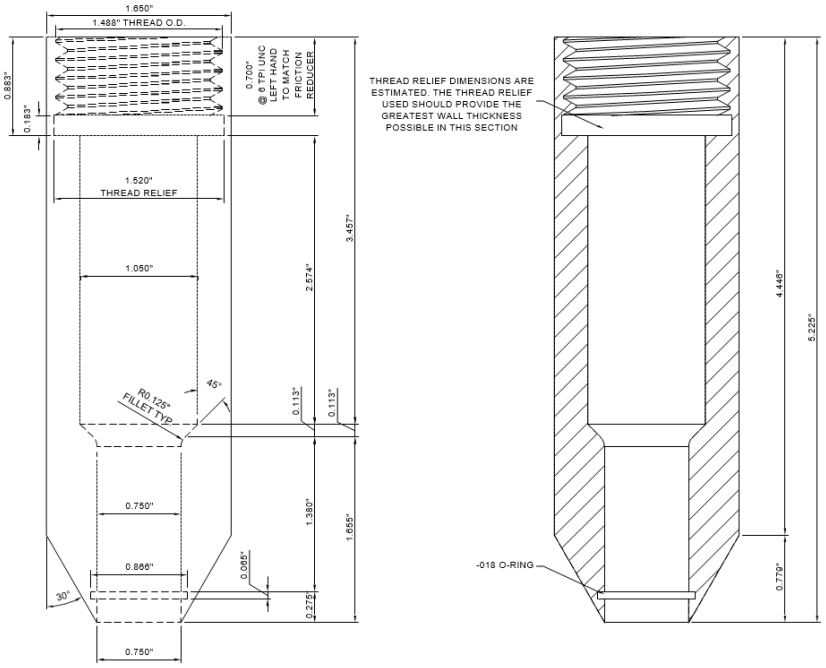
A. Nose Cone
B. Inner Rod
C. Friction Reducer
D. AWJ Connector



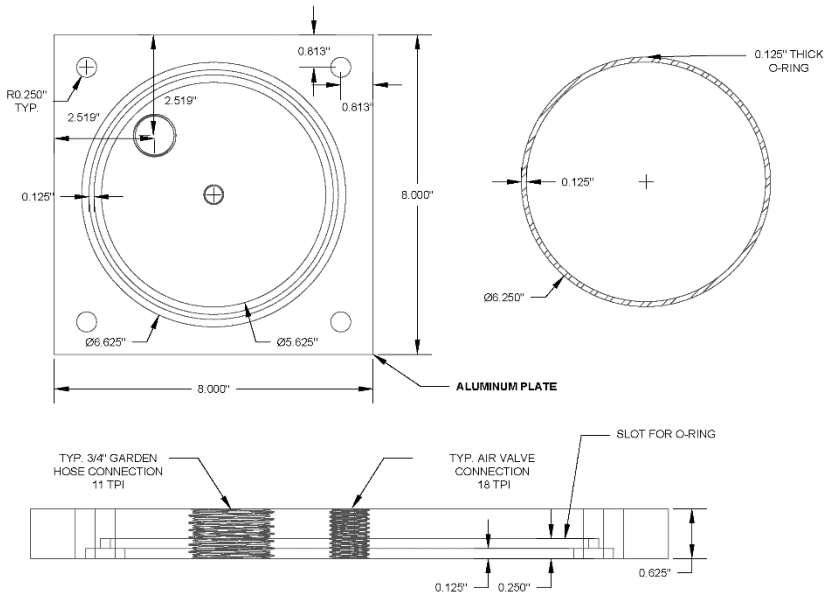


Detailed CAD Examples

Probe CAD

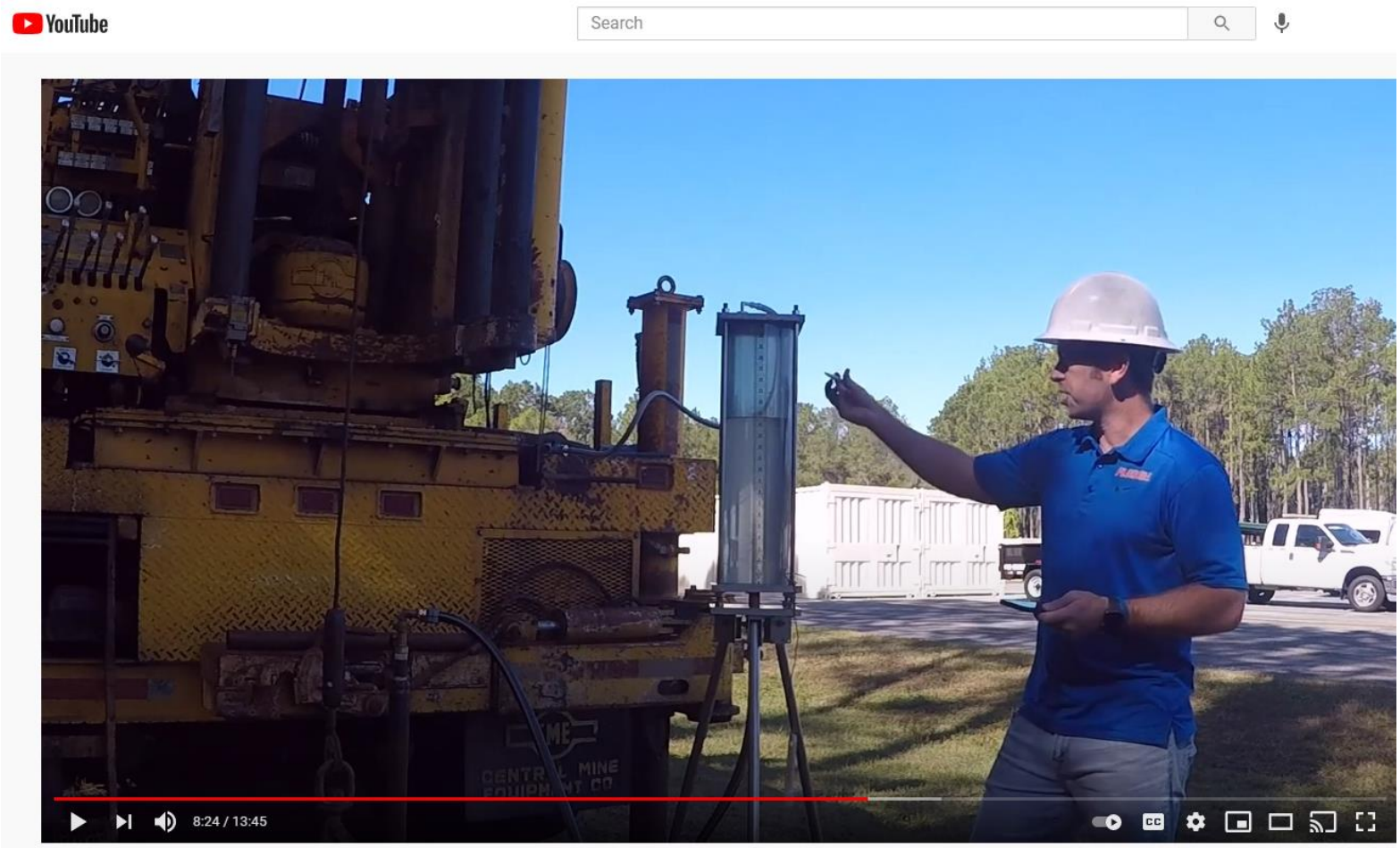


Falling Head Vessel CAD



VIP Instructional Video

https://www.youtube.com/watch?v=qOV19WIPMgE

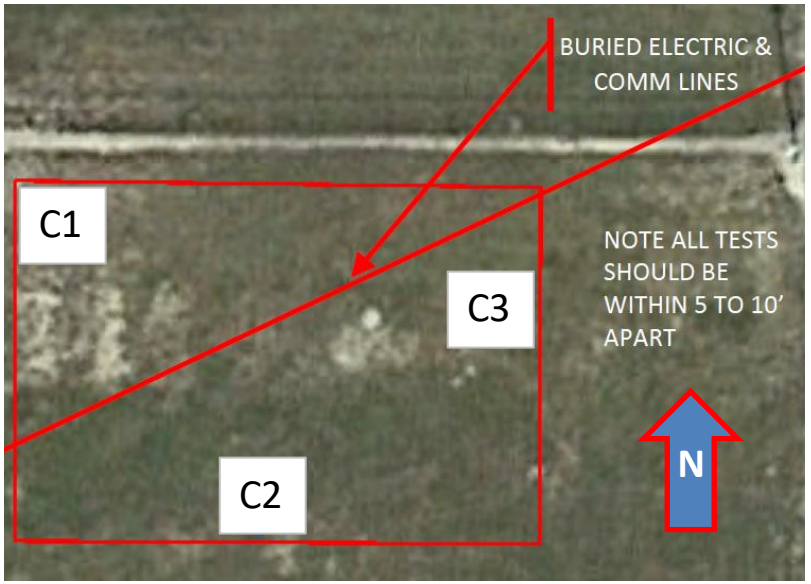


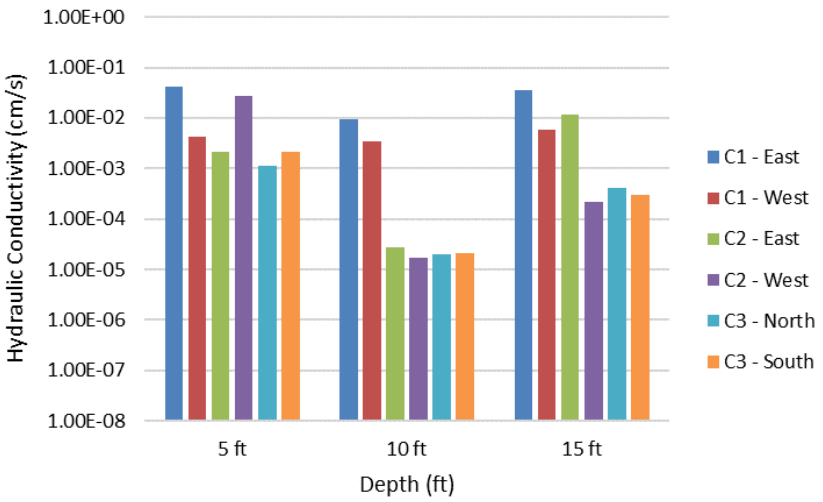
VIP Field Testing

- Field testing will be conducted at sites throughout Florida
  - FDOT districts and along the turnpike
- Additional testing will also be conducted at each site
  - Comparative conventional testing
    - Cased and uncased borehole methods
    - Laboratory testing
  - Soil classification
  - VIP push tests and SPT 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

D1 - Bartow

- Provided VIP training to D1 consultants
- Three locations tested at the site
  - 2 VIP tests per location
  - 3 tests depths
- Loose sand tailings and phosphatic waste clays present at the site
- C2 and C3 showed similar trends w/ depth
- C1 indicated higher permeability at all test depths



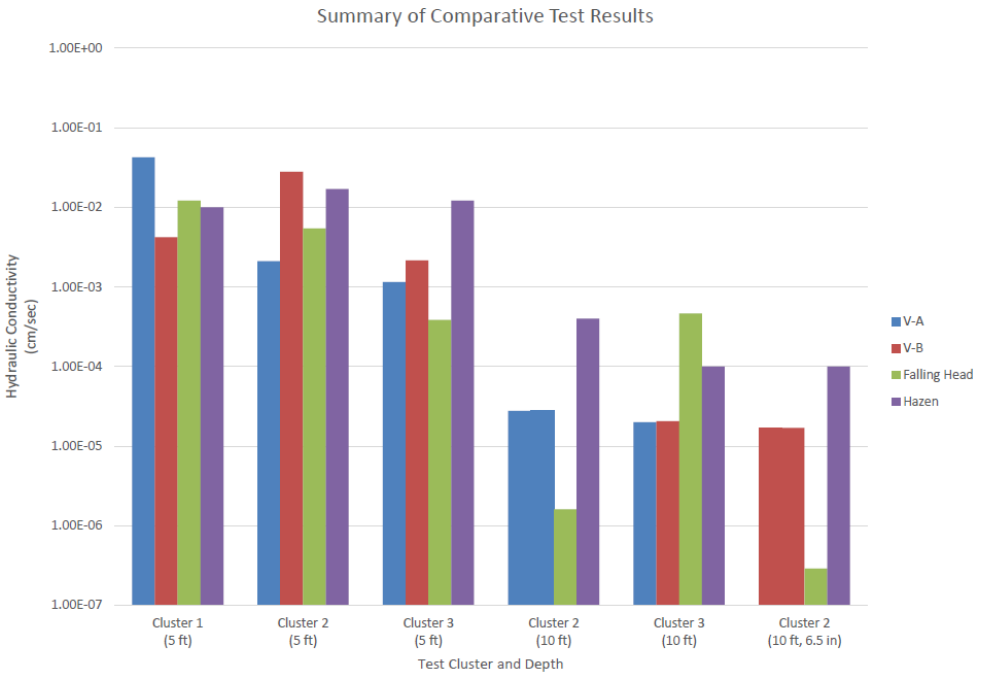


D1 – Bartow

- CPT style truck was used for VIP tests
- Custom VIP tank platform was installed
- Very precise control for opening and closing the probe
- Water supply and rig controls all within close proximity to VIP tank
  - Convenient to perform VIP tests

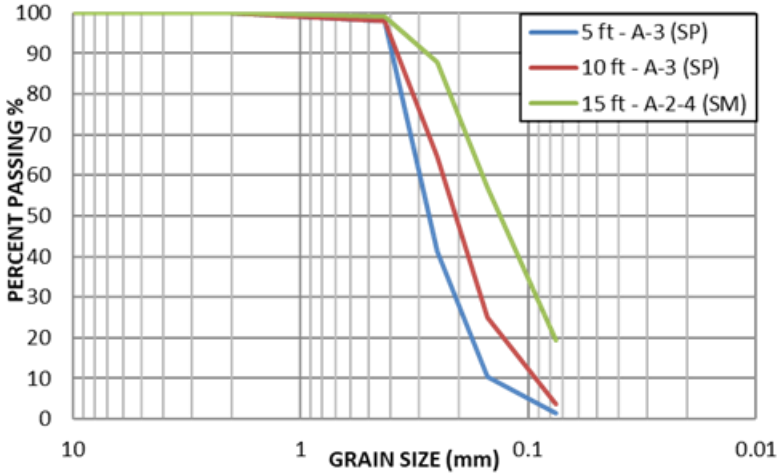
D1 – VIP vs. Laboratory Testing

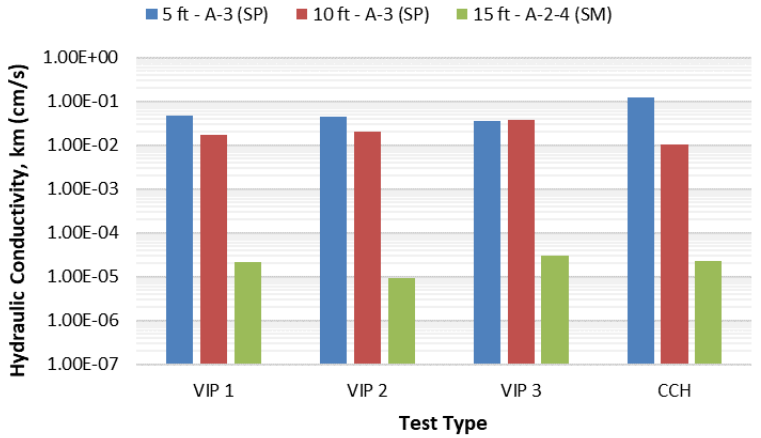
- VIP and Lab Data agreed in coarse grained soils near surface
- Results were not conclusive at greater depths with lower permeable soils
  - Hazen not intended for fine-grained soils
  - Channeling observed in lab tests
  - Recommended longer FH lab test times due to clayey soils encountered
- Stated that VIP identified lower permeability soils



D2 – Trenton – Location 1

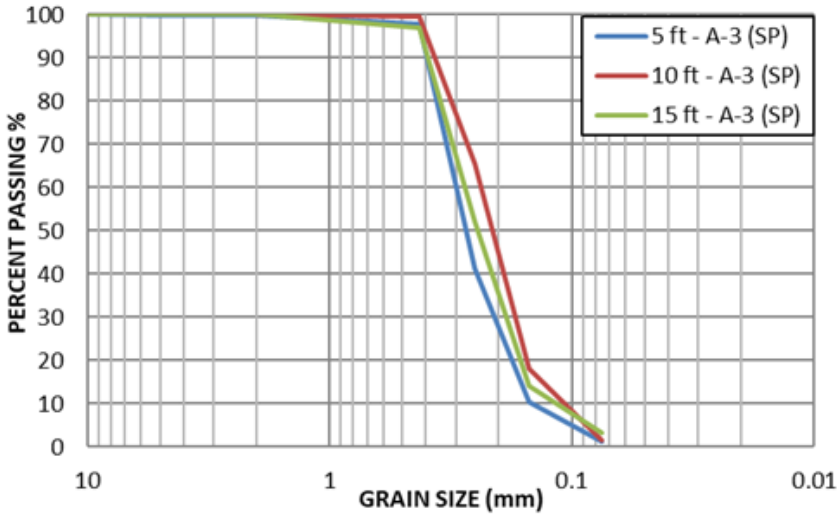
- VIP and cased constant head (CCH) test performed at 3 depths
  - Depths = 5', 10', 15'
- Sieve Analysis indicated changing soil type at 15'
  - A-3 (SP) → A-2-4 (SM)
  - 20% passing No. 200 at 15'
    - < 5% at 5' and 10'
  - Nearby boring indicated sand with red clay at 15'
- VIP and CCH both indicated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

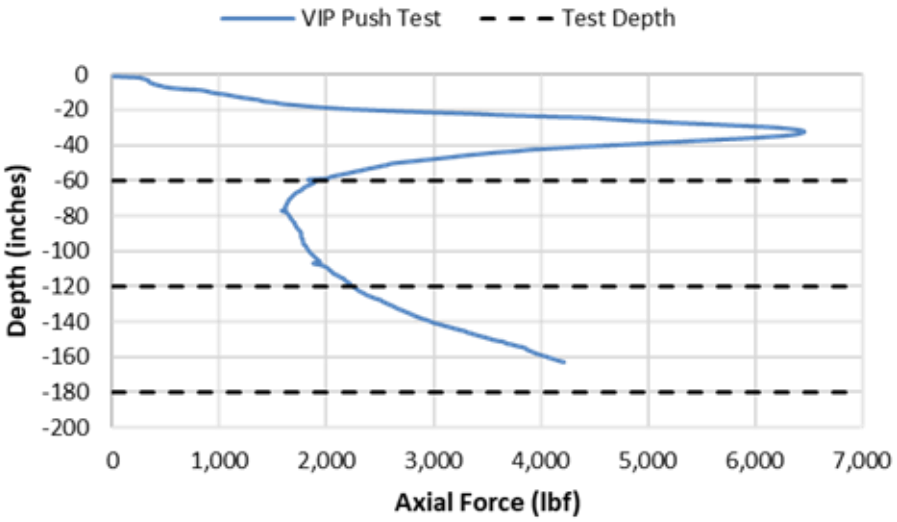


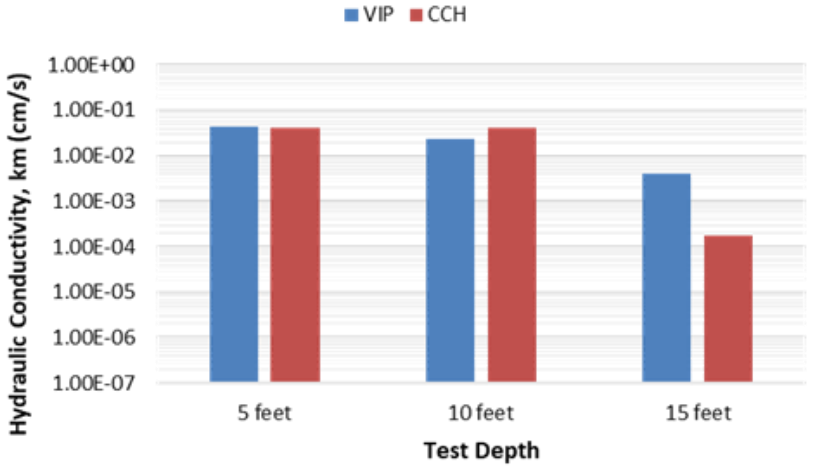


D2 – Trenton – Location 2

- 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

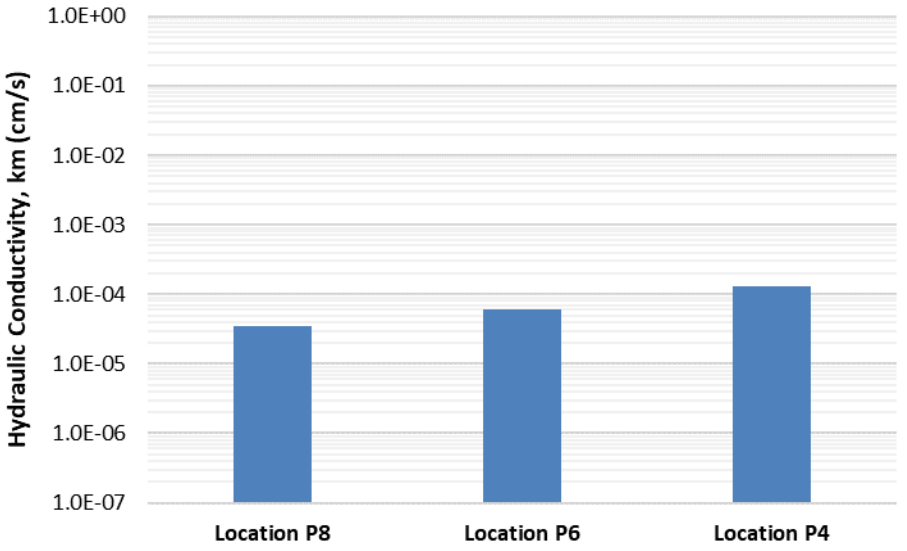






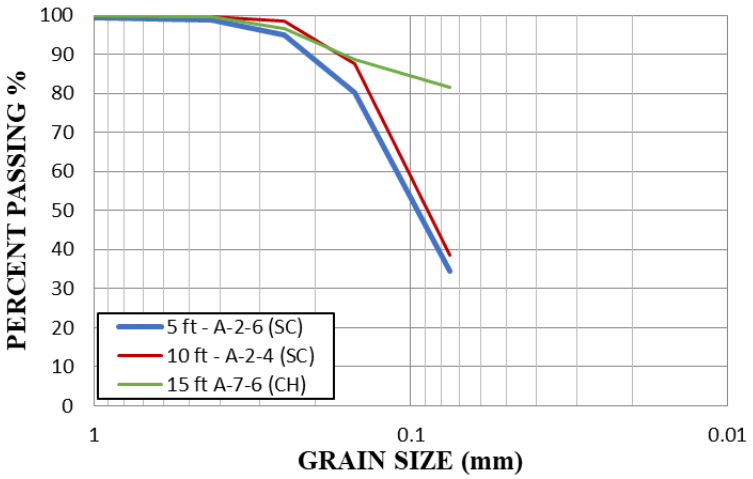
D2 – Newberry

- Investigated a potential retention pond site
  - Provided training to FDOT D2 field specialists
- Tested the hydraulic conductivity at the same elevation across the site
- Similar hydraulic conductivity across the site @ same elevation
  - Slight increase in K_m moving east to west



D2 – CR 349

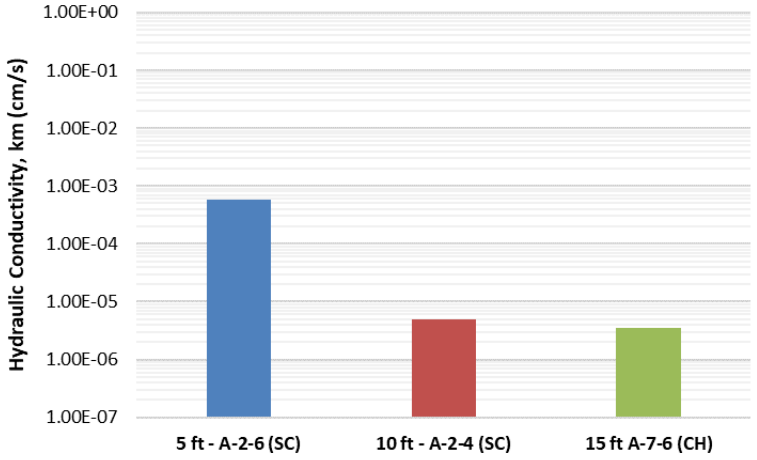
- Provided VIP training to D2 consultants
- Observed large change in k_m moving from 5’ to 10’
  - Increase in SPT blow counts
- Recorded very low k_m at 15’
  - A-7-6 / CH
  - $K_m = 3.45 \times 10^{-6}$ cm/s



5 ft
SPT N = 6

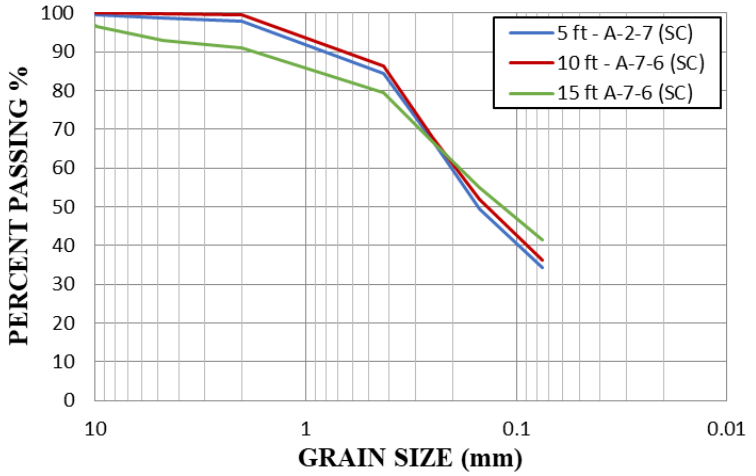
10 ft
SPT N = 27

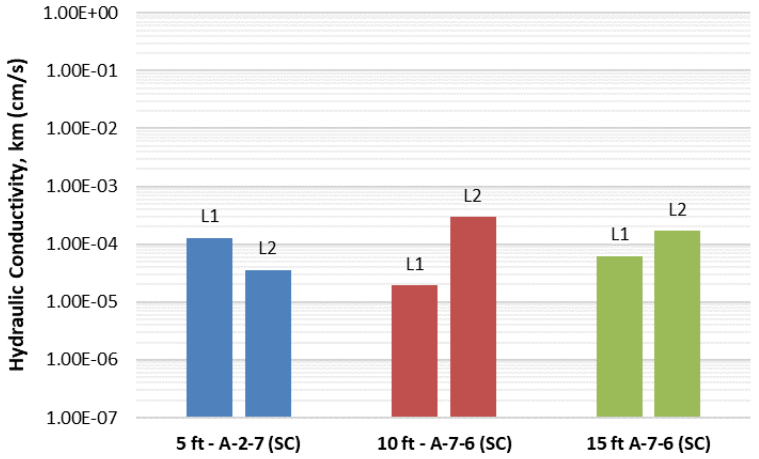
15 ft
SPT N = 25



D3 – Marianna

- Provided training to FDOT D3 Field Specialists
- Tested 2 locations at the site
  - 3 test depths per location
- Low k_m at all locations
- No clear trend of increasing k_m with depth
  - SPT N decreased with depth

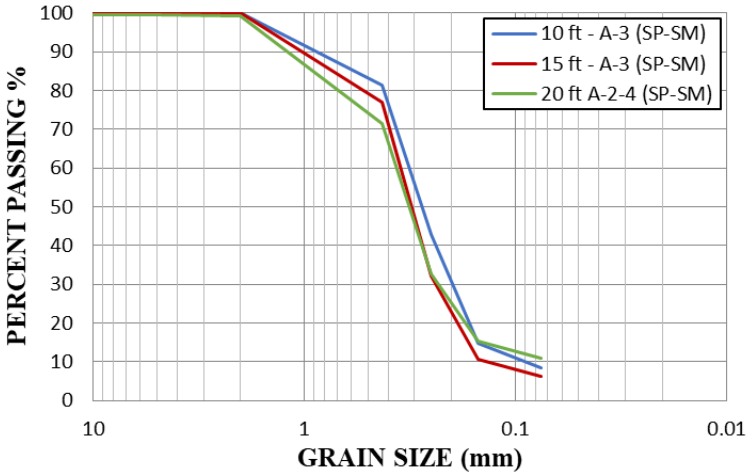


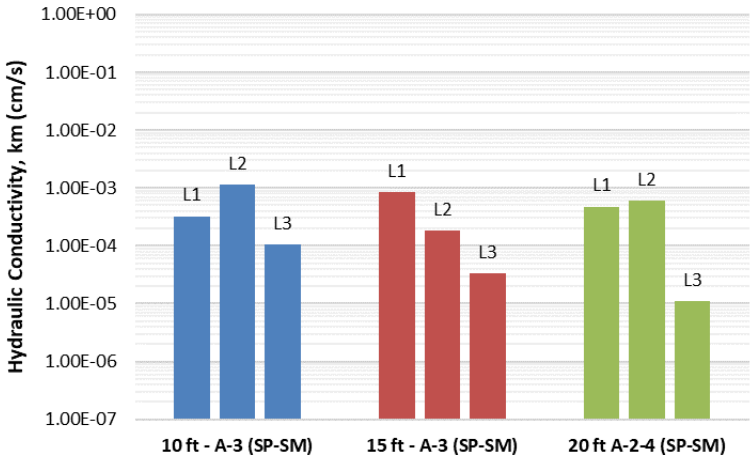


SPT N = 9 SPT N = 8 SPT N = 6

D3 – SR 231 - Cottondale

- Tested 3 locations at the site
  - 3 test depths per location
- Lower k_m at all 3 locations
- Only Location 3 indicated decreasing k_m with depth
  - SPT N variable with depth
- Often encountered dark black soil at site



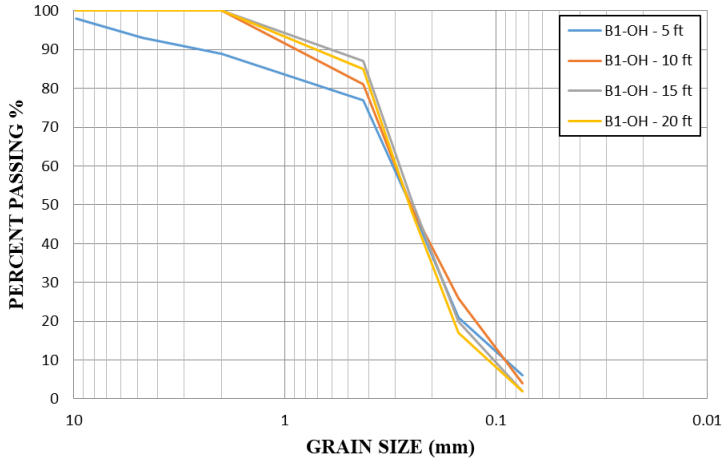


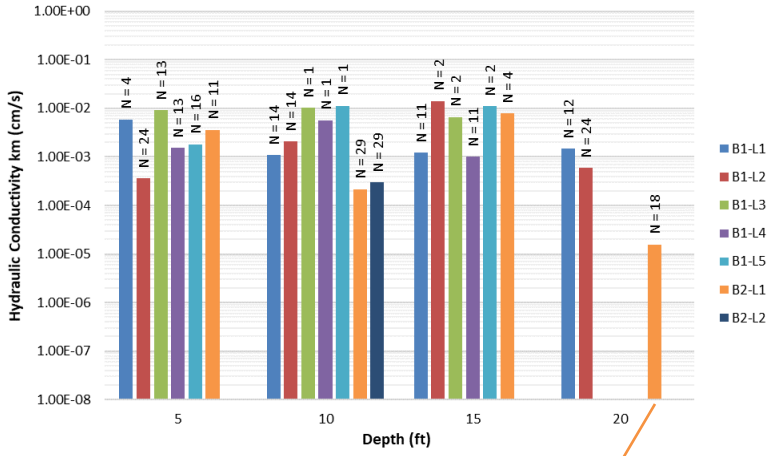
SPT N = 6 SPT N = 1 SPT N = 9

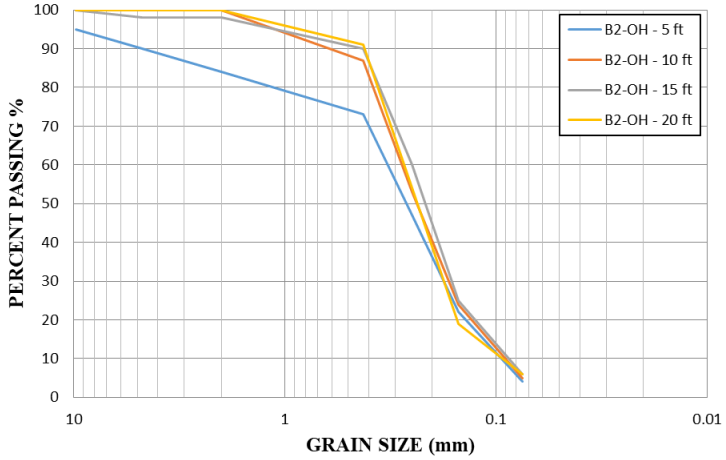
D4/6 – D4 Operations Center

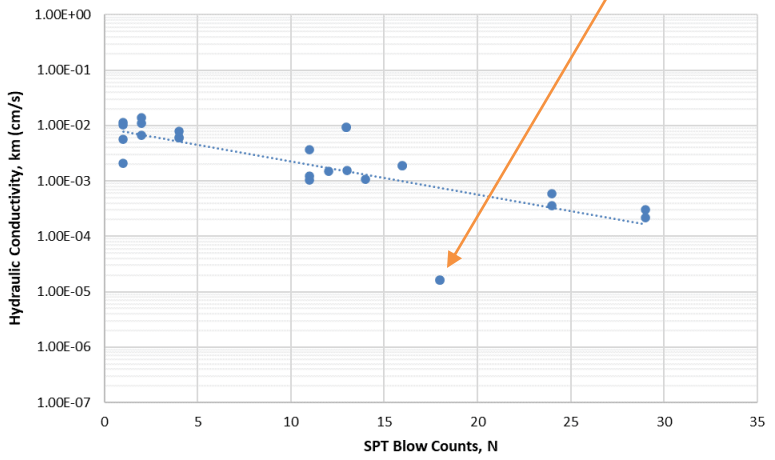
- Completed 22 VIP tests
- Depths ranged from 5 to 20 feet
- All soil was classified as A-3
- Large range of SPT blow counts
- Excellent opportunity to investigate influence of density on soil permeability

D4/6 – D4 Operations Center



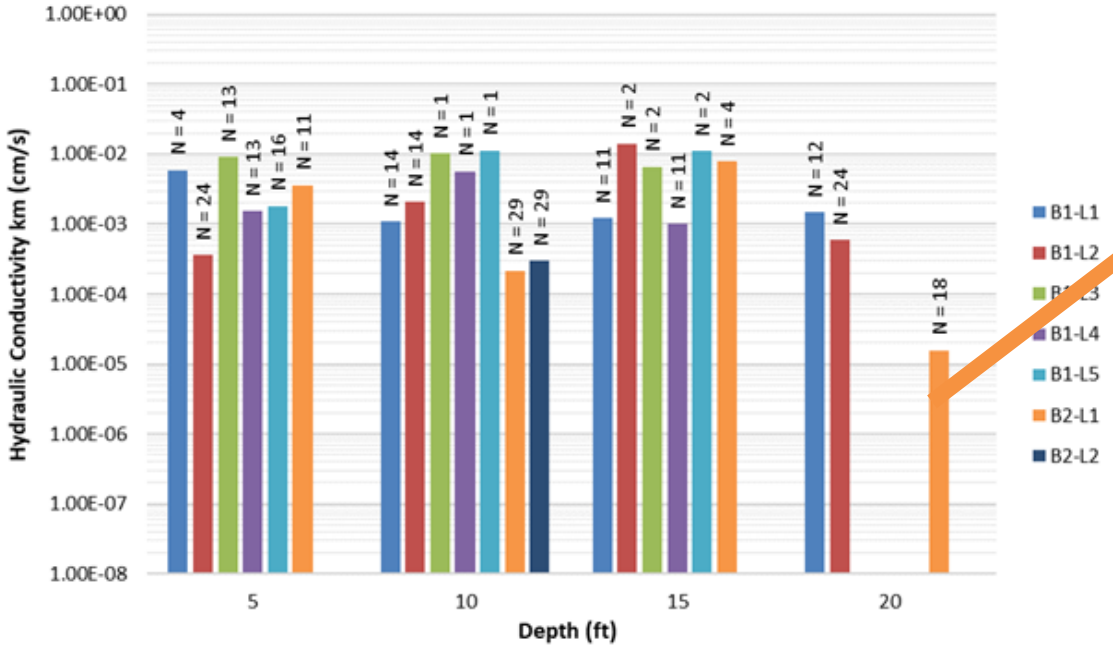






False Reading

- Too much grease was added to AWJ threads
- Transmitted through the drill string and out of the probe tip
- Grease likely permeated into soil and caused a false reading

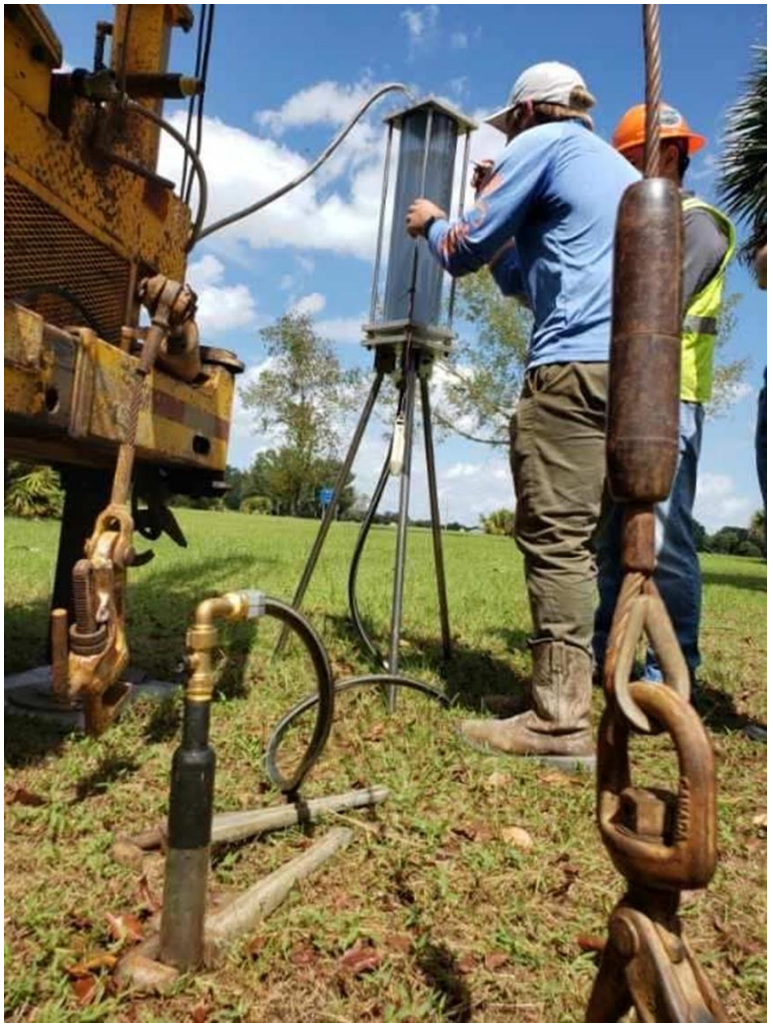


Placing the Probe Down an Open Hole

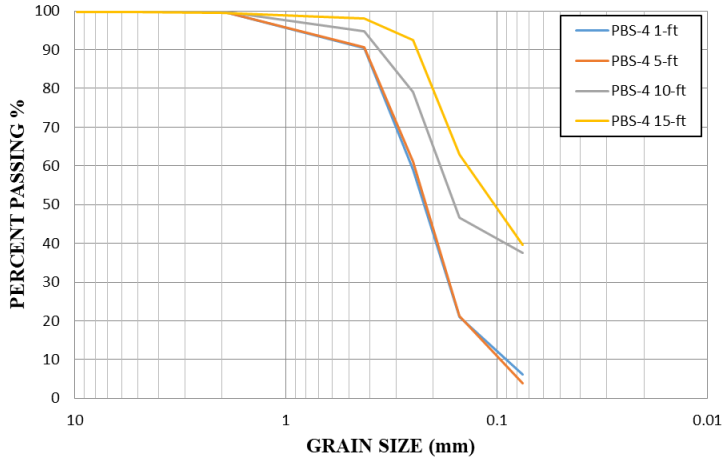
- South Florida site had shell and limestone fragments near surface
- Hand augered first 3-4 feet to pass through limestone fragments
- Placed VIP probe down the open hole
- Used electric tape to ensure probe stayed closed until the test was initiated

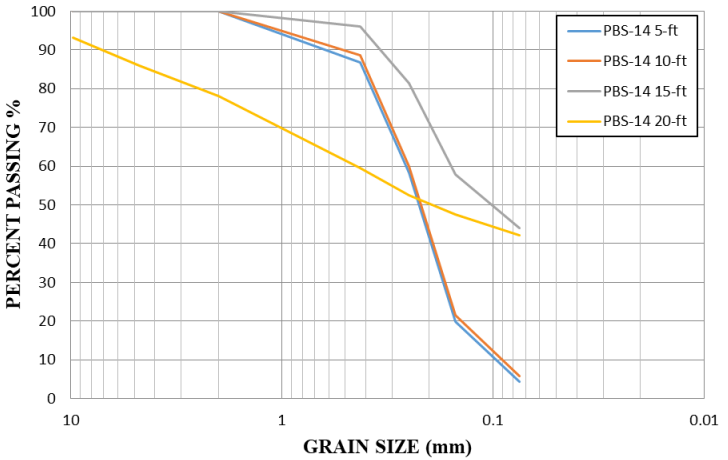
D5 – I75 Rest Area

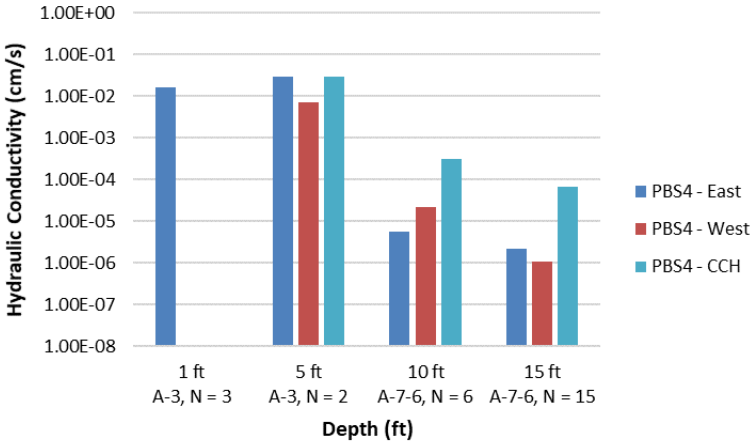
- Provided training for D5 FDOT engineers and consultants
- 21 VIP tests completed
  - 10 comparative CCH tests performed
- Investigated VIP as infiltrometer tests
  - Shows promise as a new quick infiltrometer method
- Very large range of hydraulic conductivity
  - $K_{m\text{-}max} = 4.15 \times 10^{-2}$ cm/s
  - $K_{m\text{-}min} = 8.65 \times 10^{-7}$ cm/s

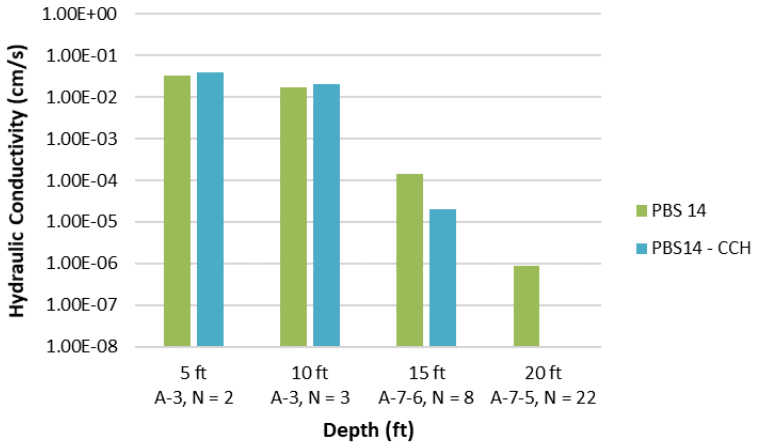


D5 – I75 Rest Area – PBS 4 & 14

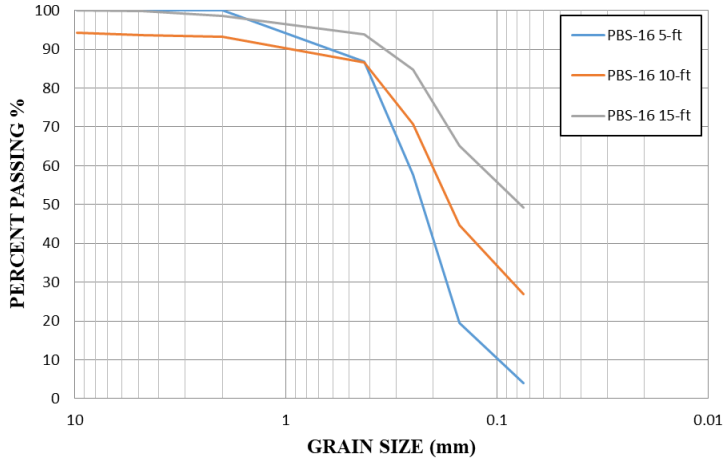


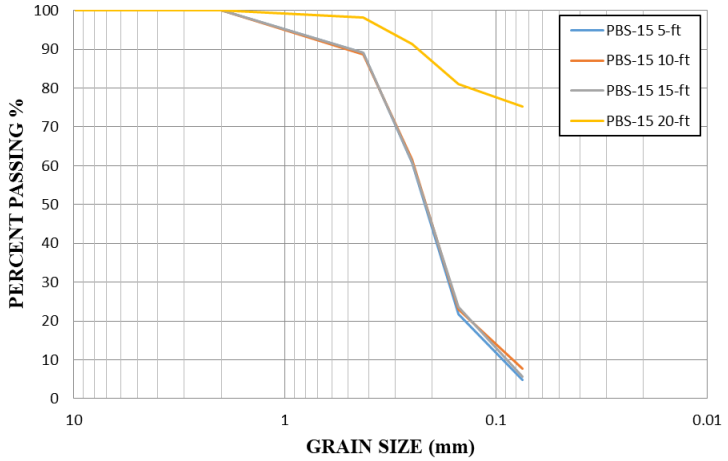


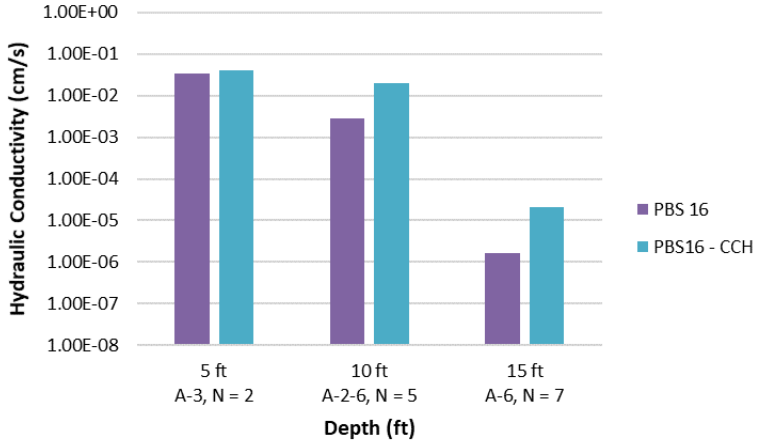


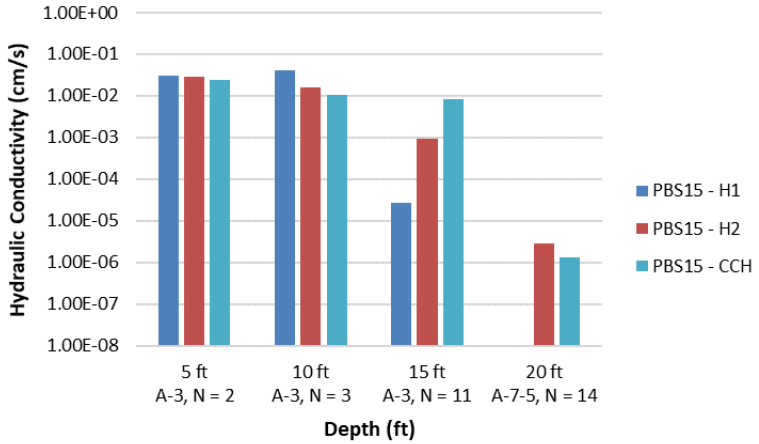


D5 – I75 Rest Area – PBS 15 & 16



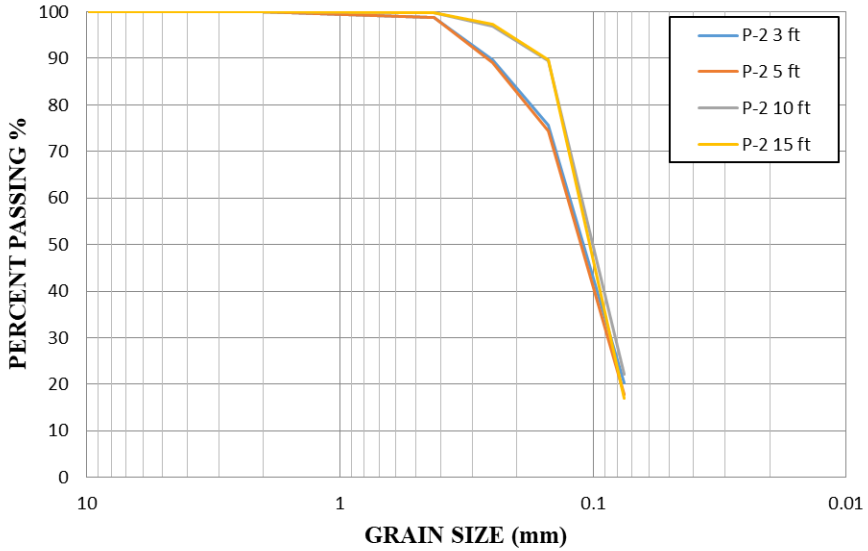


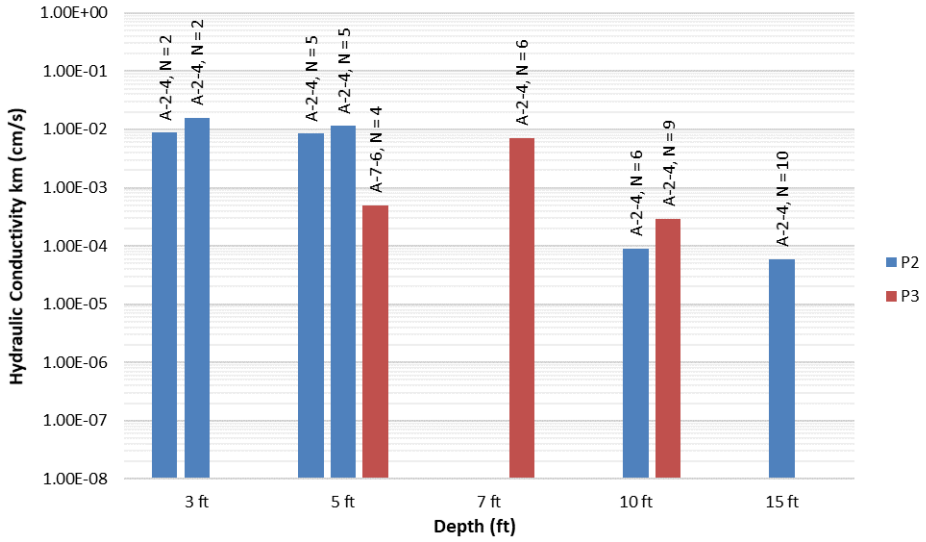


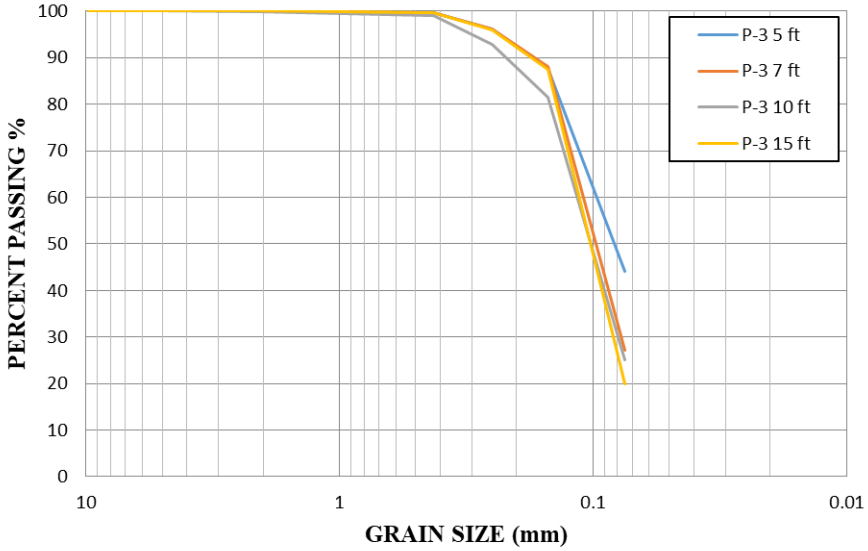


D7 – Brooksville FDOT Office

- Trained D7 Consultants and FDOT Engineers
- 9 VIP Tests Completed
- 8 of 9 tests were A-2-4
- 1 A-7-6 soil
- SPT N ≤ 10

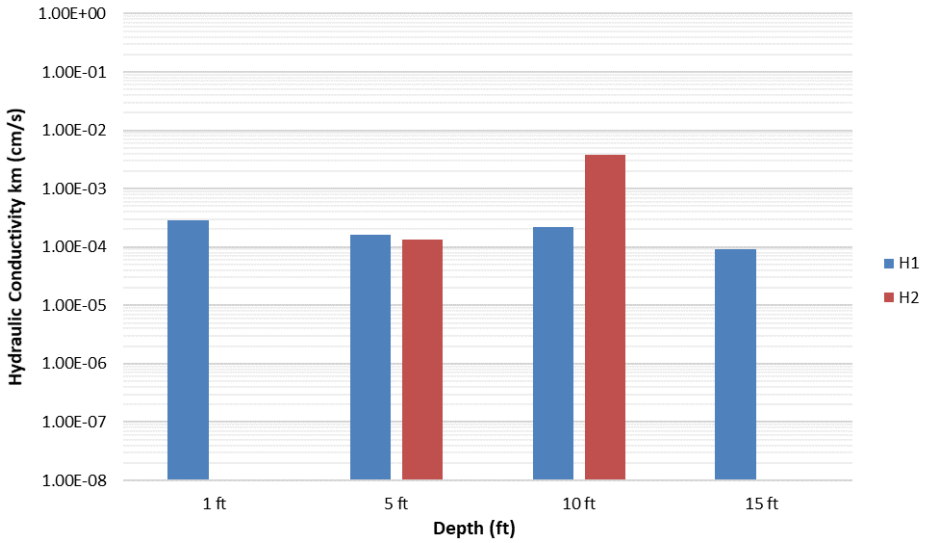






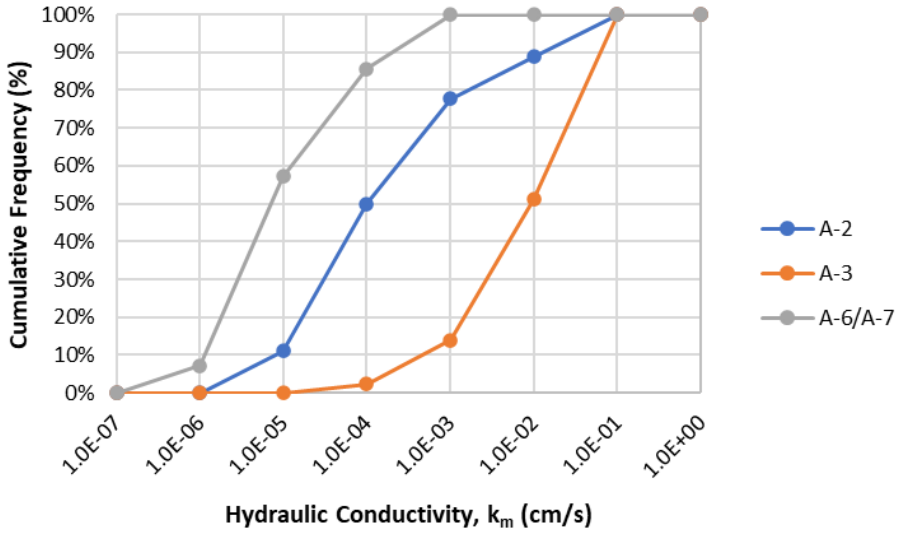
D7/Turnpike – Veterans Expressway

- 5 VIP tests were completed
  - 5 to 15 feet
  - High water table (2.6 ft) slowed testing down
- 1 VIP infiltrometer tests was completed
  - Do not to use drill rig for VIP infiltrometer tests
- Historical data indicated km range of 7.37 x 10^{-3} cm/s to 2.43 x 10^{-4} cm/s
- VIP measurements were in excellent agreement
  - Fine grained soil collected by hand auger also indicates lower permeability



Testing Summary

- 109 VIP tests total
  - 75 tests with SPT data and soil classifications
- Permeability range of K_m = 4.68 x 10^{-2} cm/s to 8.65 x 10^{-7} cm/s
- Soil types encountered were A-3, A-2-4, A-2-6, A-6, A-7-5, and A-7-6
- Predominately A-3
- VIP performed well in all soil types
  - Above and below GWT



Statistics	Fine Sand A-3	Silty or Clayey Sand A-2	Clayey Soils A-6/A-7
Mean	1.45E-02	2.21E-03	5.76E-05
Median	9.25E-03	1.10E-04	7.60E-06
Std Dev	1.47E-02	4.57E-03	1.32E-04
CV	1.01	2.07	2.28
Max	4.68E-02	1.59E-02	4.94E-04
Min	2.76E-05	4.99E-06	8.65E-07
Count	43	18	14

VIP 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
  - $k_{max} = 9.31 \times 10^{-2}$ cm/s > $k_{max} = 7.48 \times 10^{-2}$ cm/s
- Lowest permeability recorded with new VIP design
  - $k_m = 8.65 \times 10^{-7}$ cm/s
    - Lowest permeability recorded with any VIP probe
    - I-75 Rest Area in District 5 → Soil Type A-7-5 (SC) → SPT N = 22

VIP Probe Testing Notes

- Check O-rings in between tests locations when encountering a lot of silty soils
  - Fine grain soils can reduce the life of the tip O-ring
- Check O-rings between tests when testing operating in very cold weather
  - O-rings become stiffer in cold weather
- Inspect probe and drill rod throughout testing
  - Make sure no debris or grease buildup is present
- High water tables lead to longer test times
  - Reduced head to push water through soil
- Rock fragments can score the probe, use a file to smooth any roughened surfaces
- Rotate the probe inner rod after cleaning or filing to ensure concentric rotation and for binding
- Electric tape can be used to keep the probe closed when advancing down an open borehole
- The more you use the probe the better it operates

Conclusions

- The new robust probe design was successful
  - SPT hammering and direct push with large axial forces generated
  - Simplified assembly and breakdown for cleaning
- The probe functioned well in a large variety of Florida soils
  - A-3, A-2-4, A-2-6, A-6, A-7-5, A-7-6
  - Measured k_m range of 4.68×10^{-2} to 8.65×10^{-7} cm/s
  - Increased soil density decreased permeability
- The probe functioned well above and below the water table
  - Higher GWT → Longer test times
- VIP performed well in a large range of depths
  - 1 to 20 feet
- The VIP probe and test method were well received in each district
  - Potential replacement for all permeability methods used in FL
  - Could provide continuity for k_m measurements statewide
  - Very efficient and easy to use
- New FM is much improved and incorporates input from Florida geotechnical engineers across the state
  - VIP online tutorial is very thorough and easy to follow
- Mission accomplished!

Remaining Tasks

- Closeout Meeting and Draft Final Report
- Final Report

Questions?