Florida Institute of Technology

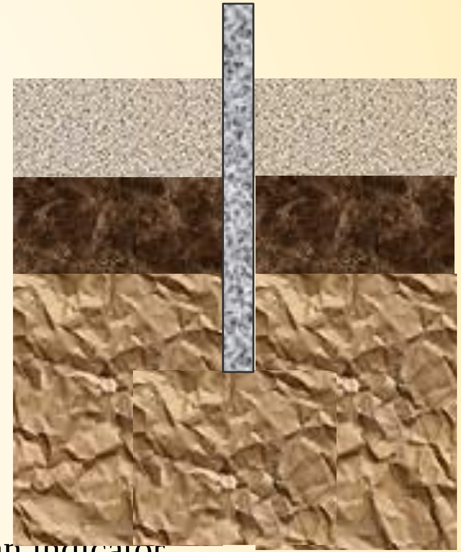
Dept. of Civil Engineering

Improving Design Phase Evaluations for High Pile Rebound Sites

By

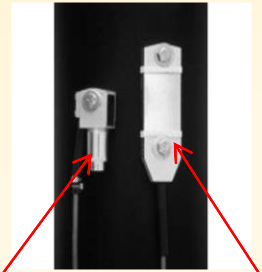
Paul J. Cosentino, Edward H. Kalajian, Yayha Sharif Eldeen, Al Bleakley, Ali Omar, Brian Wisnom, Hadeel Dekhn, Thaddeus Misilo and Alaa Shaban

Problem Statement

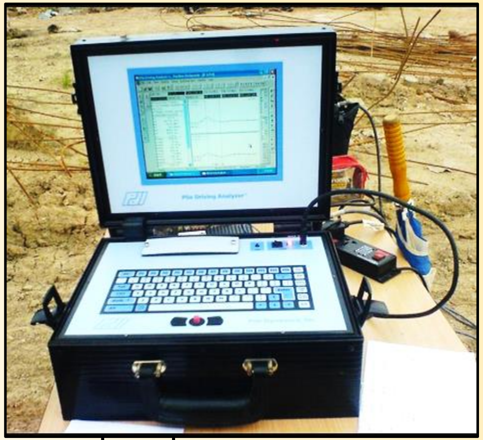


- **Definition**: >1/4" Rebound per Hammer Blow termed High Pile Rebound (HPR)
  - HPR occurs throughout Florida
  - HPR significantly increases hammer blows
  - HPR may damage the piles & hammers
  - HPR causes concerns about capacity loss
  - HPR may produce liability claims by the contractors
- **Typical Lab Testing** has shown limited trends with Fines Contents possibly being an indicator
- The lab testing **loading rate** is slow, but the pile driving is a fast dynamic loading rate

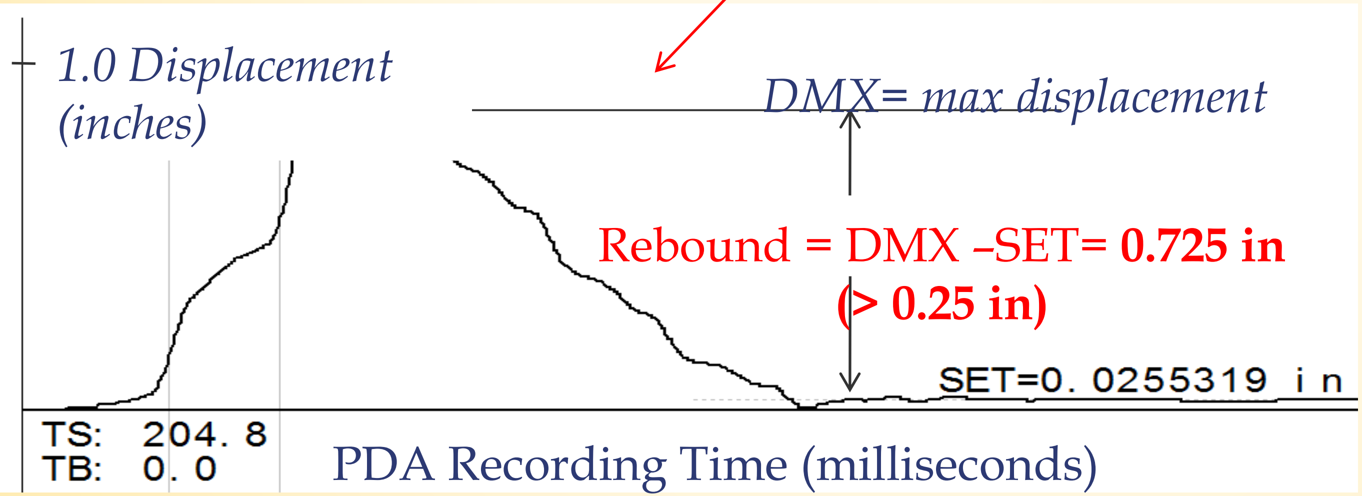
PDA data



Thanks to GRL



- The test piles are instrumented with accelerometers and strain gages.
- By double integrating ∬ accelerations, displacements versus time for each hammer blow are produced.

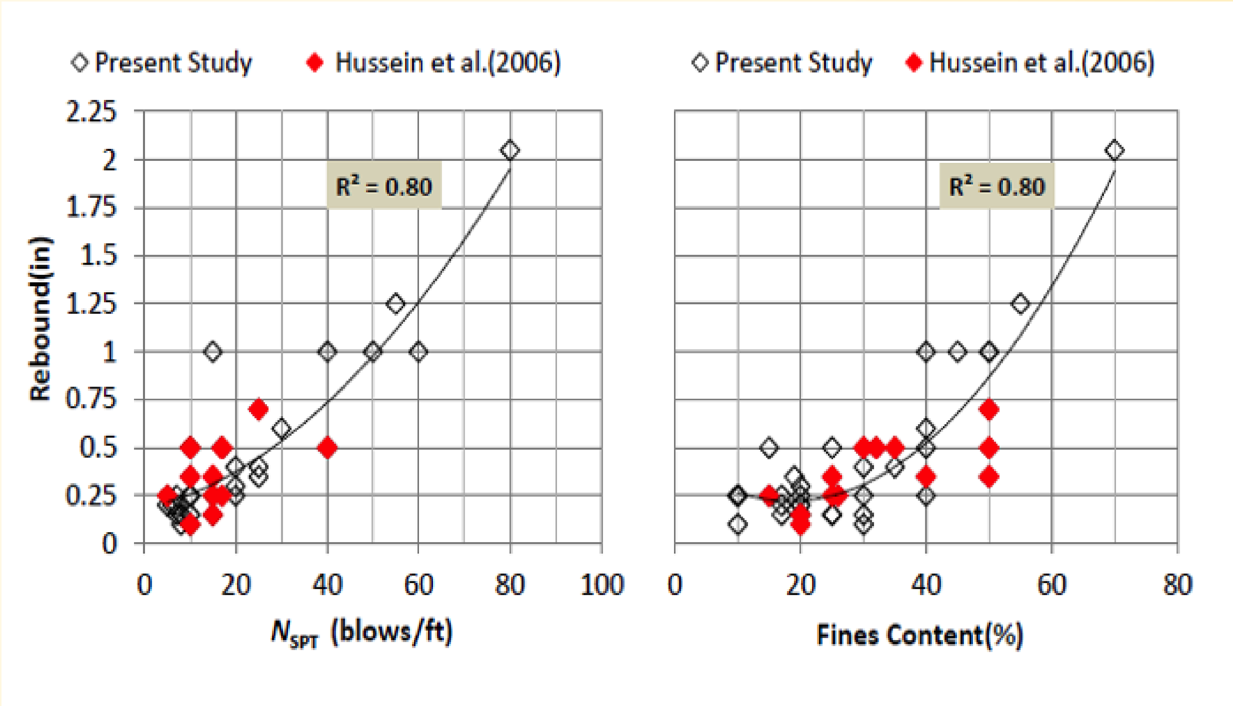


Either the digital or inspector sets can be used.

Inspector sets = 1/ pile driving blows per ft.

Background

- Correlations Published
  - Rebound vs. N from SPT
  - Rebound vs. Fines Content
- Limited Data Available
- Can these be validated?



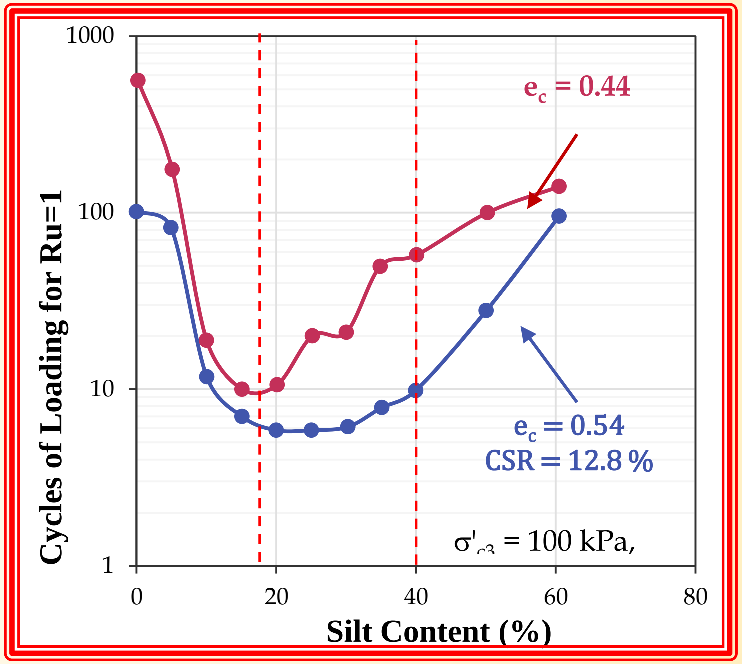
Florida Institute of Technology

Objectives

- Re-evaluate published N & FC correlations
- Identify and evaluate the geotechnical engineering properties which may cause high pile rebound
- Develop correlations to predict pile rebound during the design phase from
  - Cone Penetration Testing with Pore Pressures (CPTu)
  - SPT N values
  - Basic Engineering Properties from Grain Size & Atterberg Limits
  - Engineering Properties from Triaxial Tests including density, permeability and strength
  - Cyclic Triaxial Tests to evaluate any trends from faster loading

Selected Literature

- Large Displacement Piles Produced HPR
- HPR Encountered in Hawthorn Formation: fine sands with silts and clays
- Dash & Sitharam 2009 Cyclic Results
  - Excess Pore Pressure Ratio $Ru = \Delta u / \sigma'_3 = 1$
  - Critical Stress Ratio 15.4 or 12.8 % of $\sigma'_{failure}$
  - Initial Void Ratios e_c 0.44; 0.54
  - **From 15 to 35 % silt the behavior changes**
  - **Rate of Loading Affects Response**
- Plasticity also affects cyclic behavior
  - **High PI** Reduces liquefaction or cyclic failure potential



Methodology

- Identify Test Sites-3 Required More tested
  - CAD Drawings
  - Pile Driving Analyzing (PDA) Data from GRL
- Perform Field Investigation
  - Standard Penetration Test (SPT)
  - CPTu (i.e. Piezocone)
  - Shelby Tube Sampling
- Reduce Data, Analyze and Develop Correlations
- Conclusions & Recommendations that you'll remember ☺

❑ Identify Testing Sites

Testing Performed

Number	Description	Testing			
		SPT	CPTu	DMT	Undisturbed
1	I-4 / US-192 Interchange / Osceola County / Florida.	✔	✔	⌫	✔
2	State Road 417 International Parkway / Osceola County / Florida.	✔	✔	⌫	✔
3	I-4 / Osceola Parkway / Osceola County / Florida.				✔
4	State Road 50 and State Road 436 / Orange County / Florida.	✔	✔		
5	I-4 / State Road 408 Ramp B / Orange County / Florida.	✔	✔		
6	Anderson Street Overpass at I-4/SR-408 / Orange County / Florida.	✔	✔		
7	I-4 Widening Daytona / Volusia County / Florida.	✔	✔		
8	State Road 83 over Ramsey Branch Bridge / Walton County / Florida.	✔	✔		✔
9	Saint Johns Heritage Parkway, Brevard County	✔	⌫	⌫	✔
10	I-10 Chaffee Road, Duval County Florida	✔	⌫		✔

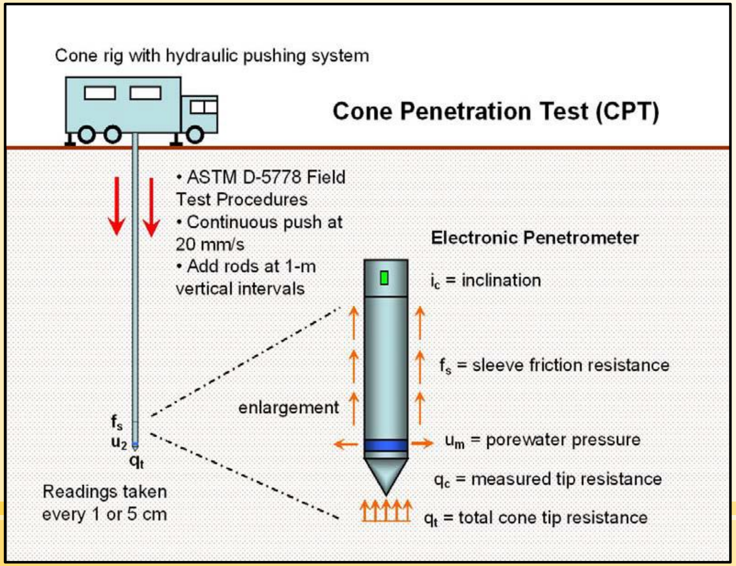
Standard Penetration Test (SPT)

- SPT tests performed as near as possible to the test pile.
- Disturbed samples retrieved every 5 ft and packaged for further lab testing.
- A soil profile for each SPT boring was developed using the Unified Soil Classification System (USCS).

Cone Penetration with Pore Water (CPTu)

CPTu Testing Near Test Pile

- Cone Tip Resistance (q_t)
- Sleeve Friction (f_s)
- Pore Water Pressure (u_2)

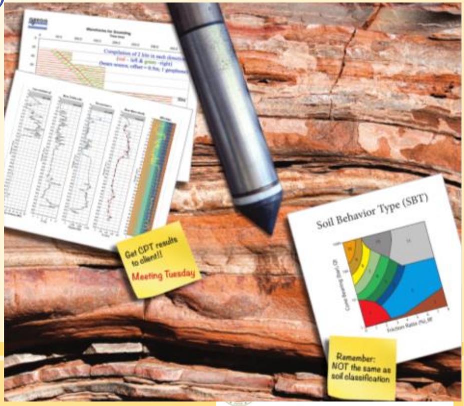


Soil Properties Estimated

- Saturated Density (γ)
- Permeability (k)
- Relative Density (D_r)
- Undrained Shear Strength (S_u)
- Fines Content (FC)
- Overconsolidation Ratio (OCR)
- State Parameter (ψ)
- Soil Behavior Type (SBT)

SOUTHERN EARTH SCIENCES, INC.

Brian Bloomfield



Thin Walled Tube Testing Near Test Pile @ Six Sites (1-3 & 8-10)

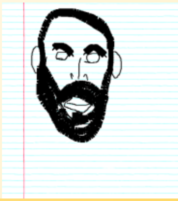
Conventional Testing

- Grain Size with Hydrometer & Limits
- Natural Moisture
- Density
- Triaxial Permeability
- CU Triaxial

Cyclic Triaxial Testing

- 1000 cycles
- Stress Levels
  - 20: 40: 60: 80 % of σ_{dmax}
- Δu; Load and Displacement recorded
- Confined based on σ'_{vo} @ sample depth

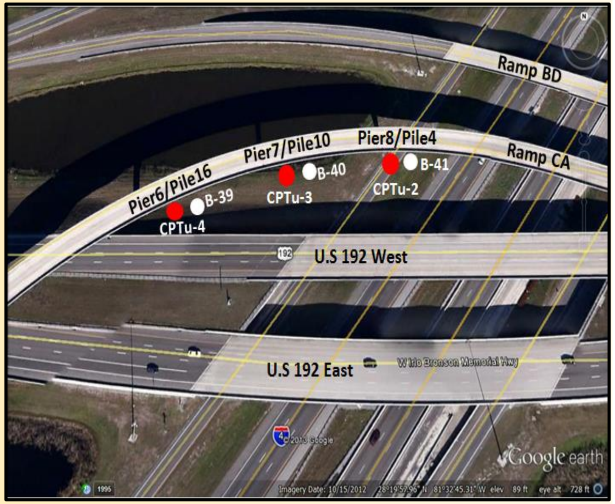
Thank you SMO !!! Glenn Johnson, Jose Hernando and That Guy☺

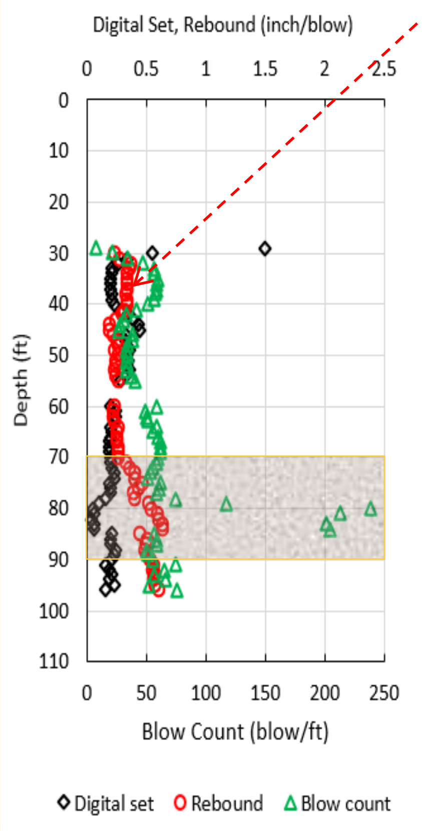


Typical Field Testing (from 2 sites)

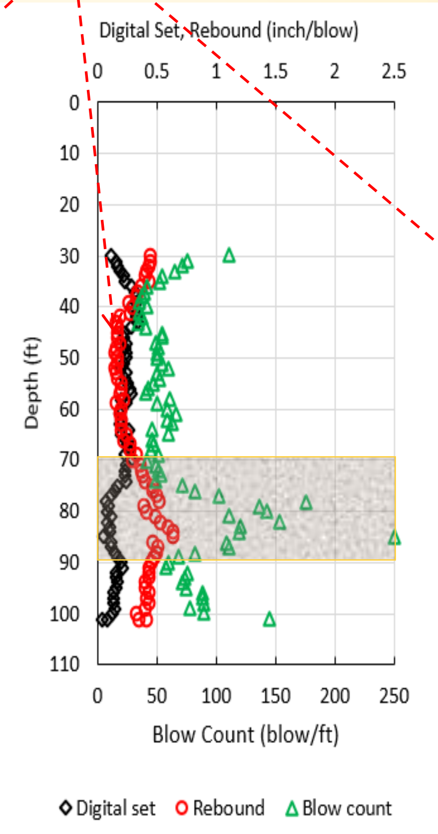
PDA Rebound (RED) between ½ and 1” from 70 to 90 ft.

Site 1: I-4 US 192 Ramp CA

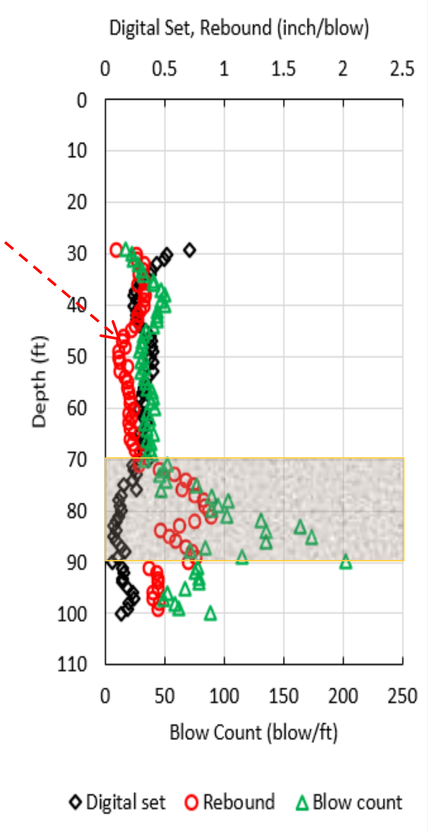




Pier 6 / Pile 16



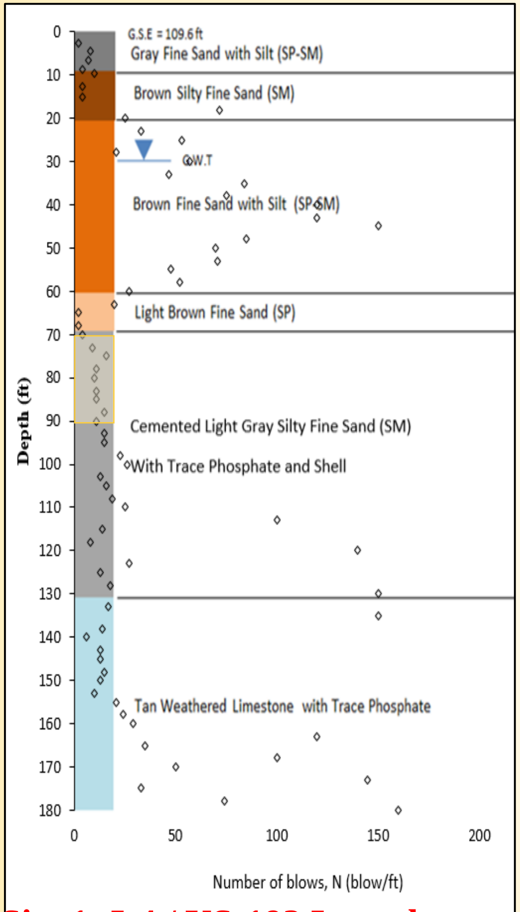
Pier 7 / Pile 10



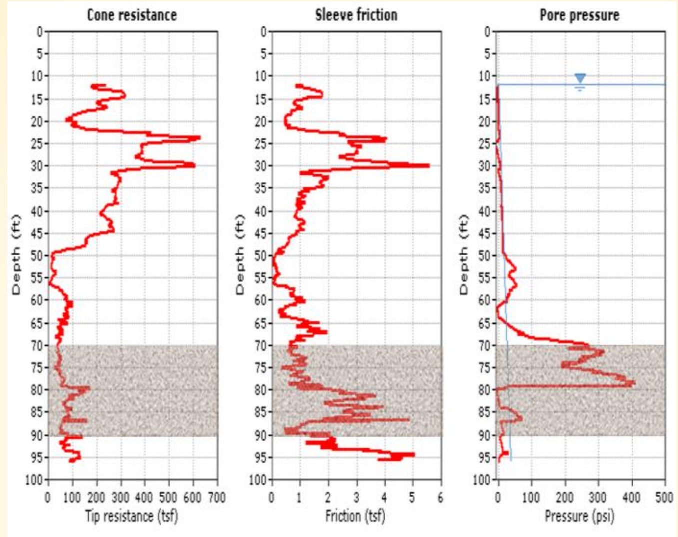
Pier 8 / Pile 4

Typical Field Testing

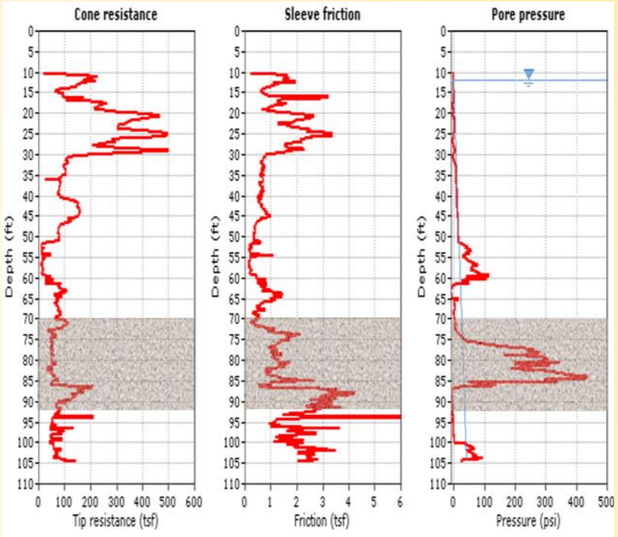
SPT N-Values and Soil Profile



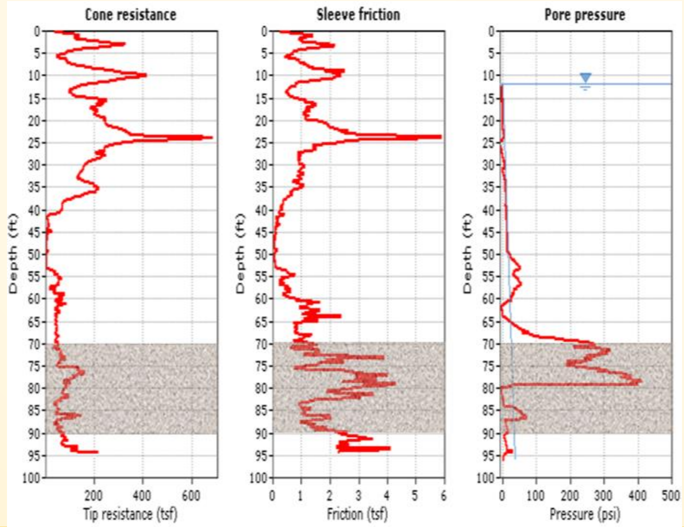
Site 1: I-4 / US-192 Interchange



Pier 6/ Pile 16



Pier 7 / Pile 10



Pier 8 / Pile 4

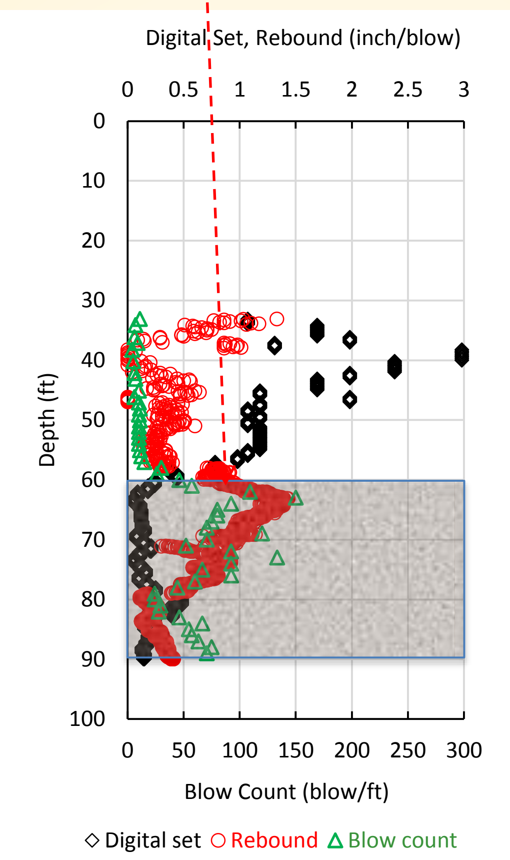
CPTu for I-4 / US-192 Interchange

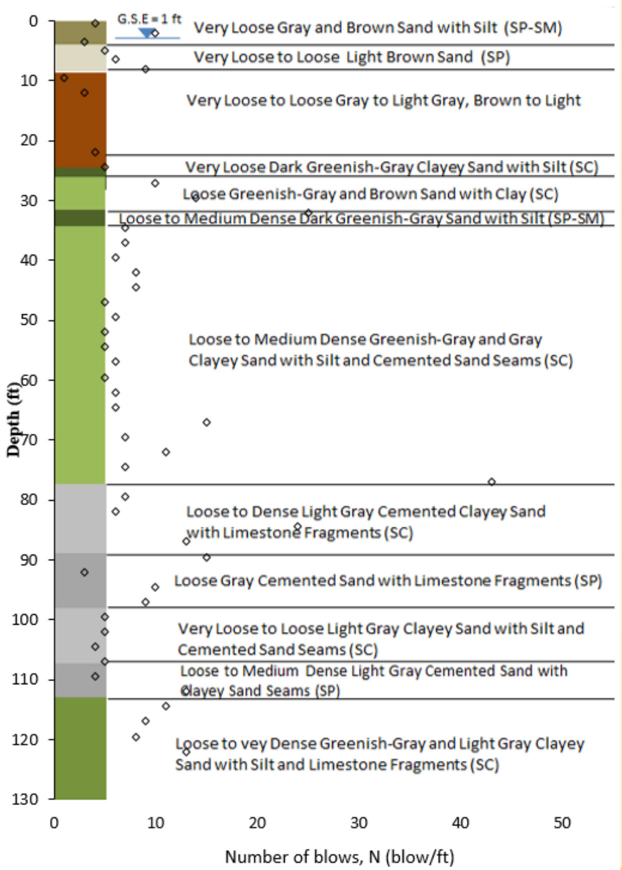
Typical Field Testing

Rebound (RED) up to 1.5 inches throughout driving most critical at 60 ft.

Site 2: SR 83 Ramsey Branch Bridge Over Choctawhatchee Bay

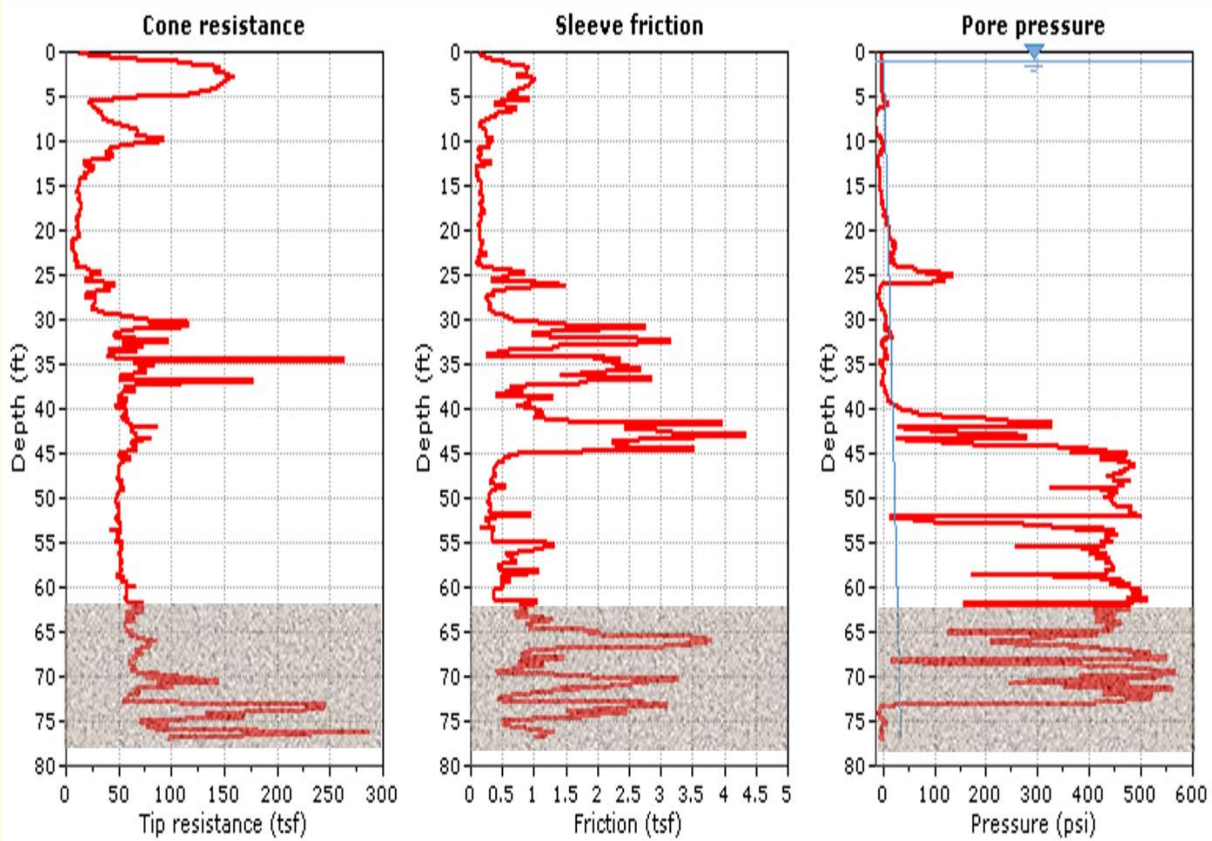
EB 5 / Pile 2





Field Testing Results

SR 83 Ramsey Branch Bridge CPTu

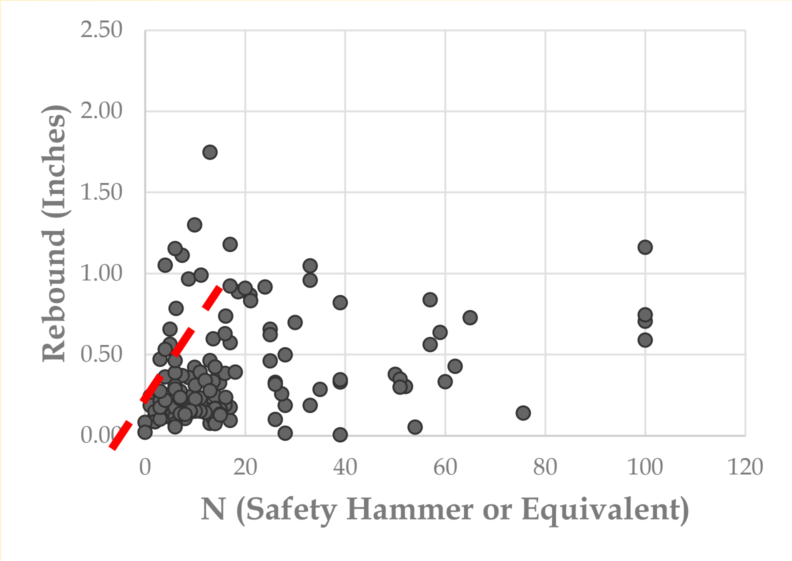


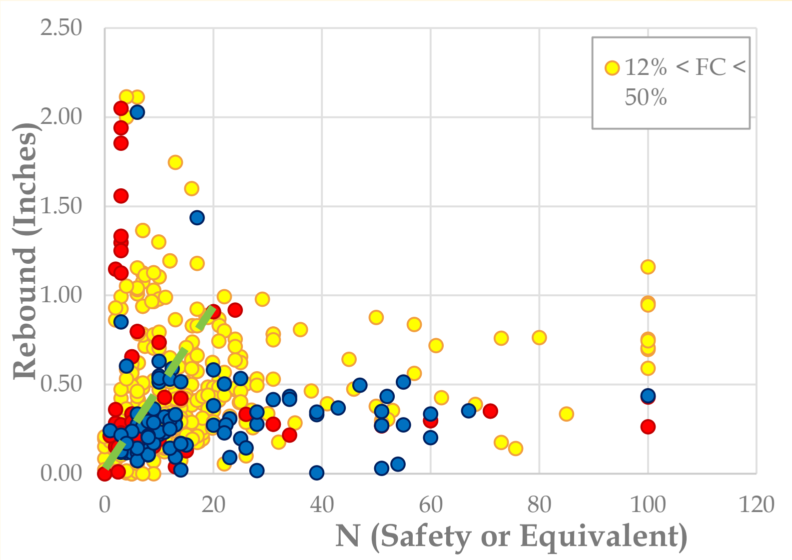
Average Field Testing Data from Seven Sites with CPTu

Site Type	Depth (ft.)	Driving Data		SPT Data	CPT Data		
		Rebound (in./blow)	Driving Blows (blow/ft.)	N_{SPT} (blow/ft.)	Point Resistance q_c (tsf)	Sleeve Friction fs (tsf)	Pore Pressure u_2 (psi)
Ave NonHPR	37-70	0.21-0.24	27-33	8-13	66-156	0.4-1.0	21-111
Ave HPR	61-77	0.36-0.81	50-172	20-23	48-150	0.7-2.5	172-240

Reevaluations of Rebound Vs. N & FC

Rebound vs. N





Shows some increase up to 1-inch; No real trends; Also evaluated various Fines Contents still no trends

Is Soil Dilation Occurring to Produce High Δu?

N_{SPT} from Anderson Street Overpass & Seed 1985 correlations

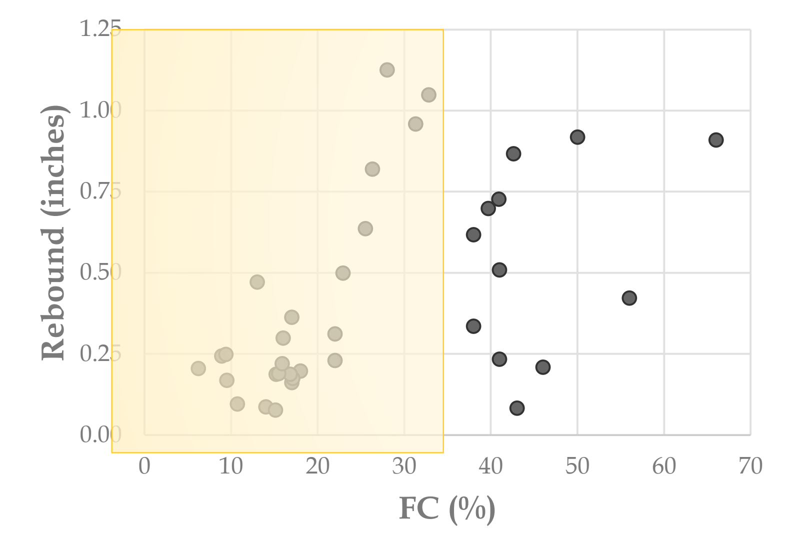
Rebound > 0.50 inches shows more frequent dilation

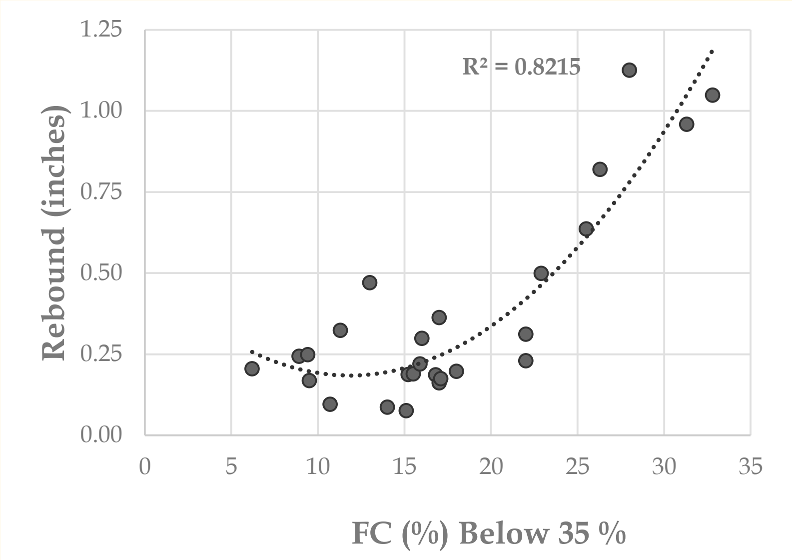
Behavior	Percentage	
	Rebound	**Nonrebound**
Contractive	**53%**	**72%**
Intermediate	**27%**	**17%**
Dilative	**20%**	**11%**
Total	**100%**	**100%**

125 samples **370 samples**

Rebound > < 0.50 inches

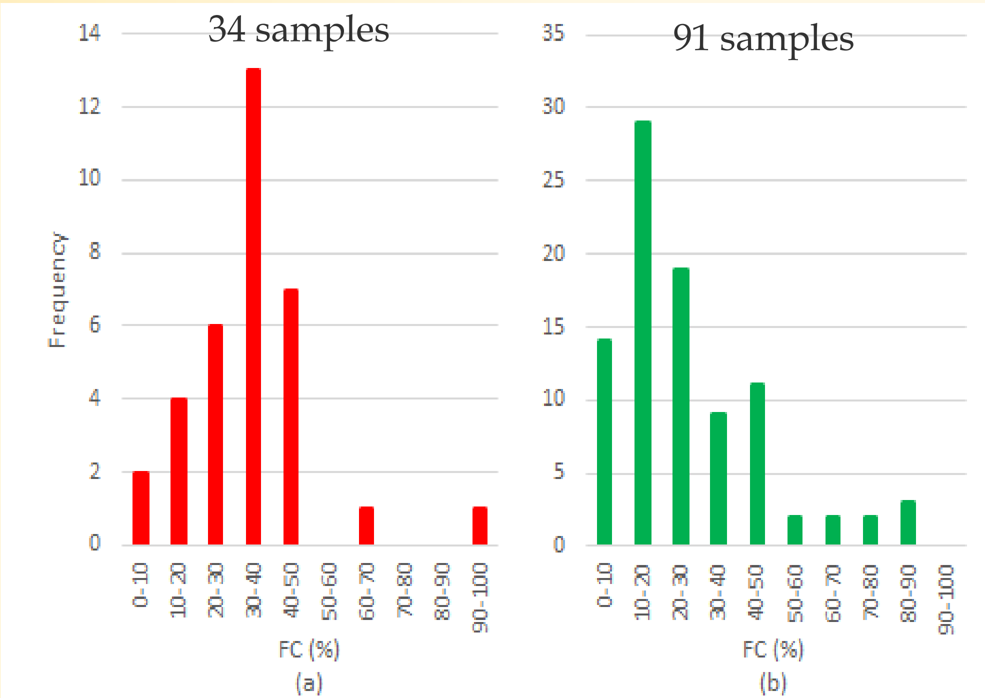
Rebound vs. Fines Content from SPT samples





Florida Institute of Technology

How Fines Content affect Rebound



Fines Content % Range		Percentages	
Min	Max	Rebound	Nonrebound
0	10	6%	15%
10	20	12%	32%
20	30	18%	21%
30	40	38%	10%
40	50	21%	12%
50	60	0%	2%
60	70	3%	2%
70	80	0%	2%
80	90	0%	3%
90	100	3%	0%
Total %		58%	31%

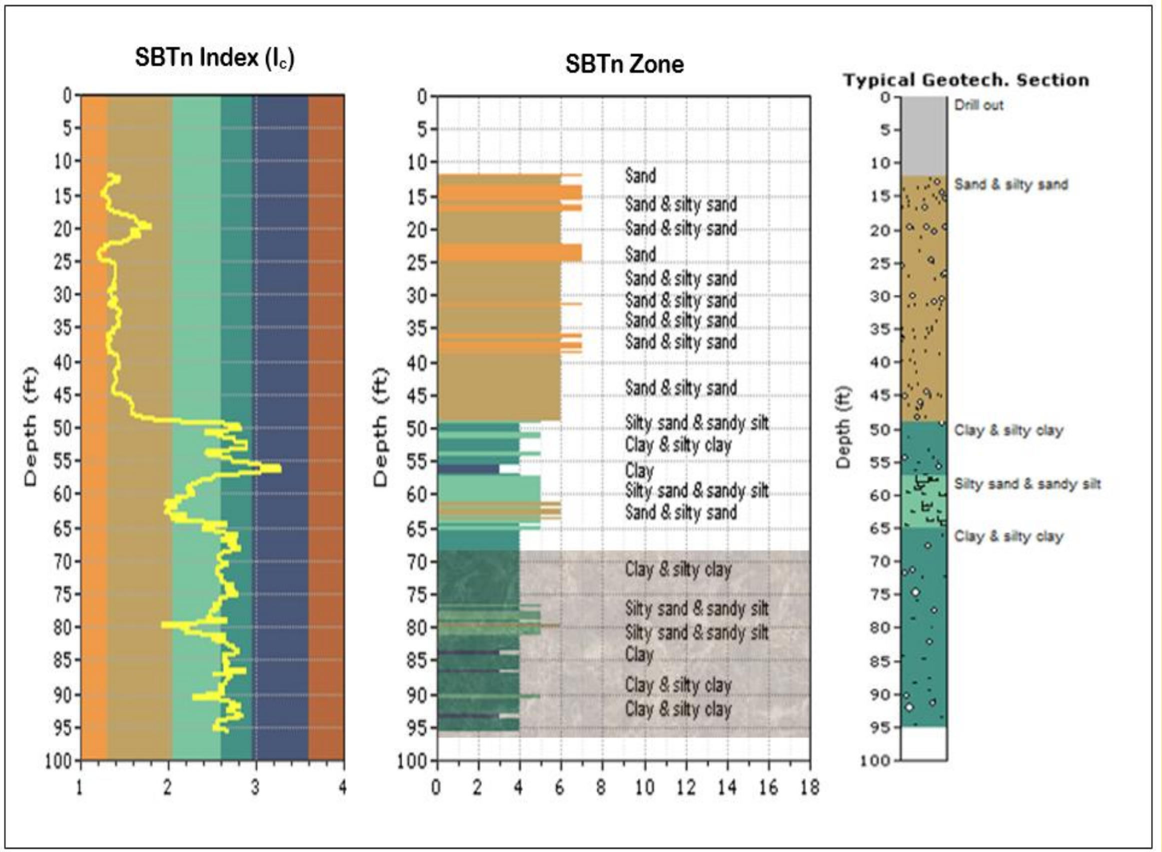
58% vs 31%

Rebound > < 0.50 inches

Analysis of CPTu Data

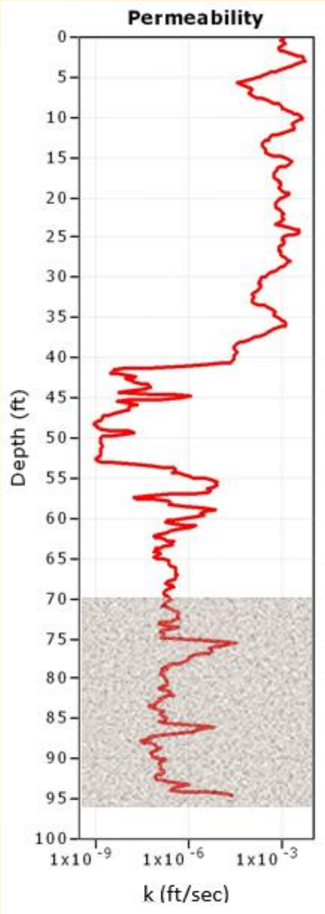
- **Soil Stratigraphy Using CPT Data**
- **Location I-4 / US-192 Interchange**

- Robertson Software **CPeT-IT** with Correlations
- Geotechnical soil properties estimated from CPTu data were used to evaluate HPR soil behavior



CPTu Estimated Permeability

Typical Results: I-4 / US-192 Interchange

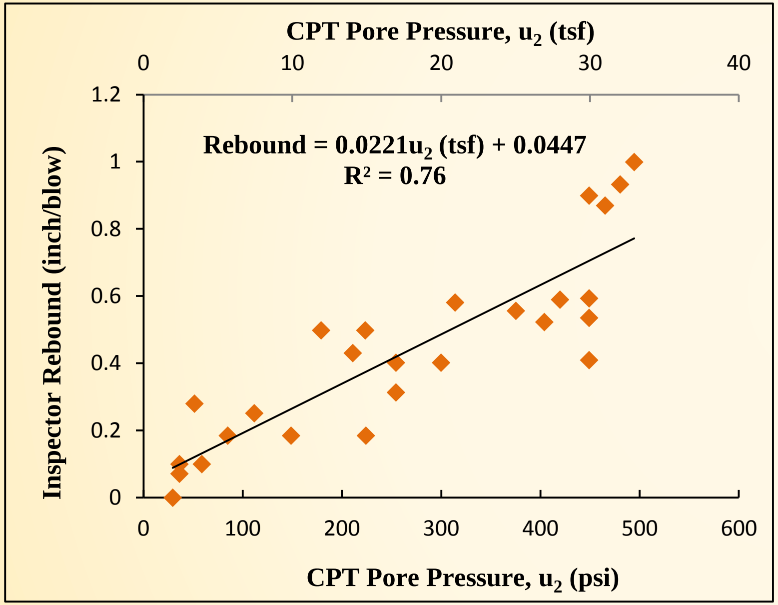


- Rebound soils: 3×10^{-3} cm/s to 1.5×10^{-6} cm/s
- Non-rebound soils: 3×10^{-2} cm/s to 3×10^{-4} cm/s

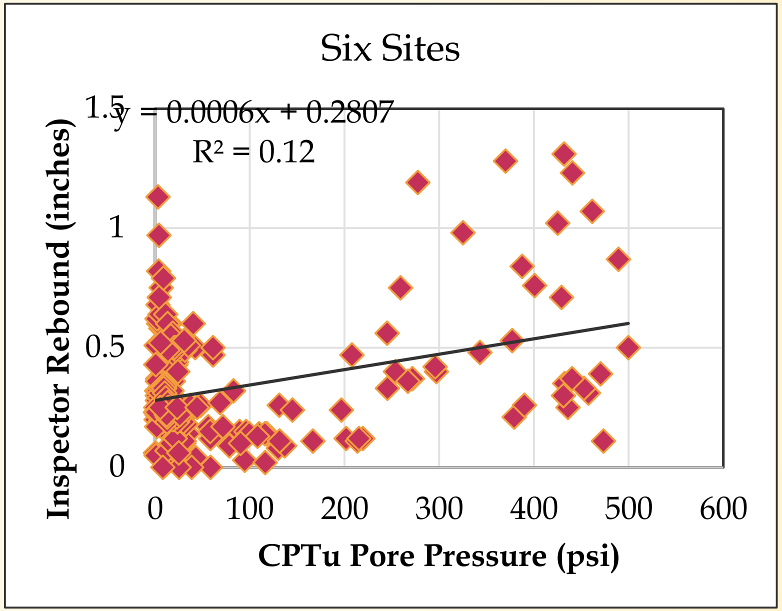
CPTu Overconsolidation Ratio (OCR)

- Soils with high OCR can also be classified as cemented soils.
  - Cemented soils behave like overconsolidated soils.
- HPR soils: OCR ranges from 5 to 10.
- NonHPR soils: OCR ranges from 0.5 to 3.

Evaluation Existing Correlation between HPR and CPT Pore Water Pressure

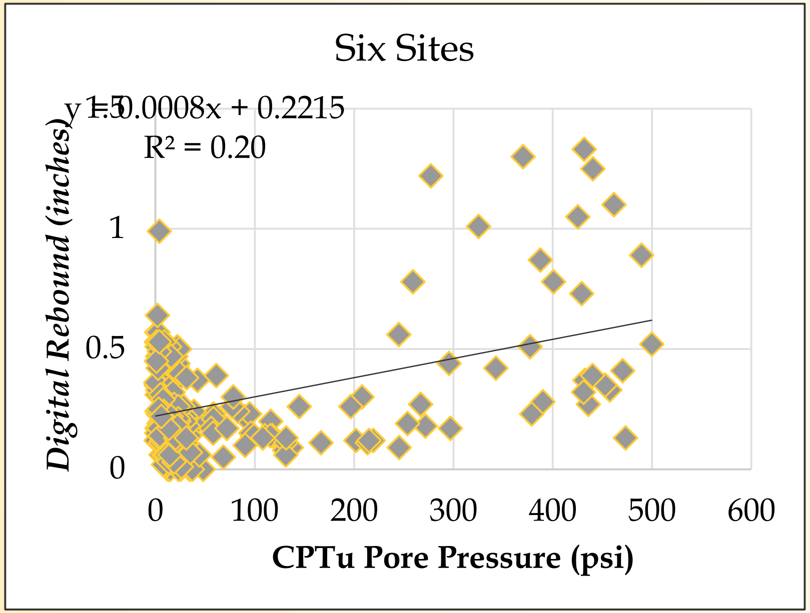


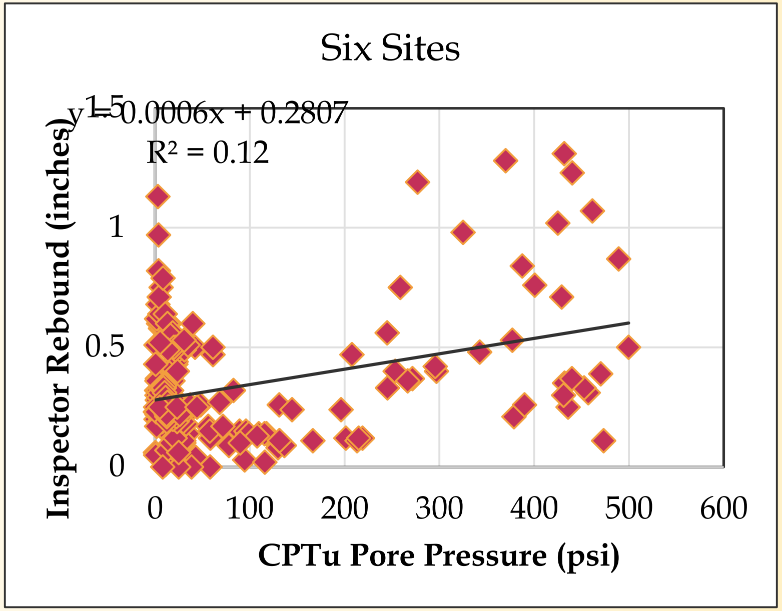
Published Correlations



Re-evaluation

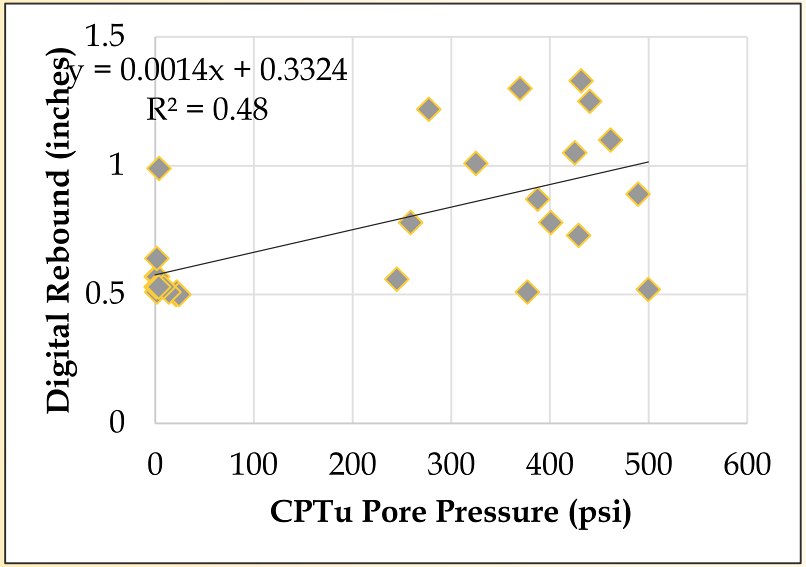
Digital vs Inspector Comparison

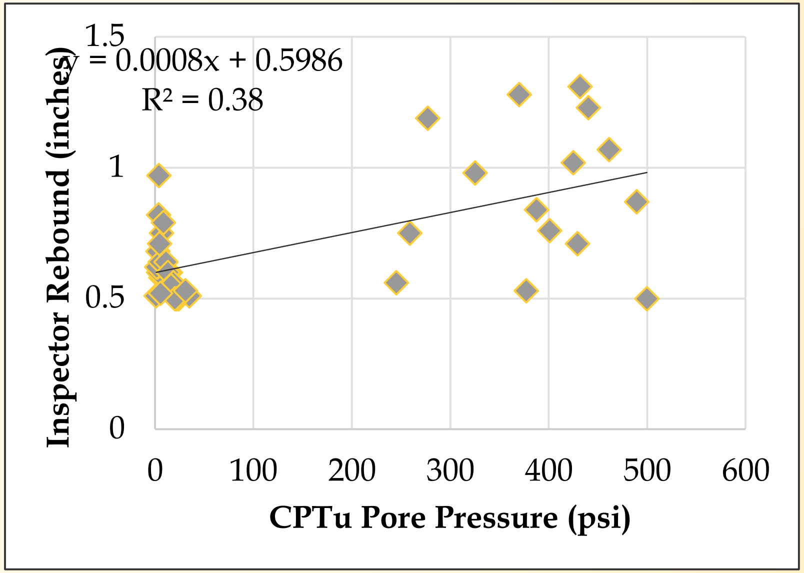




Digital Rebound (DMX-Digital SET) produces slightly higher R^2 – Less Scatter at low Δu

½ inch Rebound Six Sites R^2 improves

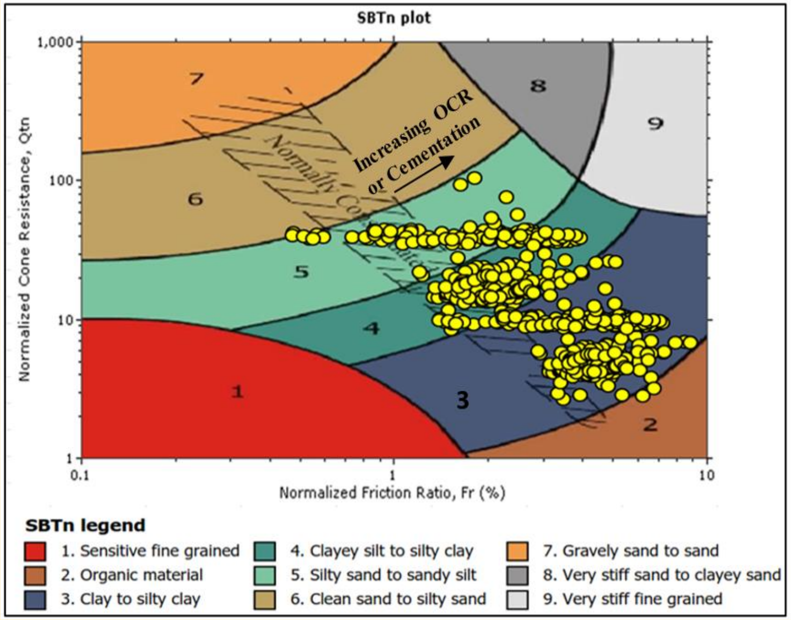




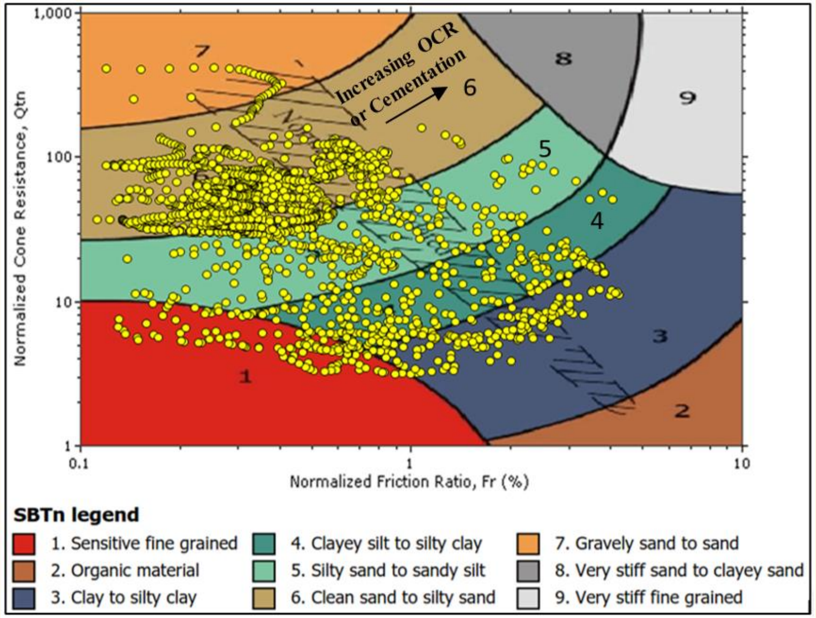
Soil Behavior Type Charts

- Based on CPTu output engineers can classify soils and Rebound Soils Show Trends
  - Robertson (1990)
  - Robertson (2012)
  - Schneider (2008)
  - Islami and Fellenius (1997)
- Caution regenerating the following trends is complex & time consuming and is presented for research purposes only

Soil Behavior Type (SBT) Tip and Sleeve Data — Robertson (1990)

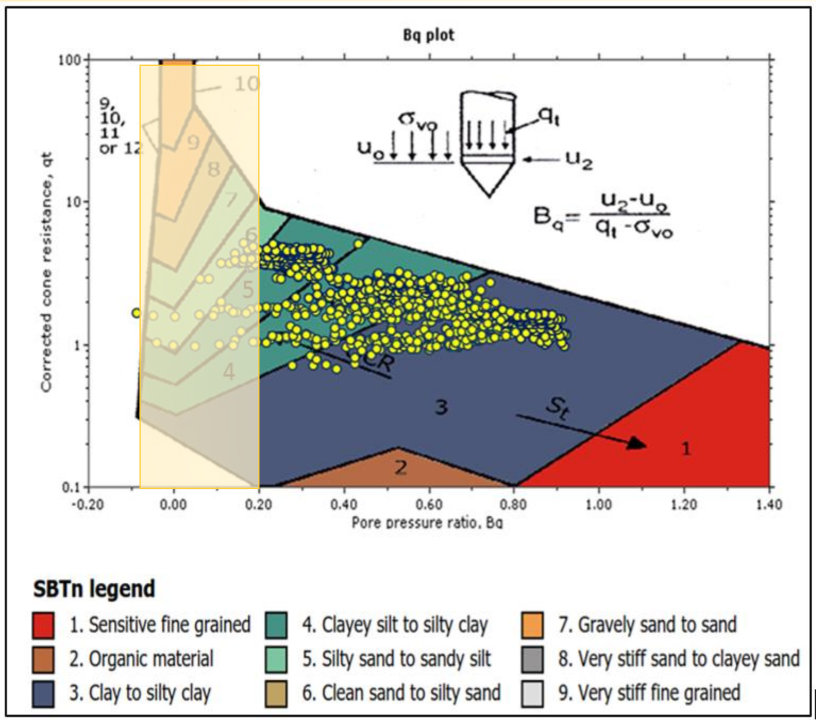


Rebound

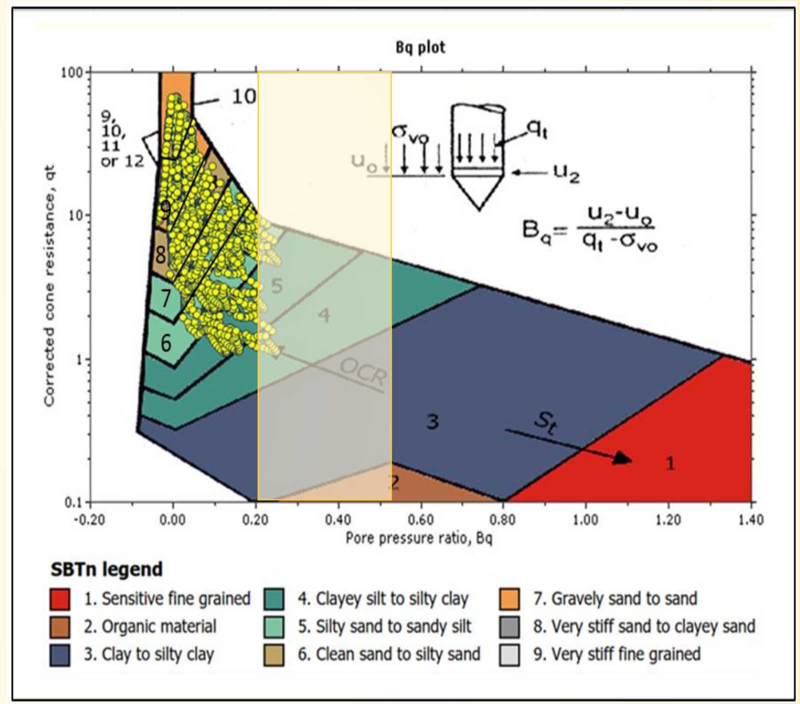


Non-rebound

Soil Behavior Type (SBT) Tip and Pore Pressure Robertson (1990)

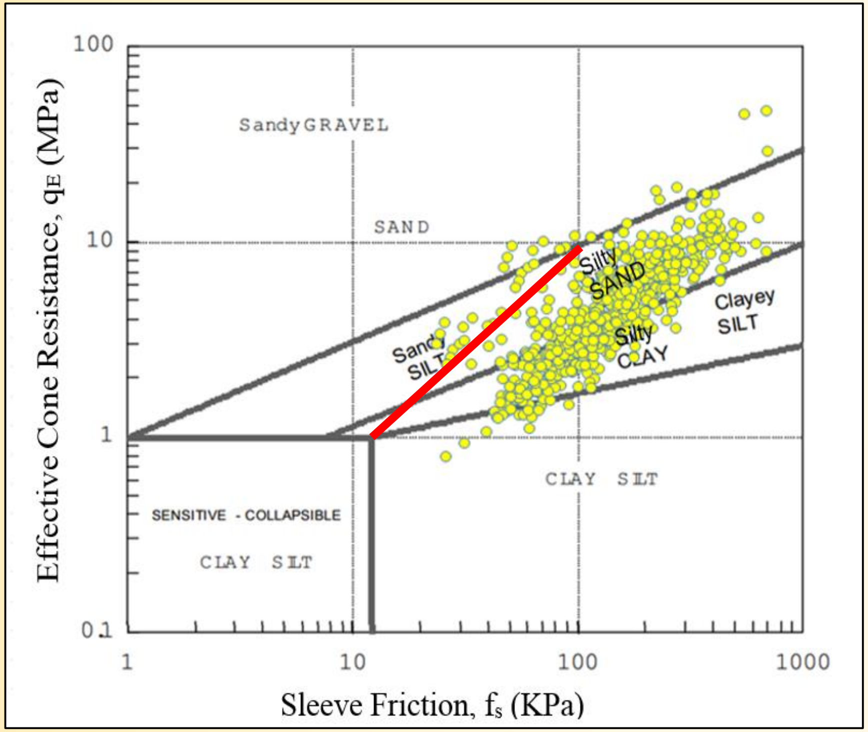


Rebound

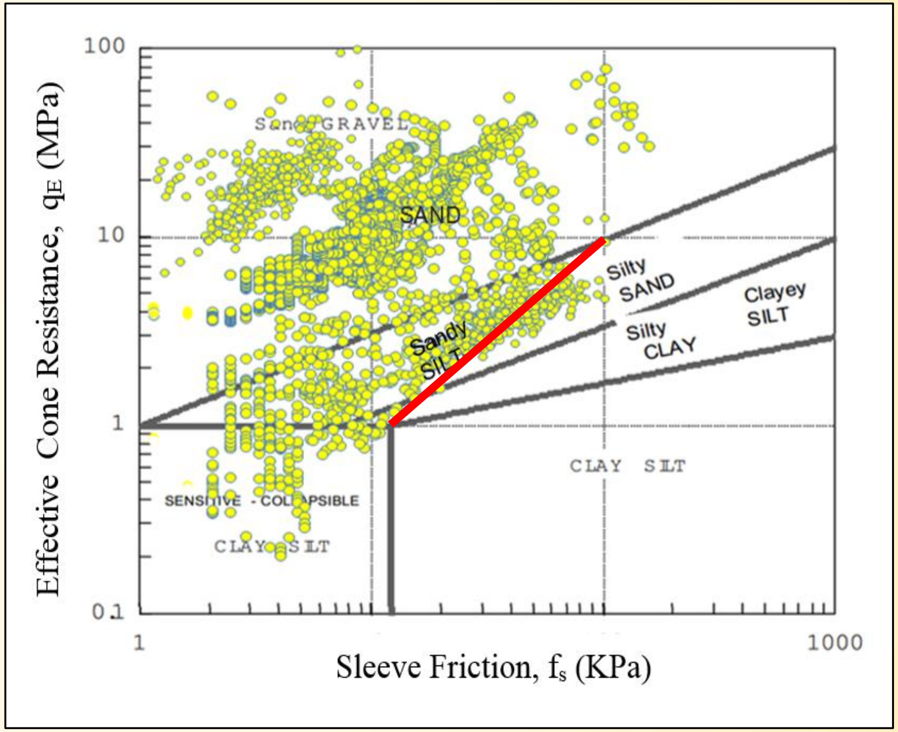


Non-rebound

Soil Behavior Type (SBT) Tip and Sleeve Eslami and Fellenius (1997)

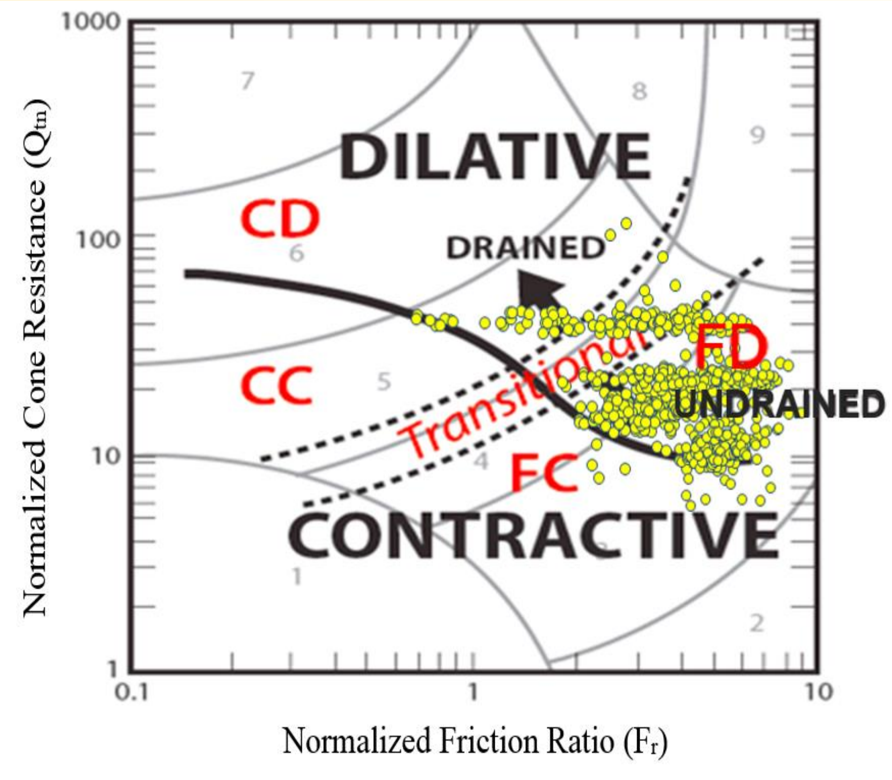


Rebound



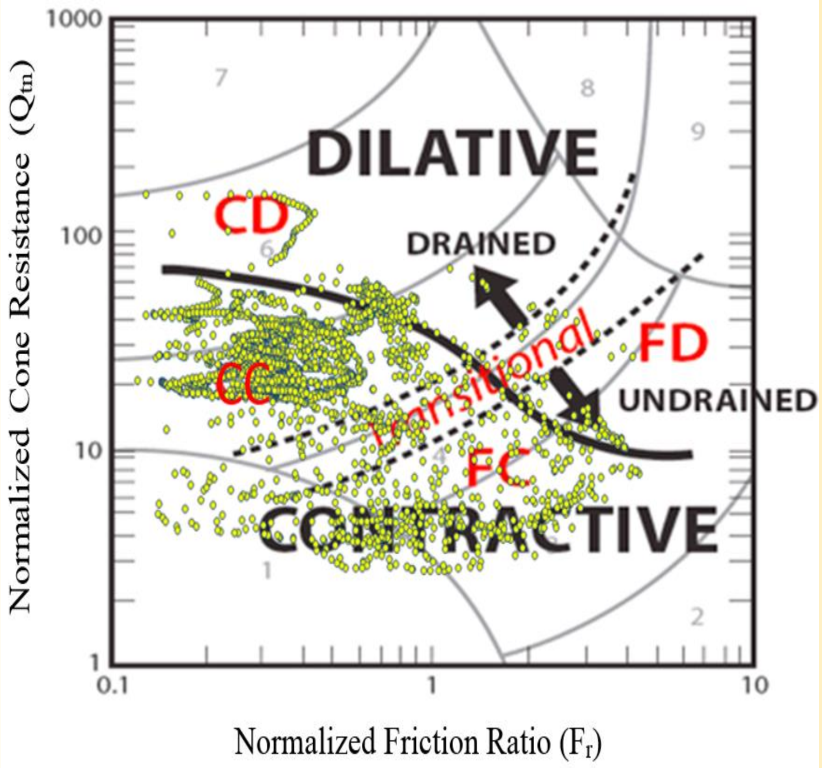
Non-rebound

Soil Behavior Type (SBT) Tip and Sleeve Robertson (2012)



Rebound

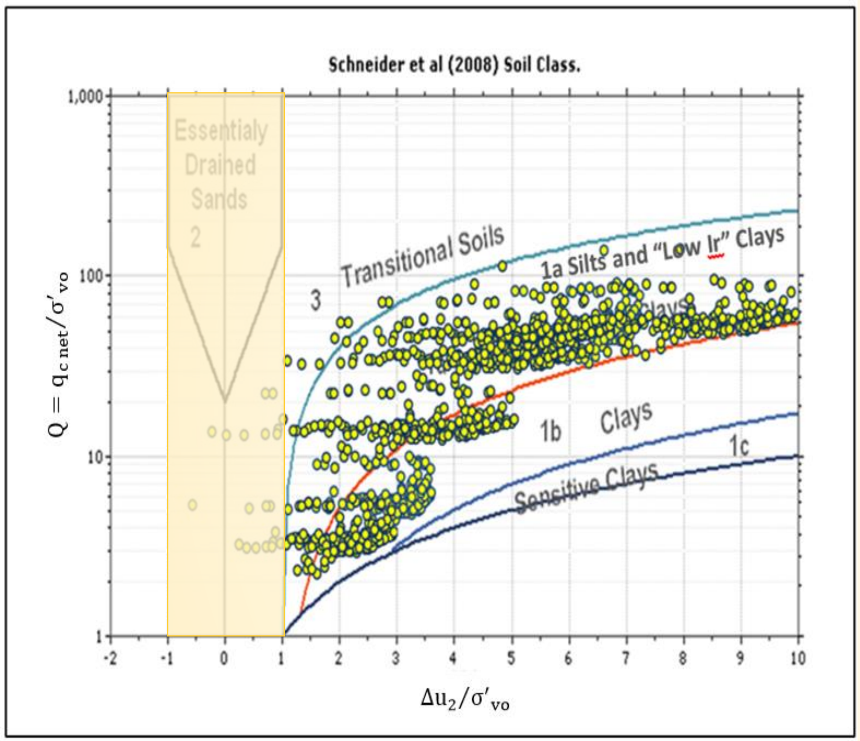
Fine Dilative (FD) Soils Rebound



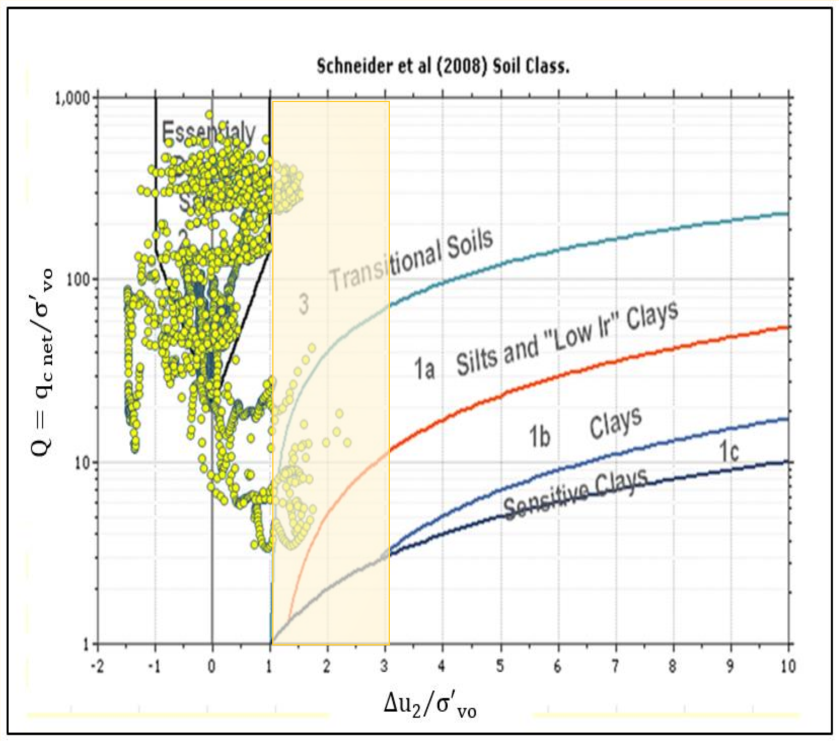
Non-rebound

Coarse Dilative (FD) Coarse Contractive (CC), Fine Contractive (FC) Soils Do Not Rebound

Soil Behavior Type (SBT) Tip and Pore Pressure Schneider (2008)



Rebound



Non-rebound

SBT Findings

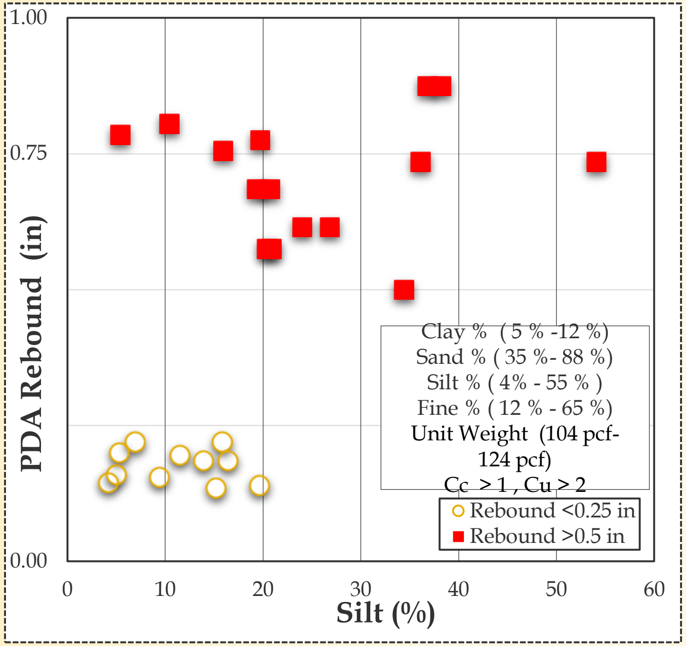
- Conventional CPT Soundings can be used
  - HPR soils fall in Zones 3-5
  - There seems to be a pore pressure threshold
  - Based on a very limited number of soundings

Shelby Tube -- Grain Size Results

- Classification with Hydrometer
  - All cohesionless soils SM regardless of rebound or no rebound behavior
  - Cohesive rebound soils all CH
  - Cohesive nonrebound soils predominately CL one SC
- Conclusion: only cohesive rebound soils showed a grain size trend

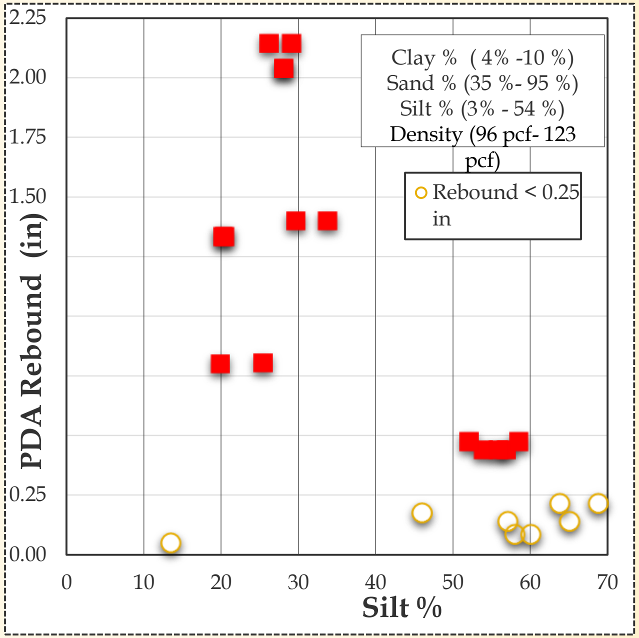
Shelby Tube -- Silt Content Results

Cohesionless Soils



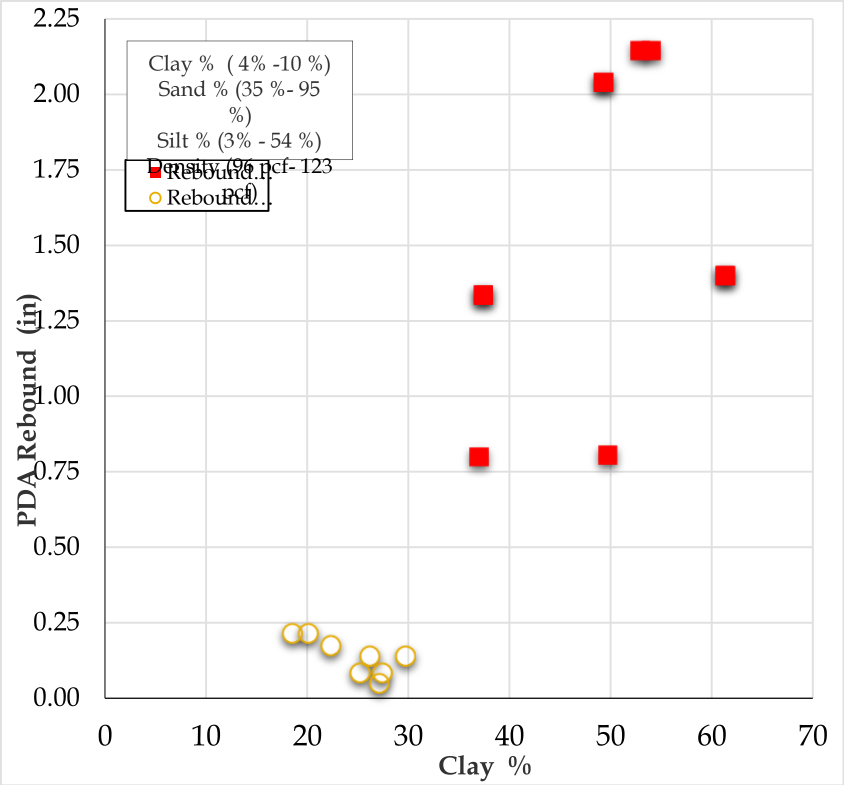
- Above 20 % Silt ALL Rebound > 0.5”

Cohesive Soils



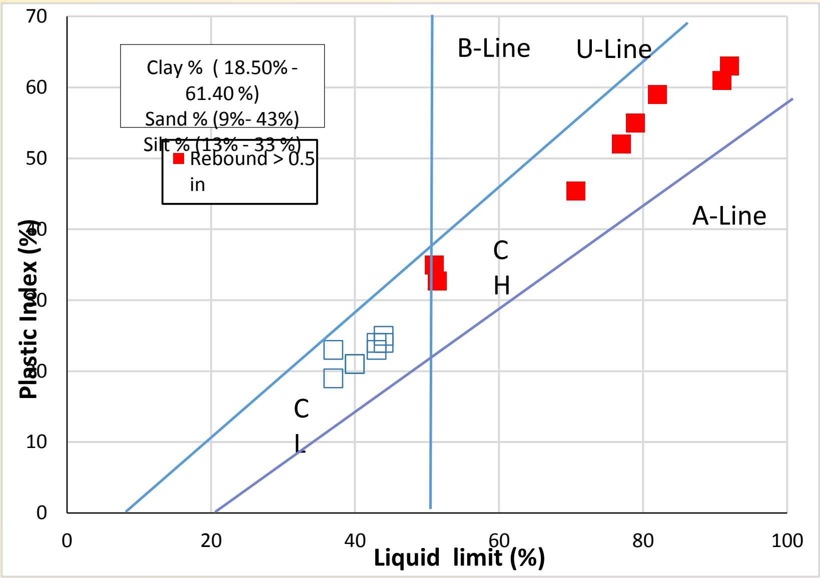
- Between 20 & 35 % Silt ALL Rebound > 0.5”

Shelby Tube – Clay Content Results



- Only Cohesive soils show trend
  - Cohesionless not shown
- All clay contents above 30% rebound

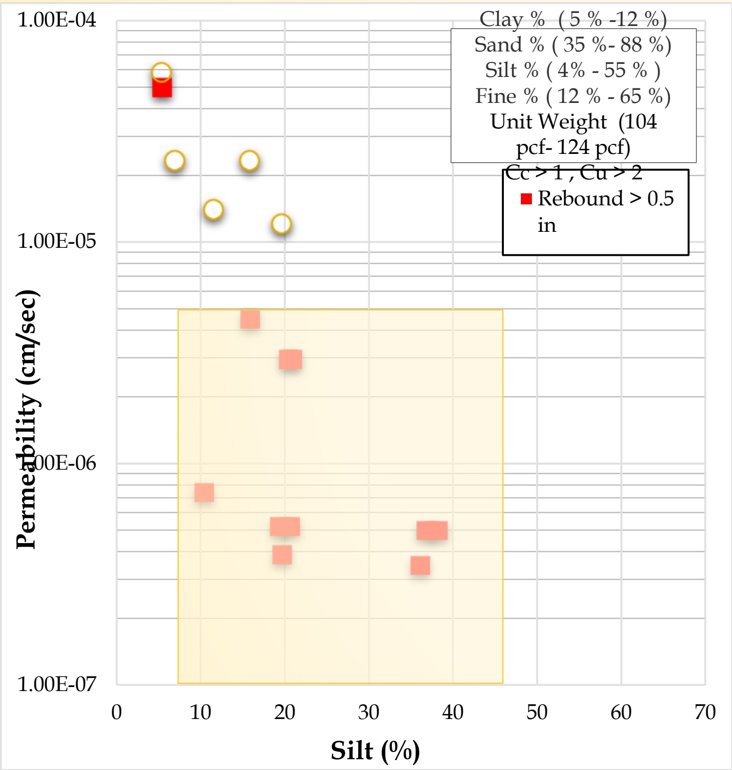
Shelby Tube --Atterberg Limits on Clays Results



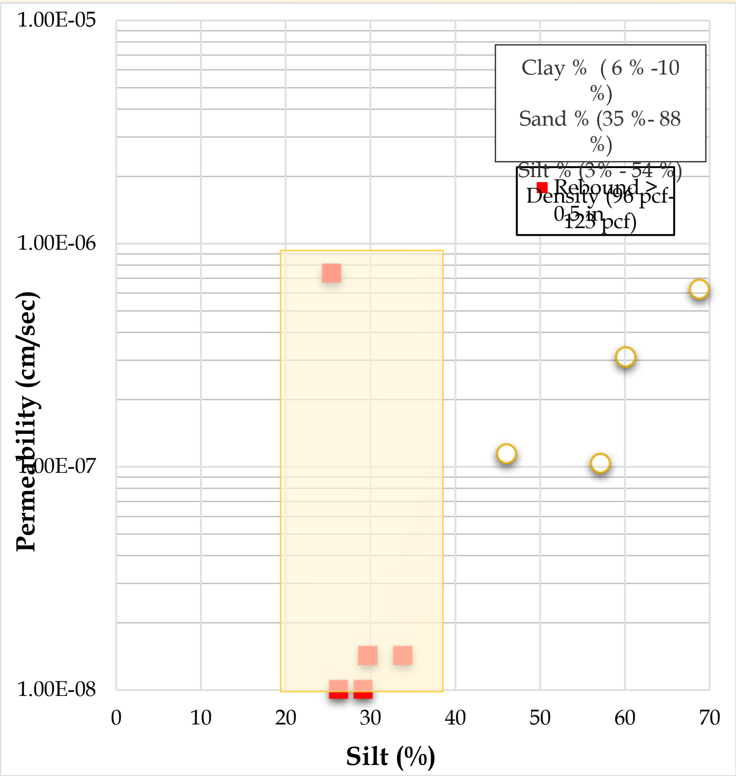
- Nonrebound Soils that are Clays all CL
- Rebound Soils that are Clays all CH
- Plot Above A-Line
- Matches Literature (Slide 6)

Shelby Tube – Triaxial Permeability Results

Cohesionless



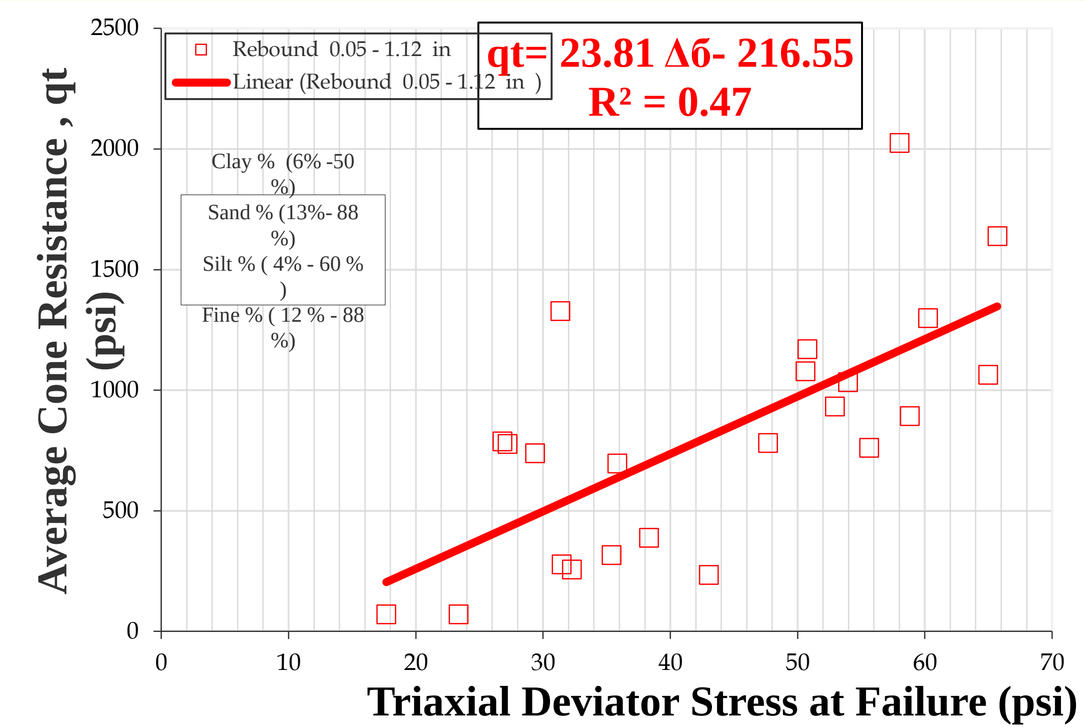
Cohesive



- Most k values below **10-6ish** cm/sec rebound > 0.5 "
- Most k values below **10-7** cm/sec rebound > 0.5 "

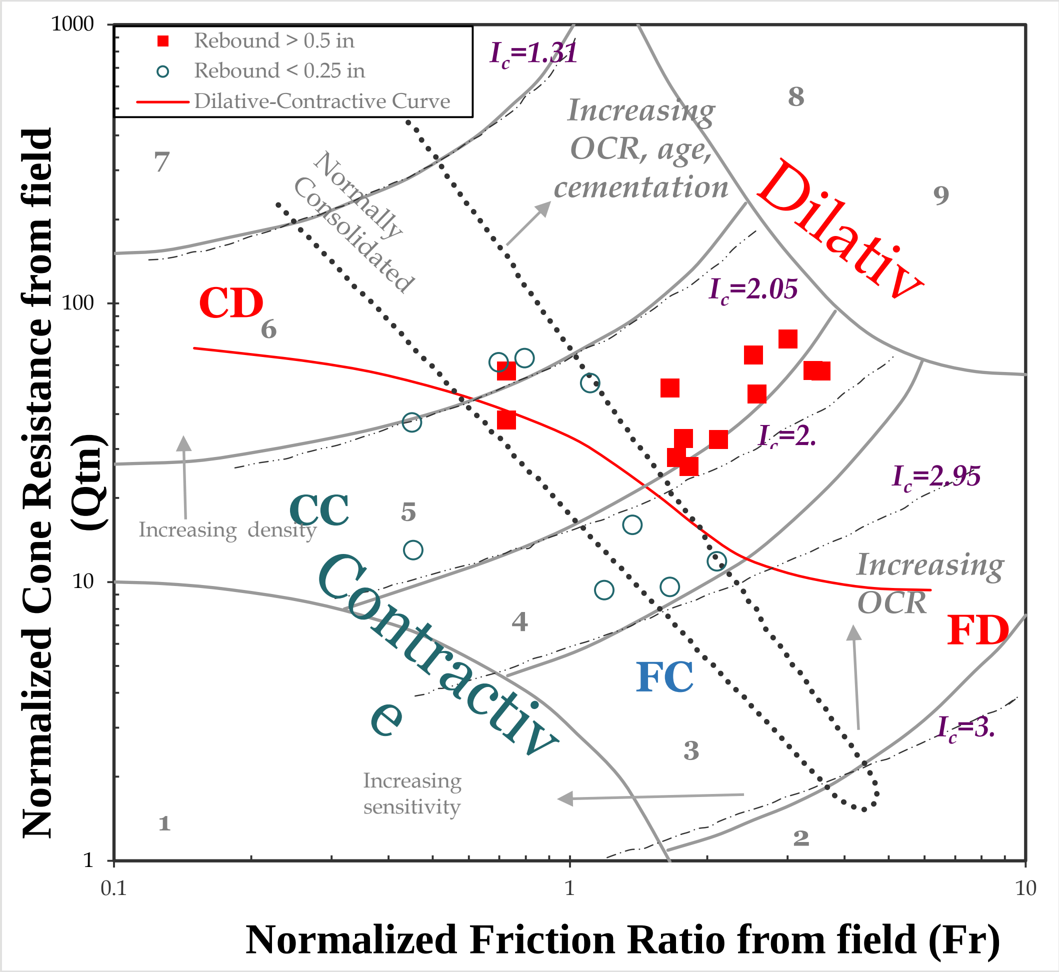
Florida Institute of Technology

Triaxial and CPT Cone Resistance Comparison



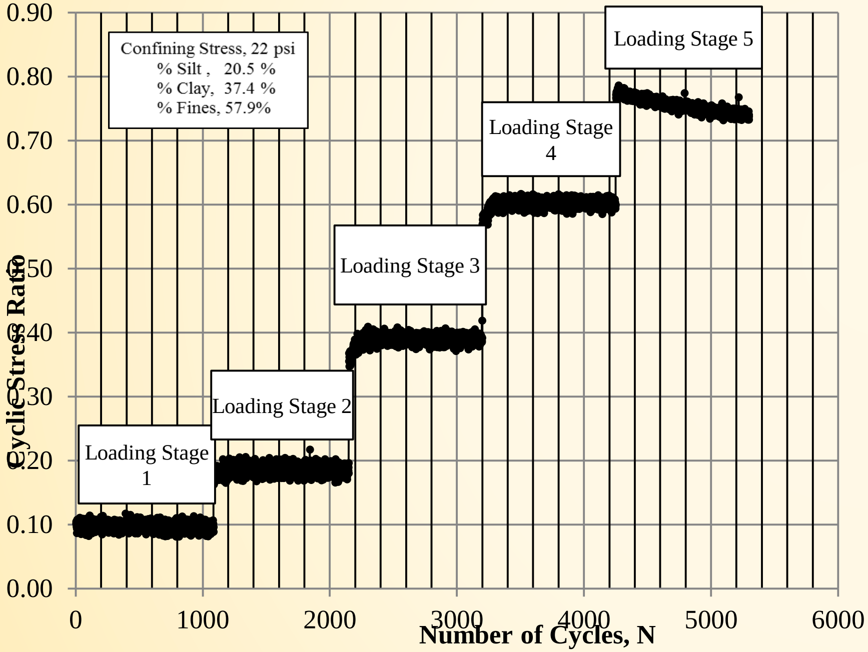
SBT Plot

- Shelby Tube sample depths and locations matched to nearest CPTu data.
- Rebound and nonrebound data on Robertson 2012 SBT chart



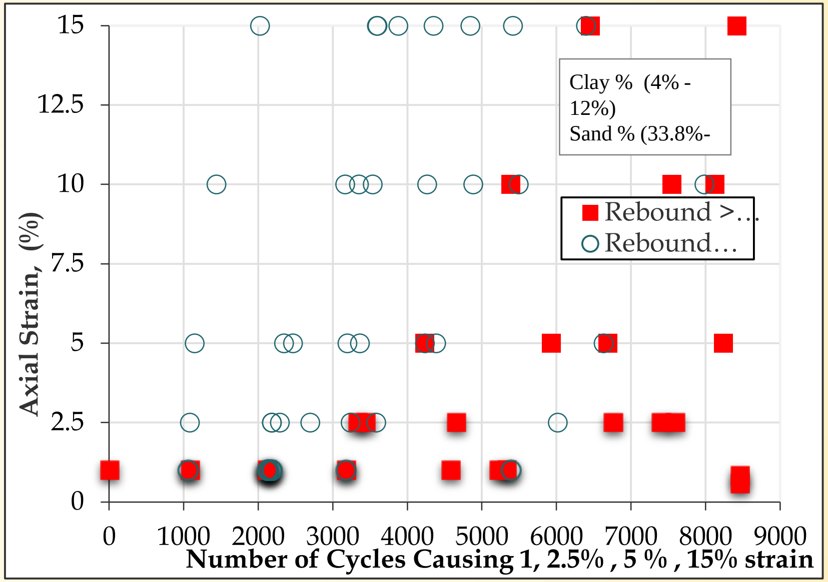
Florida Institute of Technology

Shelby Tube – Cyclic Triaxial Results



Stress Ratio could also be % failure stress

10% 20% 40% 60% 80%



HPR Soils More Resilient: Many more cycles to produce the same strain!!!!

Up to 4 times more just like the piles

Some of the Conclusions ☺

1. There is no clear Rebound versus N value Correlation when sufficient data is available
2. The Rebound versus FC correlation is weak based on a larger number of data points
3. SPT N values showed some dilative trends for HPR soils at one of the sites
4. There was no clear USCS classification difference for cohesionless HPR and NonHPR soils
5. Rebound seems to be a function of silt content greater than 20 % and less than 40% for SM soils
6. Cohesive HPR soils classified as CH, while the NonHPR cohesive soils classified as CL
7. The CPTu pore water pressures of HPR soils are very high as long as the layer is thick enough.

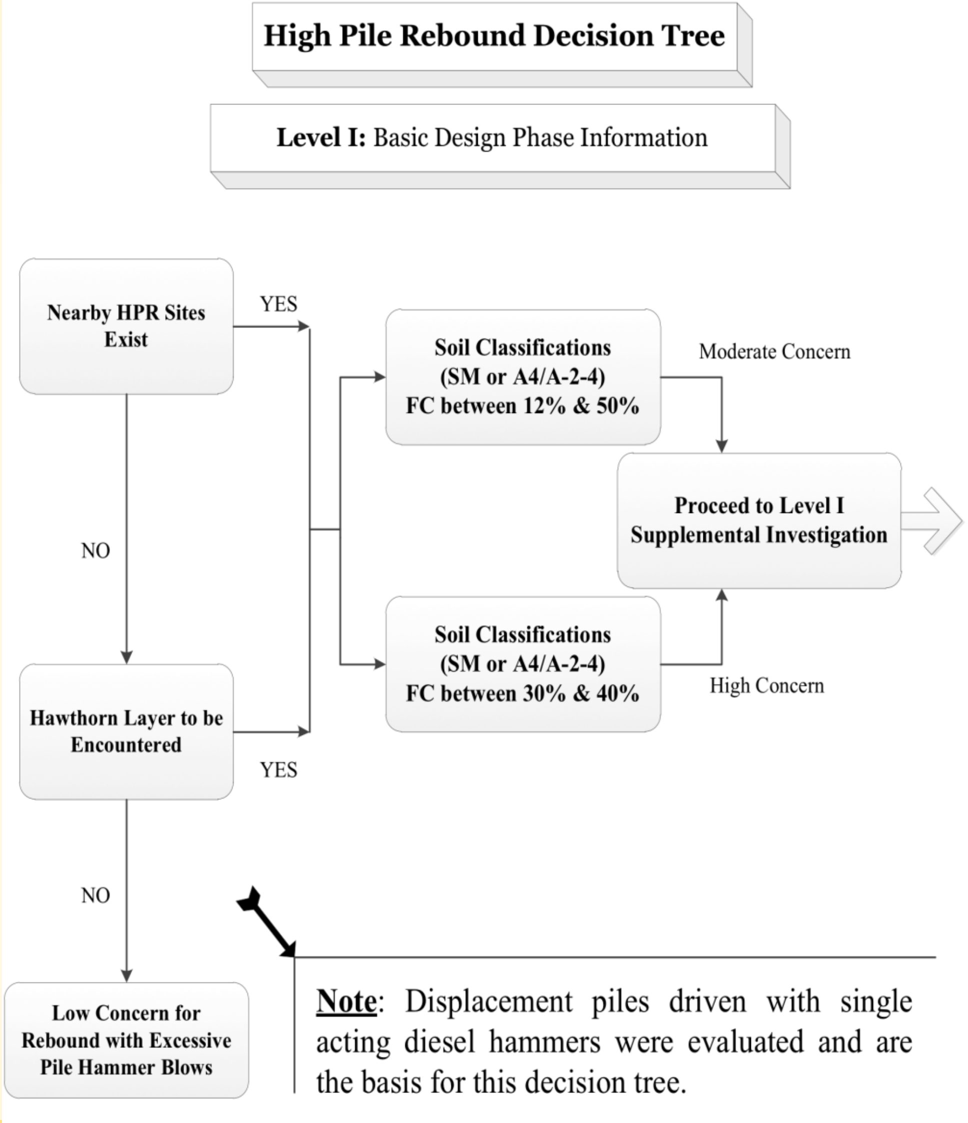
Some of the Conclusions (Cont.) ☺

8. Most SBT charts give some indication of type and behavior of rebound and non-rebound soils.
   a. Robertson (1990) Tip and Sleeve ☹
   b. Robertson (1990) Tip and Pore Pressure ☺ ☺
   c. Islami and Fellenius (1997) Tip and Sleeve ☺
   d. Robertson (2012) Tip and Sleeve (Dilative vs Contractive) ☺ ☺ ☺
   e. Schneider (2008) Tip and Pore Pressure ☺ ☺

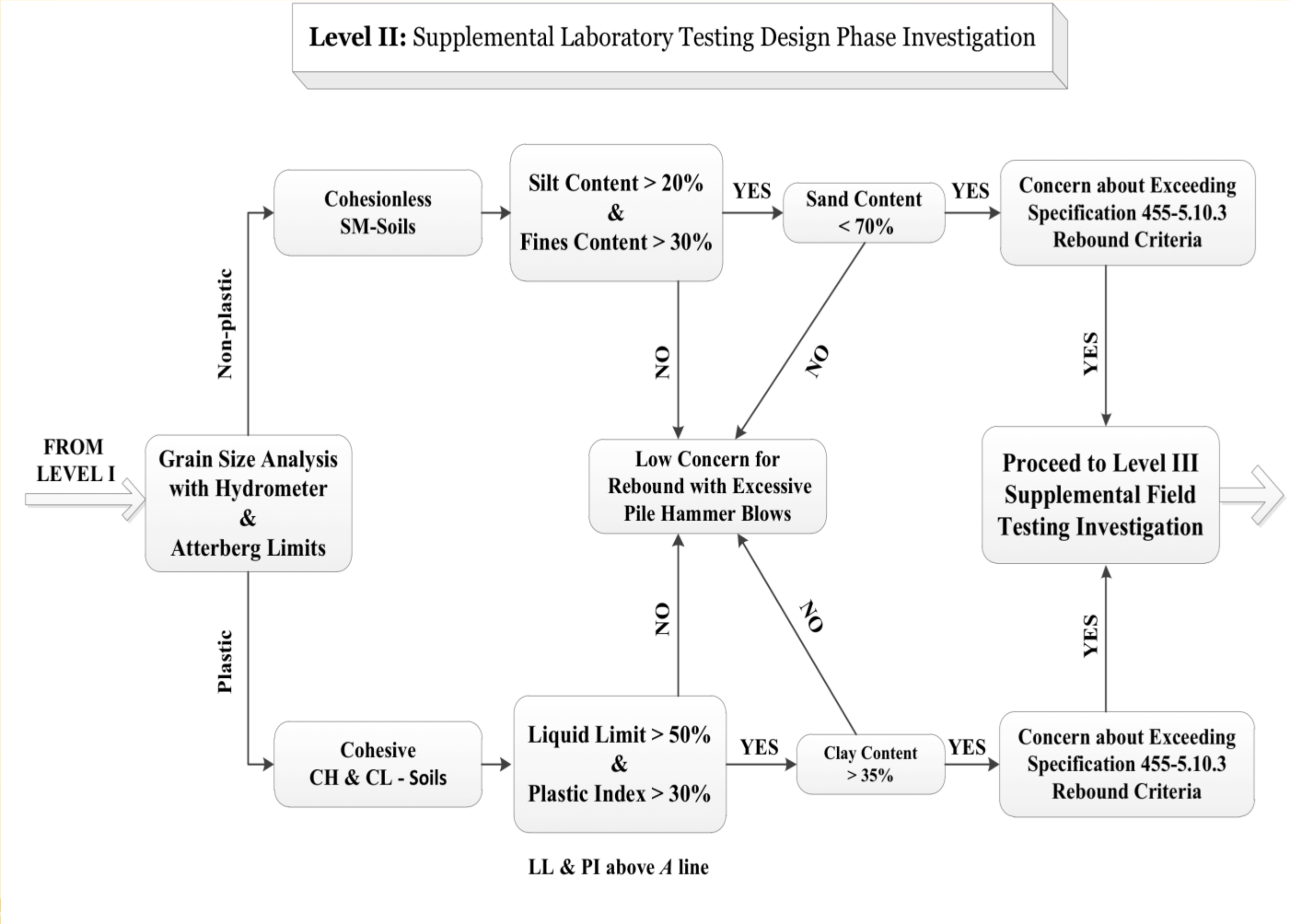
9. Permeability of HPR soils is 1-2 orders of magnitude lower than NonHPR soils (10^{-7} to $^{-8}$ to 10^{-3} or $^{-4}$ cm/s)

10. HPR soils are rate of loading dependent and two to three times more resilient (i.e., do not deflect as much during rapid loadings as NonHPR soils)

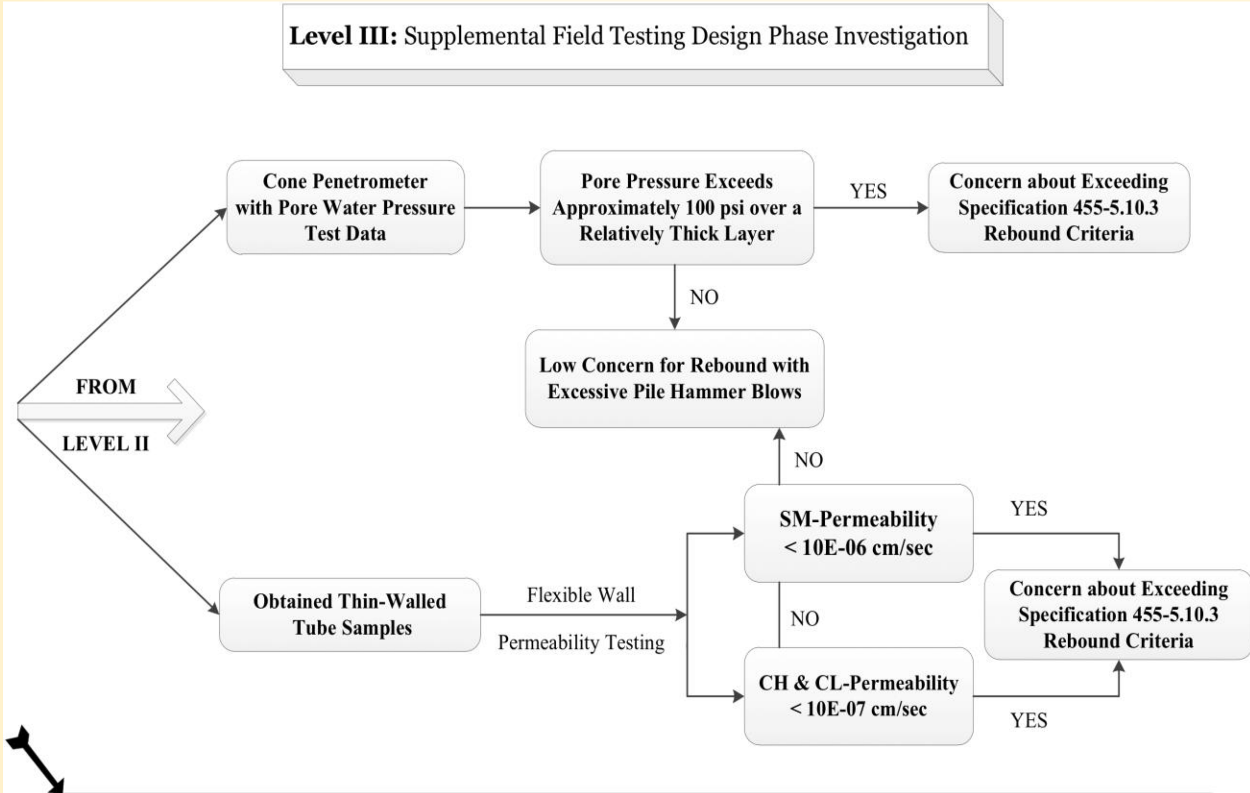
Recommended Decision Tree- Level I



Recommended Decision Tree- Level II



Recommended Decision Tree Level III



Note that stress-level cyclic triaxial testing with 1000 cycles each at stress levels at 20, 40, 60, and 80% of the failure stress from triaxial tests conducted in accordance with ASTM D4767 indicated that HRP soils required two to three times more cycles to attain 2.5, 5, 10, and 15% strain levels than nonHPR soils and are termed more resilient, which matches the phenomenon that occurs during driving in theses soils.

Thank You

A special thanks also goes to FDOT's David Horhota, Peter Lai, Kathy Gray, Bob Hipworth,
GRL's Mohamad Hussein
&
the CPT/SPT Team from FDOT State Materials Office
(Kyle, Todd, Bruce and Travis).