Florida Institute of Technology

Dept. of Civil Engineering

Engineering Properties of Pile Rebound Soils Based on Cone Penetration Testing

By

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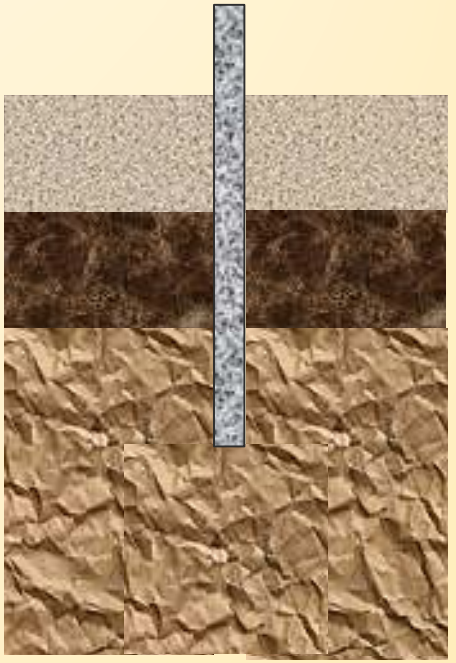
Problem Statement

- Definition: >1/4” Rebound/Hammer Blow Termed High Pile Rebound (HPR).
- HPR problems occur throughout Florida.
- HPR will significantly increase hammer blows.
- HPR may damage the piles.
- HPR may produce liability claims by the contractors.



Objectives

- Identify and evaluate the engineering properties of soil deposits which may cause high pile rebound.
- Develop correlations from Cone Penetration Testing with Pore Pressures (CPTu) to predict pile rebound during the design phase.

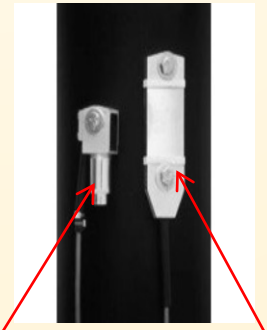
Methodology

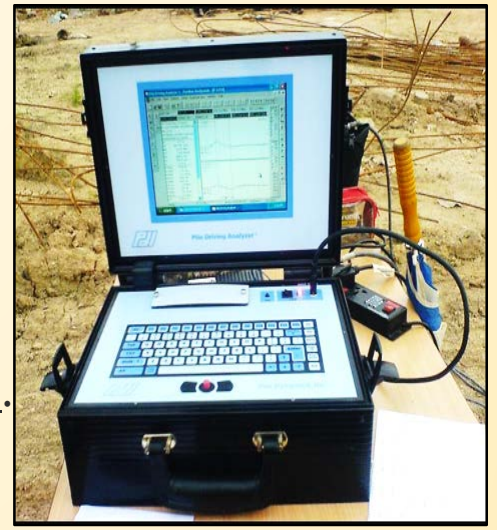
- Identify Test Sites
  - CAD Drawings
  - Pile Driving Analyzing (PDA) Data
- Perform Field Investigation
  - *Standard Penetration Test (SPT)*
  - CPTu (i.e. Piezocone)
  - *Shelby Tube Sampling*
- Reduce Data, Analyze and Develop CPTu Correlations
- Conclusions that you'll remember ☺

❑ Identify Testing Sites for Todays Presentation

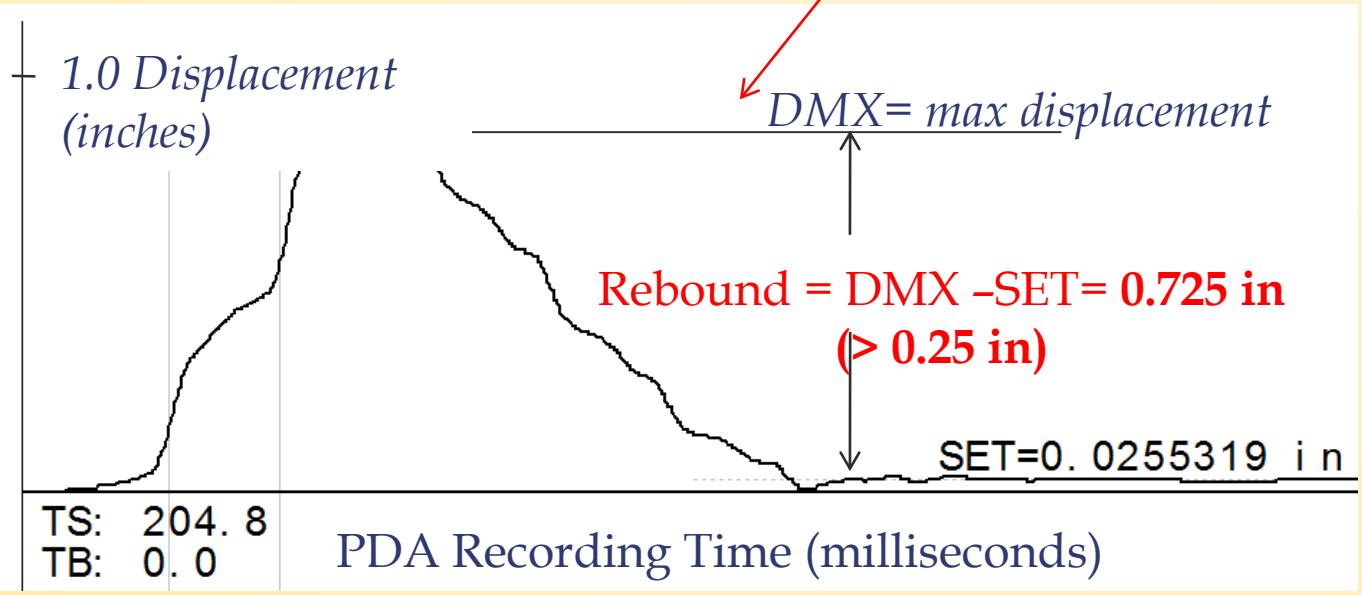
1. I-4 / US-192 Interchange / Osceola County / Florida.
2. Anderson Street Overpass at I-4/SR-408 / Orange County / Florida.
3. State Road 50 and State Road 436 / Orange County / Florida.
4. I-4 Widening Daytona / Volusia County / Florida
5. I-4 / State Road 408 Ramp B / Orange County / Florida.
6. State Road 417 International Parkway / Osceola County / Florida.
7. State Road 83 over Ramsey Branch Bridge / Walton County / Florida.

PDA data





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



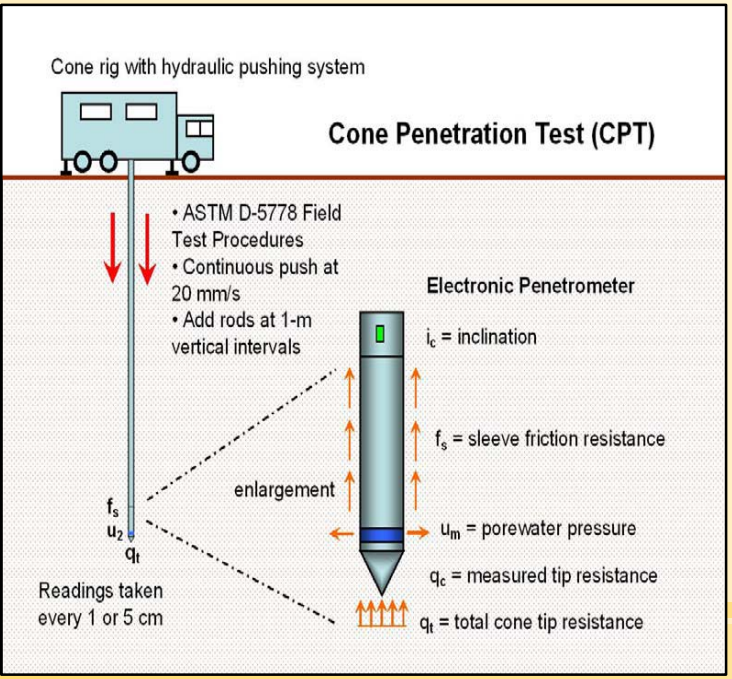
Standard Penetration Test (SPT)

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

Cone Penetration with Pore Water Test (CPTu)

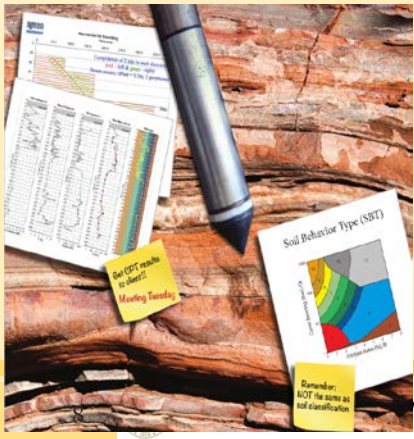
CPTu Data

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



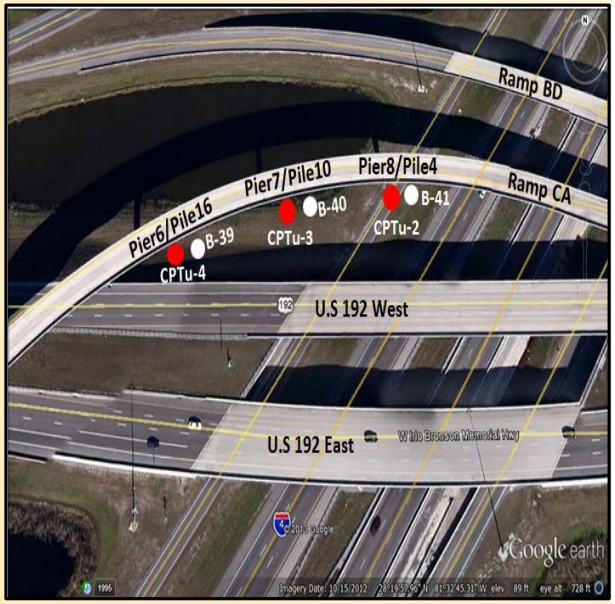
Soil Properties Estimated

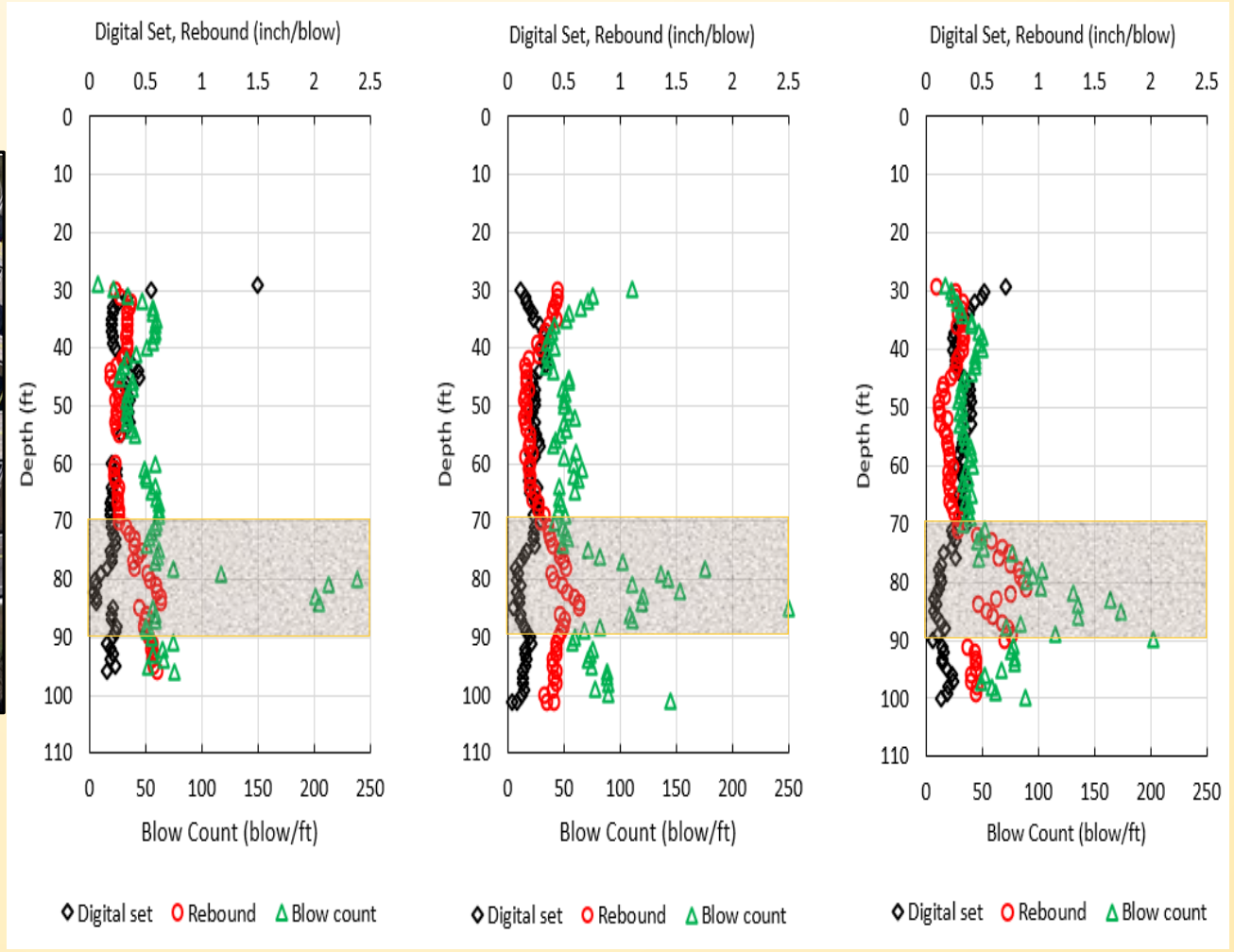
- Saturated Density (γ)
- Permeability (k)
- Relative Density (D_r)
- Undrained Shear Strength (S_u)
- Fines Content (FC)
- Overconsolidation Ratio (OCR)
- State Parameter (ψ)
- Soil Behavior Type (SBT)



Field Testing Results

✓ **PDA For I-4 / US-192 Interchange – HPR between ½ and 1” from 70 to 90 feet**

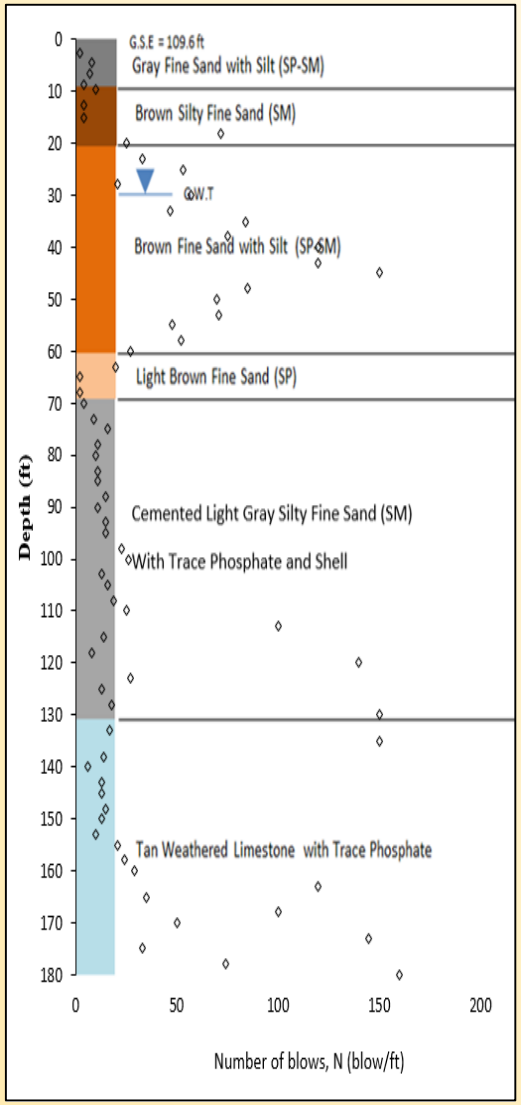


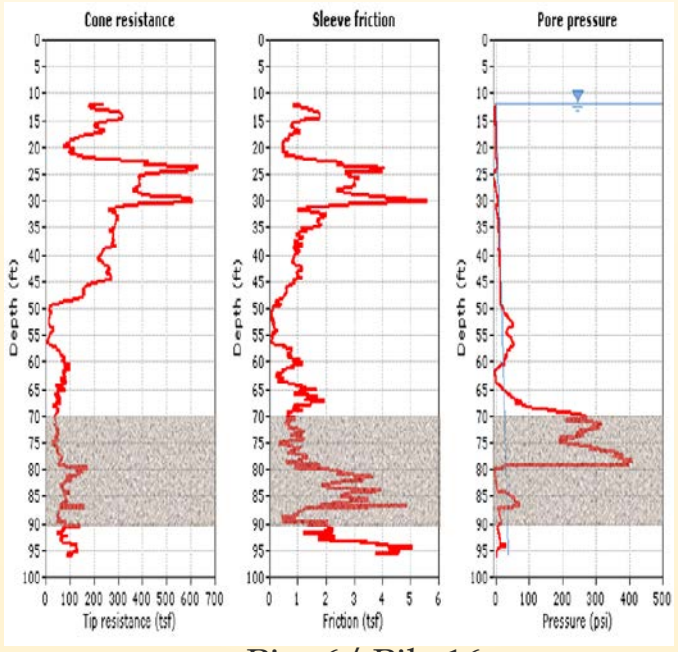


Pier 6 / Pile 16 Pier 7 / Pile 10 Pier 8 / Pile 4

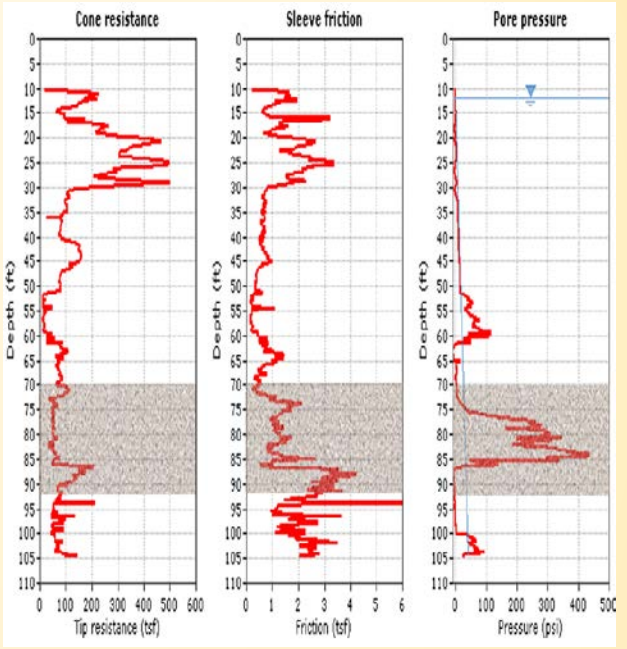
Field Testing Results

- ✓ **CPTu for I-4 / US-192 Interchange**

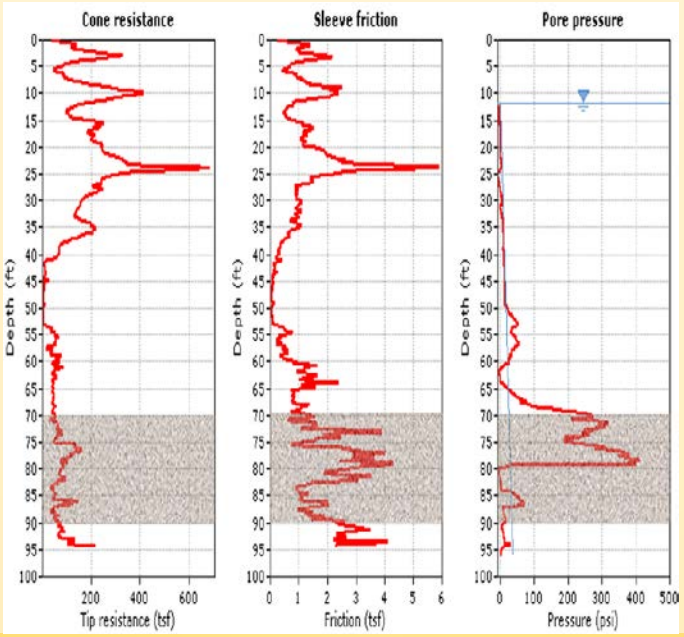




Pier 6/ Pile 16



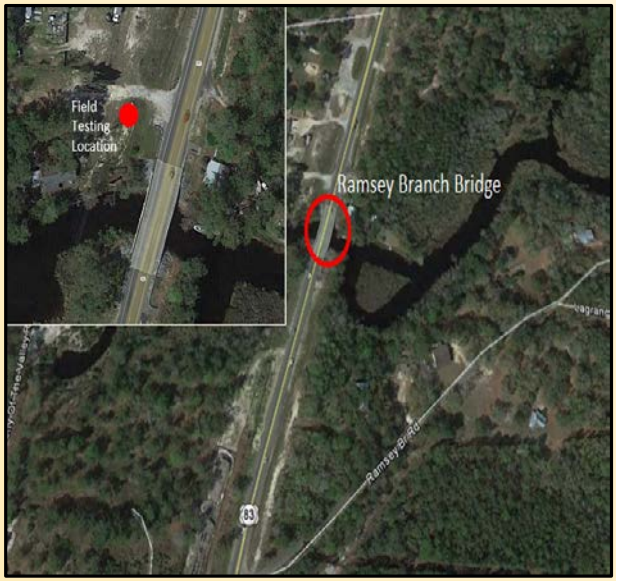
Pier 7 / Pile 10



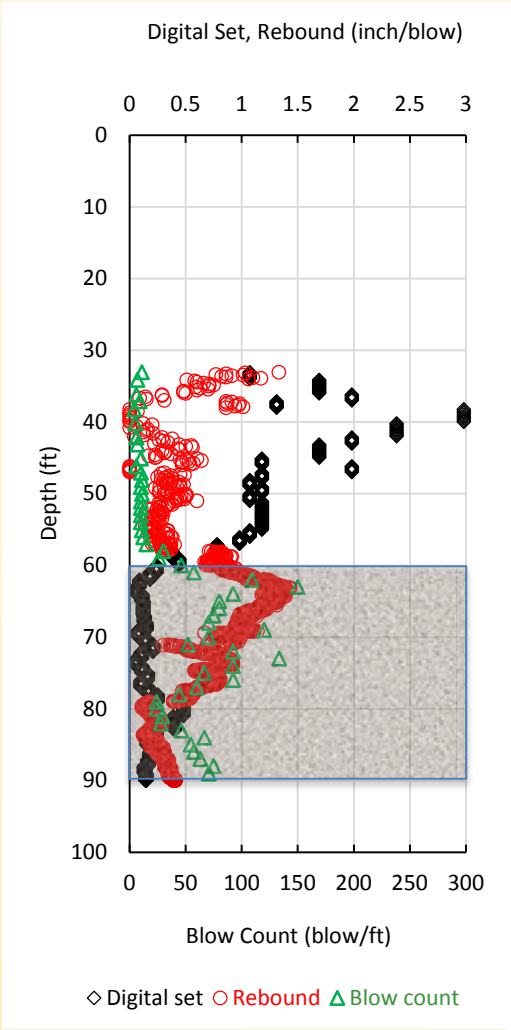
Pier 8 / Pile 4

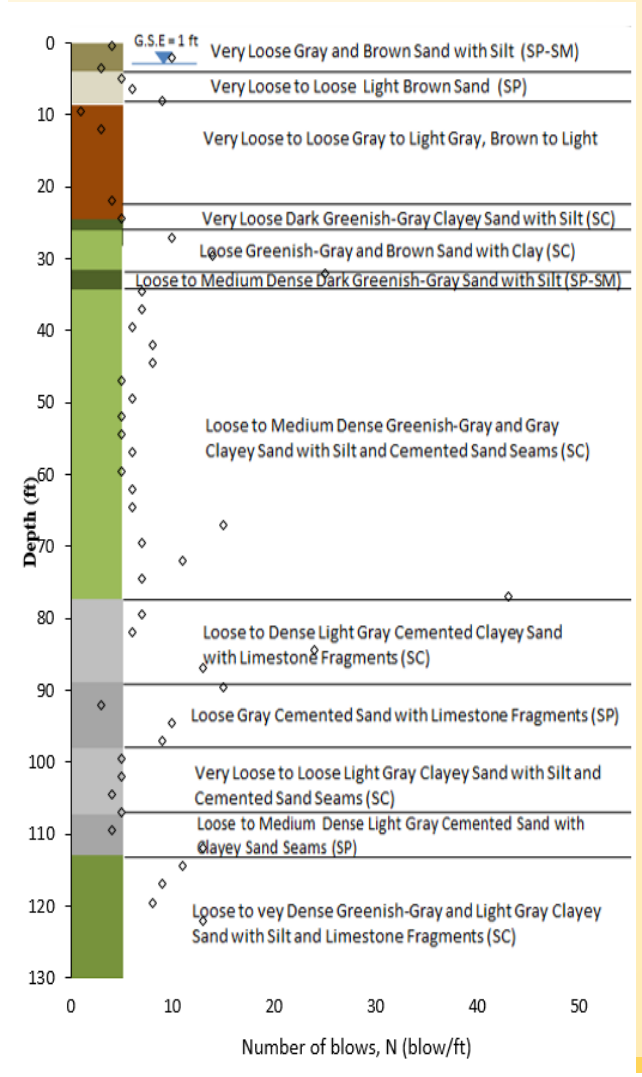
Field Testing Results

✓ **State Road 83 over Ramsey Branch Bridge – HPR up to 1.5 inches throughout driving critical at 60 feet**



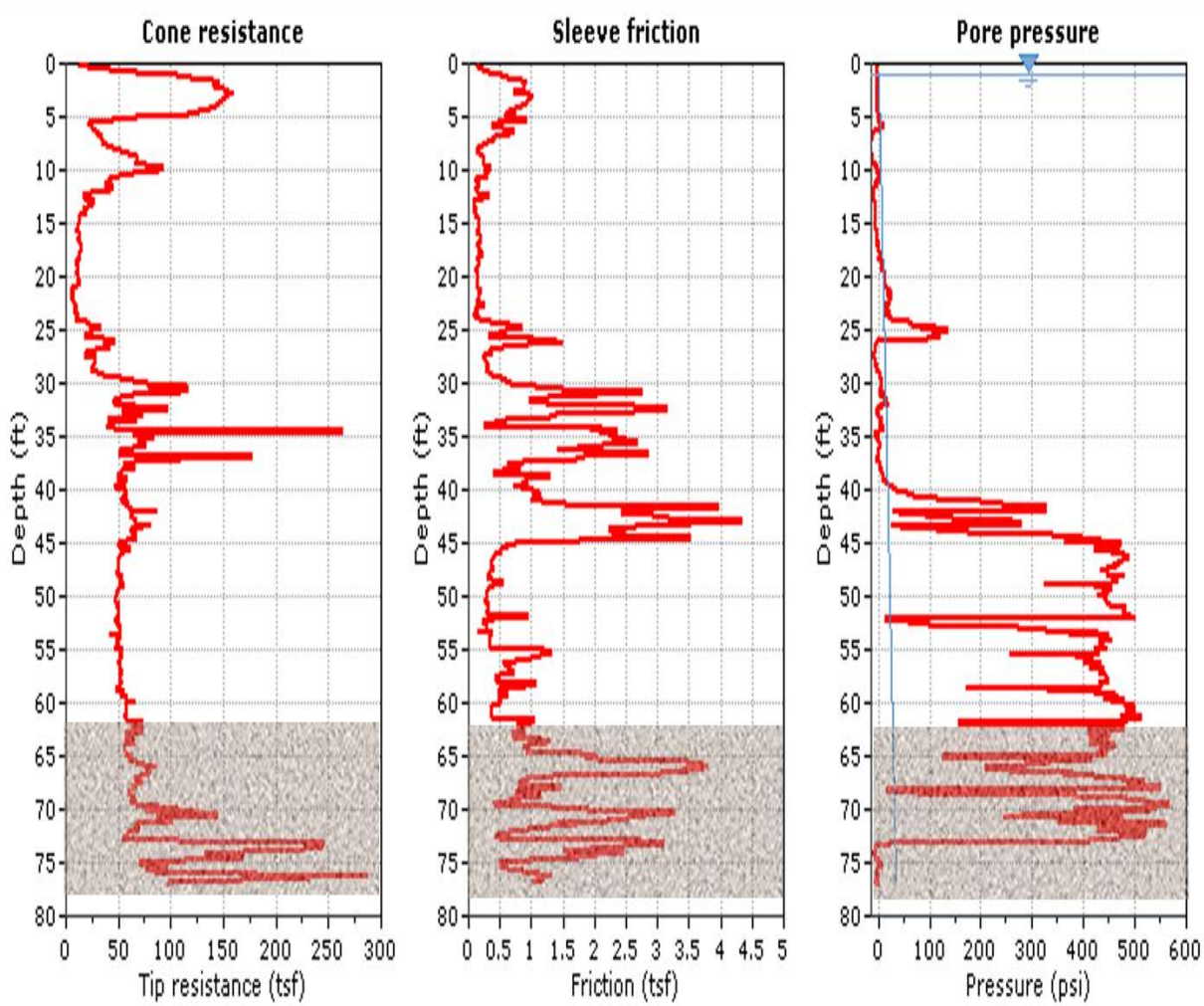
EB 5 / Pile 2





Field Testing Results

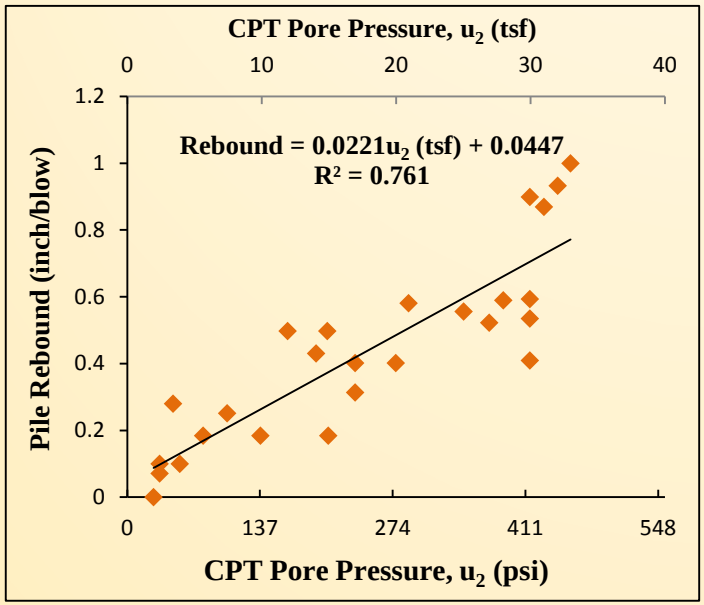
✓ **State Road 83 over Ramsey Branch Bridge**

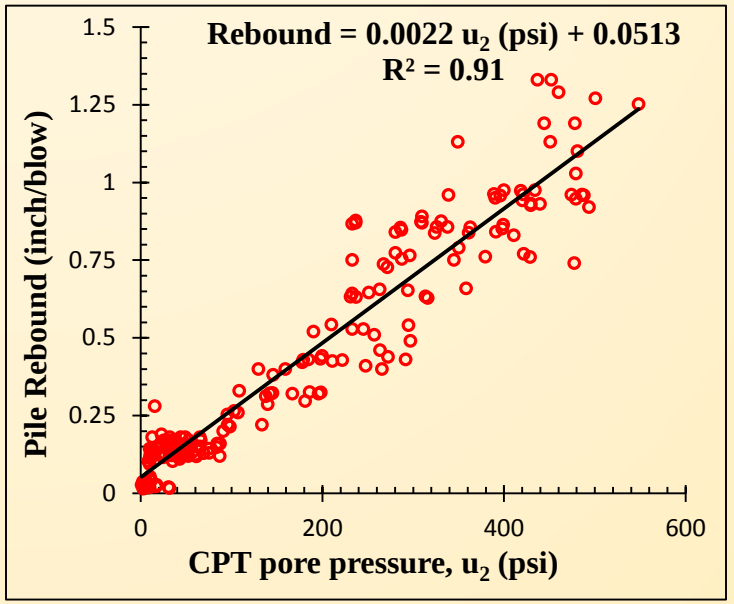


Averages from Field Testing Data for Seven Sites

Site Type	Depth (ft.)	PDA Data			SPT Data	CPT Data	
		Rebound (inch/blow)	Inspector Set (inch/blow)	Driving Blows (blow/ft.)	N	Point Resistance q_c (tsf)	Pore Pressure u_2 (psi)
Ave NonHPR	37-70	0.21-0.24	1.2-1.3	27-33	8-13	66-156	21-111
Ave HPR	61-77	**0.36-0.81**	**0.2-0.3**	**50-172**	**20-23**	48-150	**172-240**

Evaluation and Improvement of Existing Correlation between HPR and CPT Pore Water Pressure

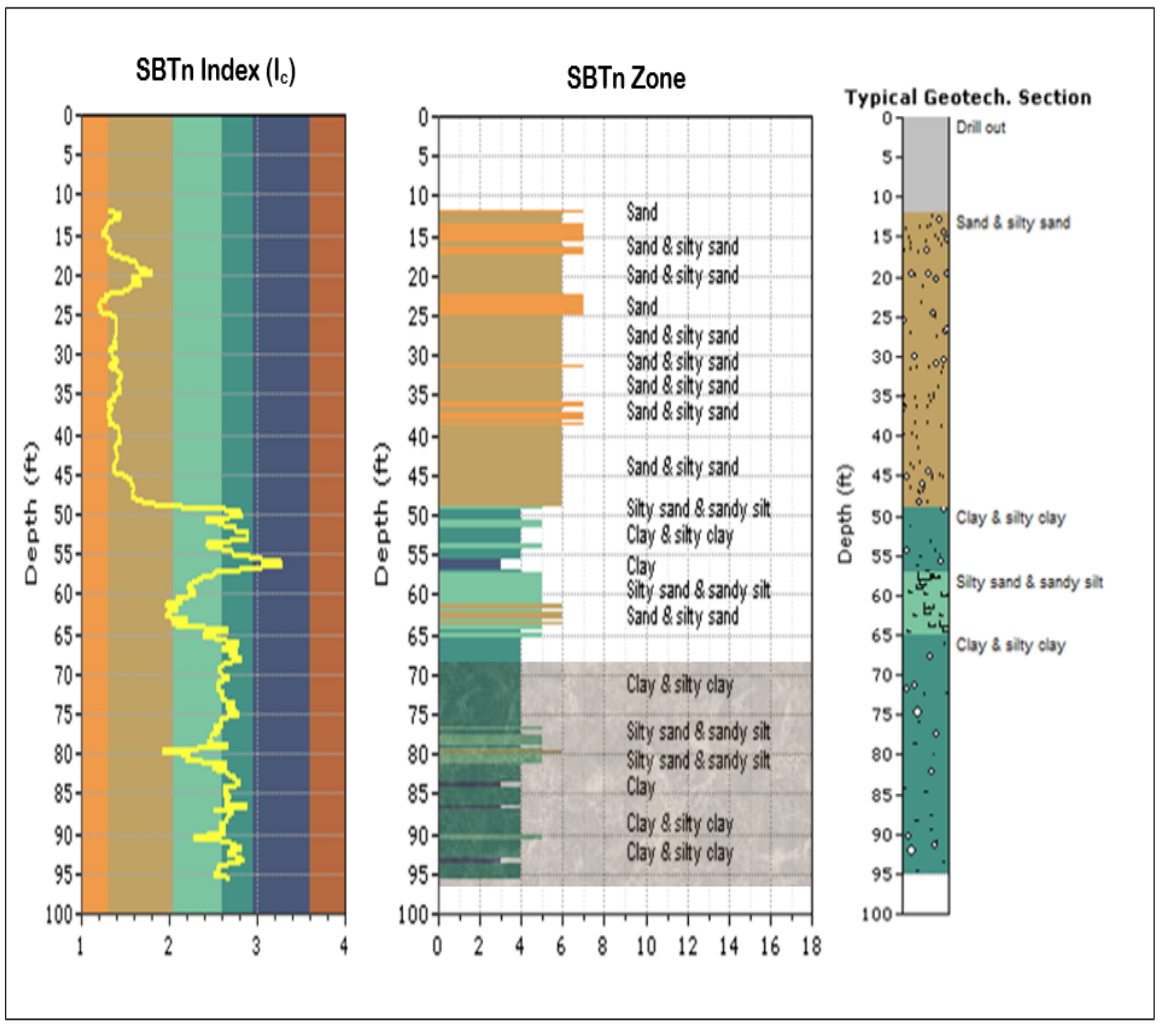




Analysis of CPTu Data

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

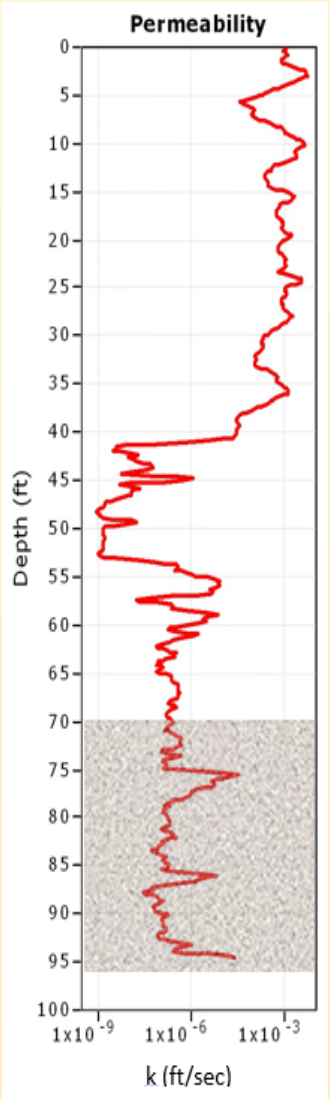
- Robertson Software **CPeT-IT** with Correlations
- Geotechnical soil properties estimated from CPTu data were used to clarify HPR soil behavior



CPTu Estimated Permeability

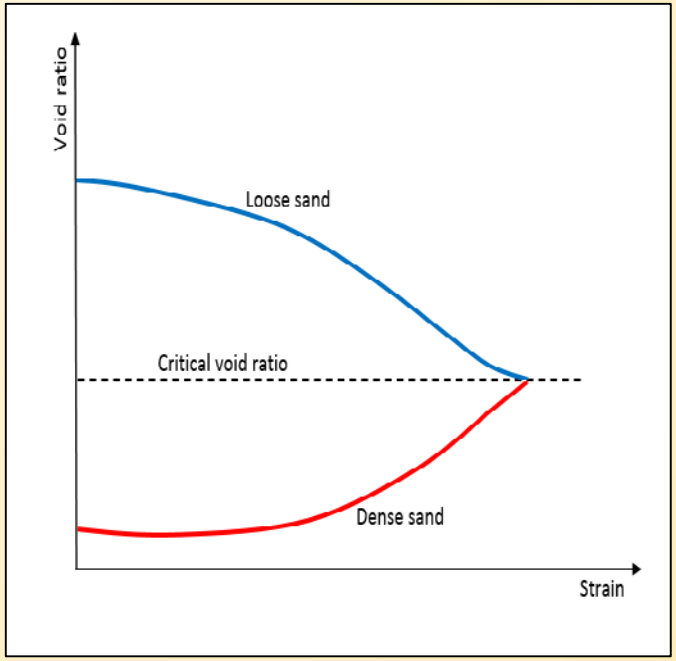
Typical Results: I-4 / US-192 Interchange

- 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 Correlations Predict Relative Density and State Parameter

- **CPTu Relative Density**
  - Rebound soils are medium dense to dense silty sand to sandy silt.
  - Non-rebound soils are loose to medium silty sand to sandy silt.
- **CPTu State Parameter**
  - The state parameter (ψ) is meaningful.
  - Difference between the existing void ratio, and the void ratio at critical state
    - $\psi = e - e_{cs}$
  - State parameter is positive in loose sands and negative in dense sands.
  - Dense soils dilate while loose soils contract.
  - Rebound soils: Negative state parameter: less than -0.05.
  - Non-rebound soils: Positive state parameter.

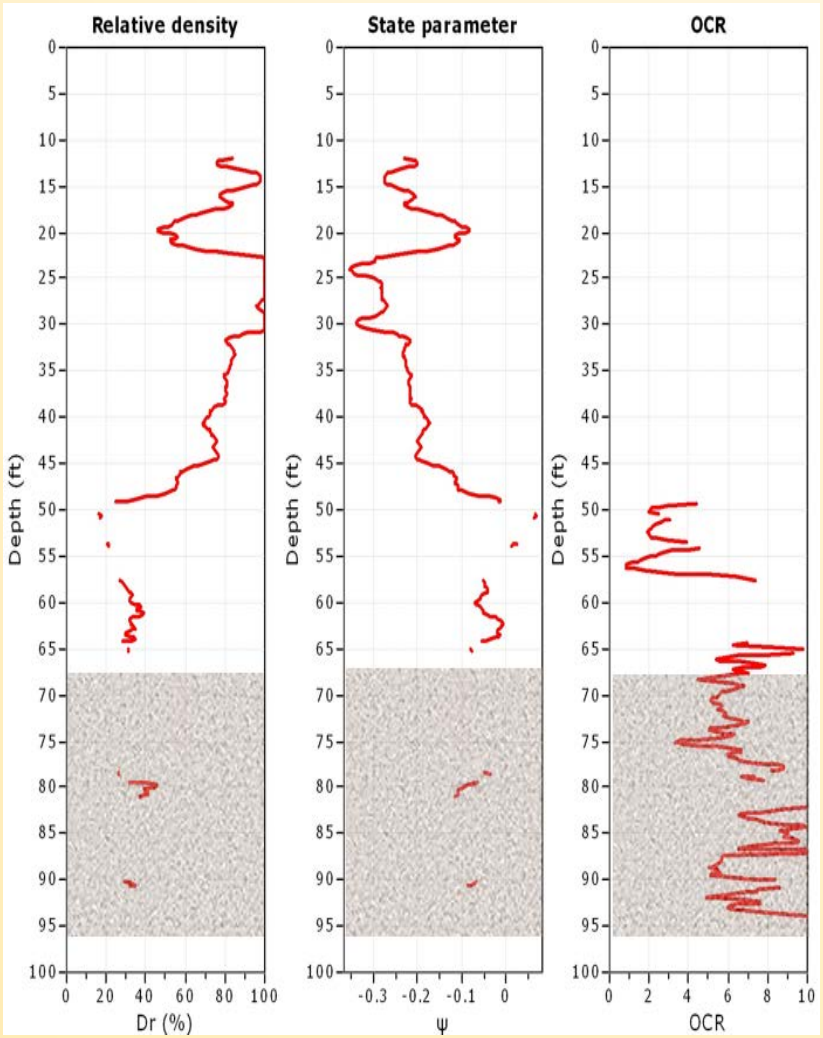


CPTu Overconsolidation Ratio (OCR)

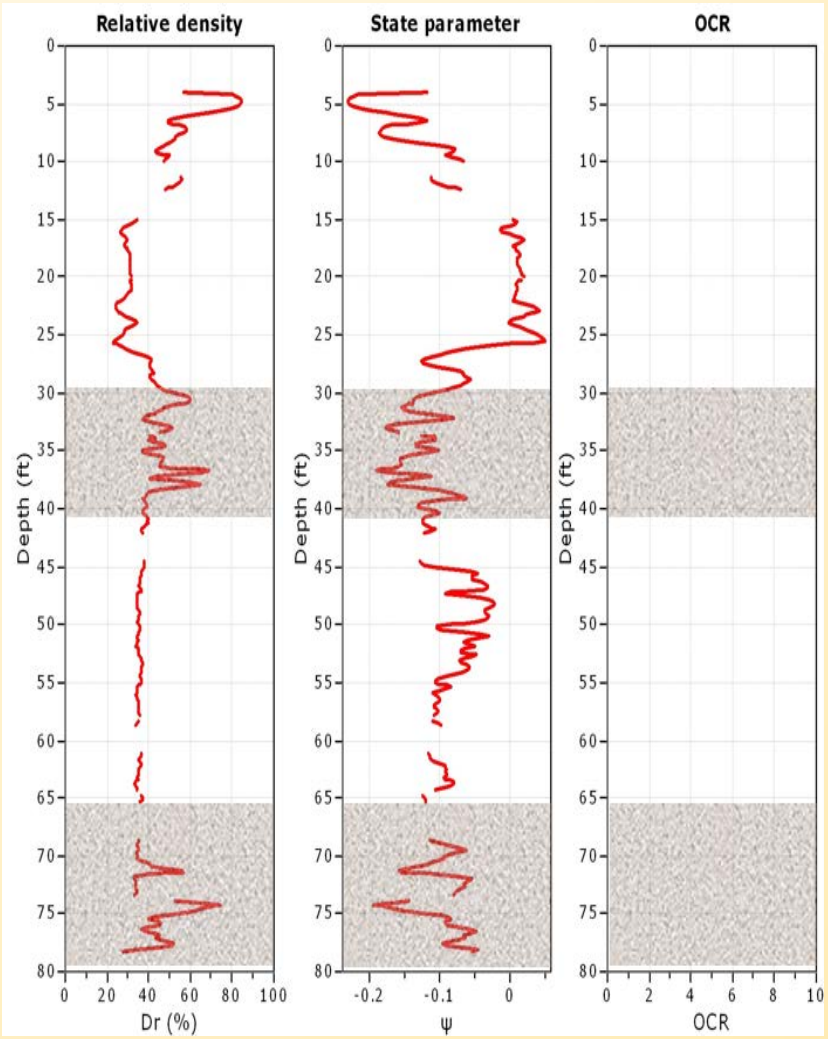
- Soils with high OCR can be classified as cemented soils.
- Cemented soils behave like overconsolidated soils.
- Rebound soils: OCR ranges from 5 to 10.
- Non-rebound soils: OCR ranges from 0.5 to 3.

Typical CPTu Relative Density, State Parameter & OCR

I-4 / US 192 at Pier 6



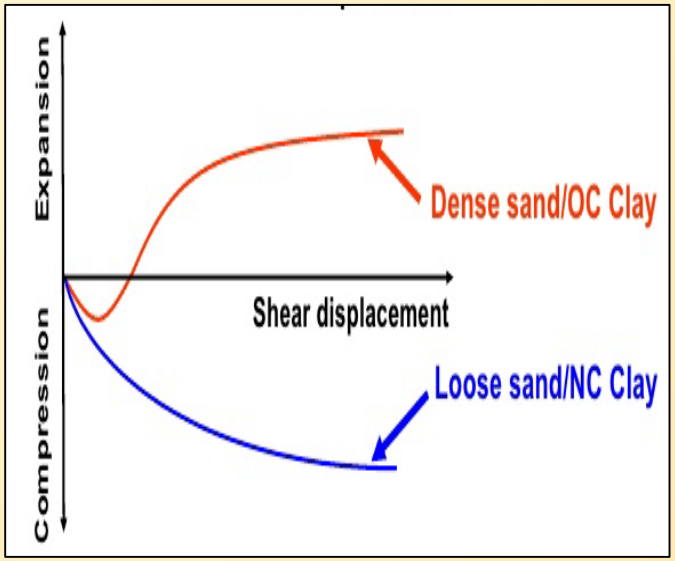
SR 83 / Ramsey Branch Bridge



Nonplastic soils do not produce values

Analysis of the Soil Properties from CPTu

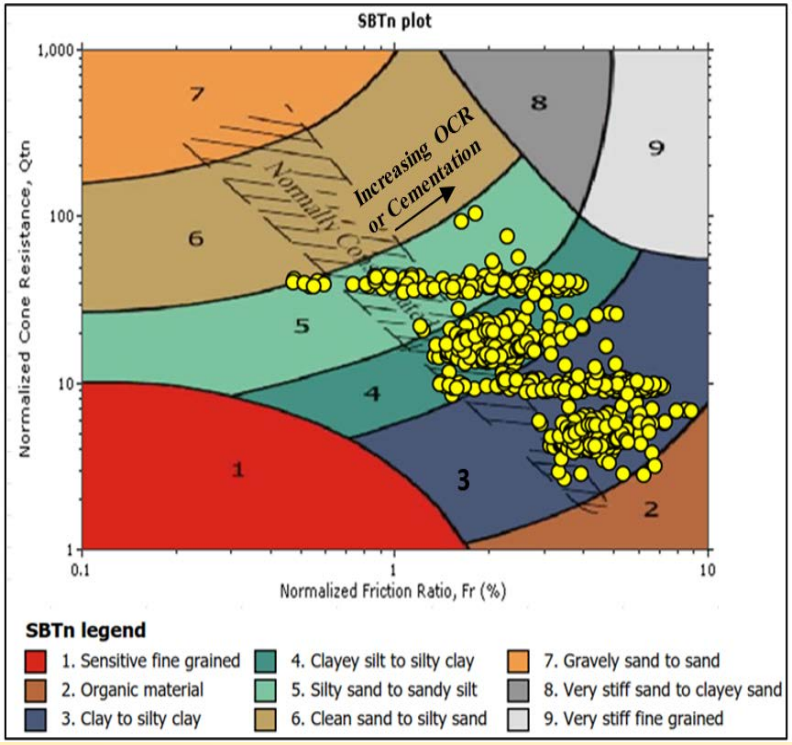
- Fine-grained soils with OCR > 4 are dilative at large strains.
- Coarse-grained soils with state parameter less than -0.05 ($e_o - e_{cs} < -0.05$) are dilative at large strains.
- Rebound soils are **DILATIVE** ------- Non-rebound soils are **CONTRACTIVE**.
- Soil dilation or contraction affects the generation of excess pore water pressures.



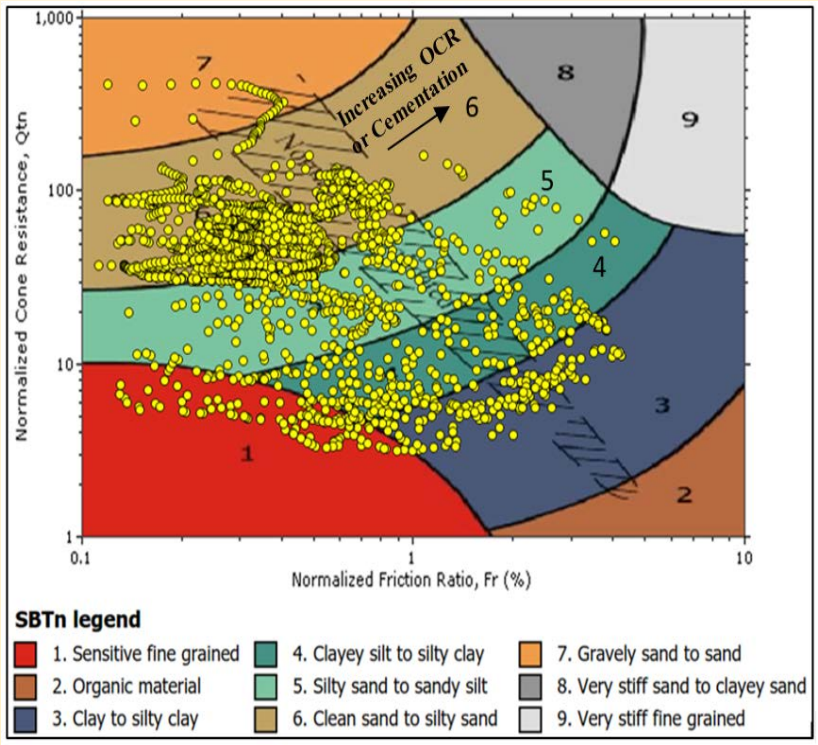
Soil Behavior Type Charts

- Based on CPTu output engineers can classify soils and Rebound soils show trends
  - Robertson (1990)
  - Robertson (2012)
  - Schneider (2008)
  - Islami and Fellenius (1997)

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

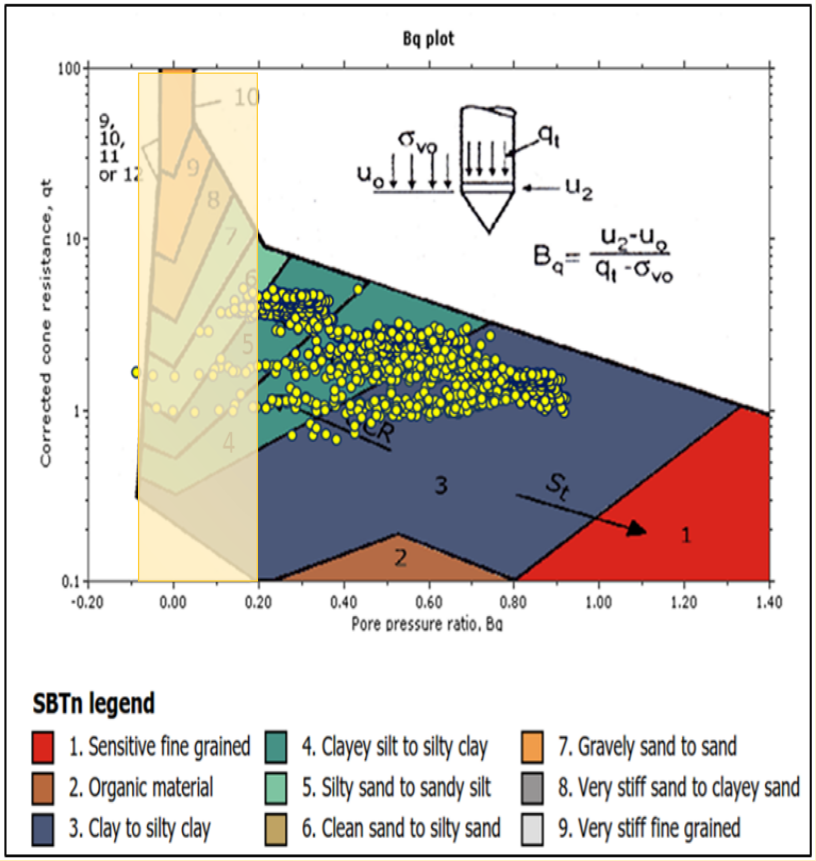


Rebound

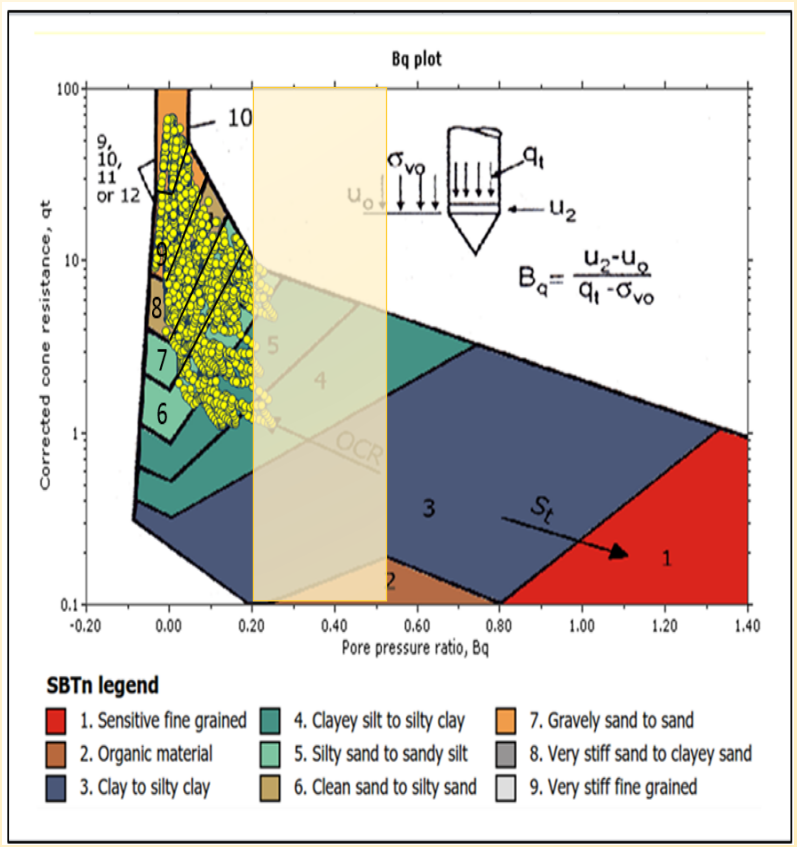


Non-rebound

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

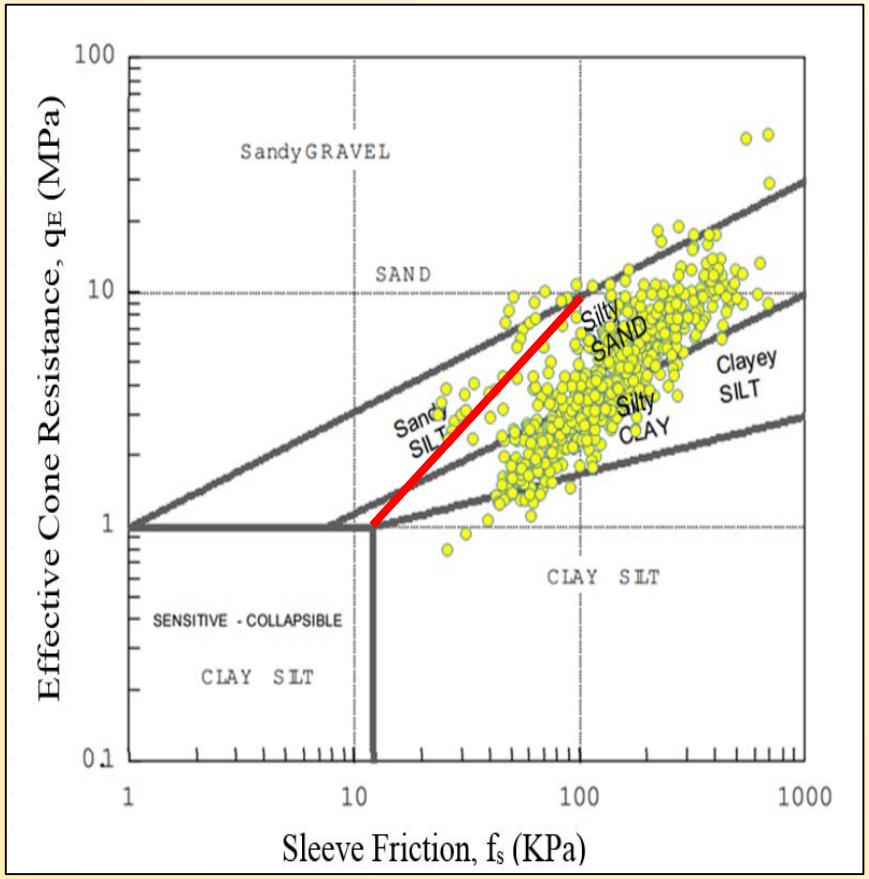


Rebound

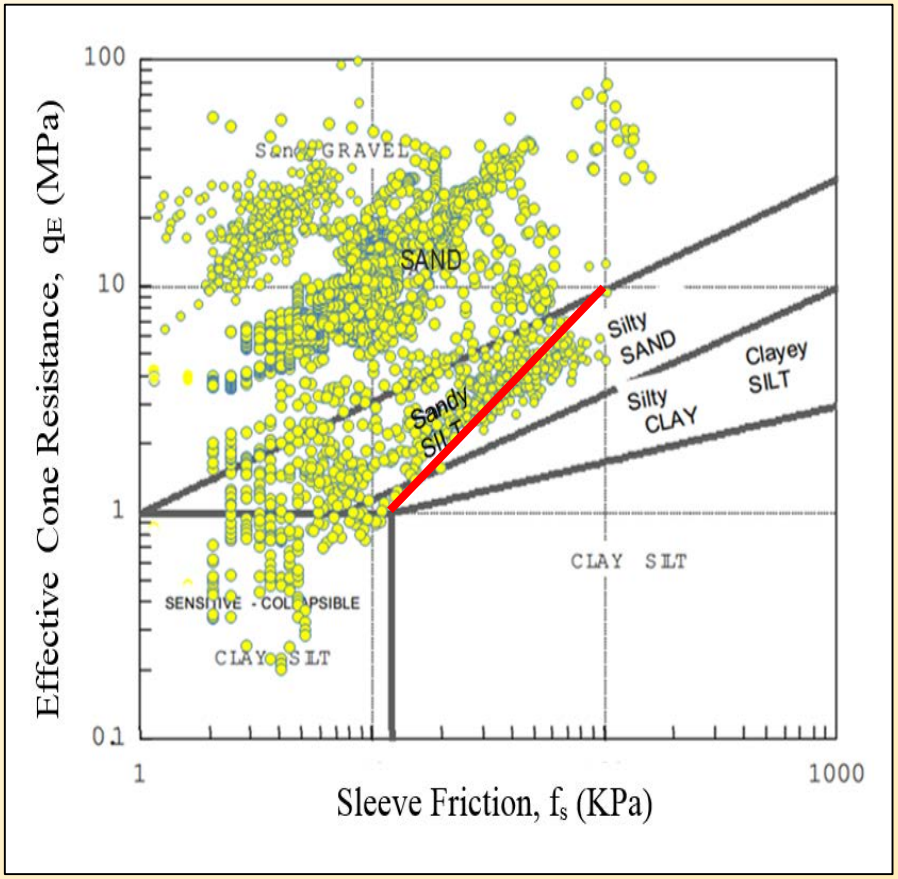


Non-rebound

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

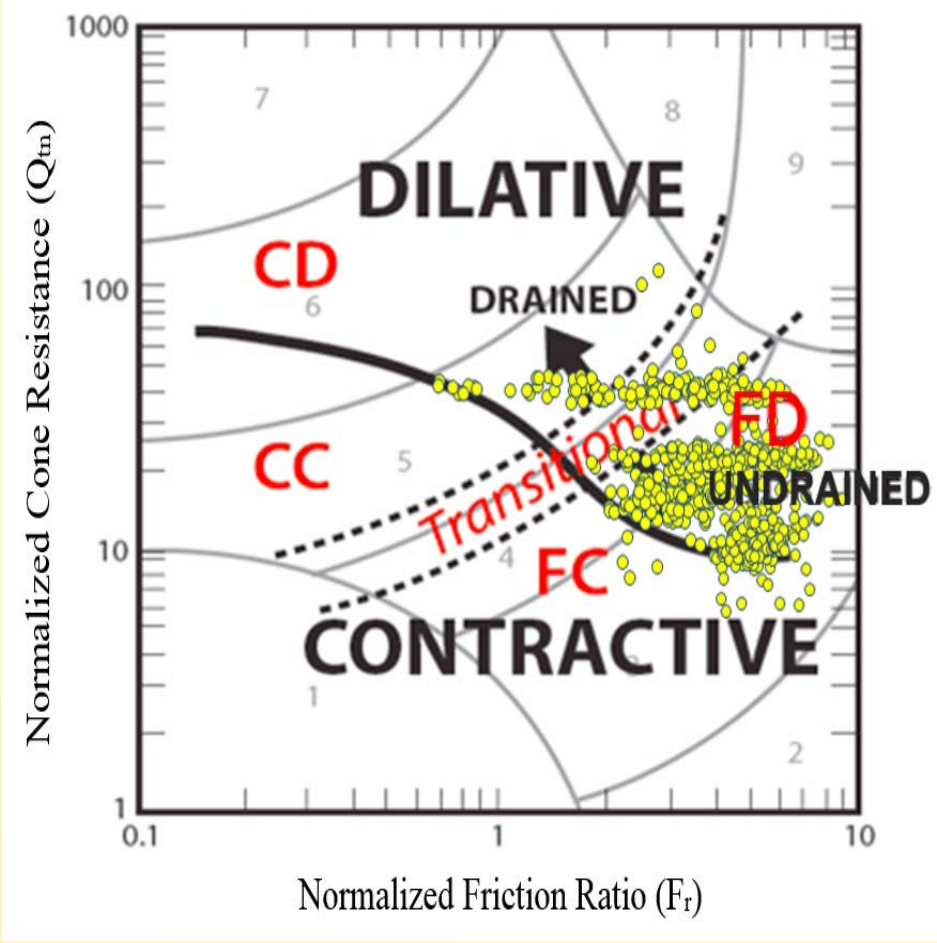


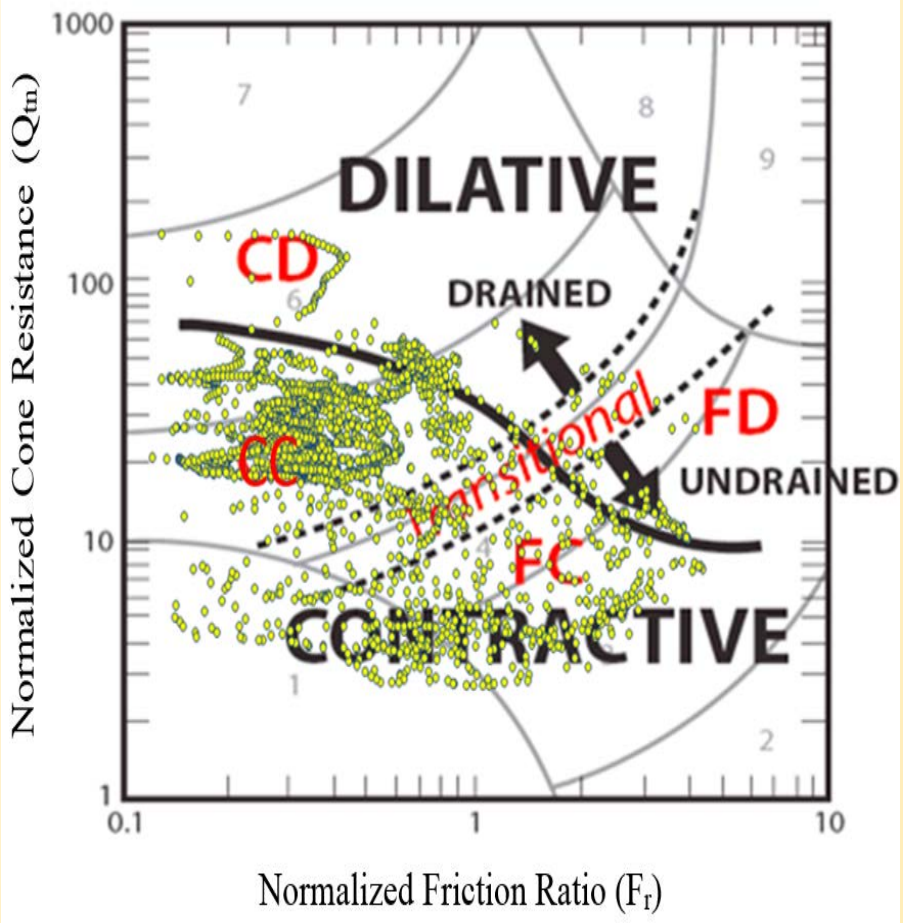
Rebound



Non-rebound

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





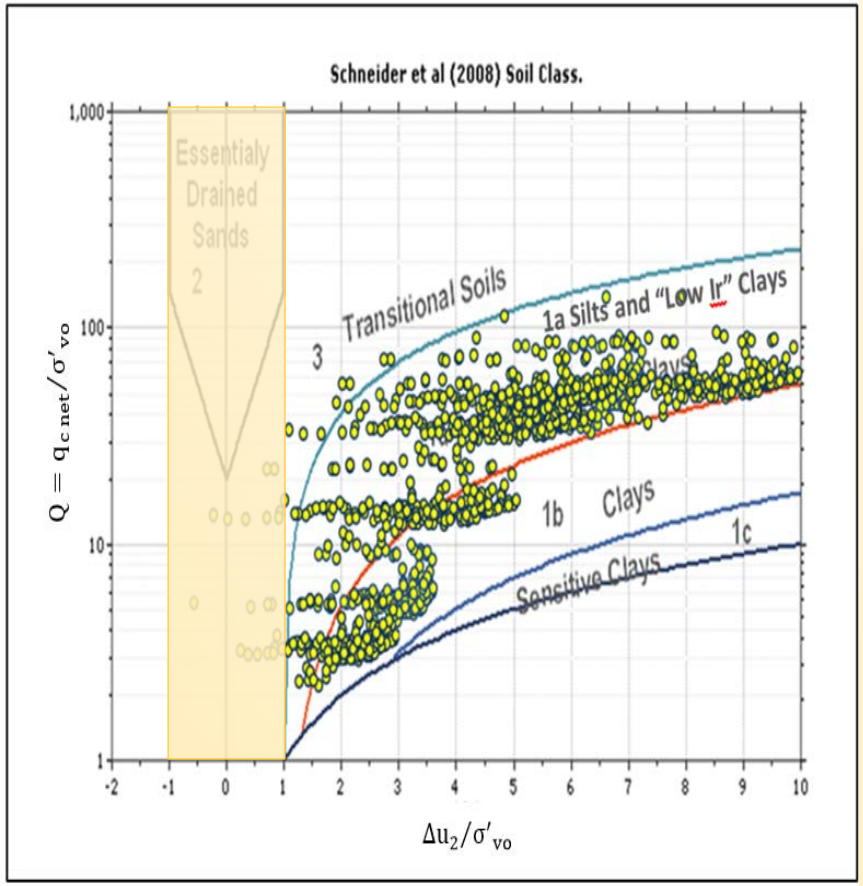
Rebound

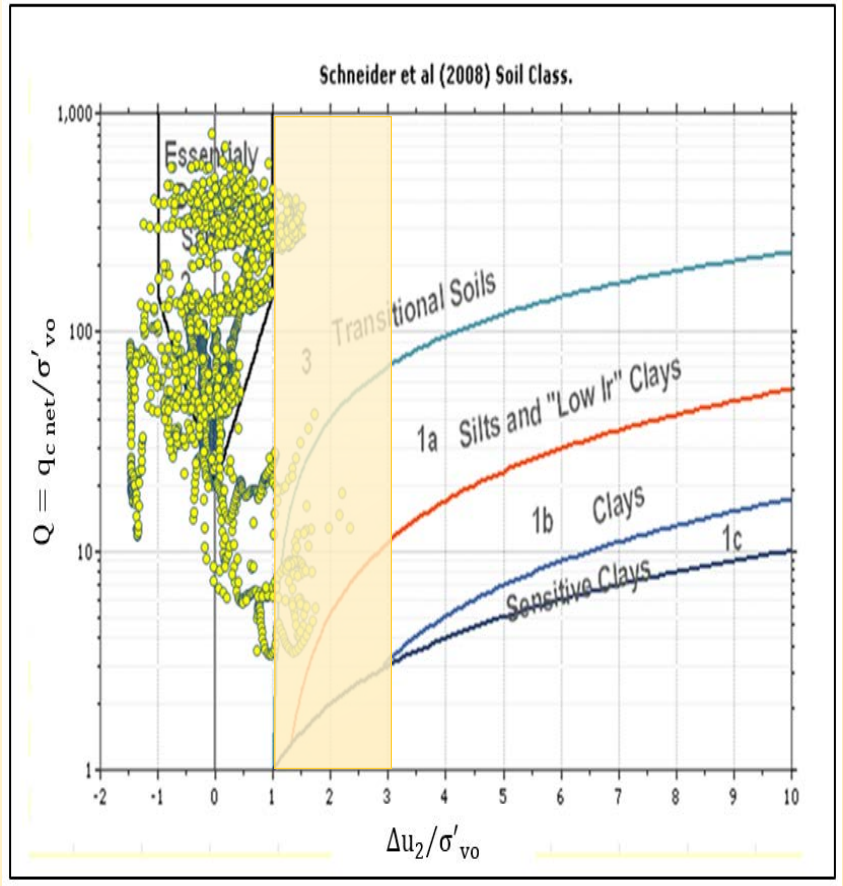
Fine Dilative (FD) Soils Rebound

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

Conclusions

1. The rebound soils are cemented silty fine sand (SM) with trace phosphate and shell or cemented clayey fine sand (SC) with fines.
2. Rebound soils are dilative while non-rebound soils are contractive.
3. The pore water pressures during CPTu testing are very high.
4. The CPT pore water pressures (u_2) are linearly correlated to the pile rebound.
5. Most SBT charts give clear 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 ☺ ☺

Thank You

A special thanks goes to David Horhota, Peter Lai, Kathy Gray, Bob Hipworth,
&
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(Kyle, Todd Bruce and Travis).