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Applying the SHANSEP Approach to In Situ Tests and Driven Pile Capacity Design in Cohesive Soils

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Key Points in this Presentation

- Gain an understanding of:
  - The importance of the SHANSEP equation in soil mechanics
  - The direct relationship of in situ and laboratory tests to the soil OCR using SHANSEP and the development of correlation coefficients
  - The benefits of applying the SHANSEP approach to design of driven piles in cohesive soils
  - This presentation draws on three papers in the ASCE Geotechnical and Geoenvironmental Engineering Journal referenced at the end

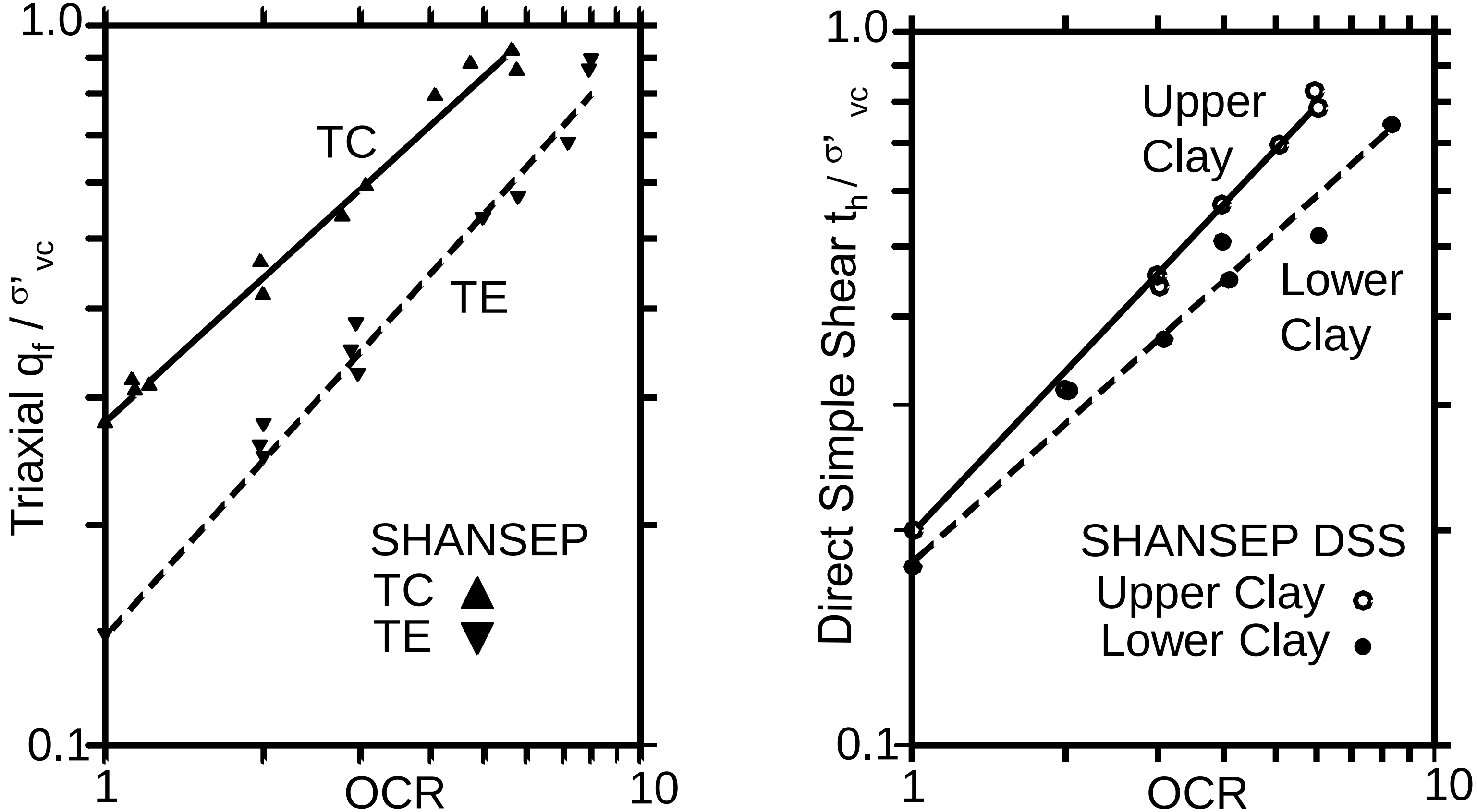
Stress History and Normalized Soil Engineering Properties (SHANSEP)

- Ladd and Foott (1974)
- Reconsolidation technique to assess the undrained strength of soils referencing OCR
- Oedometer tests key to defining soil OCR
- Define the normally consolidated behavior
  - Define the overconsolidated behavior

$$\frac{s_u}{\sigma'_{vo}} = S\,(OCR)^{m}$$

- Calculate s_u recognizing anistropy

SHANSEP Approach Ladd and Foott (1974)

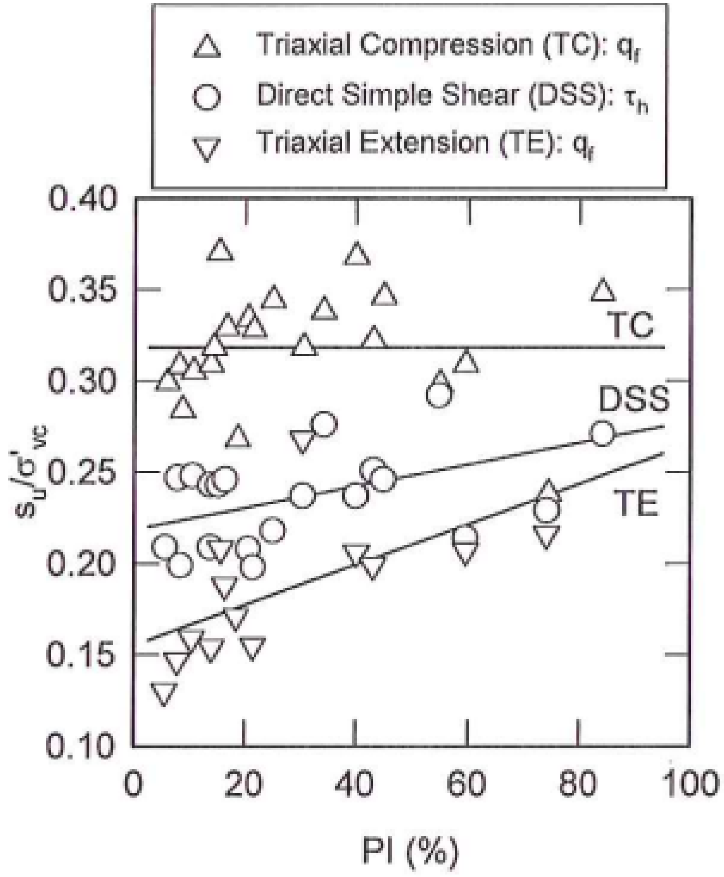


$$\frac{s_u}{\sigma'_{vo}} = S\,(OCR)^{m}$$

Boston Blue Clay – Building 68

Undrained Strength Variations

- Mode of failure is important in stability calculations but often overlooked
- Embankment mode of failure controls the stability for the linear feature
- (DSS + TC + TE) / 3
- See Ladd and DeGroot (2003)



The SHANSEP-based Approach to Design Driven Piles in Cohesive Soils

- Saye et al. (2013a) and Saye et al. (2016)

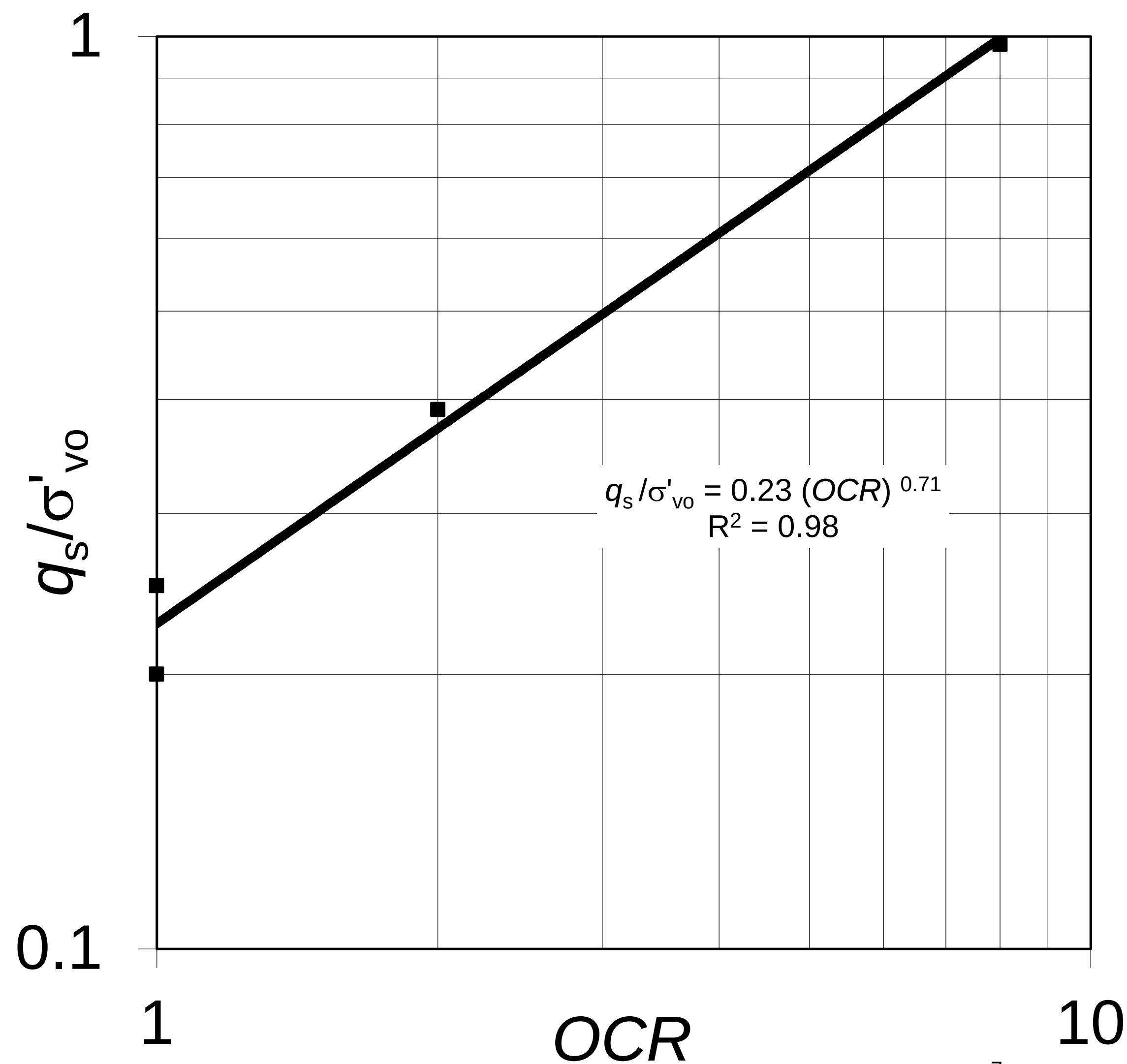
- $q_s/\sigma'_{vo} = C_l\ (q_s/\sigma'_{vo})_{NC}\ (OCR)^{m}$

- Evaluate the normally consolidated behavior
- Evaluate the overconsolidated behavior

- C_l factor recently added

Cambridge Model Pile Tests

- Adapted from Steenfeld et al. (1981) and Kraft (1982)

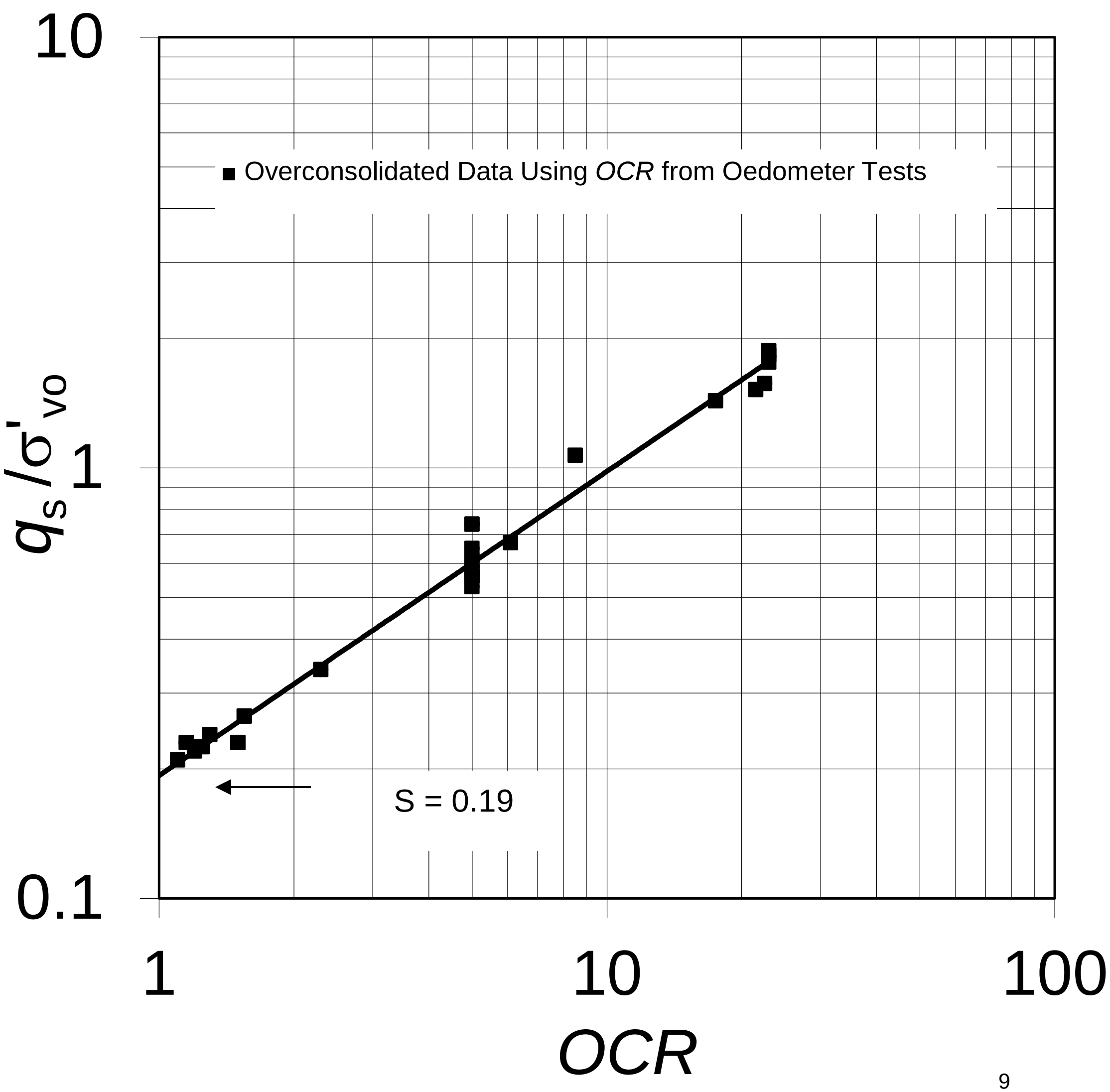


Soil Data in Historical Empirical Record

- Most soil property data in the historical record for empirical correlations of pile side resistance reference S_u UUC data
- Effort to systematically relate s_u UUC to OCR in Saye et al. (2013a)
- Key concept is to eliminate disturbed s_U UUC data from the empirical record for q_s
- Oedometer tests considered much less susceptible to disturbance than UUC tests in low OCR soils

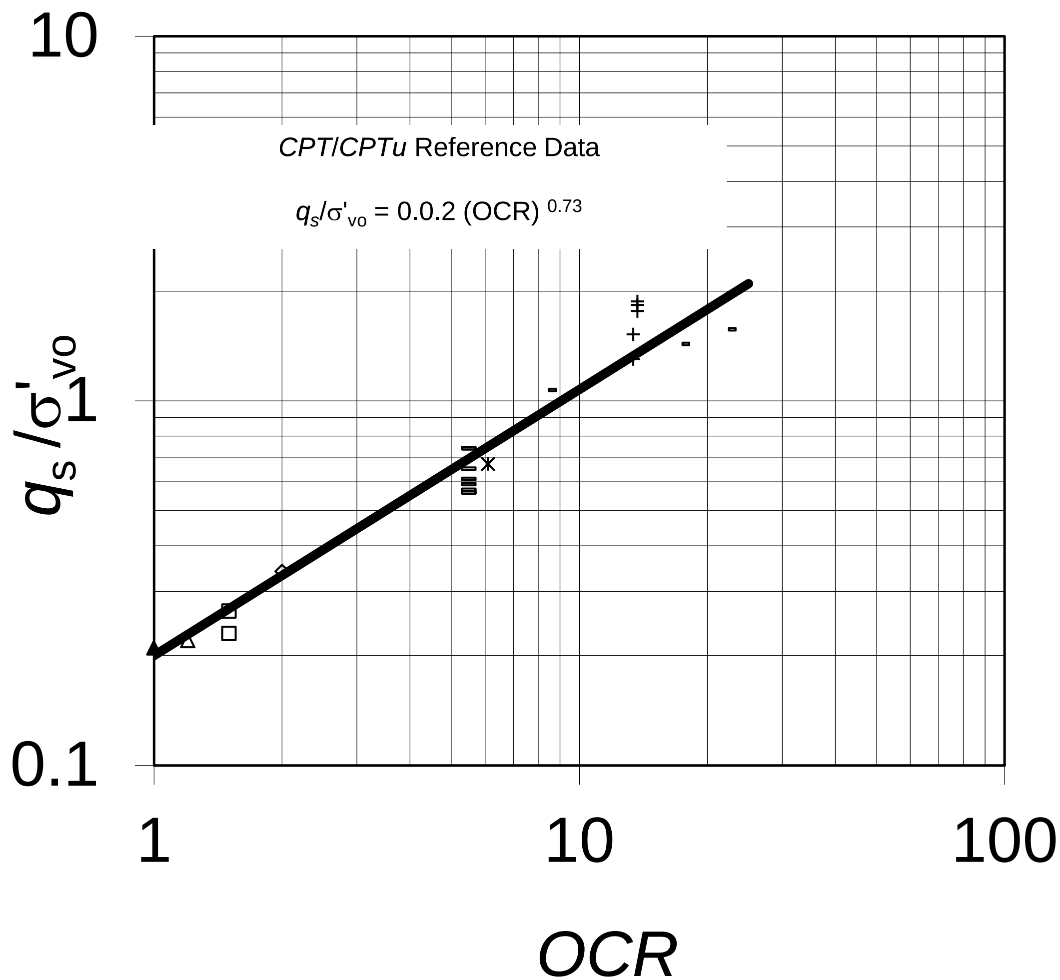
Screened OCR Data for Oedometer Test Record

- $q_s/\sigma'_{vo} = S\ (OCR)^{m}$
- S = 0.19
- m = 0.71



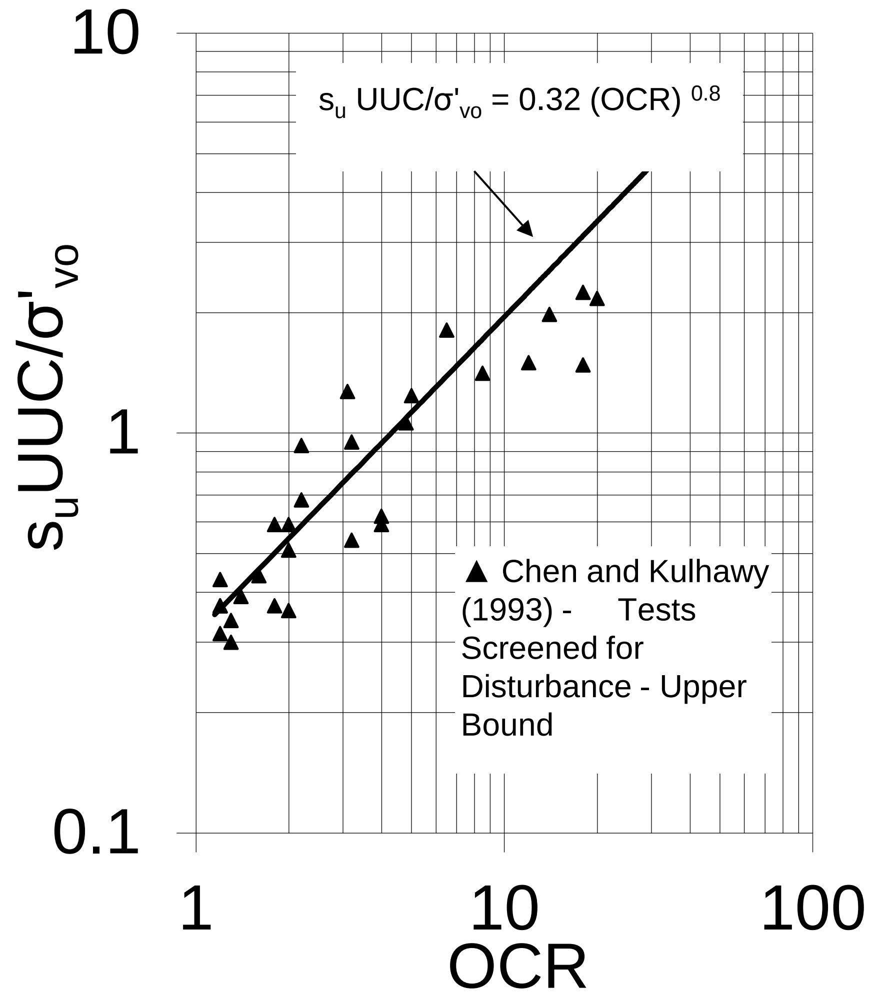
Empirical Correlation for Pile Capacity Referencing OCR Values from CPTu Tests

- $q_s/\sigma'_{vo} = S\,(OCR)^{m}$
- CPTu Reference
- S = 0.2
- m = 0.73
- OCR calculation by Saye et al. (2013b)



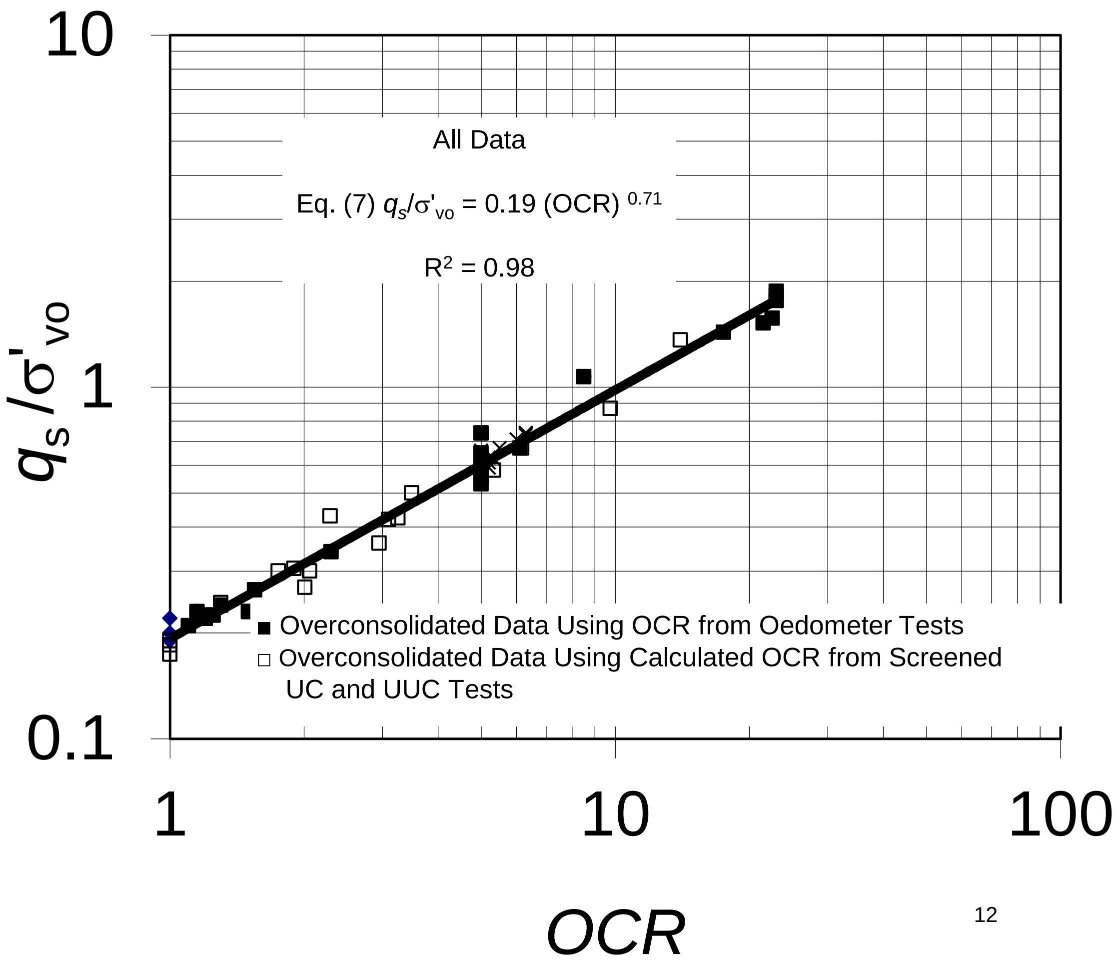
UUC Data to Assess OCR

- S_u UUC $/\sigma'_{vo} = S\ (OCR)^{m}$
- High quality samples
- S = 0.32
- m = 0.8
- S_u UUC $/\sigma'_{vo} < 0.3$ Indicates disturbed sample



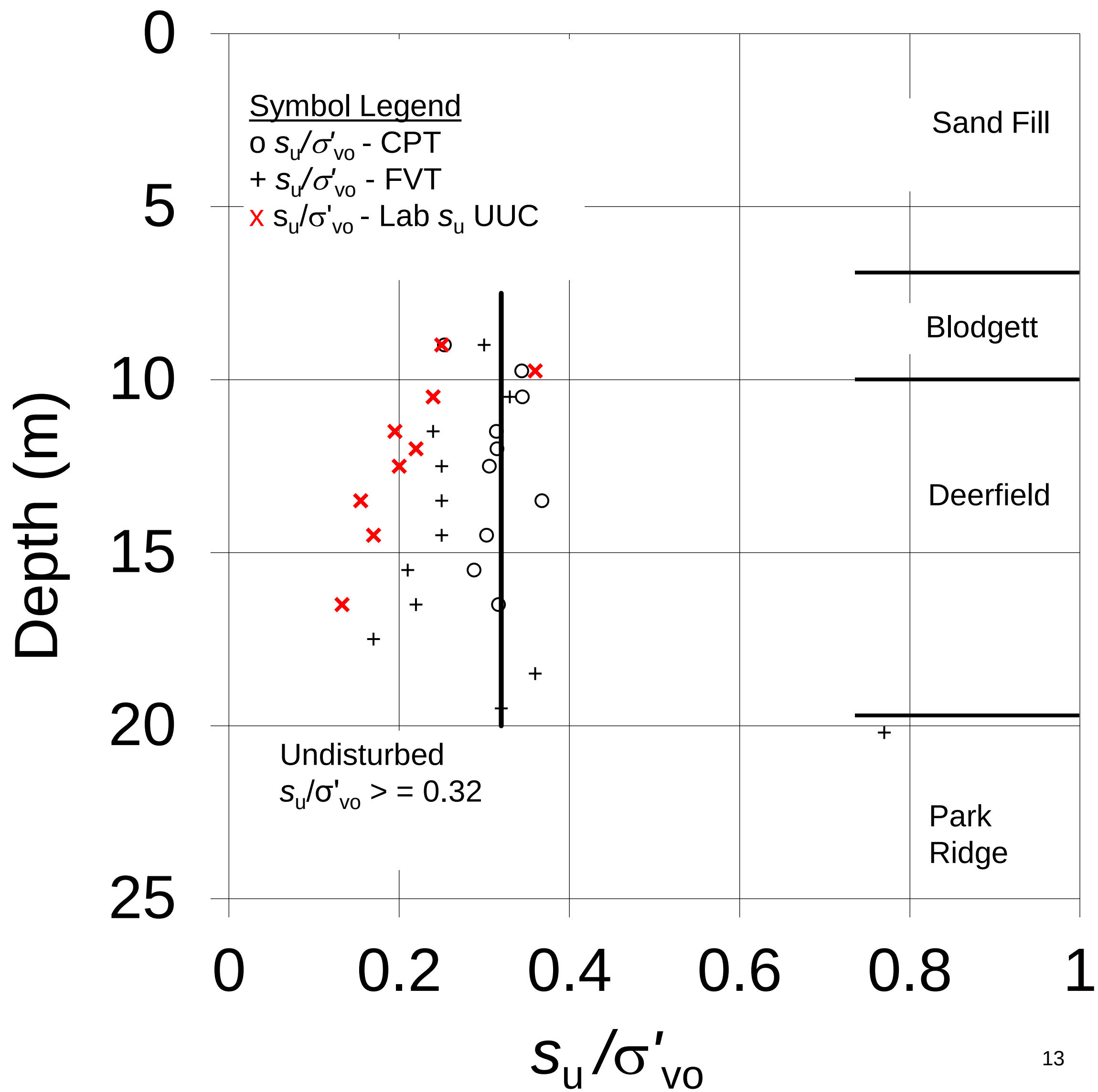
Screened OCR Data from Oedometer Test Record and Undrained Strength Tests

- Composite assessment of OCR using oedometer and s_u UUC tests
- Different from Esrig and Kirby (1979)



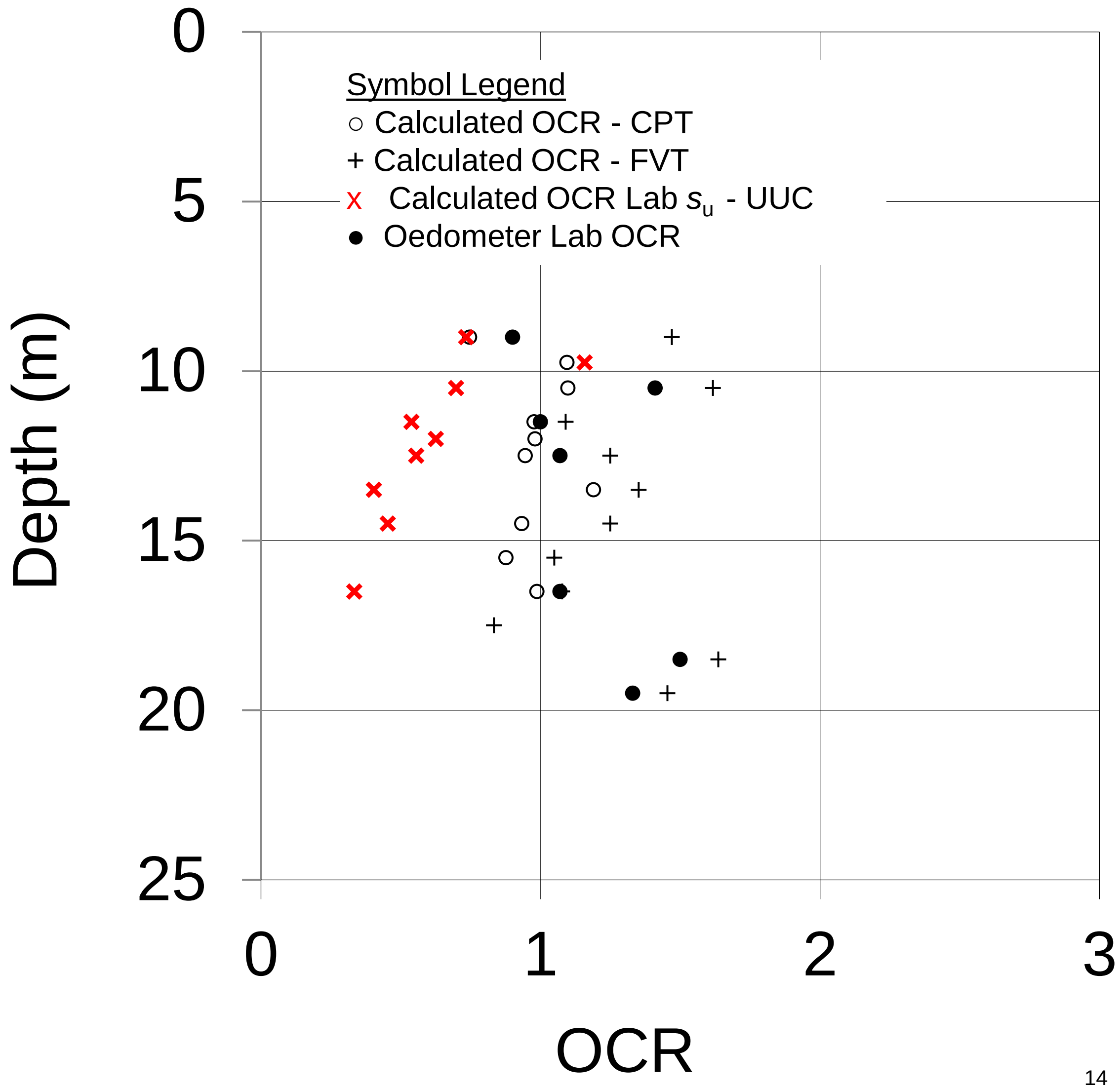
Northwestern NGES Site - Sample Disturbance

- s_u UUC $/\sigma'_{vo} < 0.3$ indicates disturbed sample
- Almost all s_u UUC data are considered disturbed
- Oedometer tests appear to be undisturbed calculated s_u/σ'_{vo} near 0.32



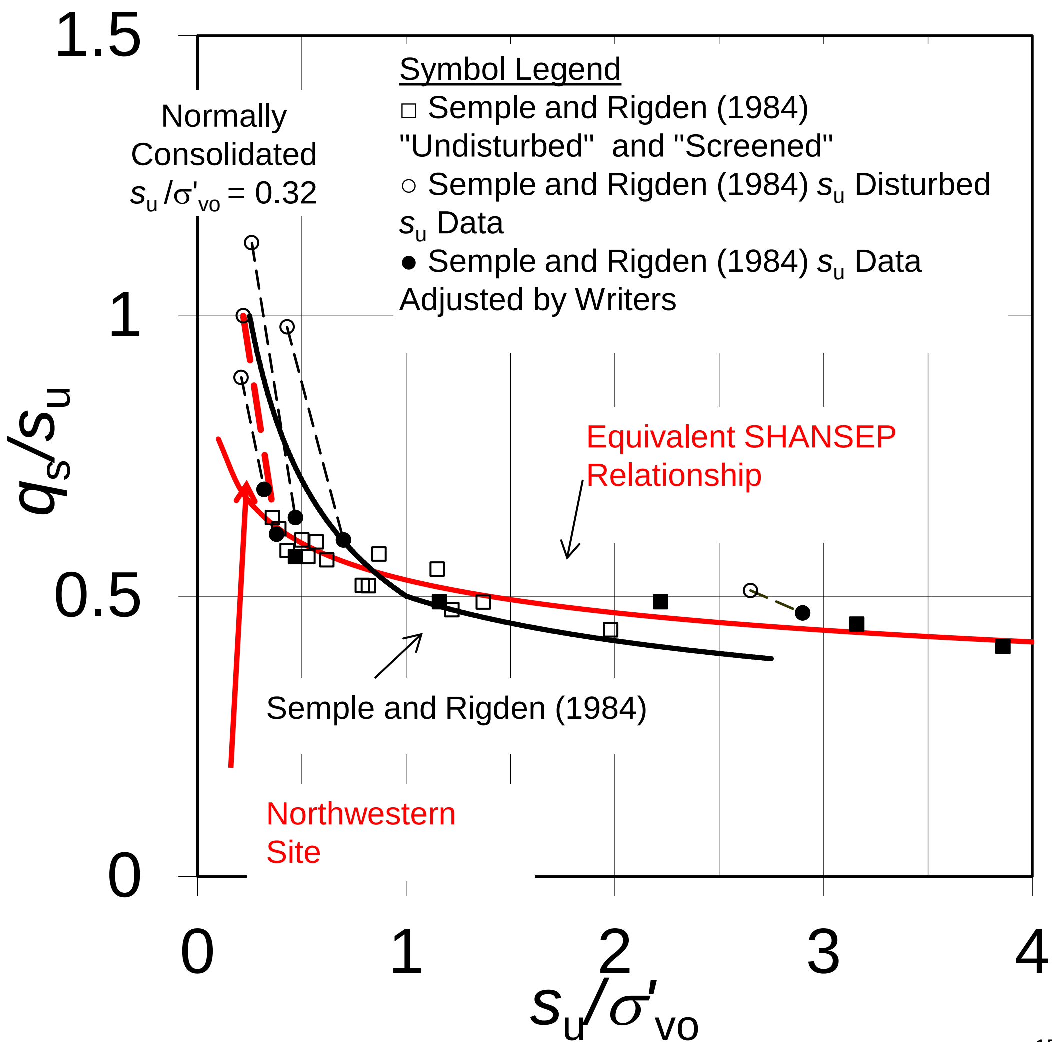
Northwestern NGES Site – Sample Disturbance

- Calculated OCR values from s_u UUC data show sample disturbance
- Laboratory oedometer tests and field vane tests show a small overconsolidation



Match Disturbance Effects in the Empirical Correlation for Pile Capacity

- Saye et al. (2016)
- Equivalent α analysis
- Effect of sample disturbance
- “Better” samples does not necessarily mean a better assessment of q_s



Better Soil Properties for Pile Design

- s_u UUC /σ'_{vo} < 0.3 — Likely disturbed
- s_u UUC /σ'_{vo} < 0.8 — Use oedometer tests to confirm OCR
- s_u UUC /σ'_{vo} > 0.8 — Likely undisturbed

- Match empirical correlation to sample quality and screening

Kiewit

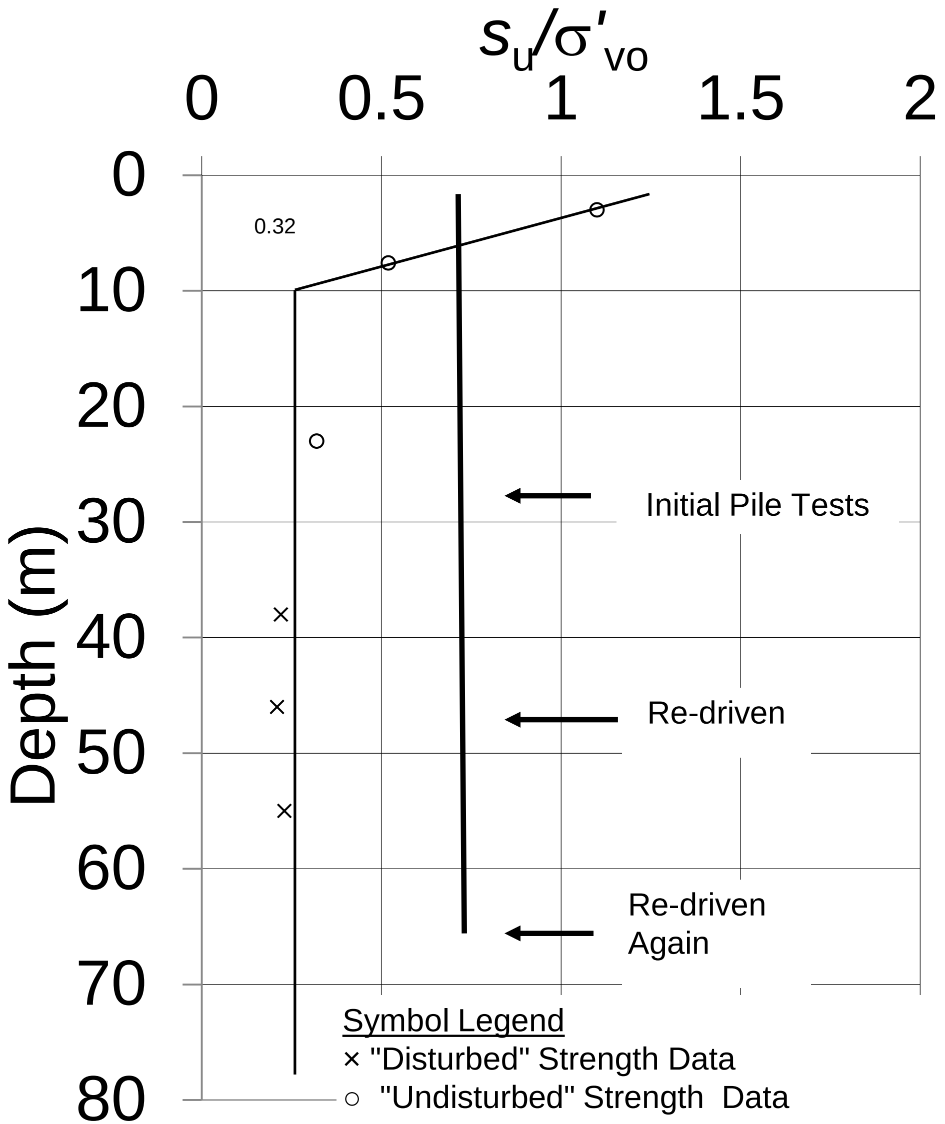
Construction Influence Factor

- Currently the SHANSEP-based approach is modified to add the effects of specific construction installation factors described in Saye et al. (2018)
- Re-driving
- Long installation time
- Vibratory hammer installation

- $q_s/\sigma'_{vo} = C_I \, (q_s/\sigma'_{vo})_{NC} \, (OCR)^{0.7}$

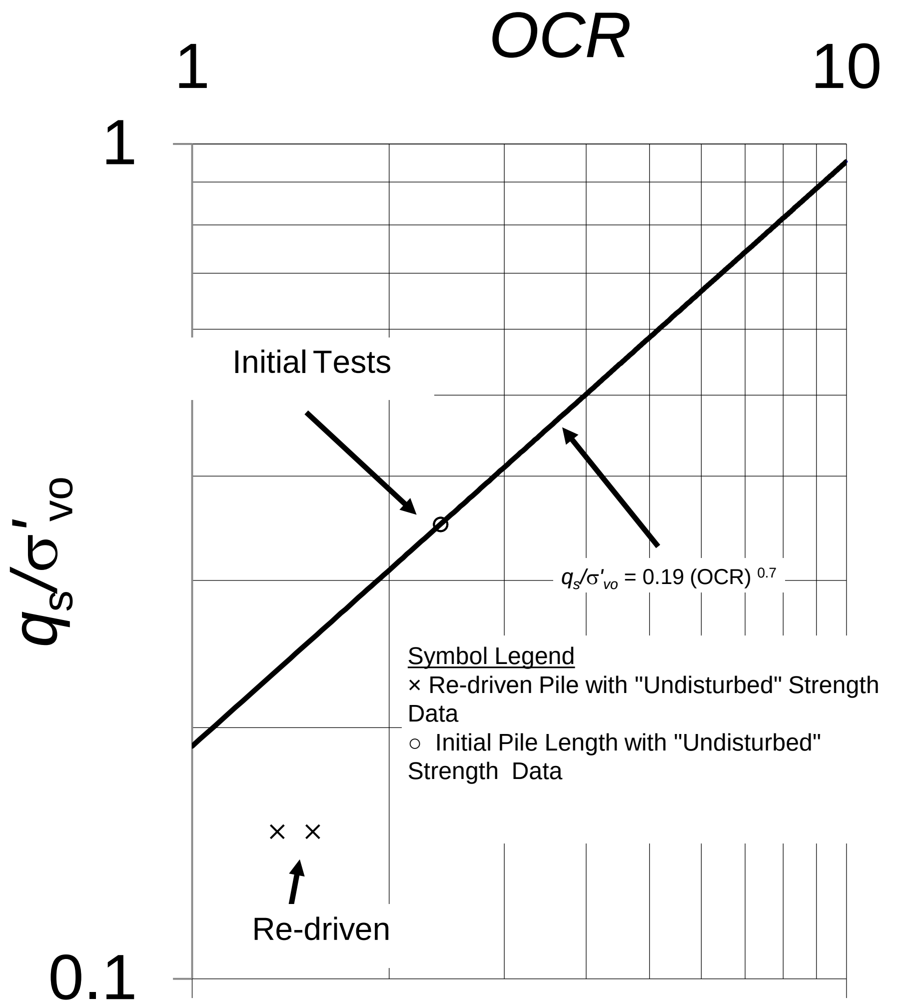
Drayton North Dakota Site – Long Re-driven Piles

- s_u UUC $/\sigma'_{vo} < 0.3$ Indicates disturbed sample
- Pile subsequently re-driven two times after set-up and load tested



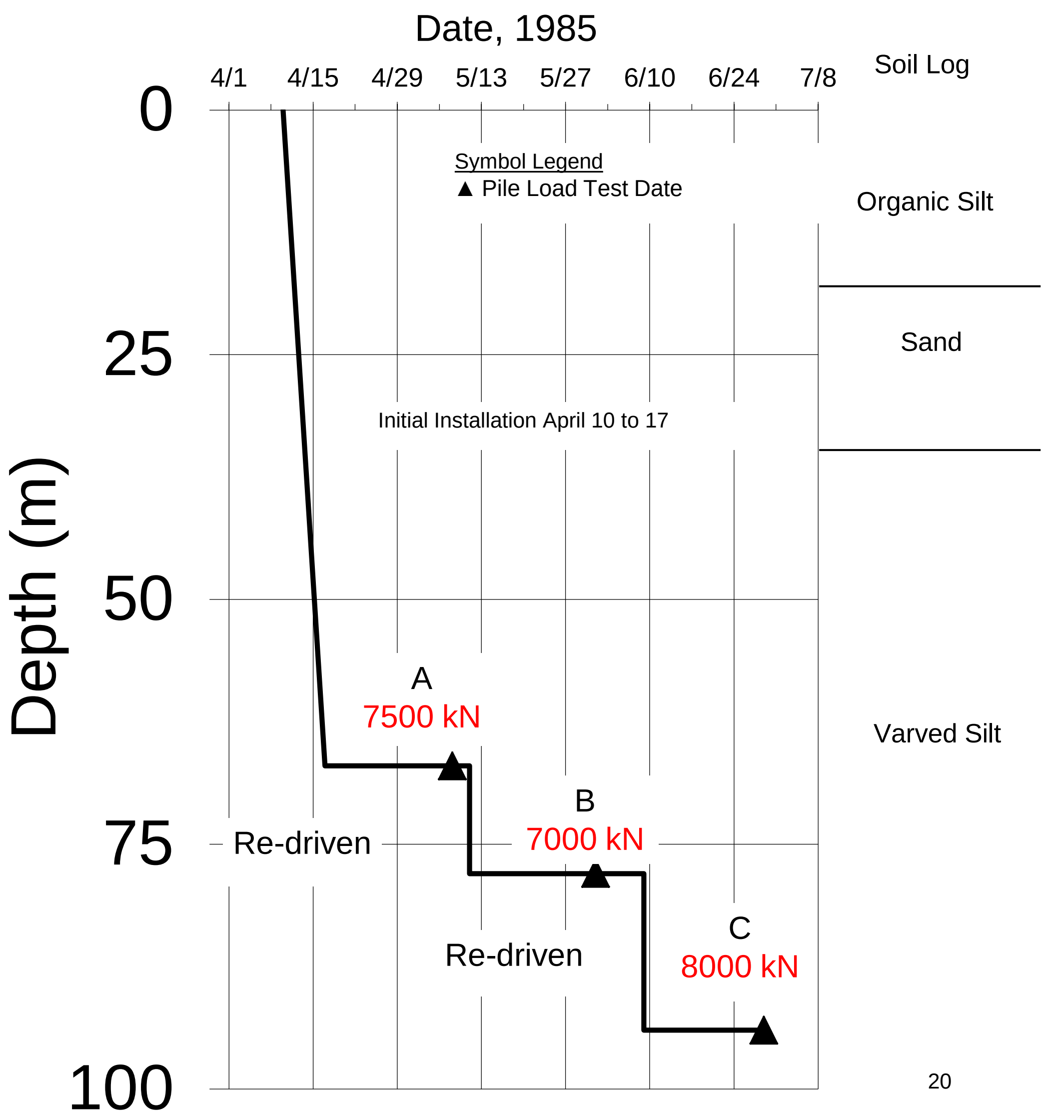
Drayton North Dakota Site – Long Re-driven Piles

- Initial tests consistent with SHANSEP relationship
- Re-driven tests show much lower q_s/σ'_{vo} values and are impacted by the method of installation
- Re-driven piles should not be in the empirical case history record for q_s correlations
- C_l = 0.5 for re-driven pile section

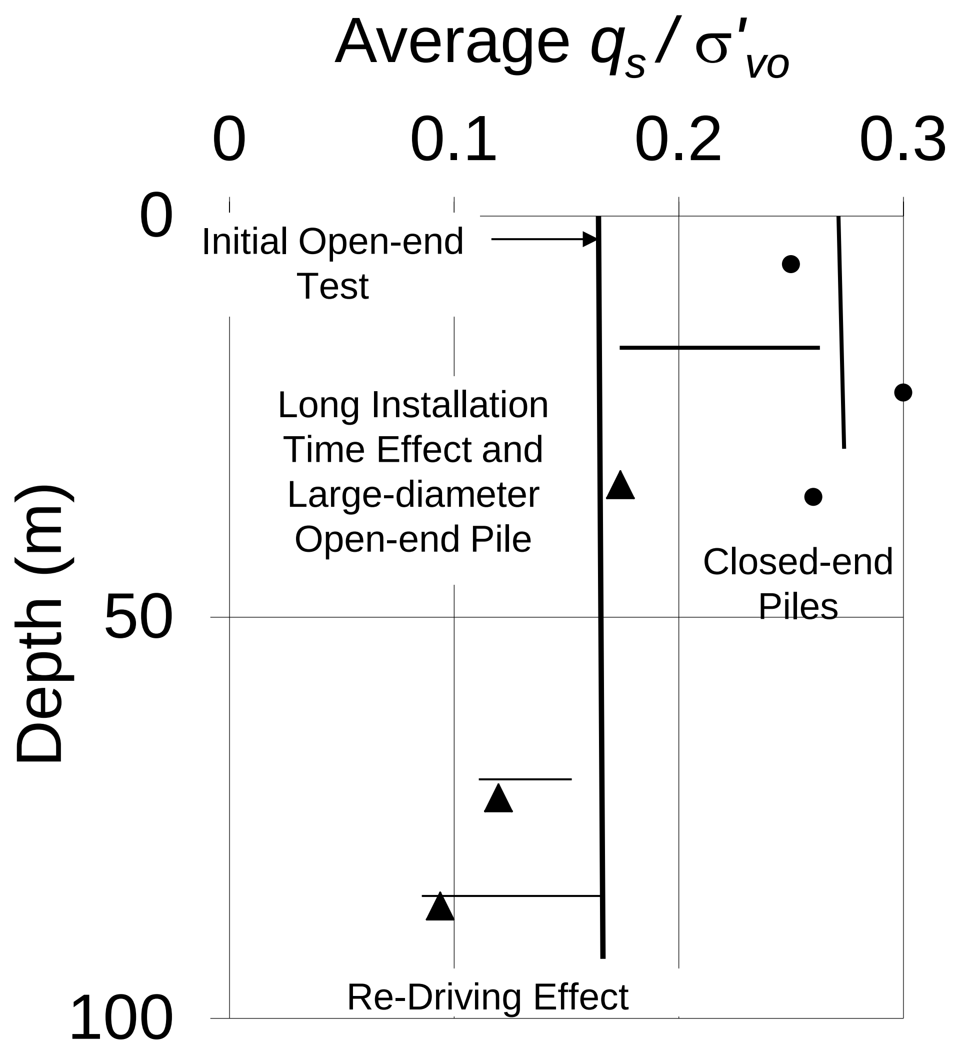


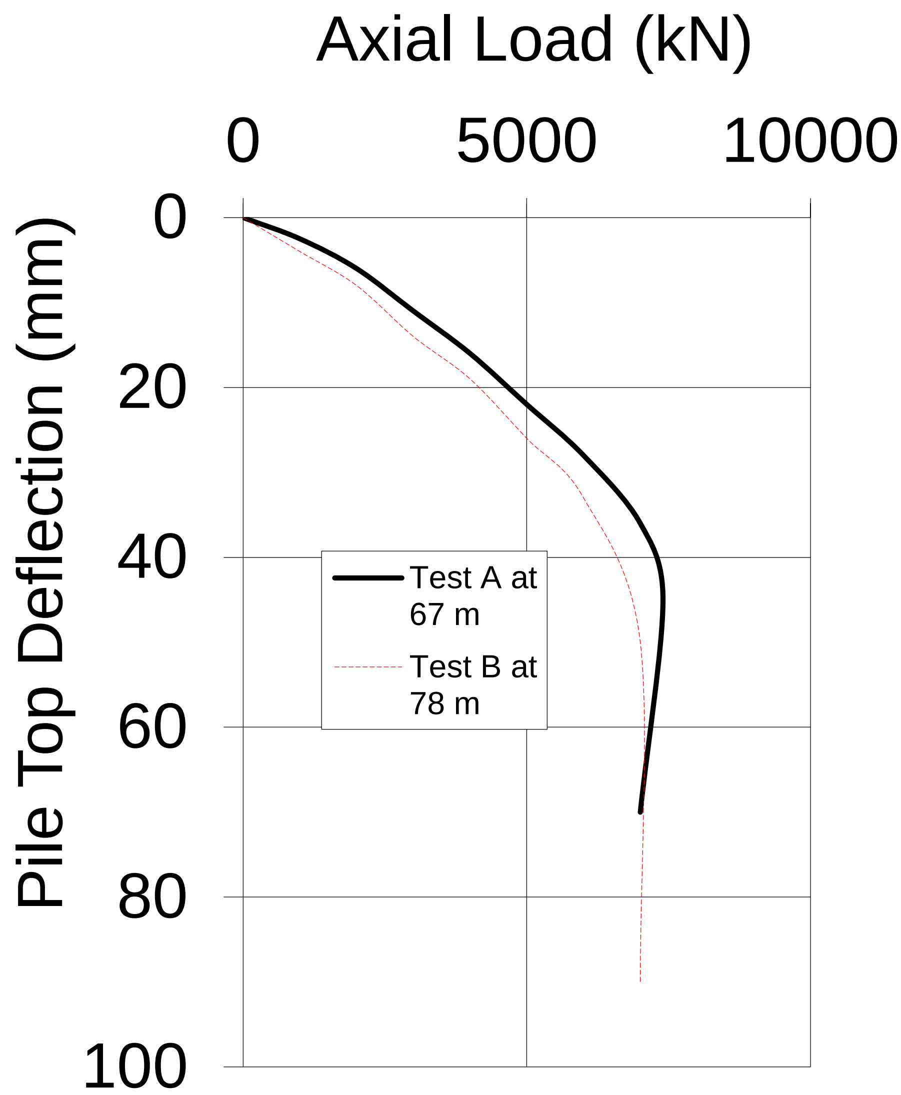
Annacis Bridge – Long Installation Time and Re-Driven Pile

- Open-ended pipe pile bearing in Fraser River alluvium
- First section driven in a 7 day time interval
- Pile subsequently re-driven and load tested two times
- Test B was driven 11 m deeper but showed lower capacity than test A

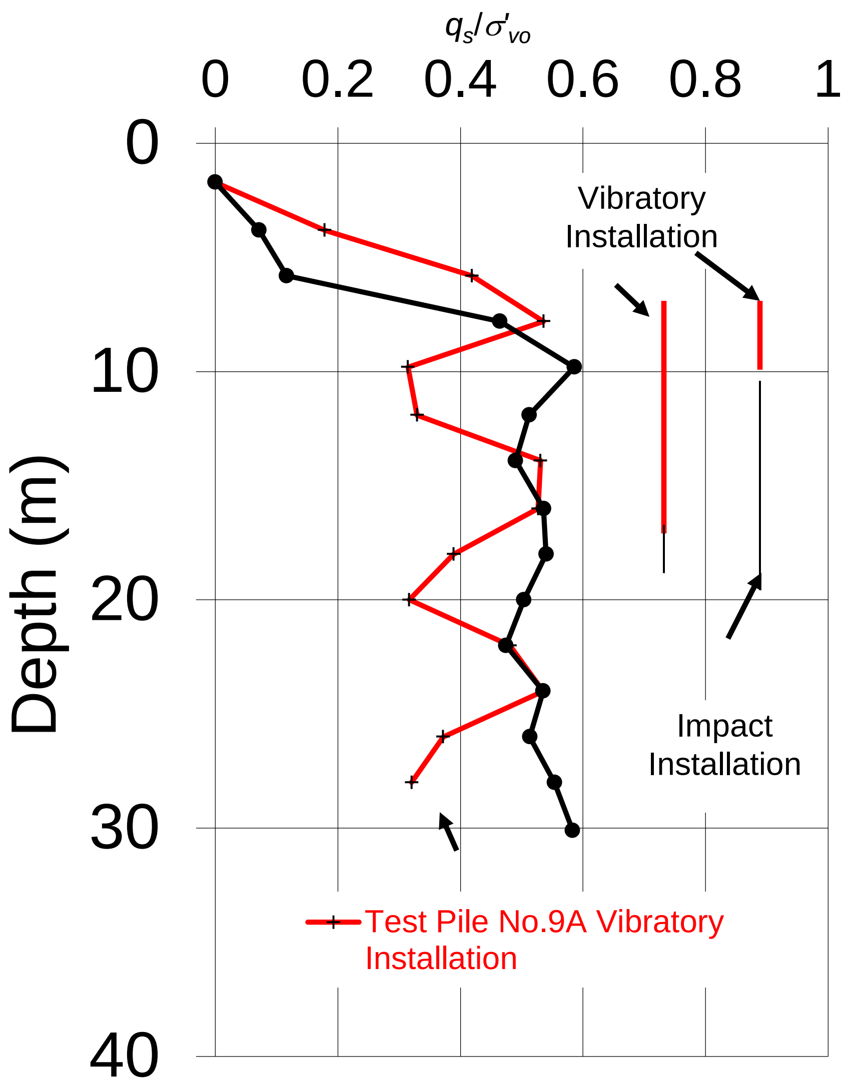


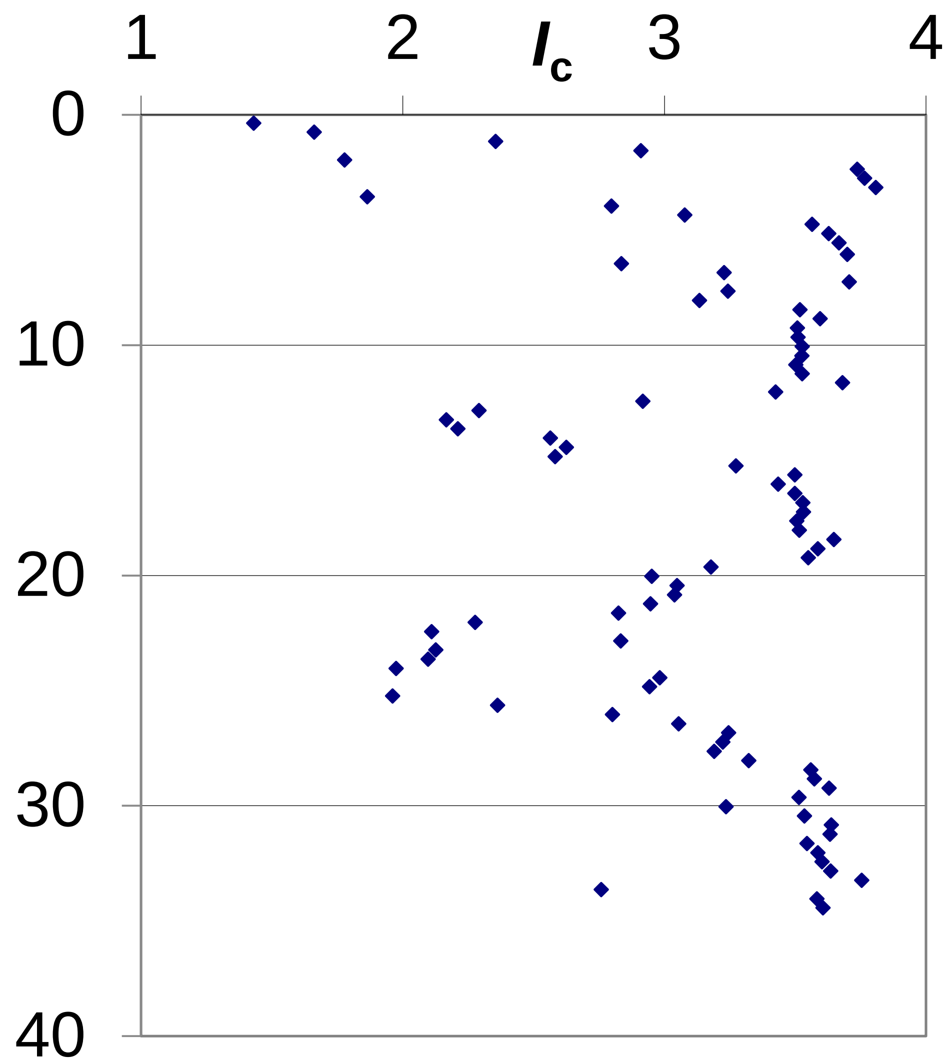
Annacis Bridge – Long Installation Time



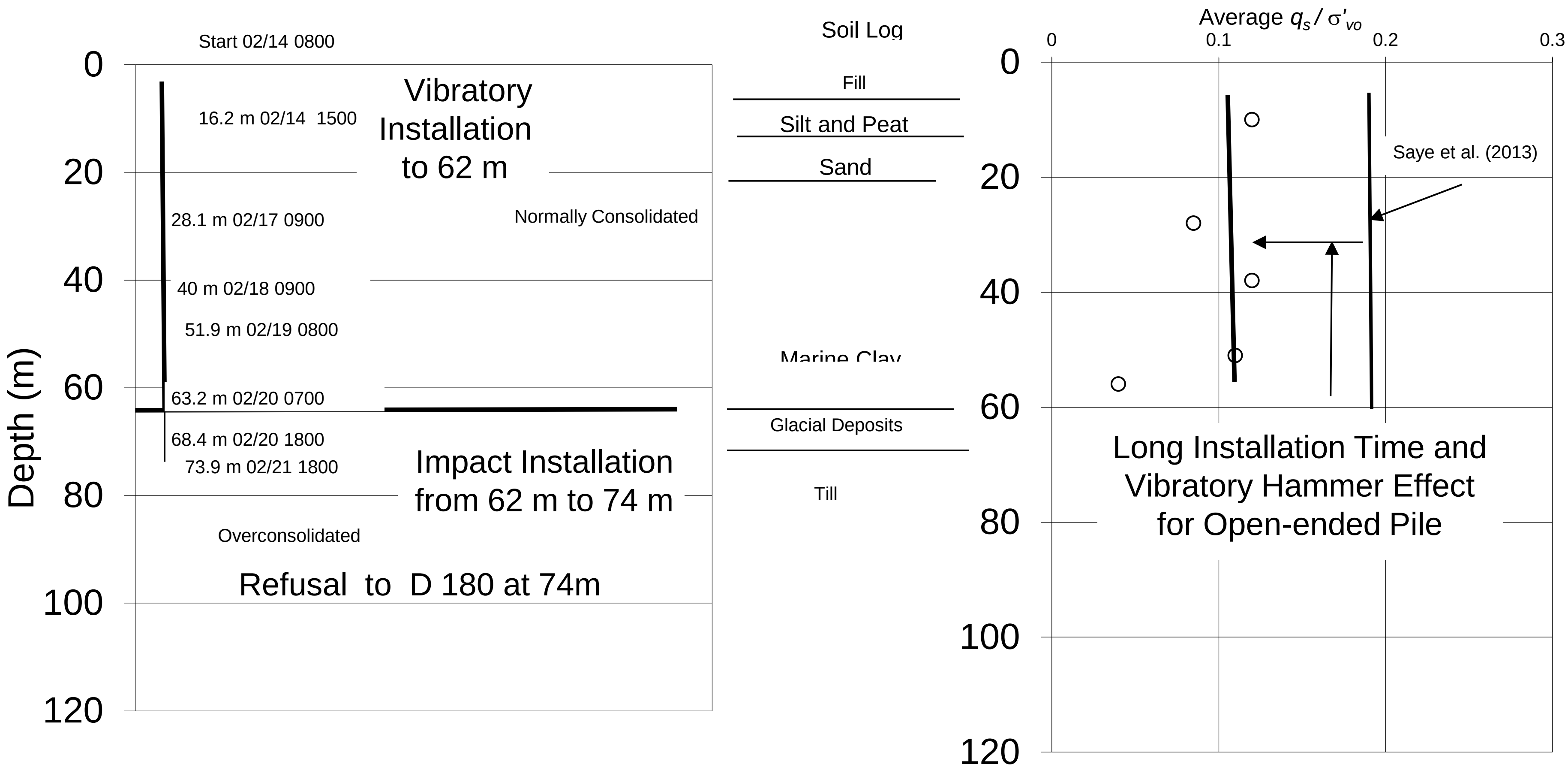


Vibratory Hammer Installation – NOLA Site



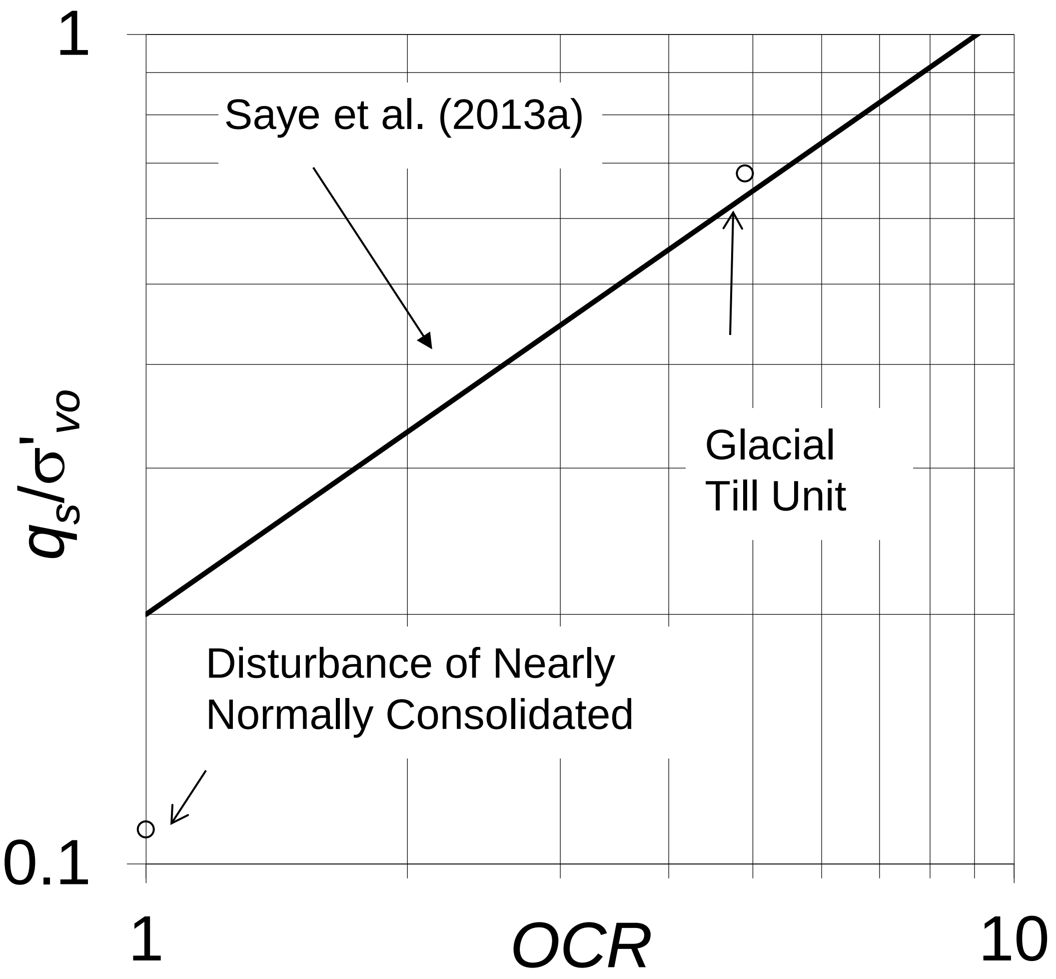


Port Mann Bridge Adapted from Petek et al. (2012)



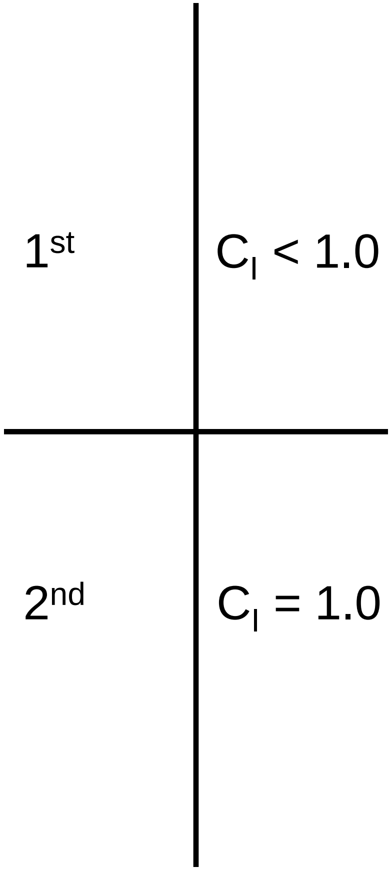
Port Mann Bridge

- Nearly normally consolidated soils weakened by long installation time at Port Mann
- This disturbance is considered unavoidable
- Reasonable calculated capacity of overconsolidated glacial deposits with SHANSEP approach



Spliced Pile Example

- Upper Section $C_l = 0.5$
  - Vibratory hammer installation
  - Long delay time for splicing
- Lower section $C_l = 1$ for impact hammer installation with un-interrupted drive to tip
- Instrumented pile load test to confirm C_l value



SHANSEP Approach Applies to Each In Situ Test Method

- Ladd et al. (1998) – piezocone tests
- Normalize test result to σ'_{vo}
- Relate to OCR
- The normally consolidated normalized value = S
- Determine the increase in test results with increasing overconsolidation = exponent m

$$\frac{\text{In Situ Test Parameter}}{\sigma'_{vo}} = S\,(OCR)^{m}$$

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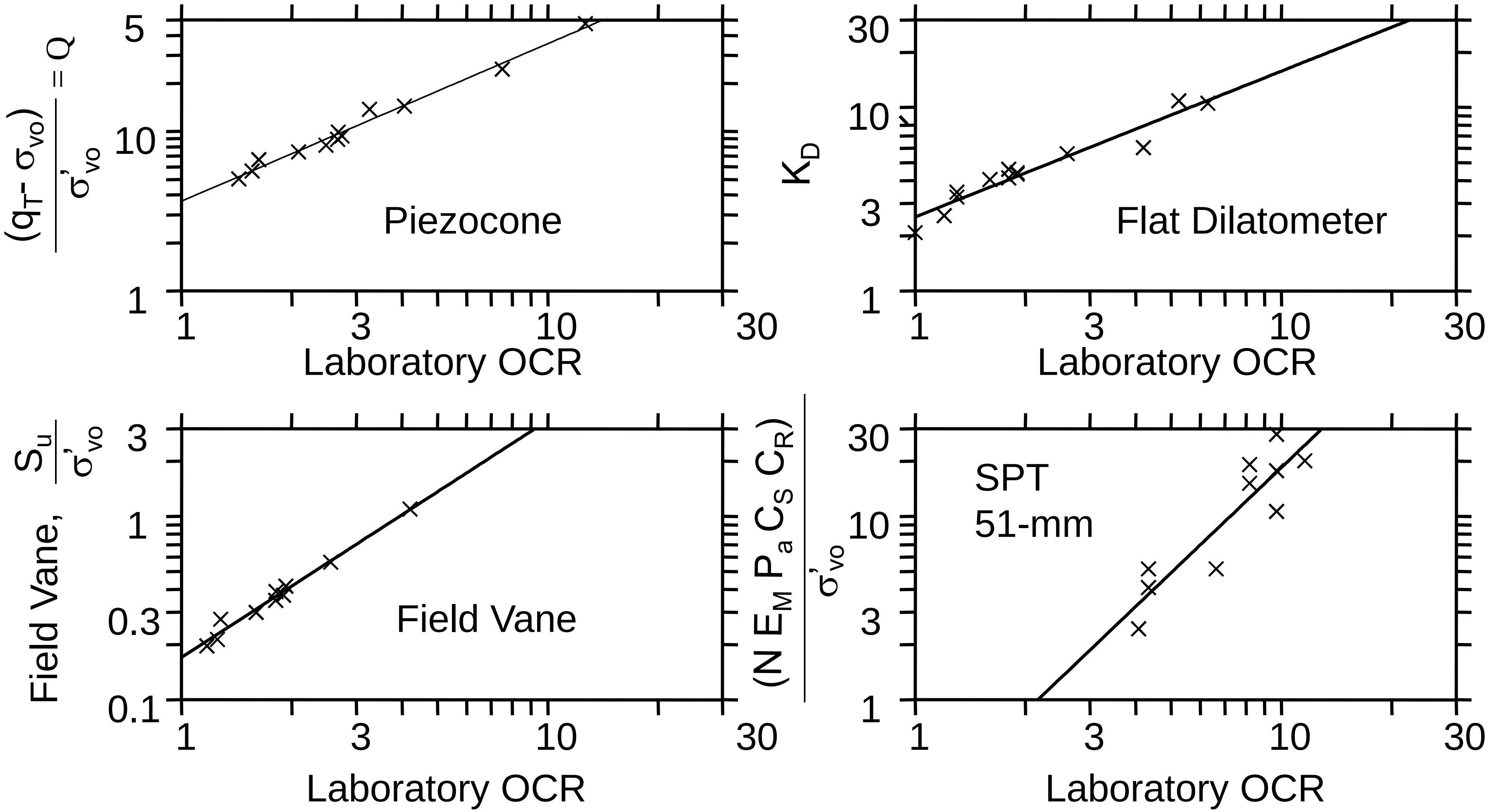
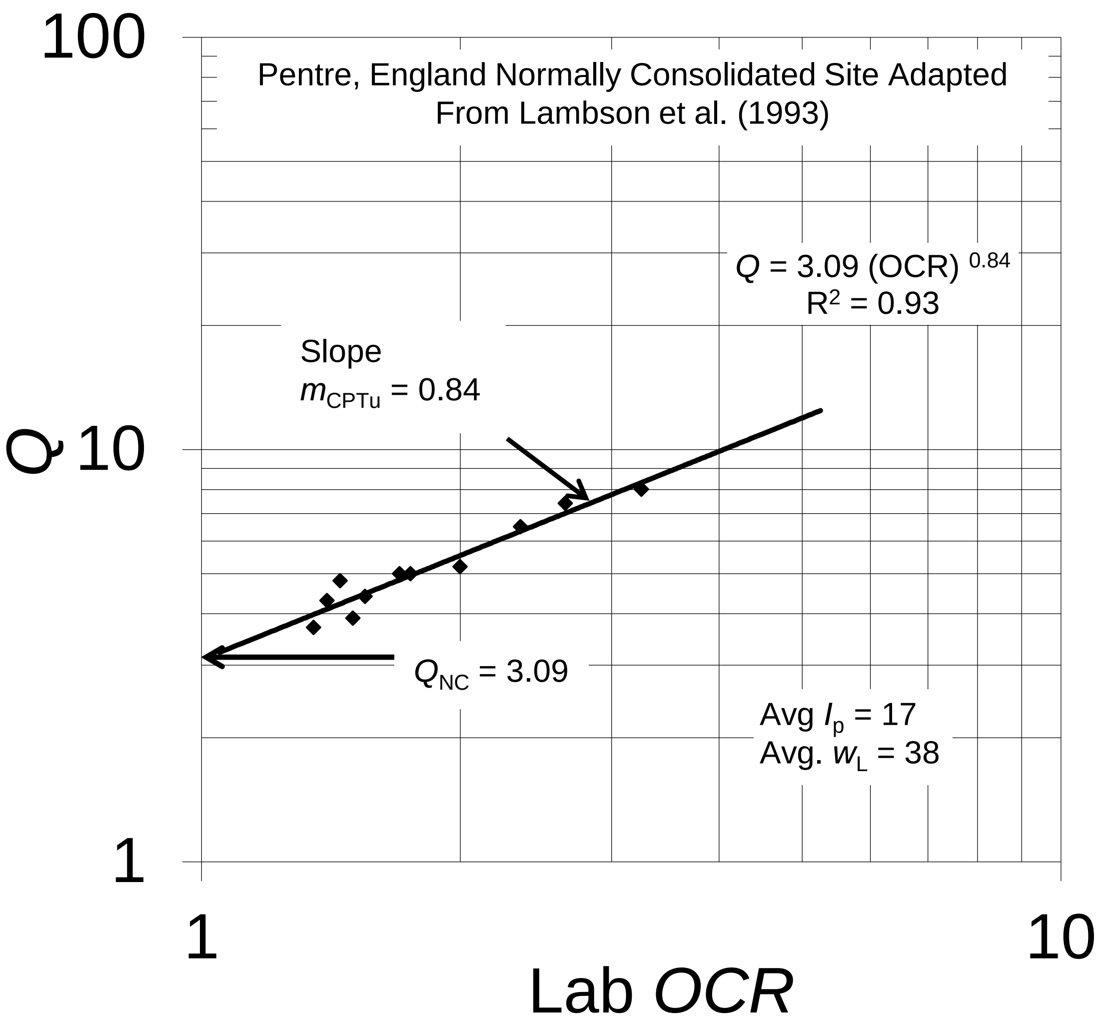


Piezocone Data to Assess OCR

- $Q = Q_{NC}\,(OCR)^{m\,CPTu}$
- High quality samples for correlations
- Q_{NC} = Varies with soil index properties
- m_{CPTu} = Varies with soil structure and soil index properties

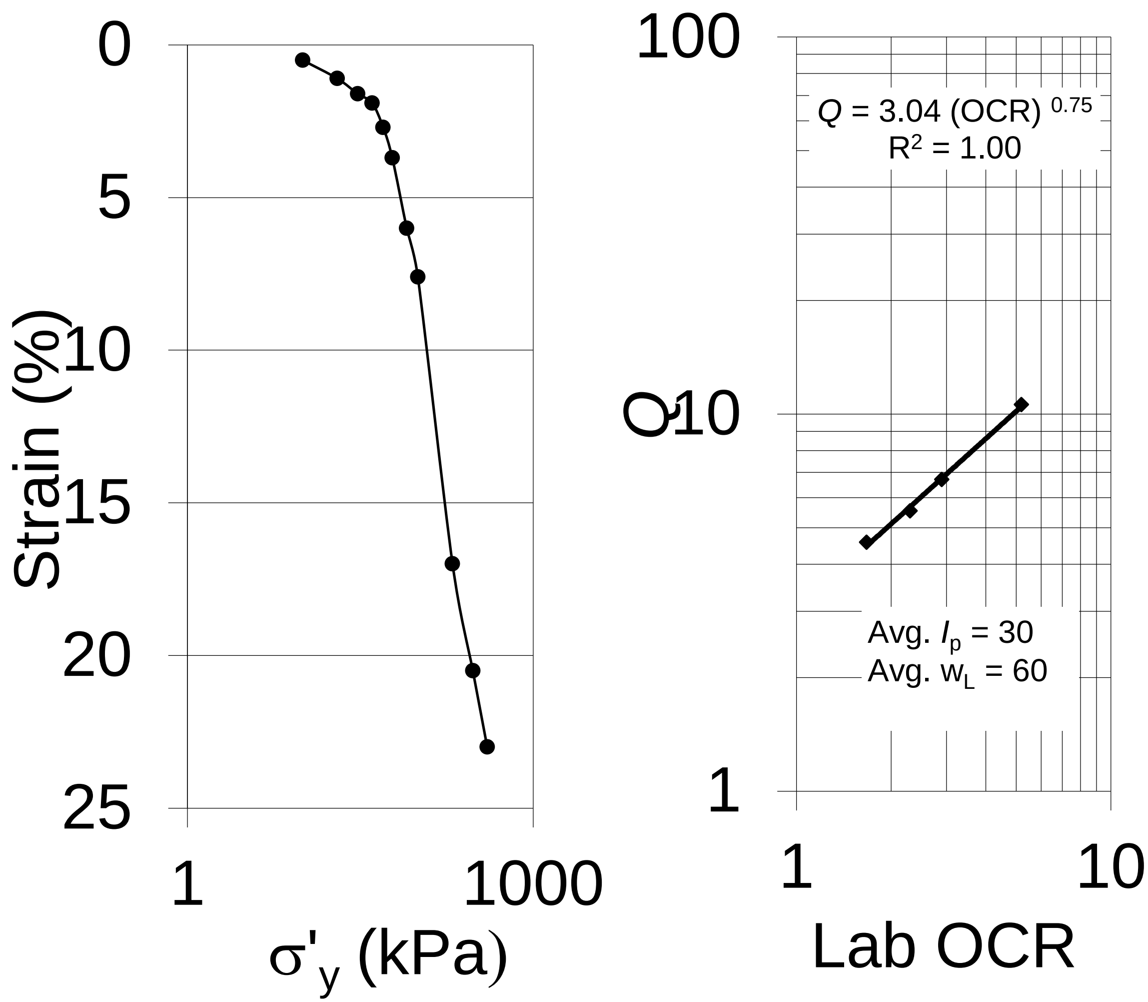


Piezocone Data to Assess OCR

- A key improvement to Saye et al. (2013b) is recognition of the effects of soil structure for overconsolidated soils

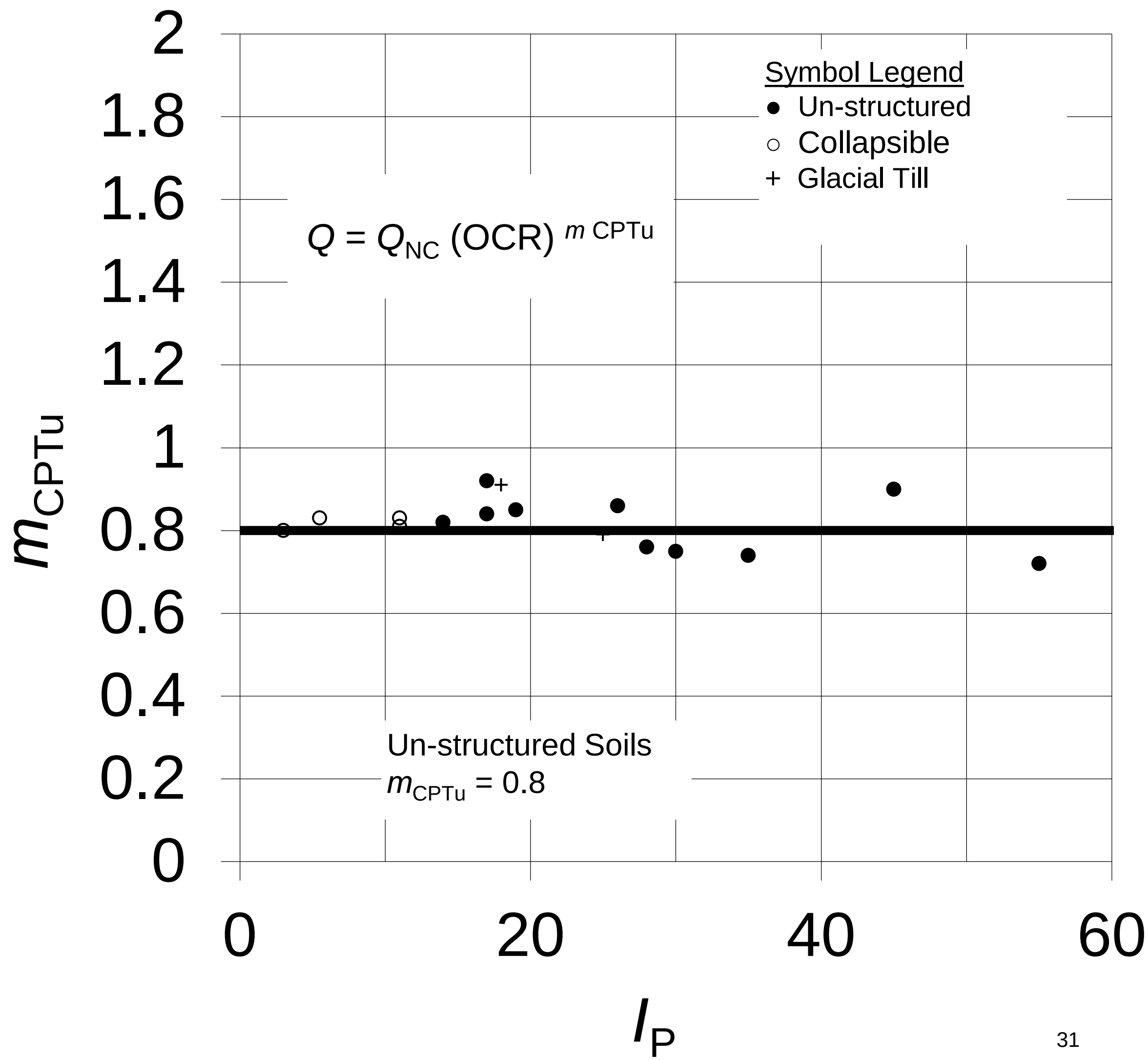
Unstructured Soil Behavior

- Linear virgin compression line
- $m_{CPTu} < 1$
- Changes in overburden control OCR



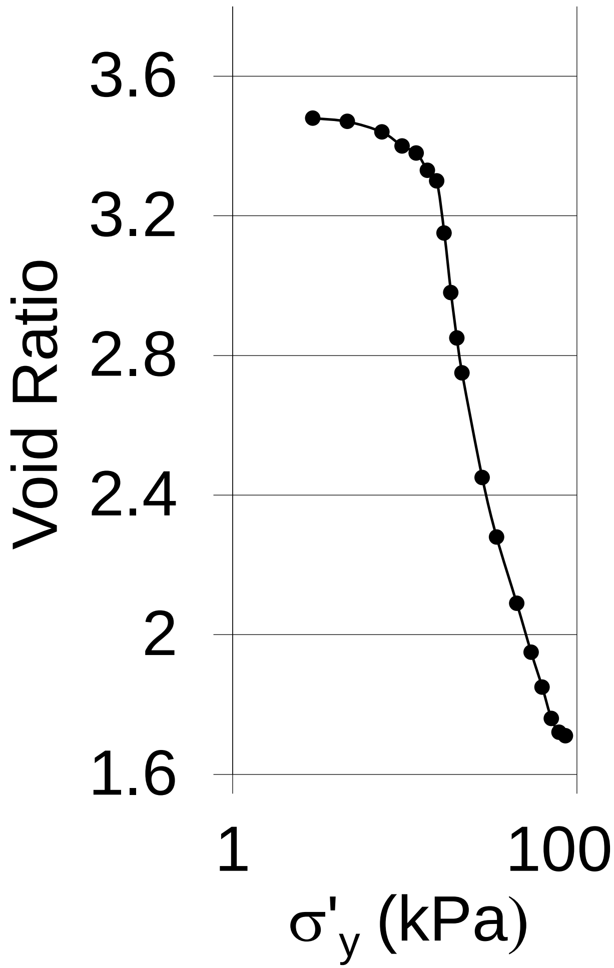
m_{CPTu} for Unstructured Soils

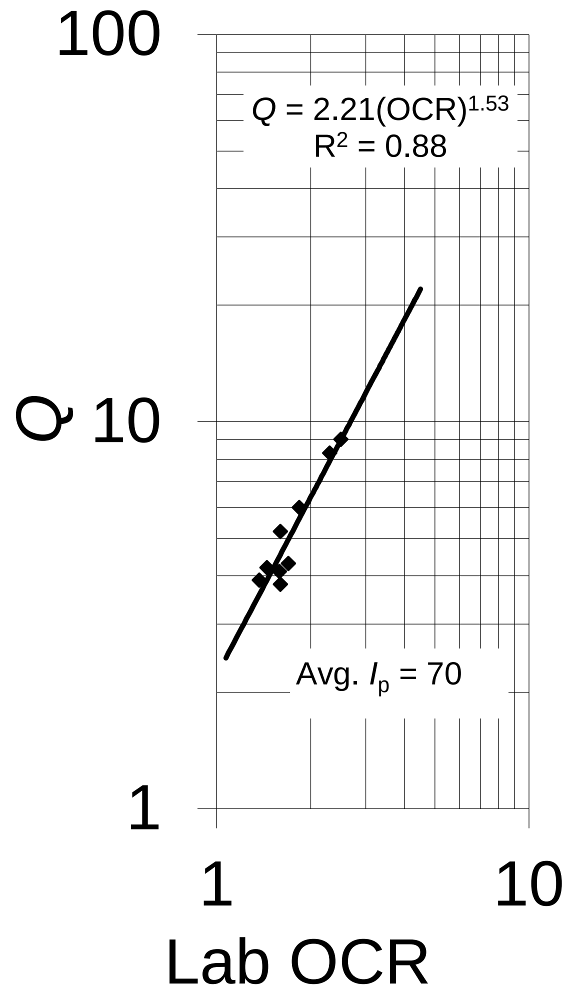
- m_{CPTu} = 0.8 for unstructured soil behavior



Structured Soil Behavior

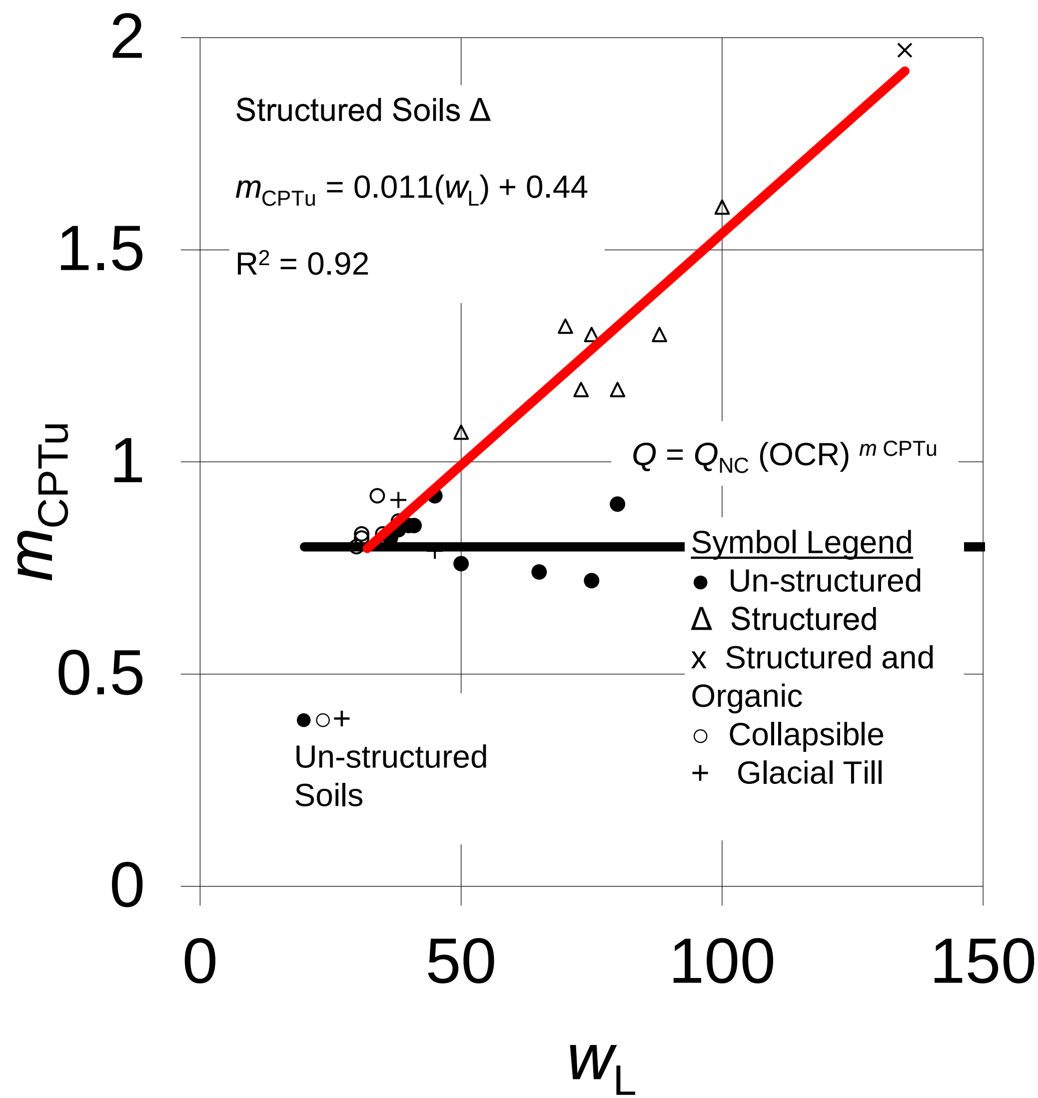
- Non-linear virgin compression line
- $m_{CPTU} > 1$
- Secondary compression and ageing are key components of OCR





Piezocone Data to Assess OCR – Structured Soils

- m_{CPTu} varies with soil index properties for structured soil behavior
- $m_{CPTu} > 1$
- Update Saye et al. (2013b) with
- $m_{CPTu} = 0.011\ w_L + 0.44$
- $m_{CPTu} = 0.014\ I_p + 0.67$

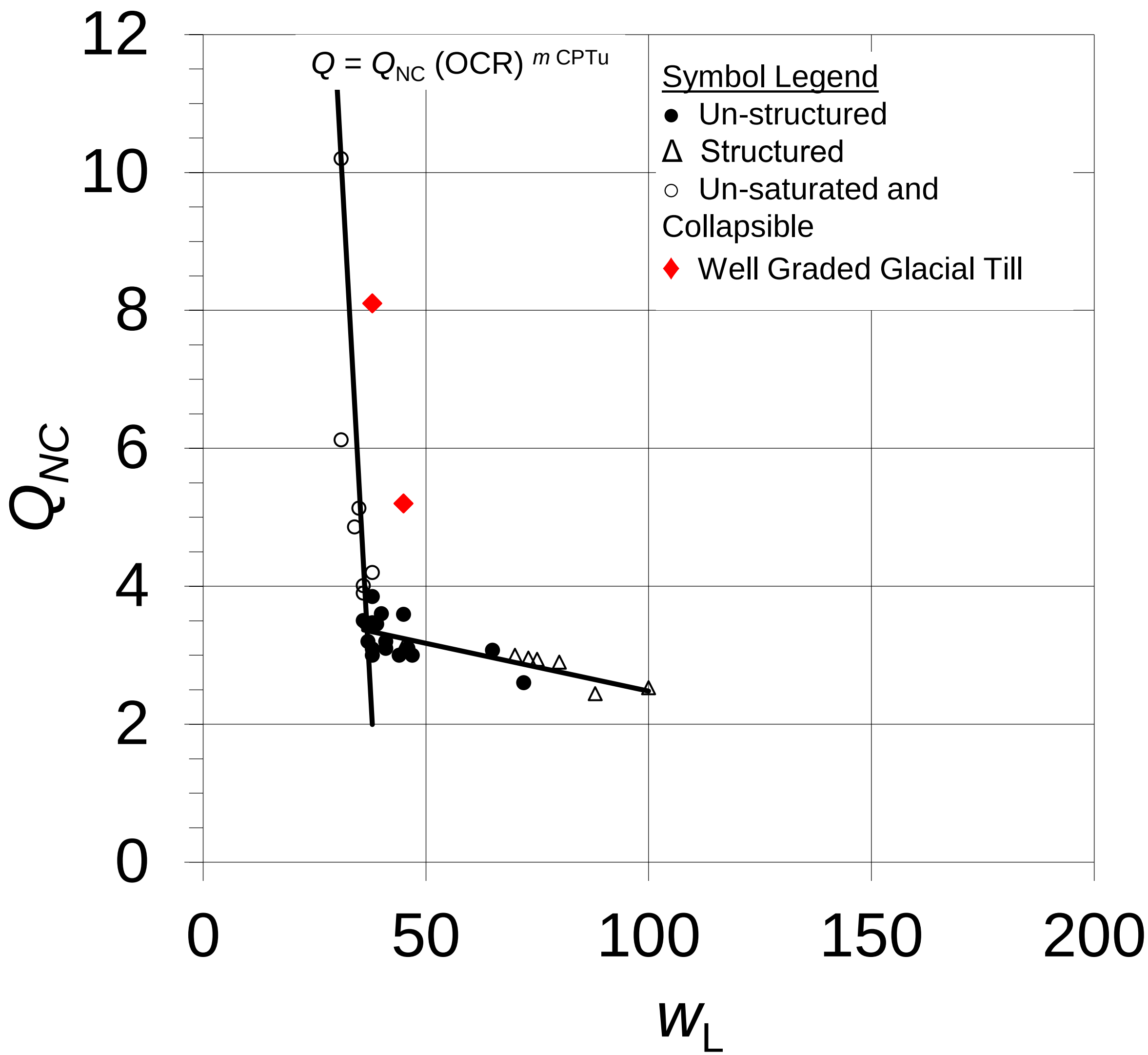


Piezocone Data to Assess OCR

- Q_{NC} varies with soil index properties for both structured and unstructured soil behavior
- Q_{NC} variations for unsaturated low plastic soils and Peorian Loess
- Replace Eq. (6a) and (8a) in Saye et al. (2013b) with:
- $Q_{NC} = 46.4 – 1.17\ w_L$
- $Q_{NC} = 18.5 – 1.28\ I_p$

Exception for glacial till

- Well-graded materials like glacial till require a project-specific correlation for correlations referencing index properties



Verification Testing

- High quality samples for oedometer tests
- ϵ to σ'_{vo}
- Structured / unstructured behavior
- Determine soil index properties
- Confirm OCR and adjust correlation coefficients if needed
- Oedometer tests in same borehole
- Boring matched with CPTu

Conclusions

- A key aspect of the SHANSEP approach is the separation of the normally consolidated behavior from the overconsolidated behavior
- The m_{CPTu} exponent provides a convenient way to address structured and unstructured soil behavior

Conclusions In Situ Tests

- Sites underlain by cohesive soil have an OCR that can be assessed with both laboratory and in situ tests
- In situ and laboratory test results from a wide variety of methods are consistent with the SHANSEP relationship (Ladd and Foott 1974)

$$\text{Normalized test value} = S\,(\text{OCR})^{m}$$

$$\text{OCR} = [\text{Normalized Value}/S]^{1/m}$$

- S and m vary with soil index properties

Conclusions In Situ Tests

- Structured soil is associated with $m_{CPTu} > 1$
- Unstructured soil is associated with $m_{CPTu} < 1$
- The SHANSEP approach addresses these soil structure changes

Conclusions In Situ Tests

- Develop:
  - Local empirical correlations – geologic materials
  - Project-specific correlations
  - Index property correlations
- Validate the SHANSEP correlation coefficients

Conclusions Driven Closed-ended Piles

- The SHANSEP approach provides an efficient approach to evaluate the side adhesion of closed-ended and small diameter open-ended pipe piles
- Construction influence factor is added to accommodate the detrimental effects of re-driving piles, long installation times, and vibratory hammer installation

Acknowledgement

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