

# Session Report 2: CPT Interpretation



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**WISCONSIN**  
MADISON

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# Interpretation of soil behaviour

- Strength
- Stiffness
- Compressibility
- Water Flow Characteristics

$\tau_f$  ( $\phi'$  &  $\psi'$ ,  $s_u$ )  
G (or E)  
 $1/K'$  ( $\kappa$ ,  $\lambda$ ,  $C_C$ ,  
 $C_S$ , M or  $D'$ )  
k (or  $c_v$ ,  $c_h$ )



# Outline

- Characteristics of papers
- Strength
- Stiffness
- Compressibility
- Water Flow Characteristics
- Soil State
- Soil Classification
- Discussion

Please see Session Report in Proceedings for classification of papers

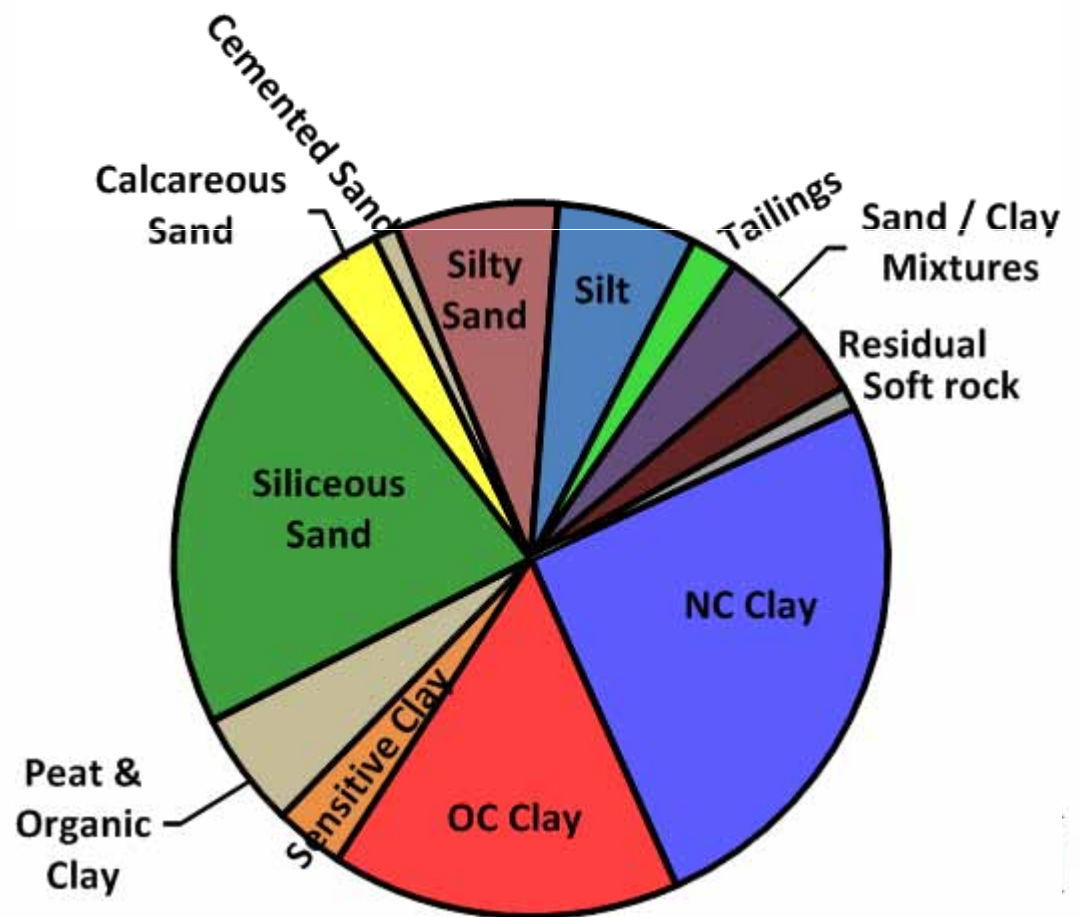


# Characteristics of Papers



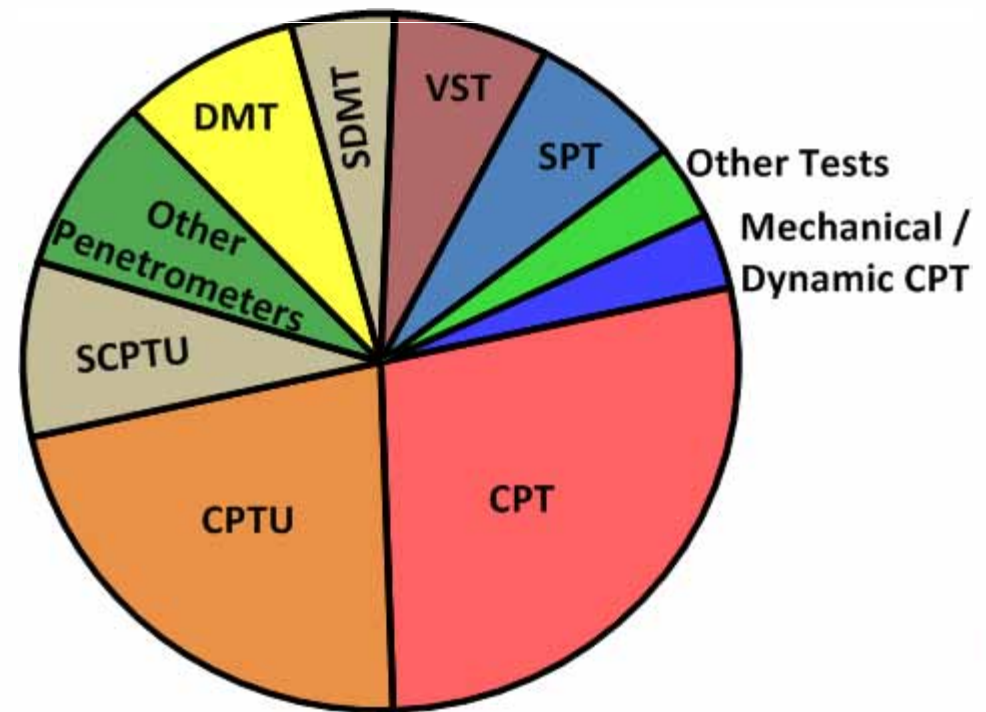
# Characteristics of Papers

- Nearly 60 papers
- 28 Countries
- $\approx 13$  Soil 'Types'



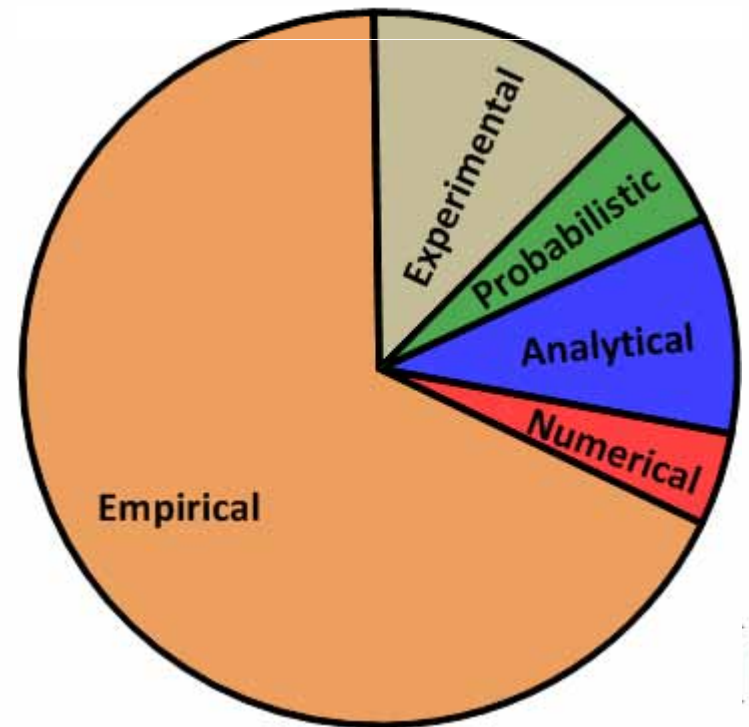
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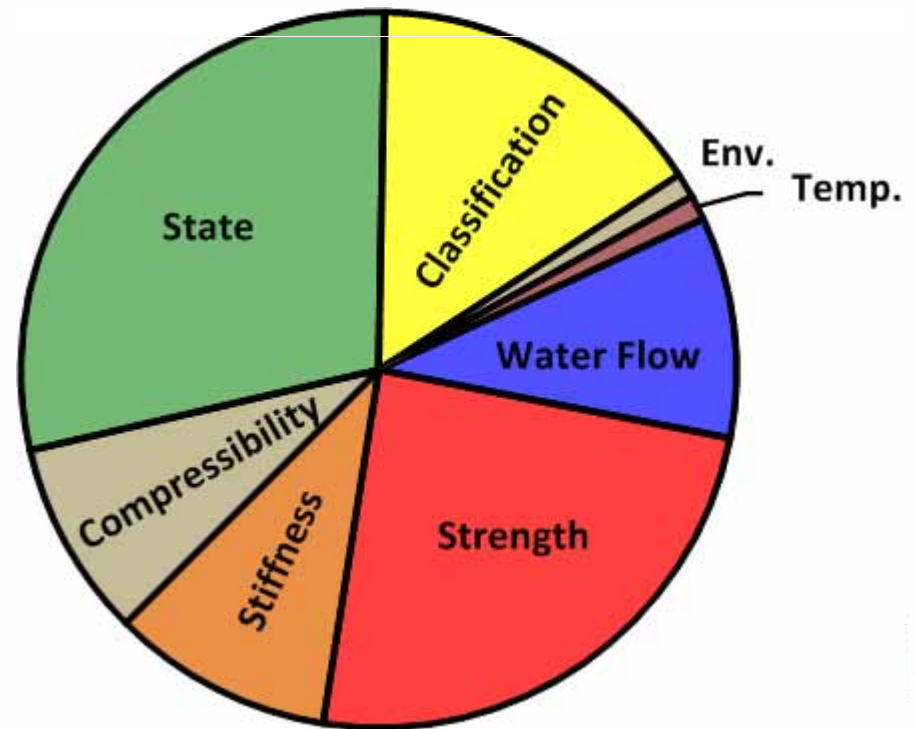
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- $\approx 5$  Analysis Methods



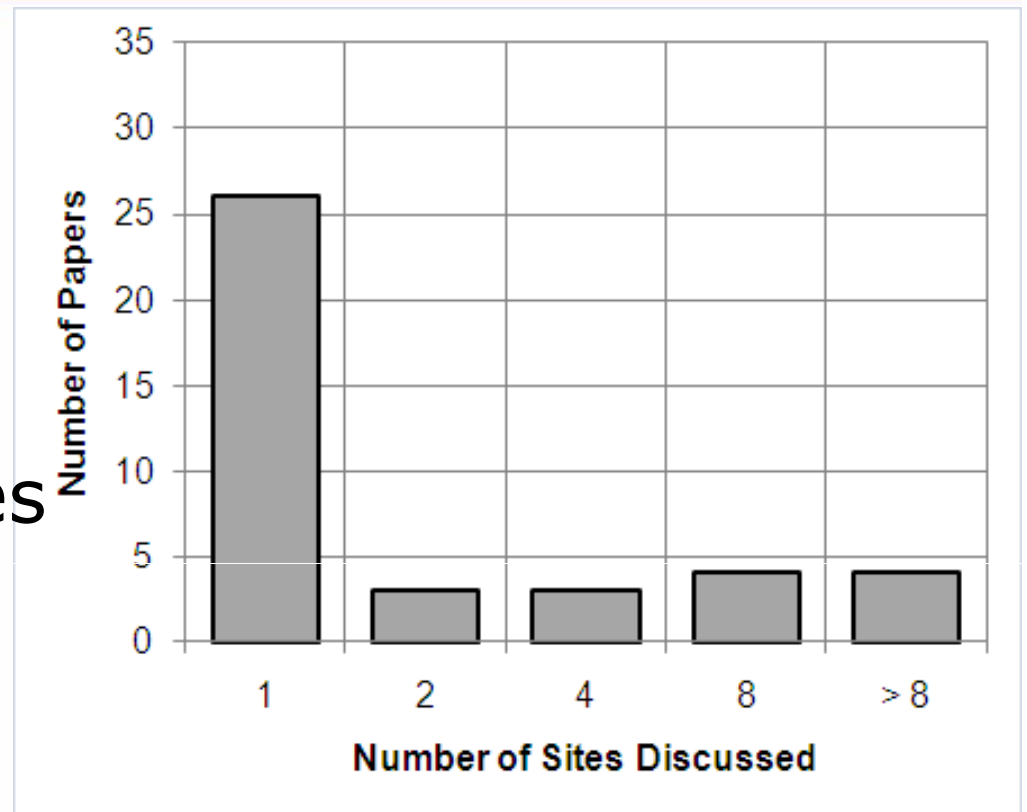
# Characteristics of Papers

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- $\approx 5$  Analysis Methods
- $\approx 8$  Analyzed Characteristics



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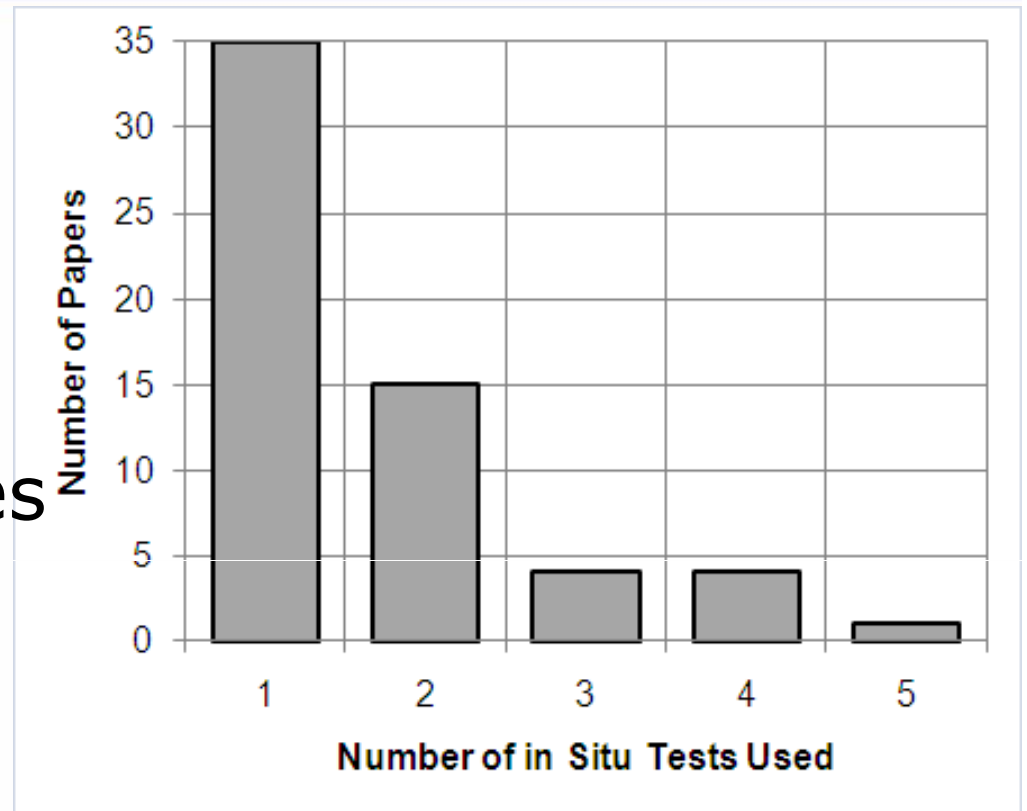
## Characteristics

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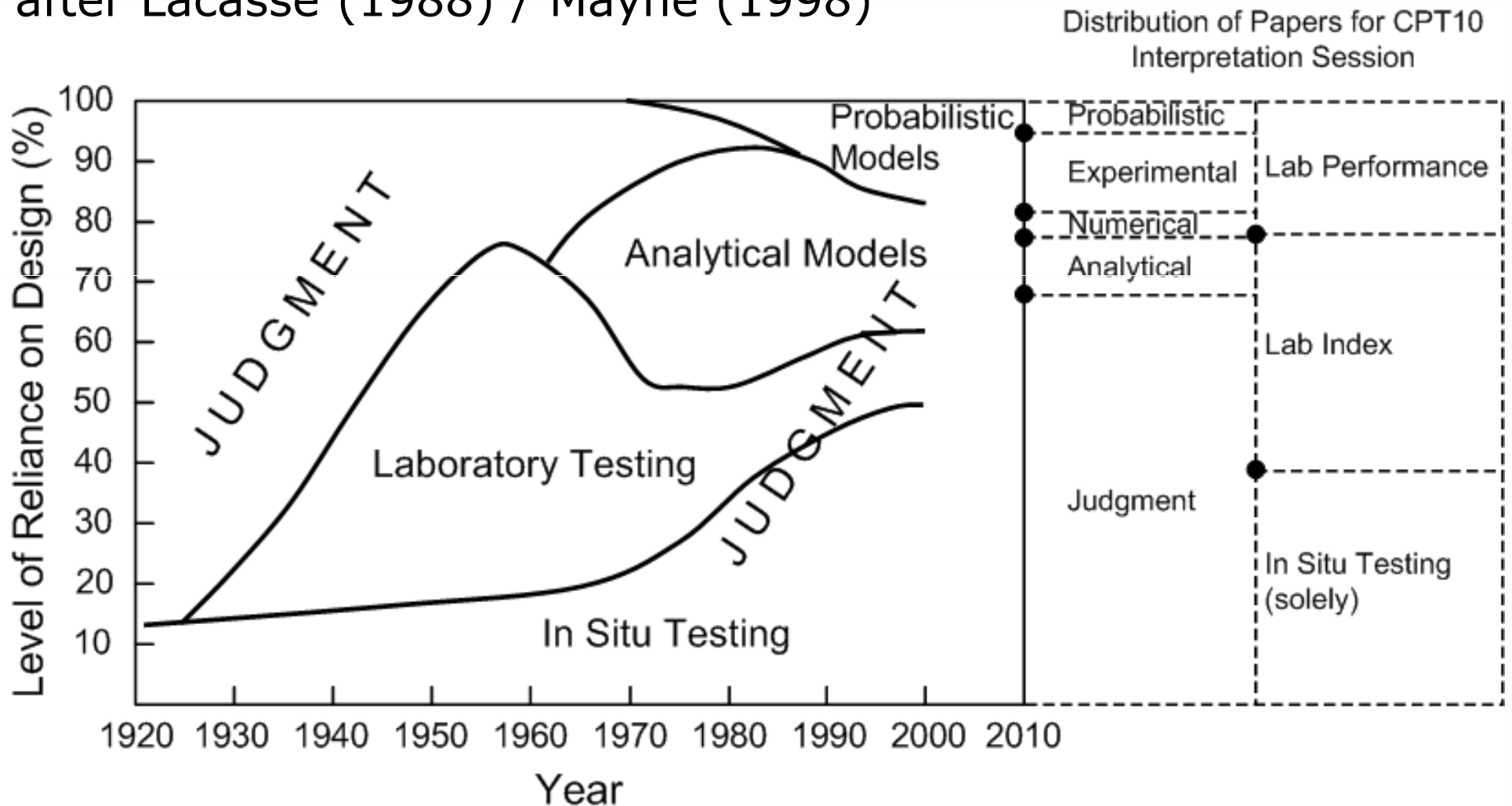


## Characteristics

- Mostly single sites
- Mostly CPT/variants

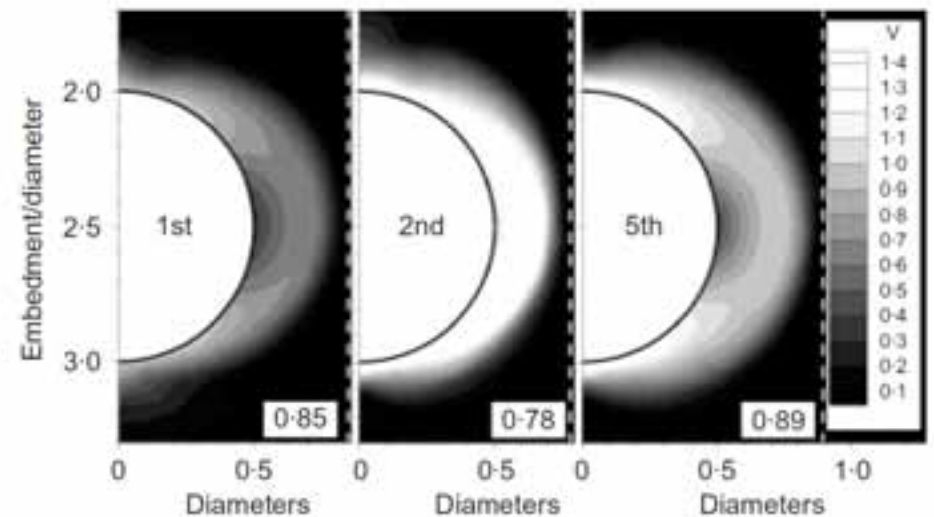
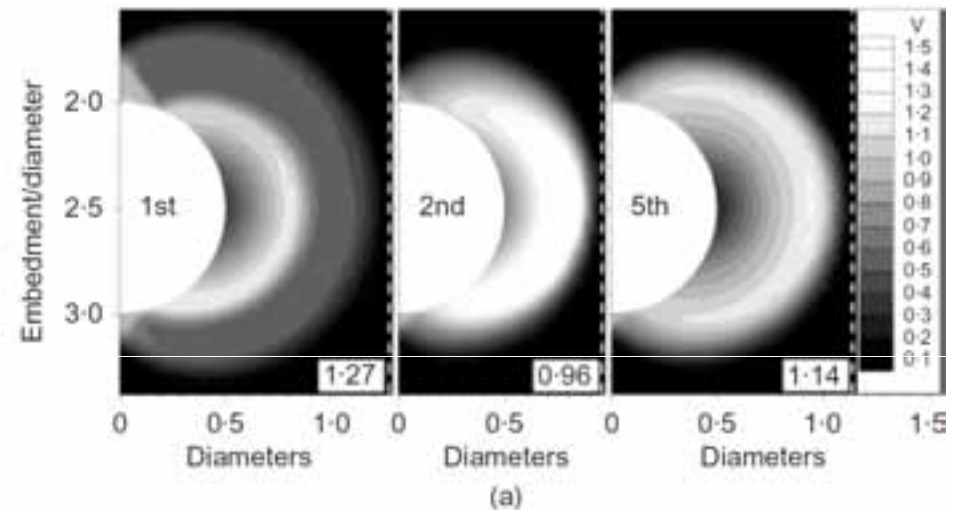
# Evolution of Practice

- Large reliance on judgment / experience after Lacasse (1988) / Mayne (1998)



# Evolving Research

- Difficulties for numerical / analytical methods due to soil constitutive models and large strains
    - Structure / aging
    - High stress compressibility / particle crushing
    - Stress dependent dilation
    - Stress and strain dependent stiffness
- Zhou & Randolph 2009



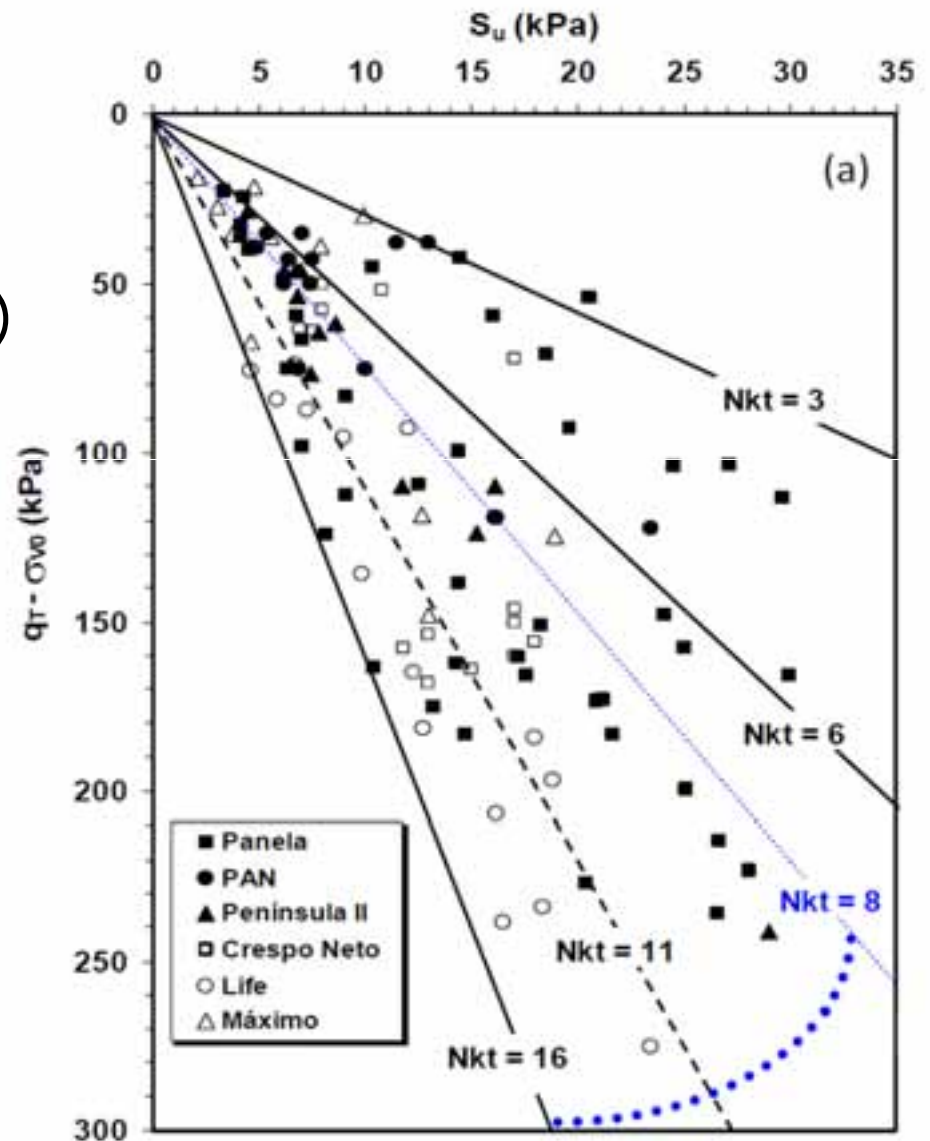
# Strength



# Undrained Strength (14 papers)

- $s_u = (q_t - s_{v0}) / N_{kt}$
- $N_{kt} = (q_t - \sigma_{v0}) / s_u$
- CPT'95;  $N_{kt} = 8-27$
- Randolph 2004 (soft clay)
  - $N_{kt-vane} = 13.7$ ;  $COV = 17\%$
  - $N_{T-bar} = 11.6$ ;  $COV = 7\%$

*Almeida et al.*

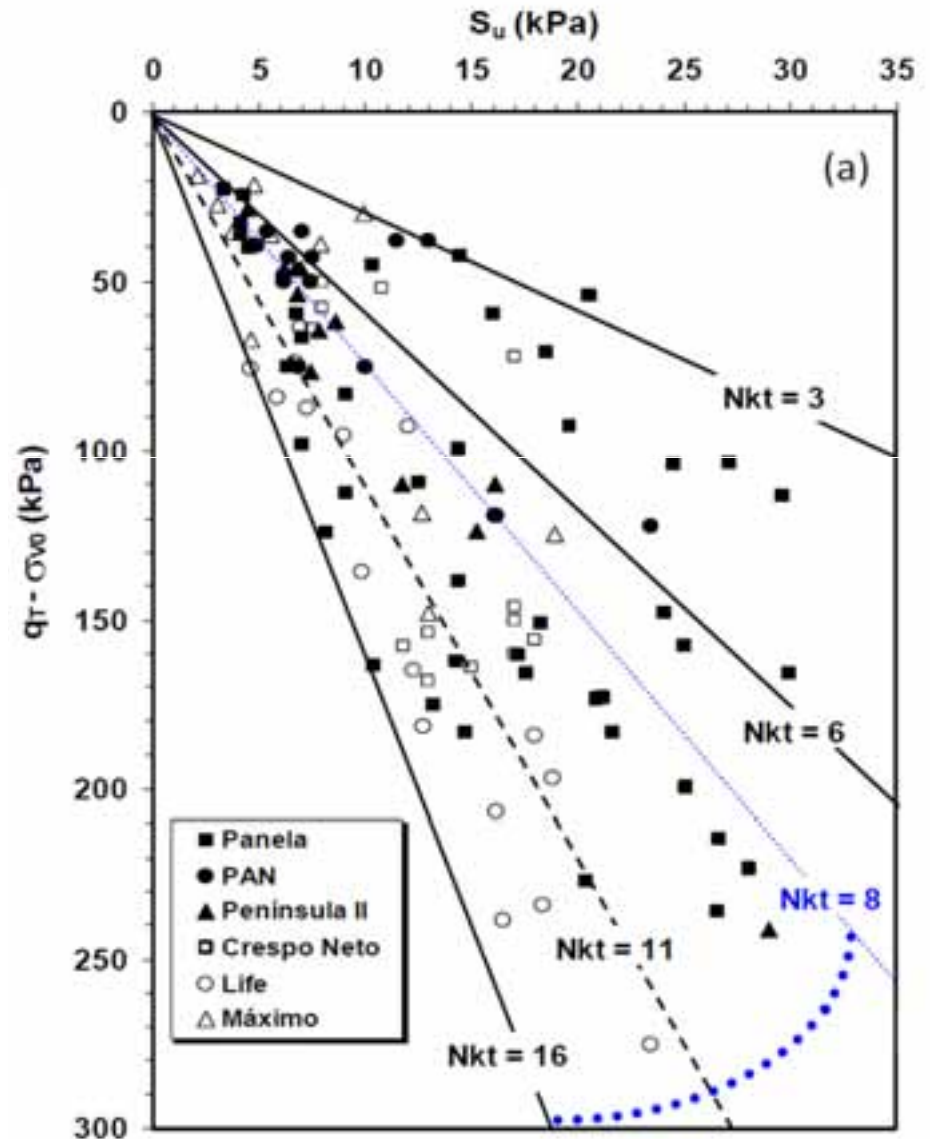


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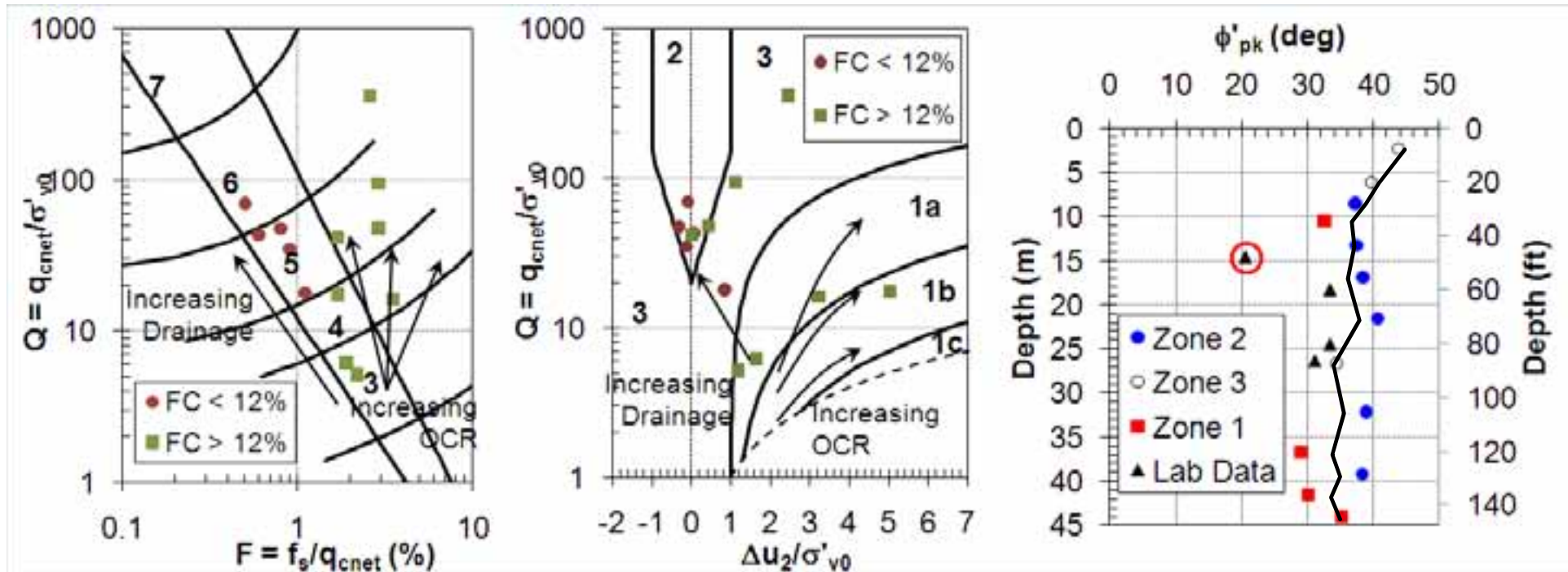
	$S_{u,meas}$ ↓ $N_{kt,app}$ ↑	$S_{u,meas}$ ↑ $N_{kt,app}$ ↓	$q_{cnet}$ ↑ $N_{kt,app}$ ↑
Disturbance	X		
Fissuring	X		
Sensitivity	X		
Spatial Variability	X	X	X
$S_{u,VST}$ VS. $S_{u,DSS}$		X	
Rate ↑ (Viscous CPT)			X
Rate ↑ (Viscous VST)		X	
Rate ↓ (Consol)			X
VST Consol		X	
CPT area ratio			
Drift in CPT baseline			

*Almeida et al.*



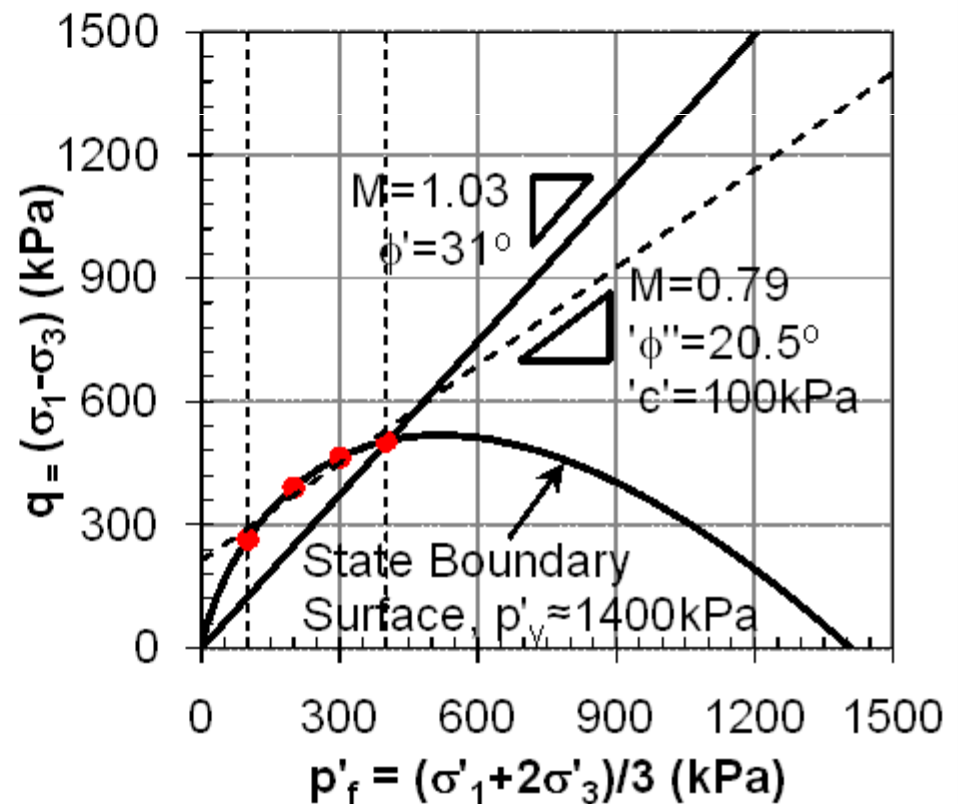
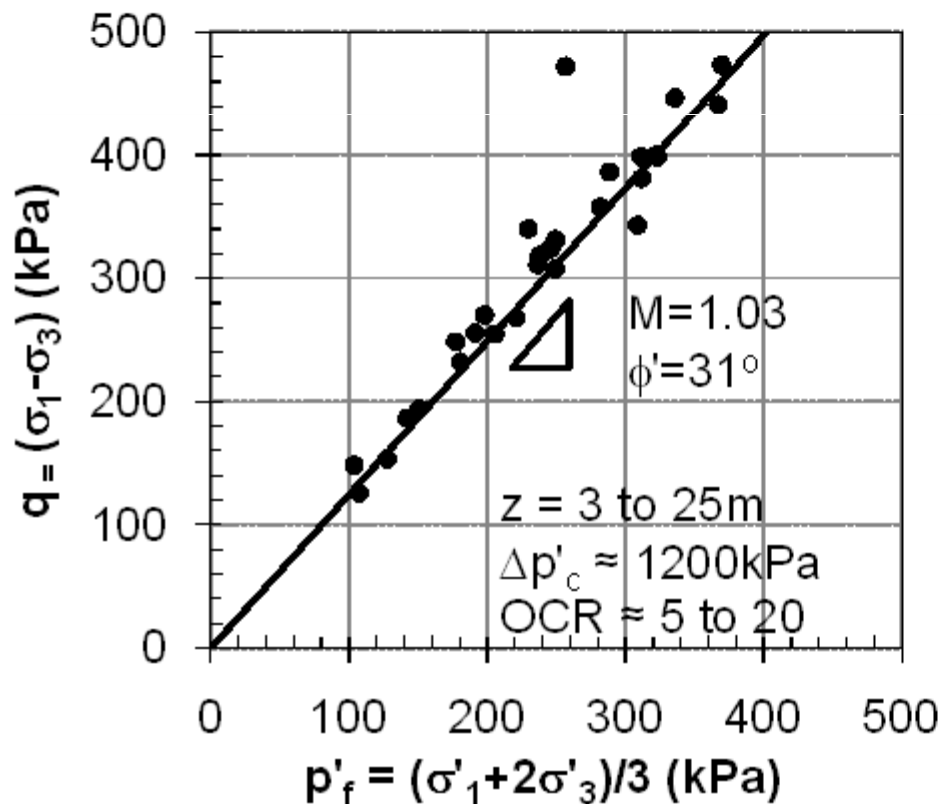
# Friction Angle (4 papers) (*McNulty & Harney*)

- Sands and Silty Sands
- Correlations to  $\phi'_{pk}$
- Drained or Undrained Behavior
- $I_C$  fines content correction? (*Robertson*)
- Low  $\phi'$  in OC clay layer?



# Friction Angle

- OC clays, Milwaukee, WI;  $\phi'_{cv} = 31^\circ$
- Peak friction angle due to interlocking when OC
- $\phi'_{pk}$  decreases with OCR leading to apparent  $c'$ ; not representative of material behavior

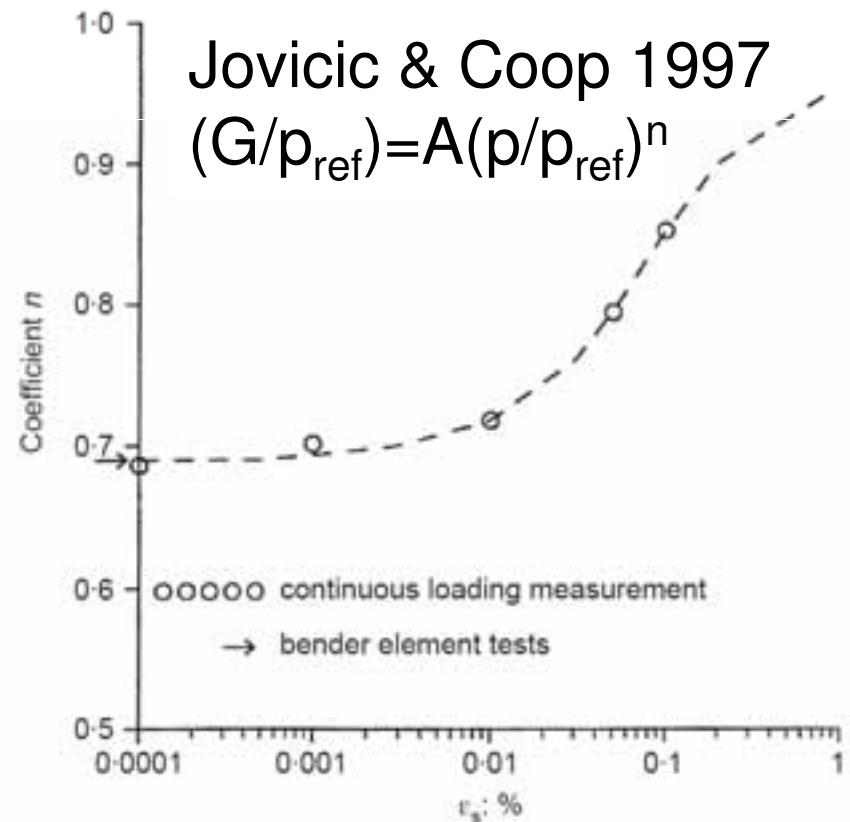
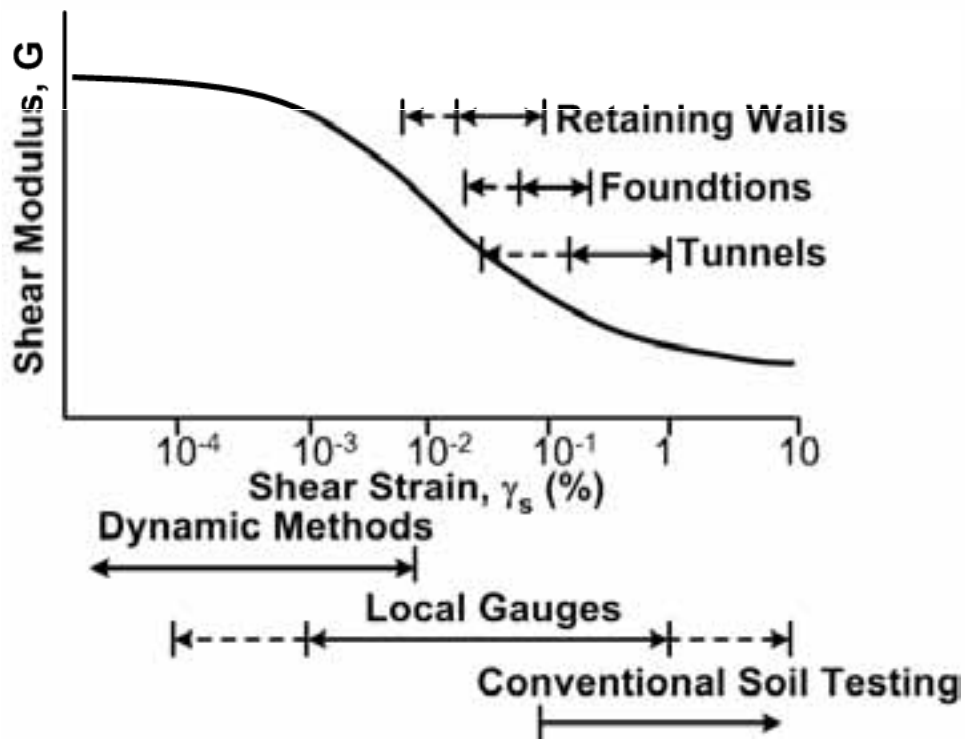


# Stiffness



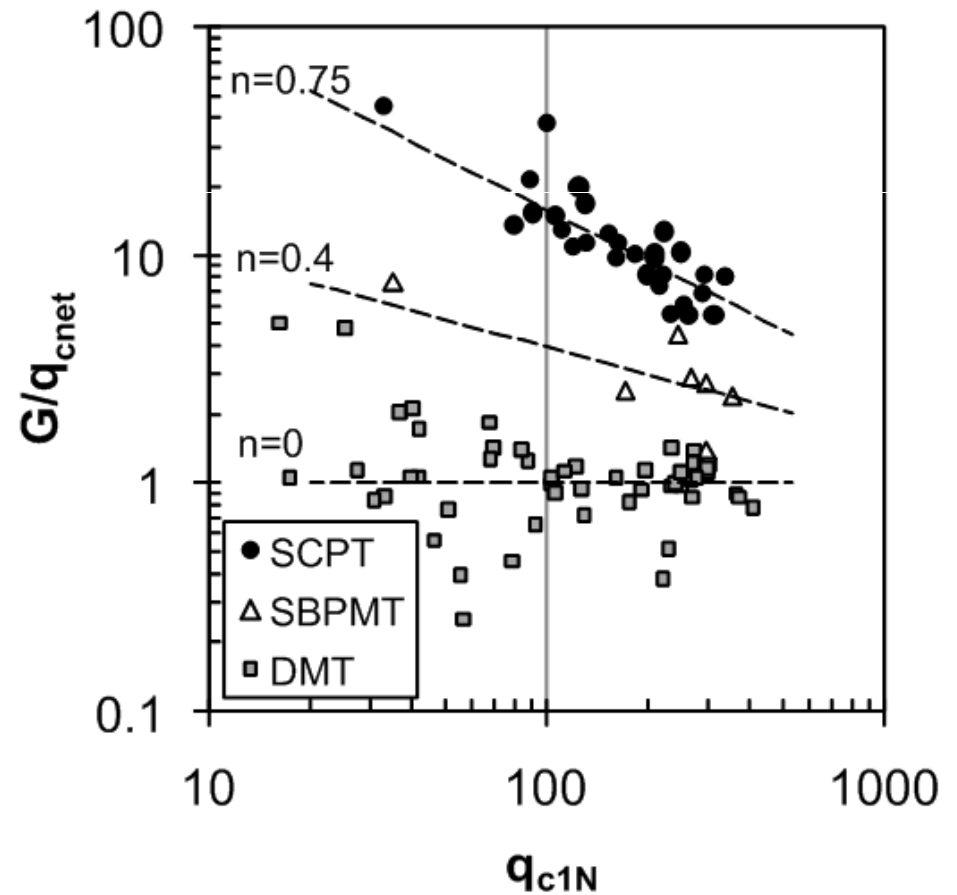
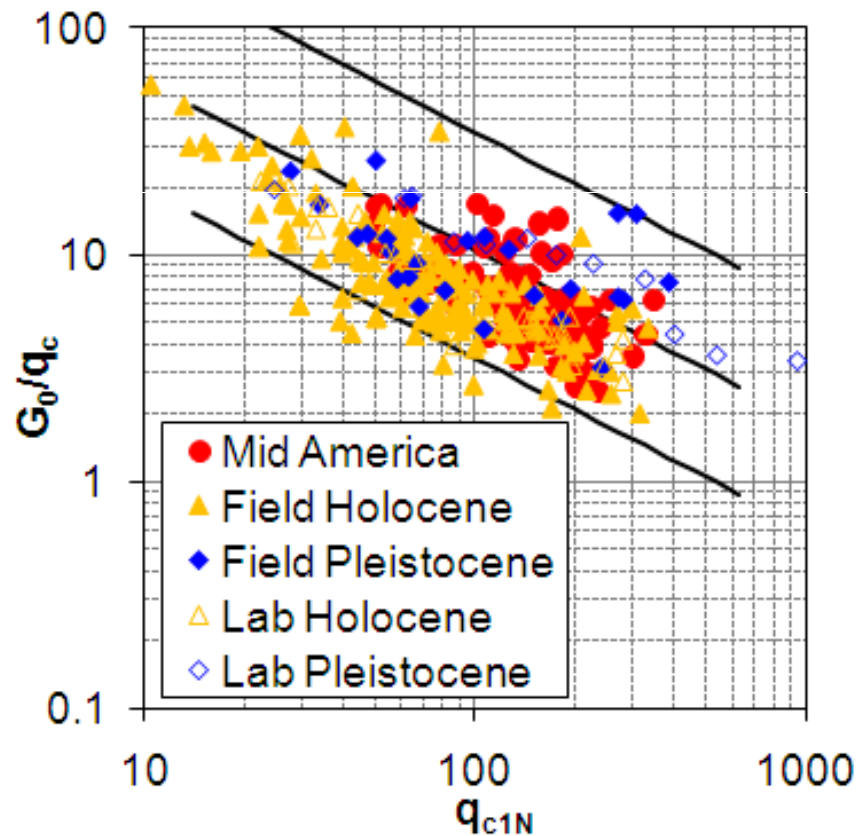
# Correlations to CPT tip resistance [ $5 (V_s), 3 (G_0)$ ]

- $G_0 = \rho V_s^2$ ; Seismic Cone
- Focus on sands
- Larger strain stiffness of PMT & DMT



# Correlations to CPT tip resistance

- $G/q_{cnet} = K_G \cdot q_{c1N}^{-n}$
- Is there bias towards  $q_{c1N}$  (relative density)?
- Is this strain level dependant?

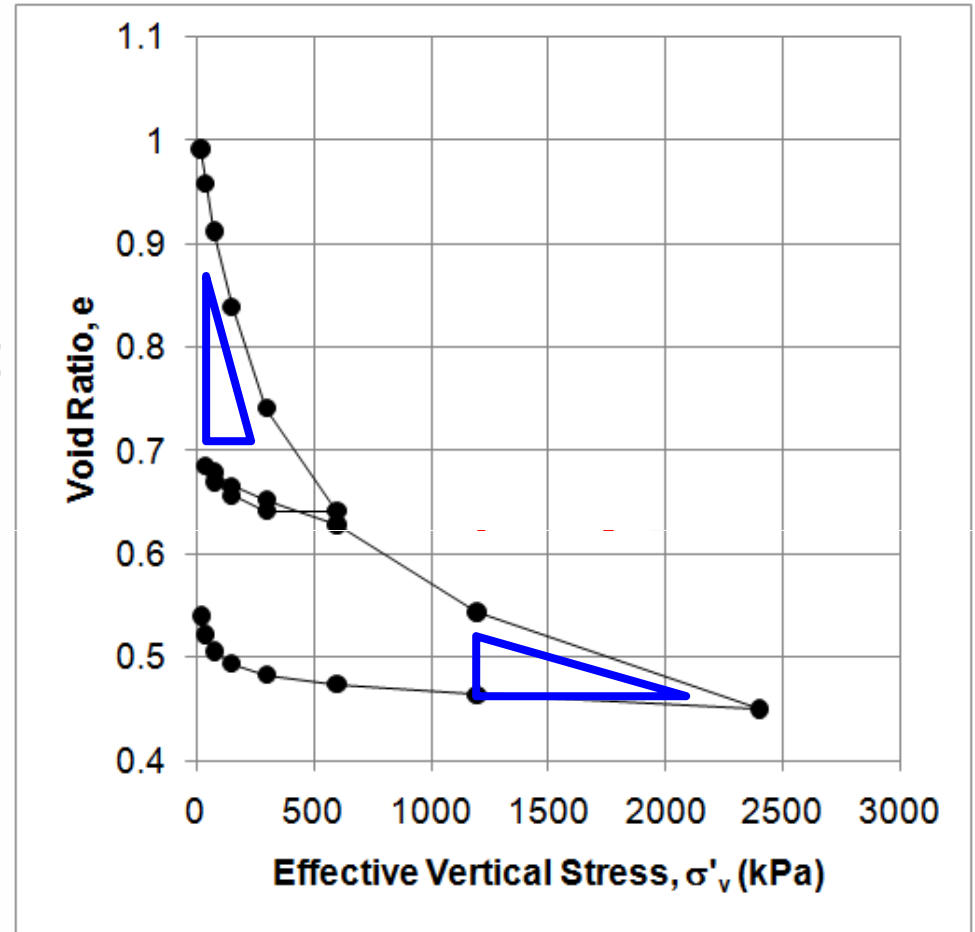


# Compressibility



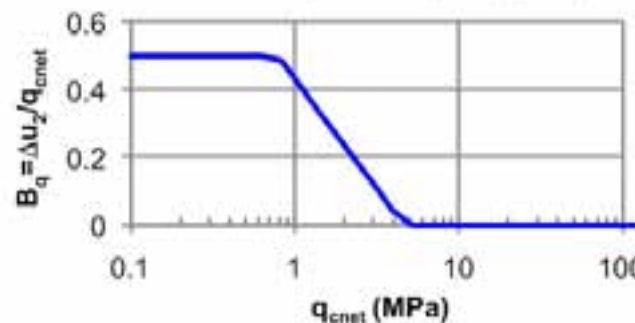
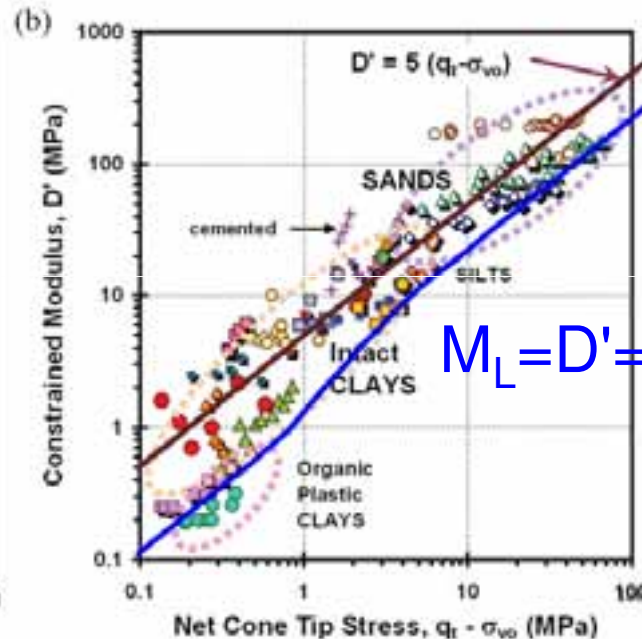
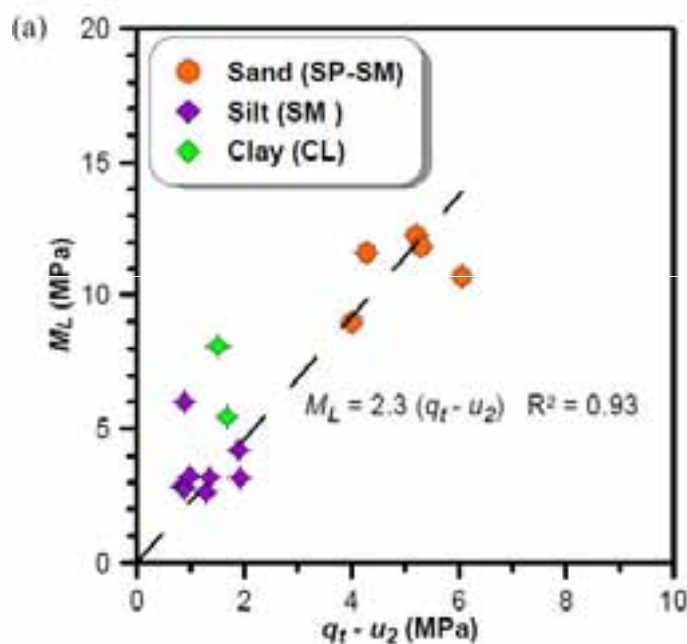
# Compressibility (9 papers)

- $C_c = \Delta e / \Delta \log \sigma'_v$
- Soil compressibility decreases as  $\sigma'$   $\uparrow$
- $M = D' = 2.3(1 + e_0)\sigma' / C_c$
- Measured
  - Oedometer
  - DMT
  - Embankment
- Stress level
  - $\sigma'_{v0}$
  - $p'_c$
  - $\sigma'_{v0} + 110\text{kPa}$



# Compressibility

- $q_{cnet} - u_2 = q_{cnet}(1 - B_q)$
- Is  $q_t - u_2$  indicative of effective stress below tip?
  - Shear & octahedral components of  $\Delta u_2$



$$M_L = D' = 2.3(q_{cnet} - u_2)$$

Toni et al.

Mayne 2007



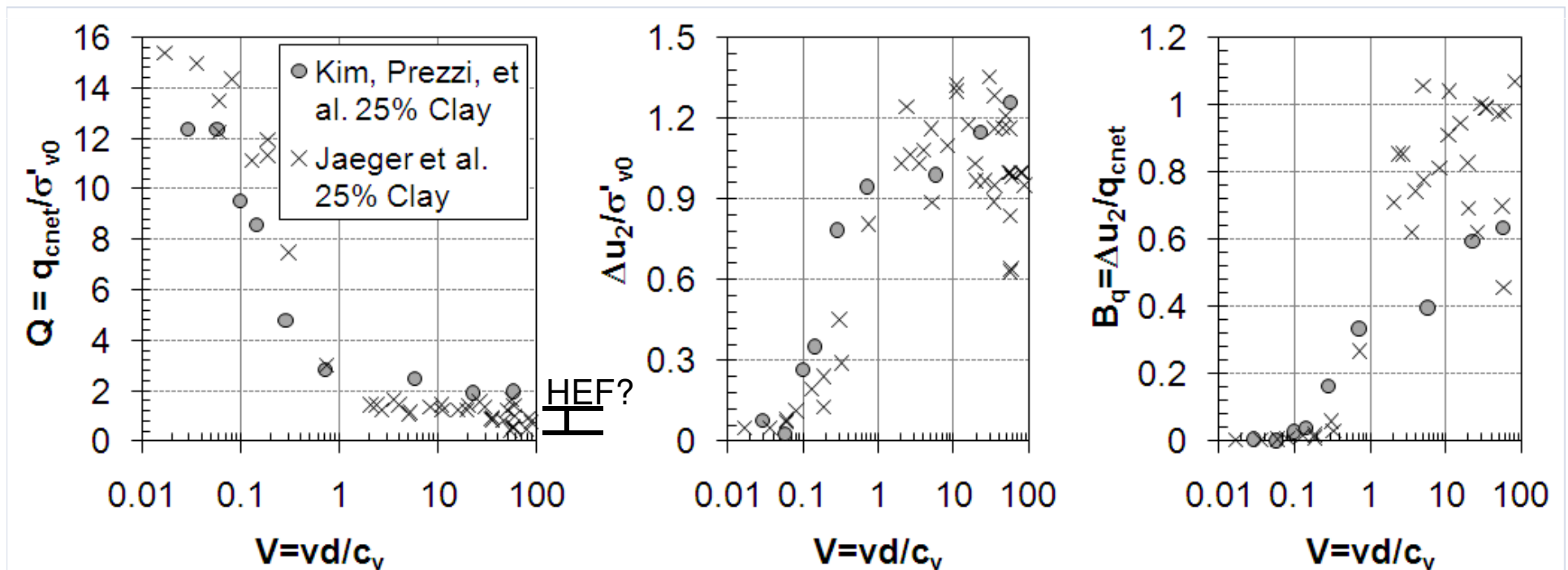
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# Water Flow Characteristics



# Water Flow Characteristics (7 papers)

- Dissipation Tests
- Injection methods
- Correlations to fines content /  $I_C$
- Variable Rate Penetration,  $V=vd/c_v$
- $Q \cdot B_q = \Delta u_2 / \sigma'_{v0}$

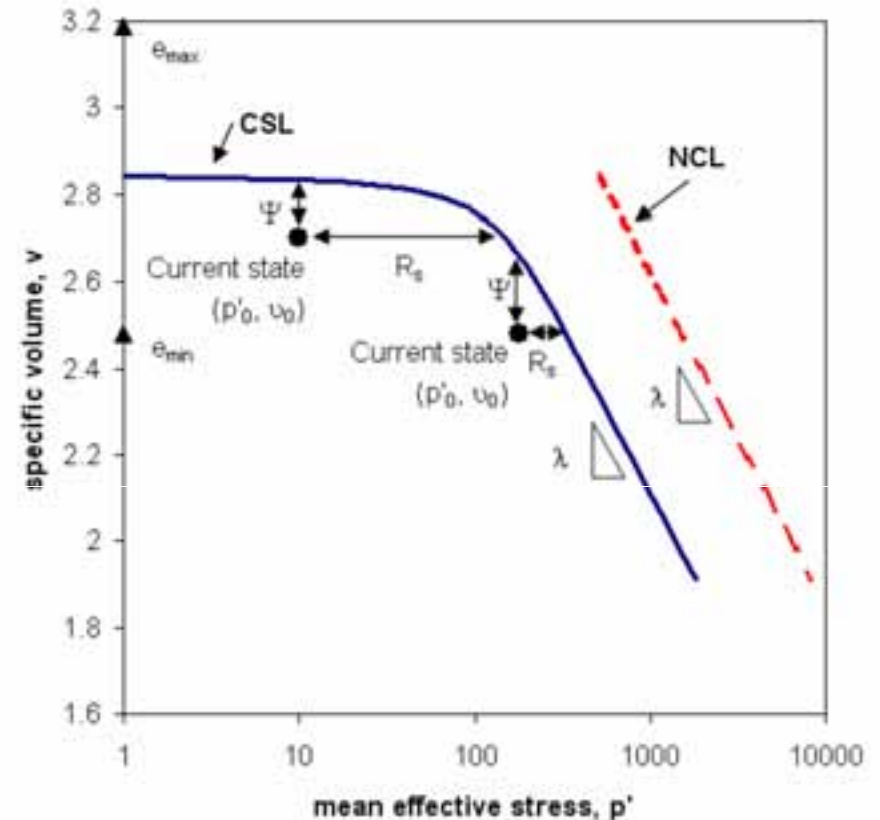


# Soil State



# Sands (9 papers)

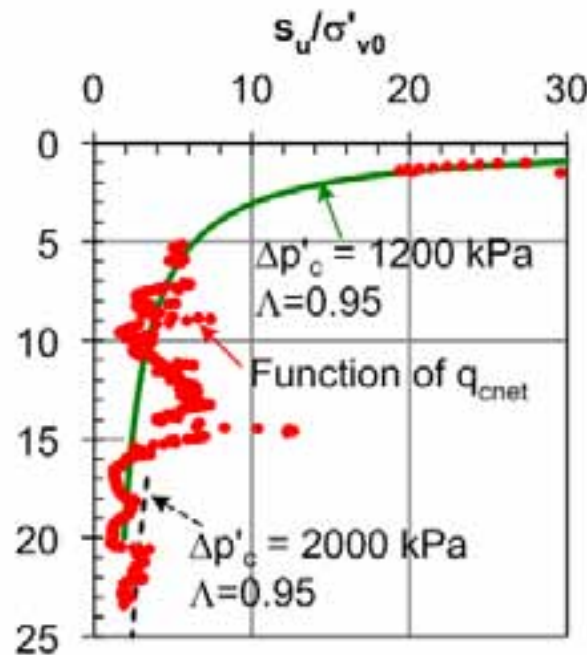
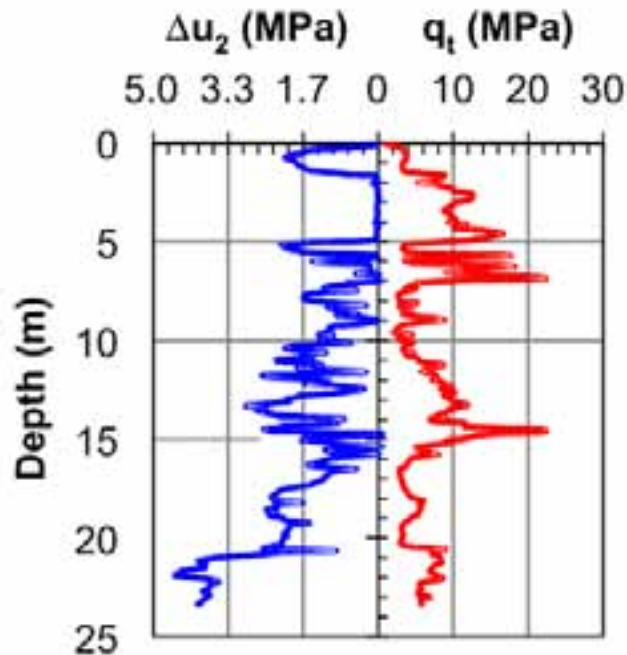
- Behaviour controlled by:
  - Friction
  - (stress dependent) Dilation
  - Secant Shear Modulus
  - Horizontal effective stress
  - Compressibility / Crushing
- $D_r$ ,  $\Psi_0$ , or  $R_s$ ?



# OCR / Stress History (9 papers) (*Liao et al.*)

- 35m bluff removal
- $p'_c$  in clay overestimated
- Unknown stress history

$$\frac{s_u}{\sigma'_{v0}} = \left( \frac{s_u}{\sigma'_{v0}} \right)_{NC} \cdot OCR^\Lambda$$

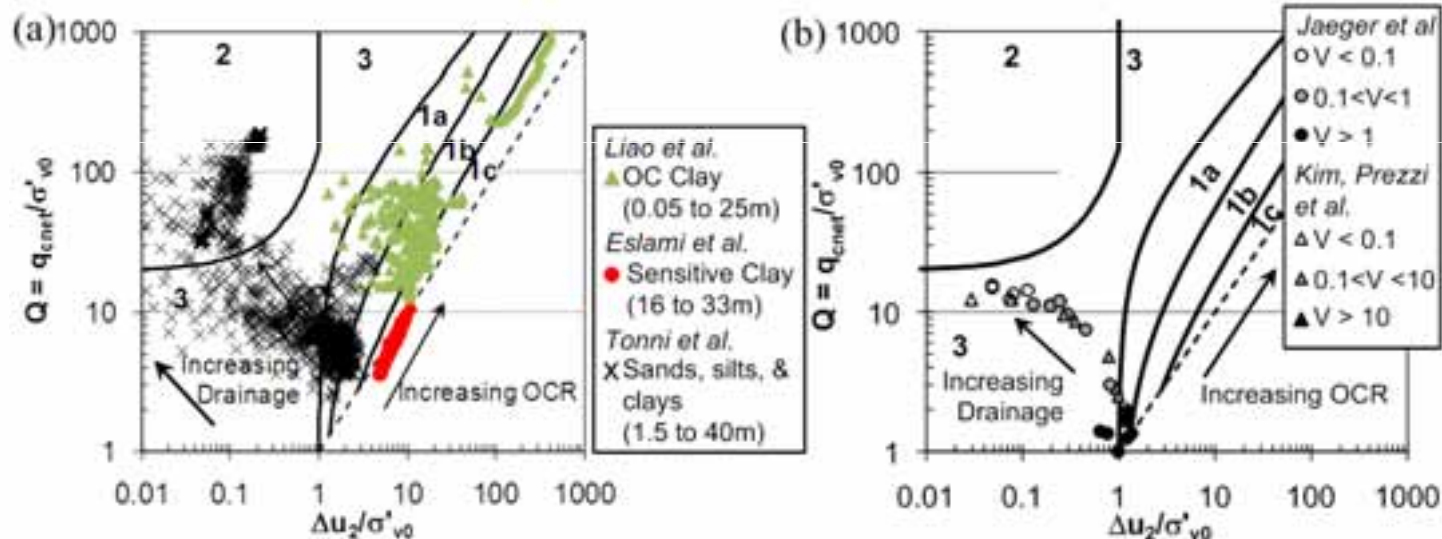


# Classification



# Classification (13 papers)

- Normalized parameters for rational interpretation ( $Q$ ,  $B_q$ ,  $F$ ,  $\Delta u_2/\sigma'_{v0}$ ,  $V=vd/c_v$ )
- Separate influence of state and water flow characteristics,  $Q$  &  $\Delta u_2/\sigma'_{v0}$ ;  $V=vd/c_v$



Zone	Description
1a	SILTS and 'Low $I_p$ ' CLAYS
1b	CLAYS
1c	Sensitive CLAYS
2	Essentially drained SANDS

Zone	Description
3	Transitional soils
	- silt, sand, clay mixtures
	- sandy SILT
	- silty SAND
	- residual soils
	- fissured CLAY

# Summary / Conclusions



## Summary / Conclusions

- CPT data from a wide variety of sites with complementary lab & in situ test data
- Most interpretation builds on previously developed methods and discusses similarities / differences for site specific conditions
- Systematic framework for evaluations
  - Separate partial consol from changes in state
  - Couple strength and stress history with CSSM
  - Relative density or state parameter for sands
- Need larger number of statistical, numerical, and analytical studies
  - Realistic soil models now available



Thank You

Discussion - Mark

