Profiling Overconsolidation Ratio in Clays by Piezocone and Flat Dilatometer Tests

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Cavity Expansion-Critical State Model for CPTu-OCR

Soil Properties:

$M = 6 \sin\phi'/(3-\sin\phi')$

ϕ' = effective stress friction angle

C_c = compression index

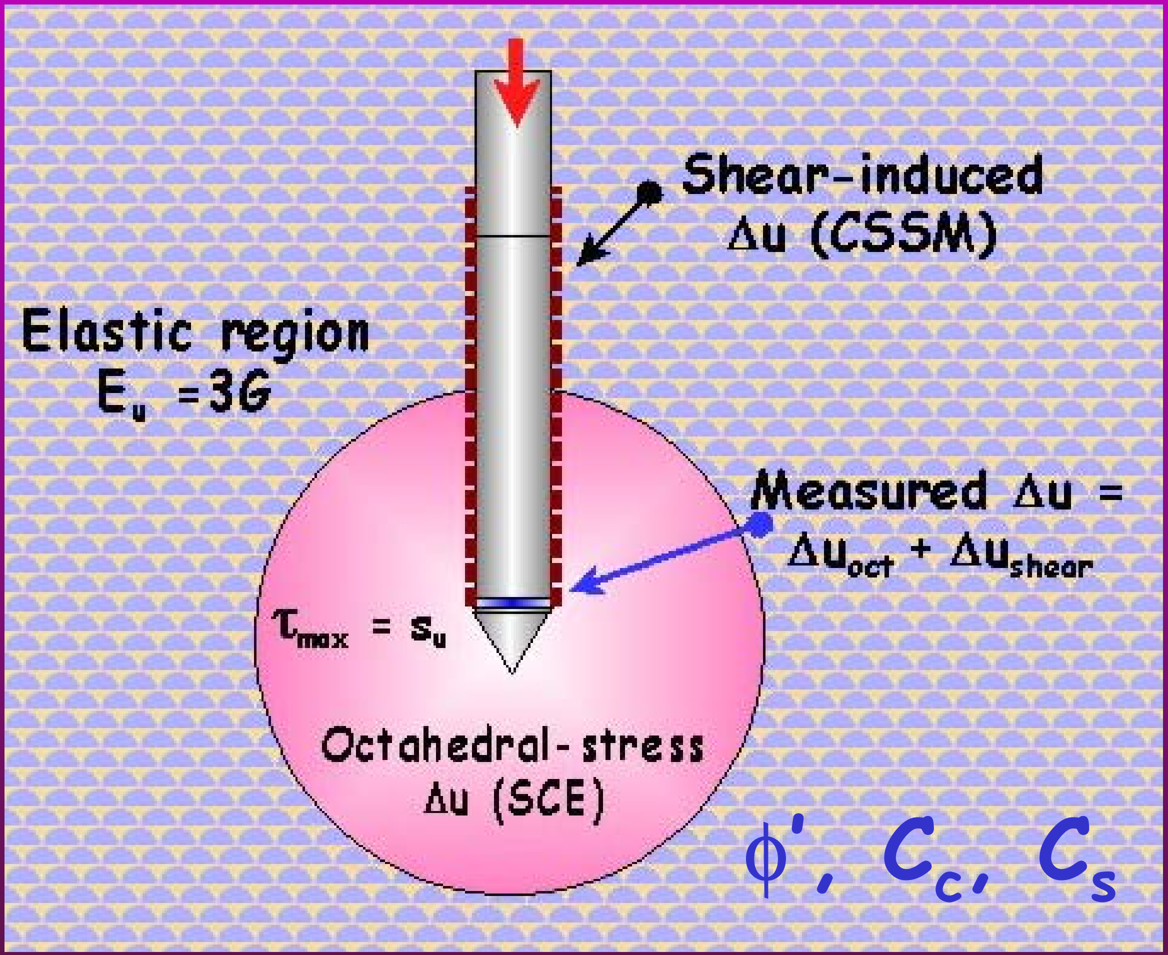
C_s = swelling index

$\Lambda \approx 1 - C_s/C_c$

$I_R = G/s_u$ = Undrained Rigidity Index

G = shear modulus

s_u = undrained shear strength

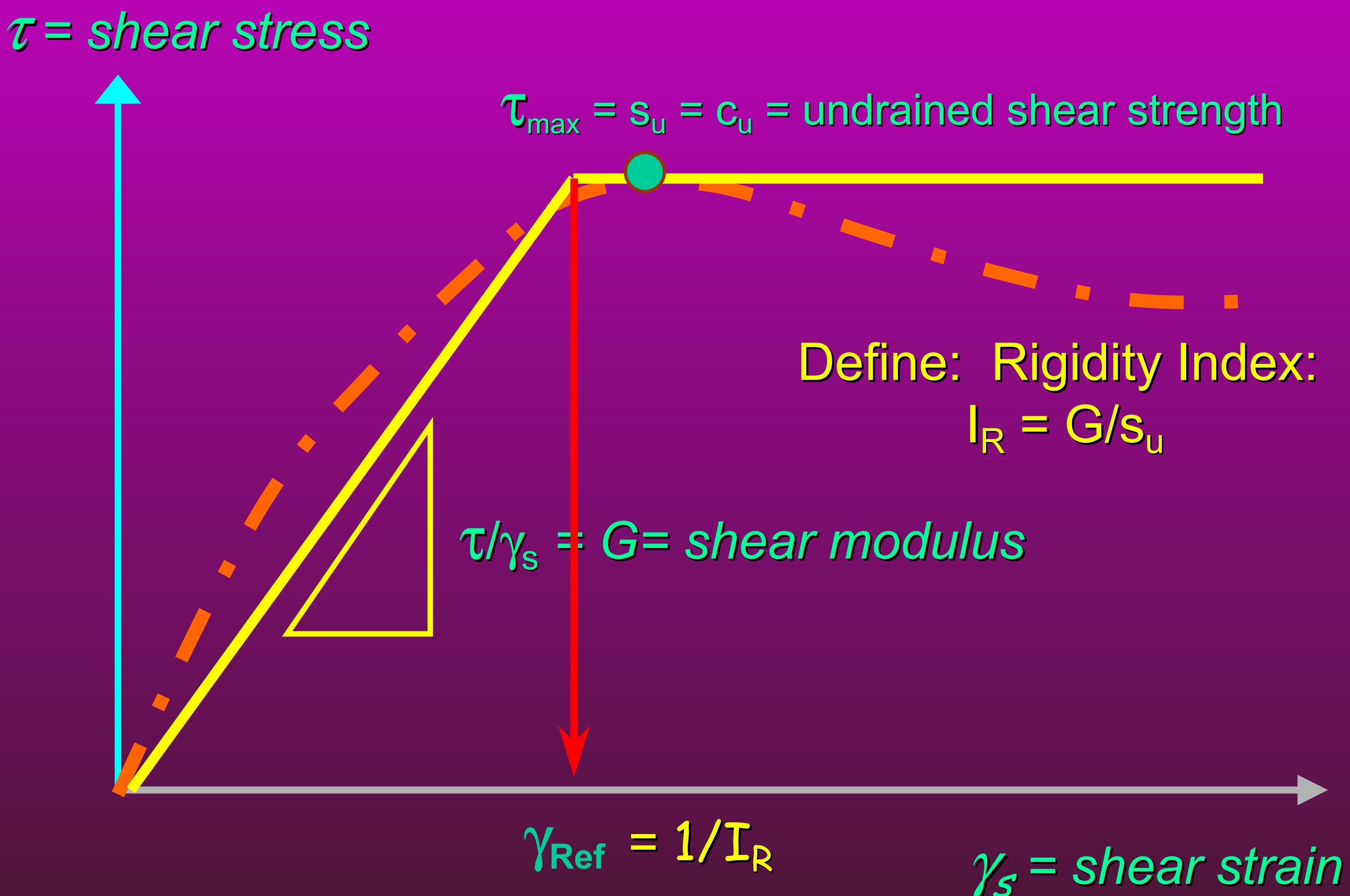


Cavity Expansion-Critical State Model

- Cone Tip Resistance: $q_t - \sigma_{vo} = N_{kt}\, s_u$
- $N_{kt} = (4/3)\,[\,\ln(I_R) + 1] + \pi/2 + 1$
- $s_u = (M/2)\ \sigma_{vo}'\ (OCR/2)^{\Lambda}$

$$OCR = 2\left[\frac{(2/M)(q_t - \sigma_{vo})/\sigma_{vo}'}{(4/3)(\ln I_R + 1) + \pi/2 + 1}\right]^{(1/\Lambda)}$$

Determine Undrained Rigidity Index



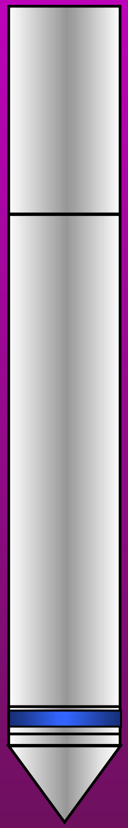
Cavity Expansion-Critical State Model

- $\Delta u_{meas} = \Delta u_{oct} + \Delta u_{shear}$
- Spherical Cavity Expansion: $\Delta u_{oct} = (4/3)\, s_u \ln(I_R)$
- CSSM: $\Delta u_{shear} = \sigma_{vo}' \,[1 - (OCR/2)^{\Lambda}]$
- CSSM: $s_u/\sigma_{vo}' = (M/2)(OCR/2)^{\Lambda}$

$$OCR = 2\left[\frac{(\Delta u/\sigma_{vo}') - 1}{(2M/3)\ln(I_R) - 1}\right]^{(1/\Lambda)}$$

Type 2 Piezocone Model for OCR

- $\Delta u_{meas} = \Delta u_{oct} + \Delta u_{shear}$
- $\Delta u_2 = (2/3M)\ \sigma_{vo}'(OCR/2)^{\Lambda} \ln(I_R) + \sigma_{vo}'[1-(OCR/2)^{\Lambda}]$
- $q_t - \sigma_{vo} = (M/2)\ \sigma_{vo}'(OCR/2)^{\Lambda}[(4/3)(\ln I_R + 1) + \pi/2 + 1]$



Cavity Expansion CPTu$_2$ Model

$$OCR = 2\left[\frac{1}{1.95M+1}\left(\frac{q_T - u_b}{\sigma_{vo}'}\right)\right]^{1/\Lambda}$$

where $M = 6\sin\phi'/(3-\sin\phi')$ and $\Lambda \approx 1 - C_s/C_c$

Fixed Wall Chamber Tests

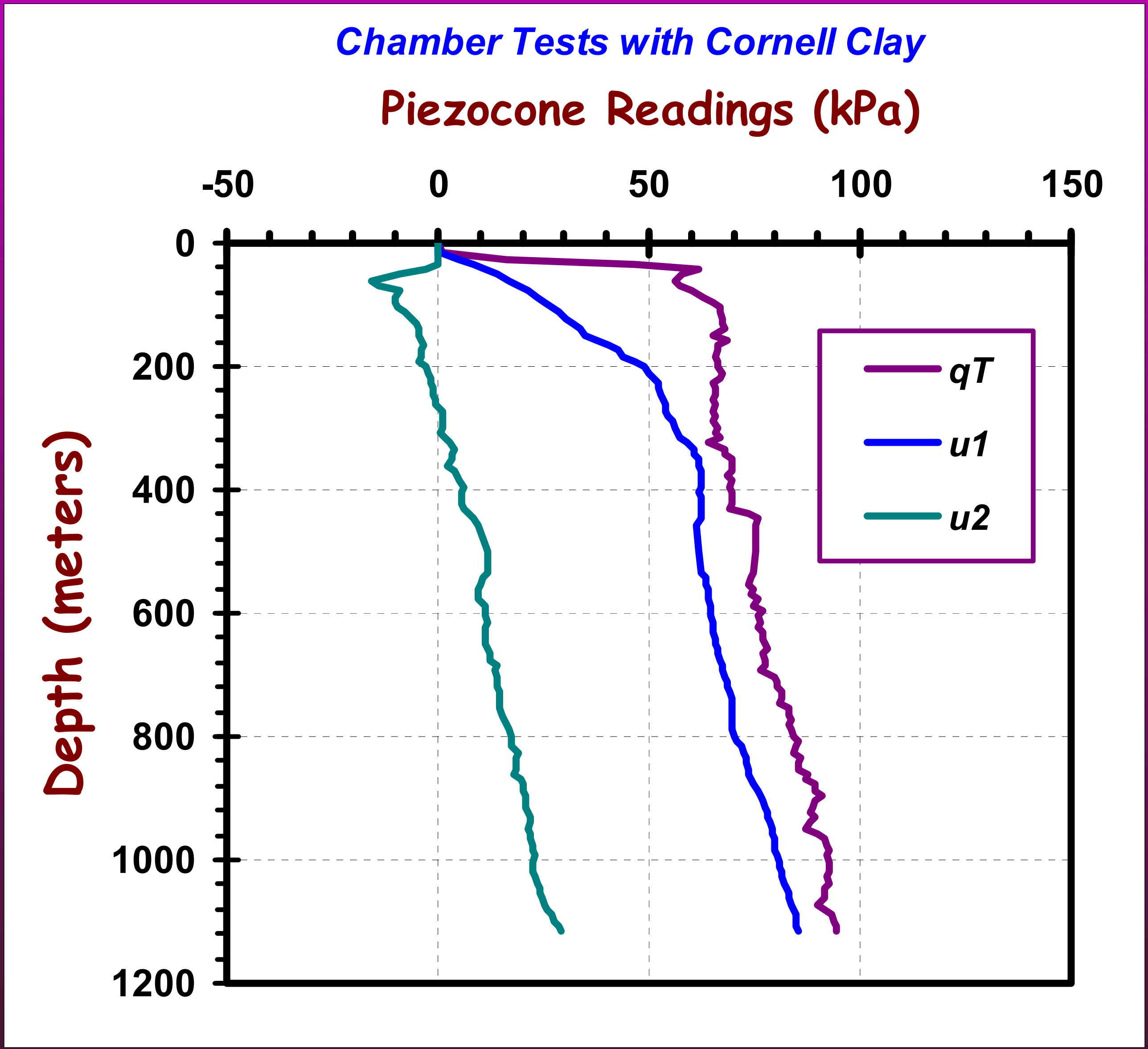
- Kaolinitic Clay from Slurry
- Prestressed in Steel Chambers and Unloaded to atmospheric conditions
- Extensive lab testing (consol, triaxial, direct simple shear, K_o-tests)
- Miniature in-situ tests (electric cone, piezoprobe, vane)

Fixed-Wall Chamber Testing at Cornell University

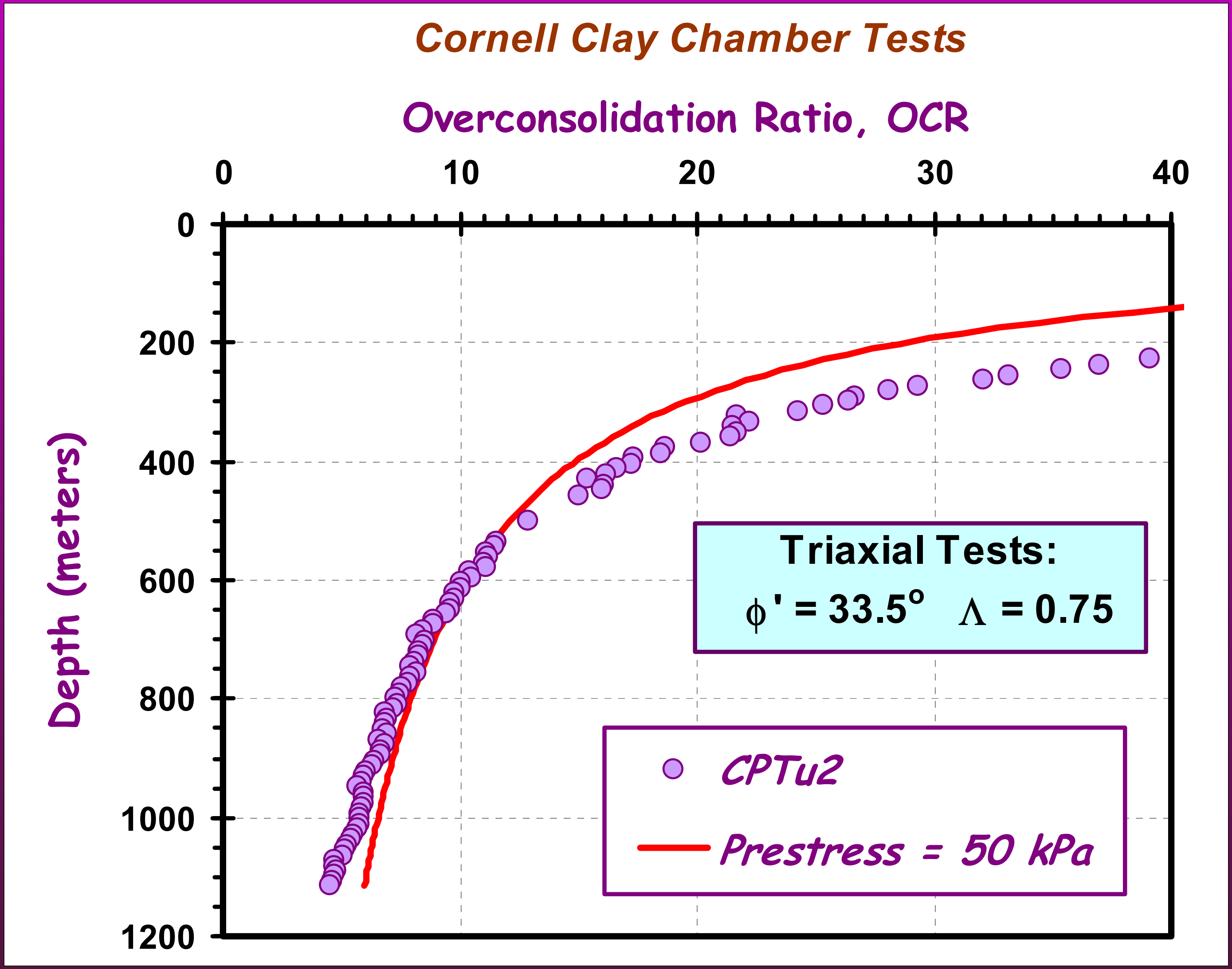
- Kaolin-silica mixture
- LL = 33, PI = 11
- w_n = 34 %
- Prestressed to 0.5 atms

Chamber:
d = 1.5 m
H = 2.3 m

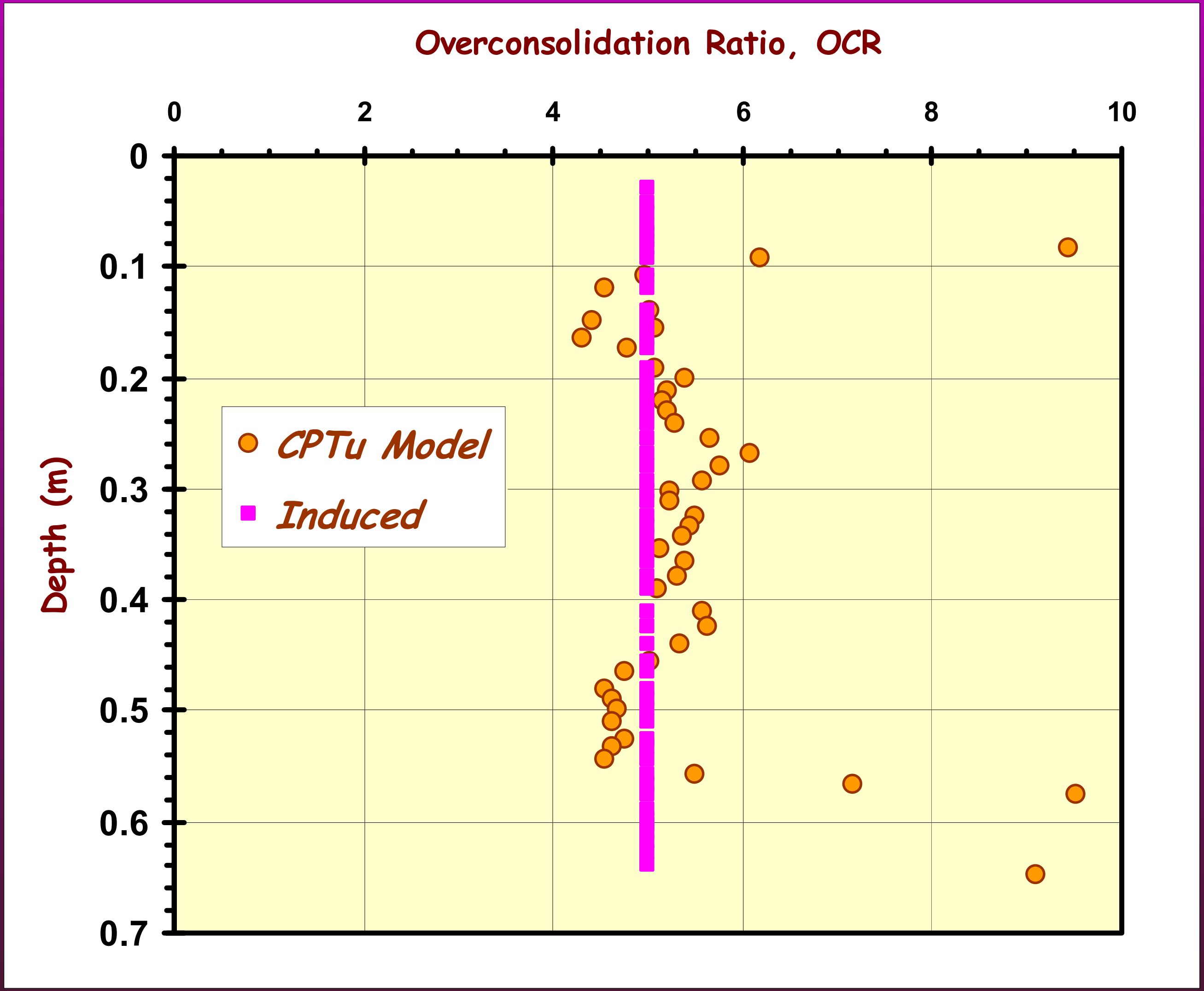
Miniature Cone & Piezoprobe Data



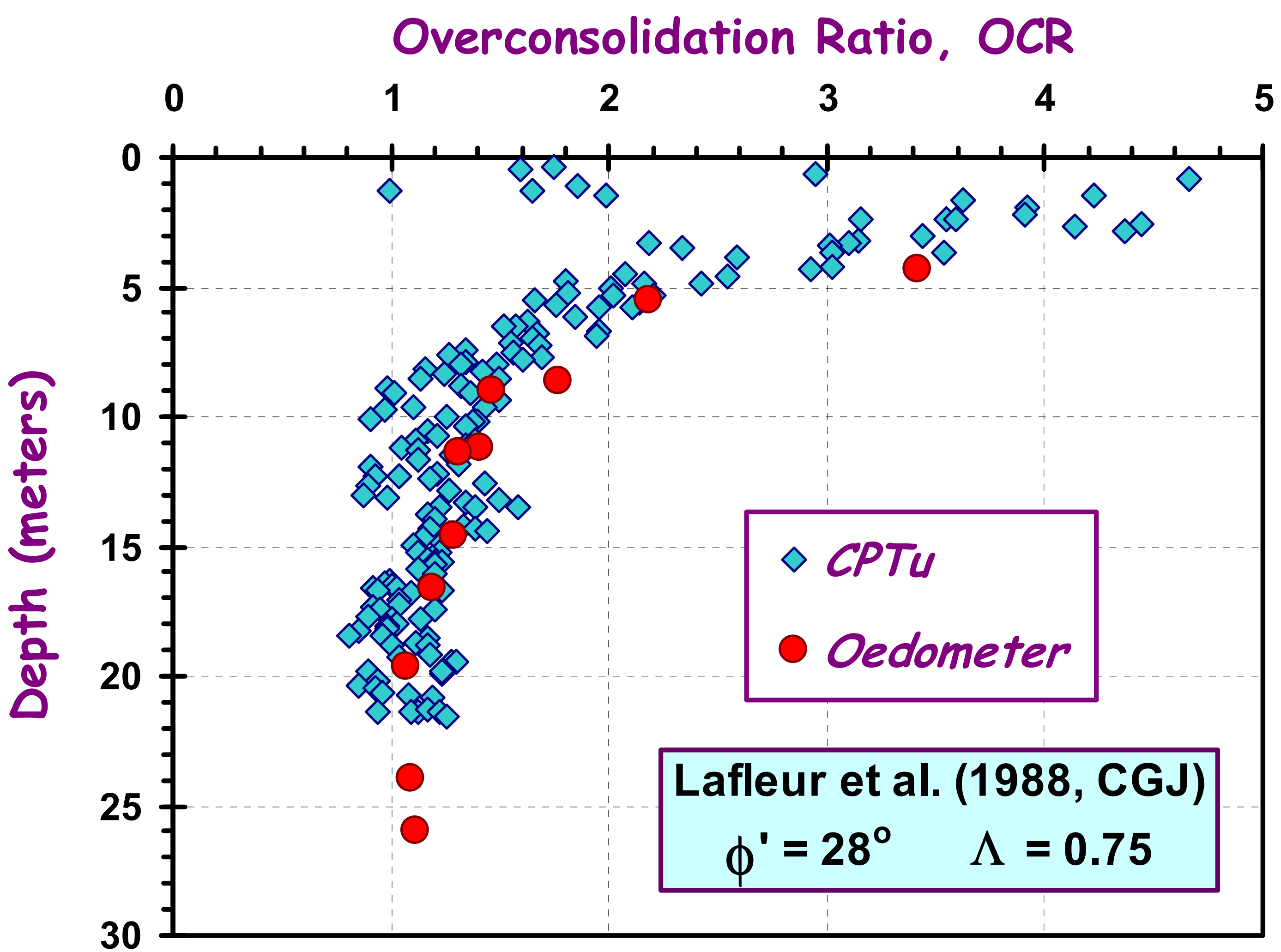
Applied & Predicted OCRs in Kaolin

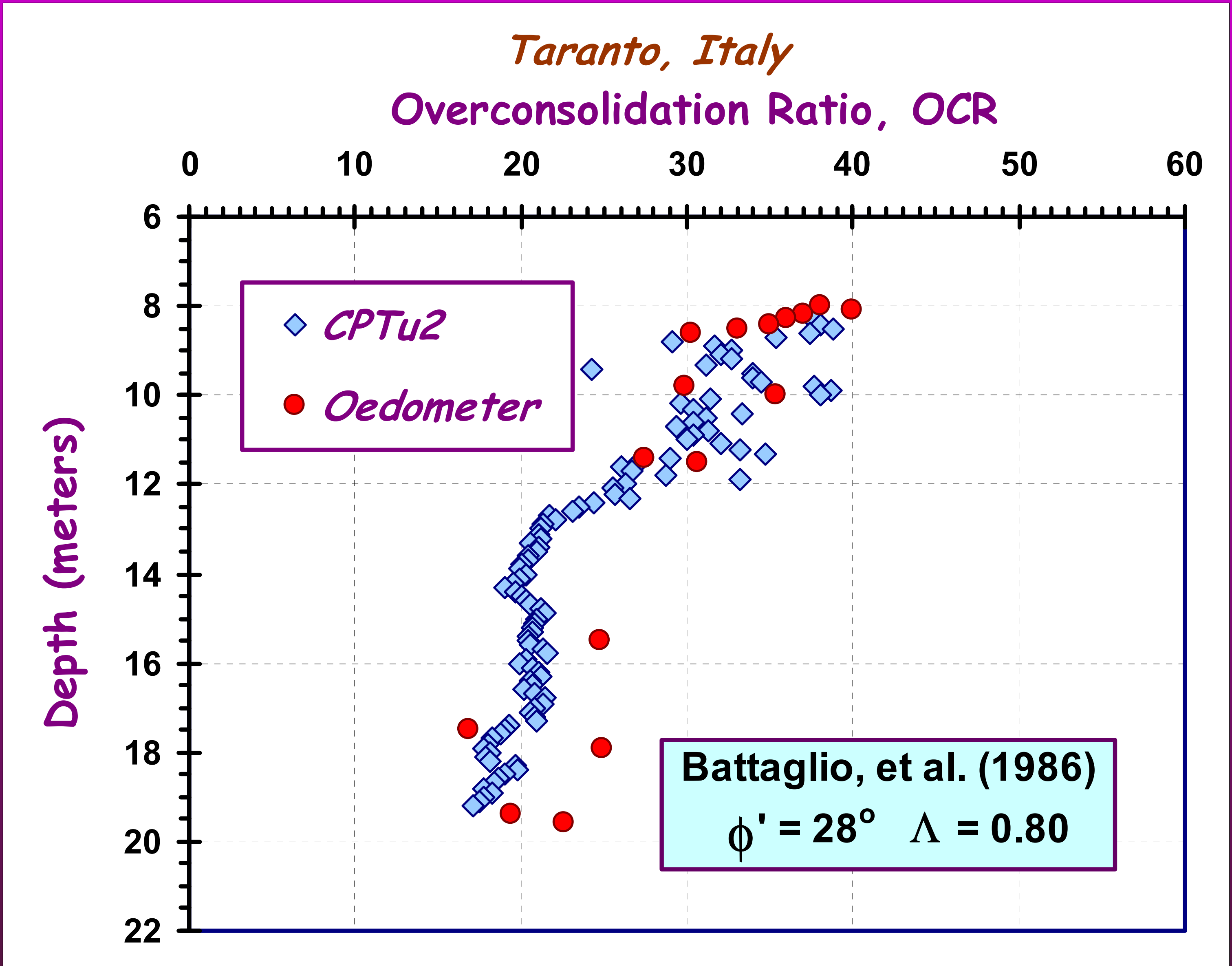


K50 Kaolinitic Clay in Flexible Wall Chamber Tests (Kurup & Tumay, 1993)

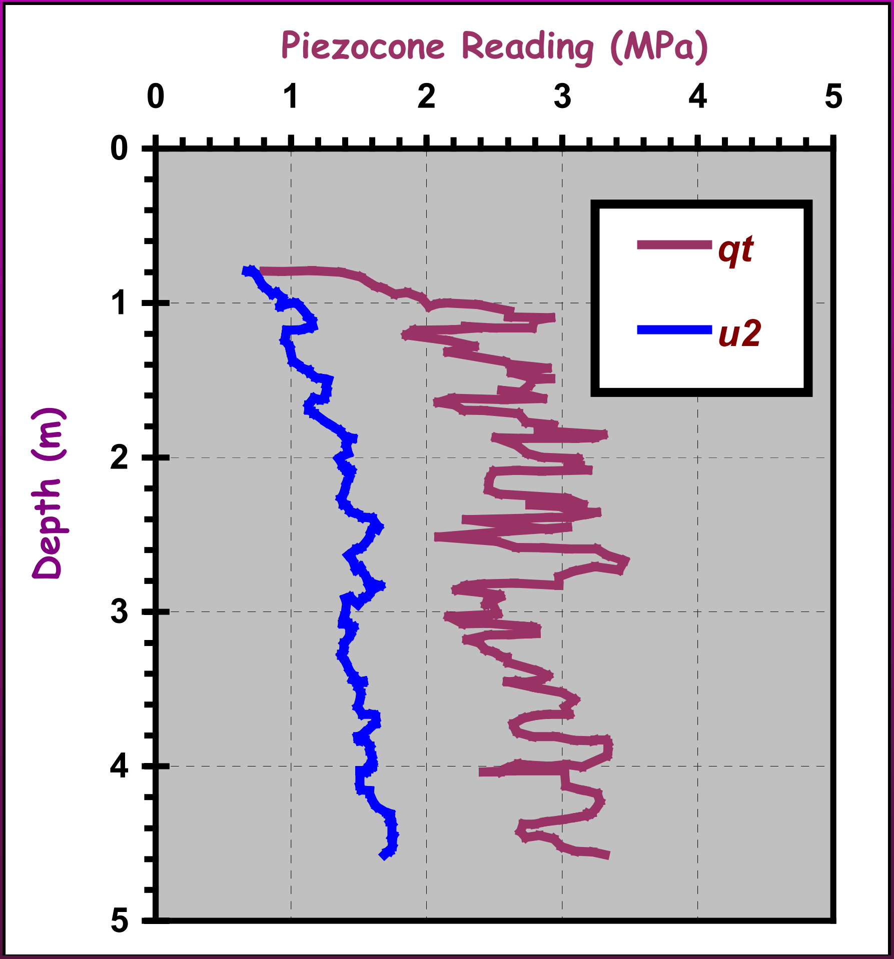


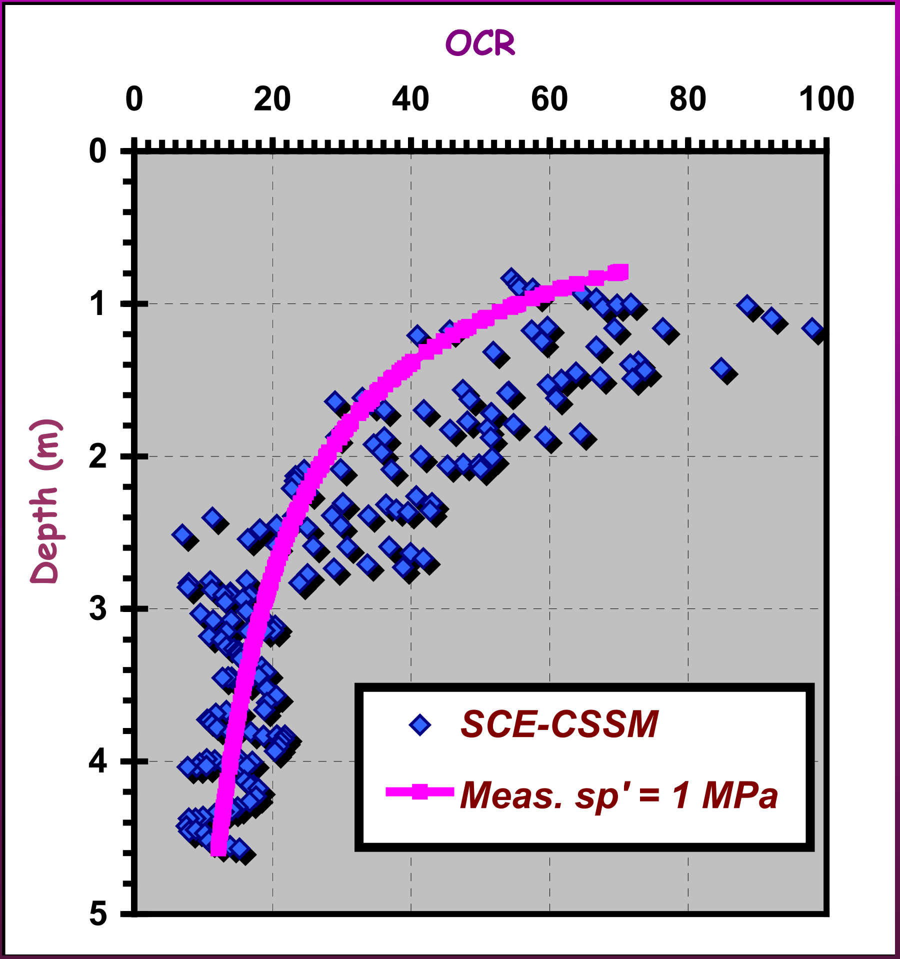
St. Hilaire, Quebec




Taranto, Italy
Overconsolidation Ratio, OCR
0
10
20
30
40
50
60
6
8
10
12
14
16
18
20
22
Depth (meters)
CPTu2
Oedometer
Battaglio, et al. (1986)
φ' = 28° Λ = 0.80

Saint Jean Vianney, Quebec
LaRochelle, et al. (1988)





OCR from Type 1 Piezocones

$$OCR = 2\left[\frac{1}{1.95M}\left(\frac{q_t - u_1}{\sigma_{vo}'} + 1\right)\right]^{(1/\Lambda)}$$

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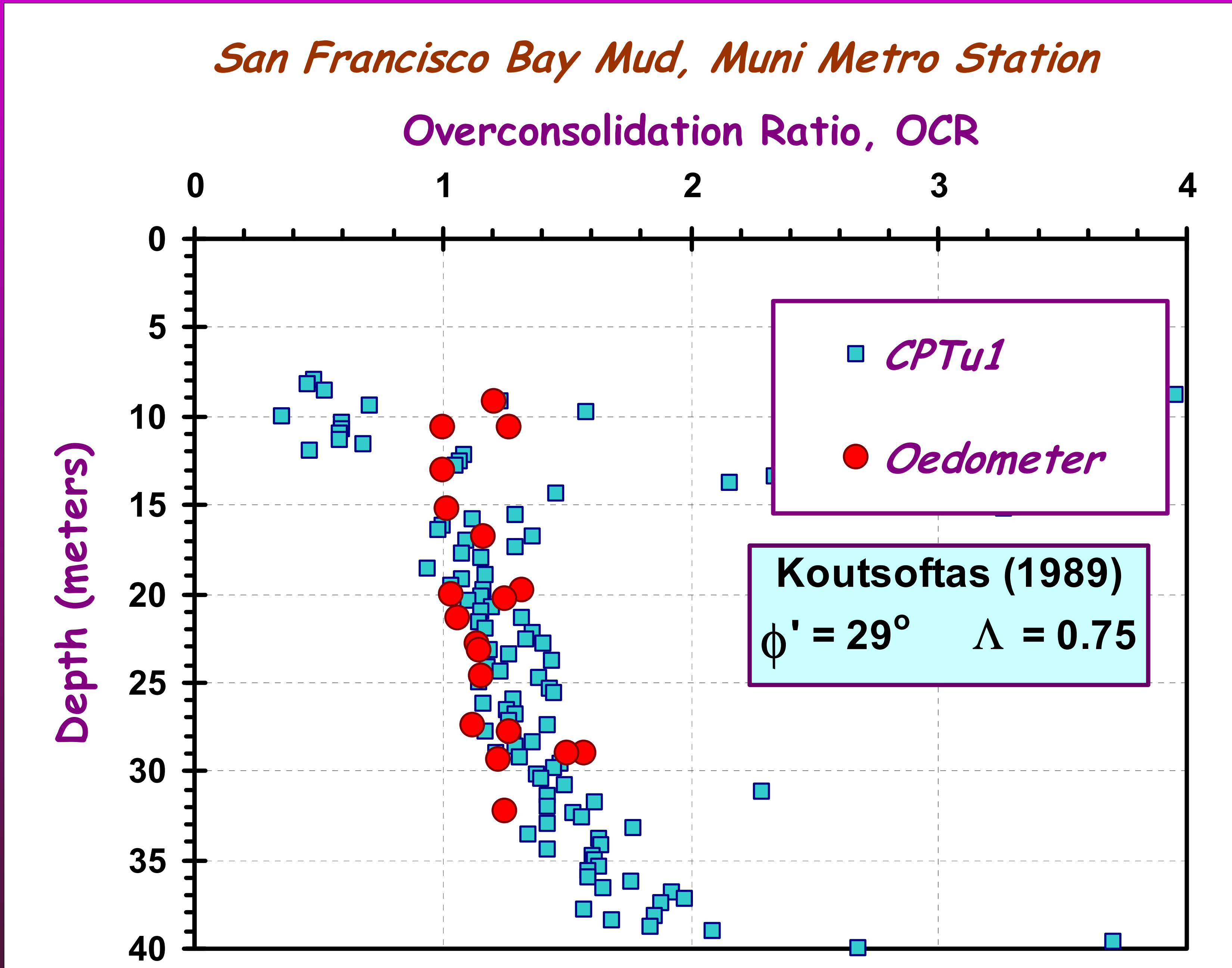
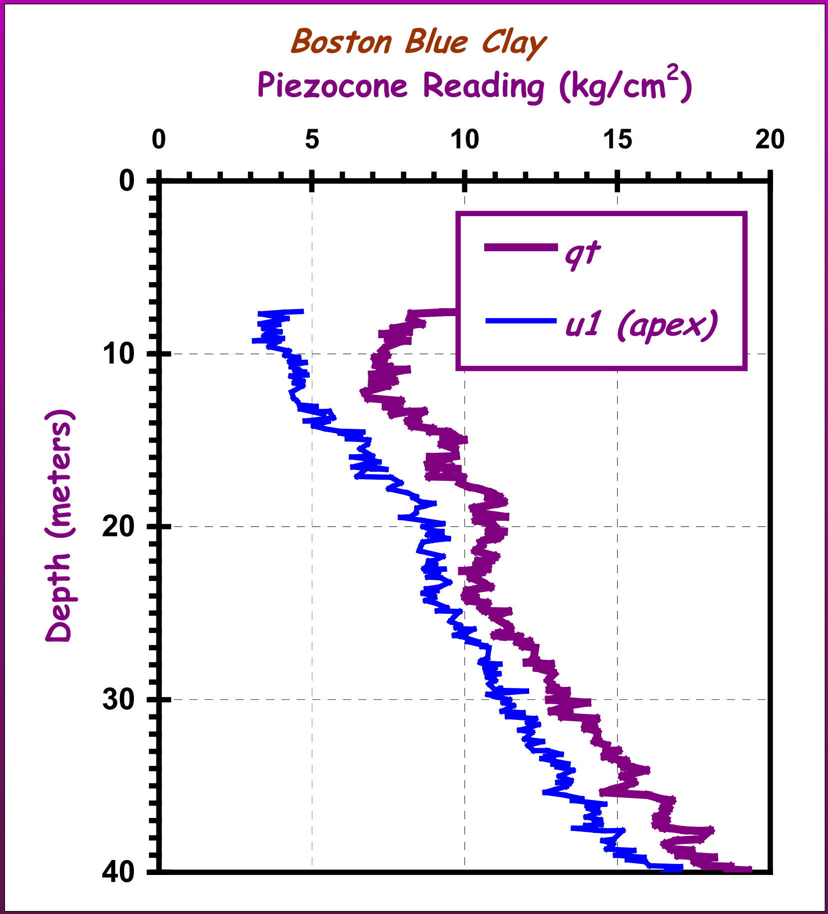
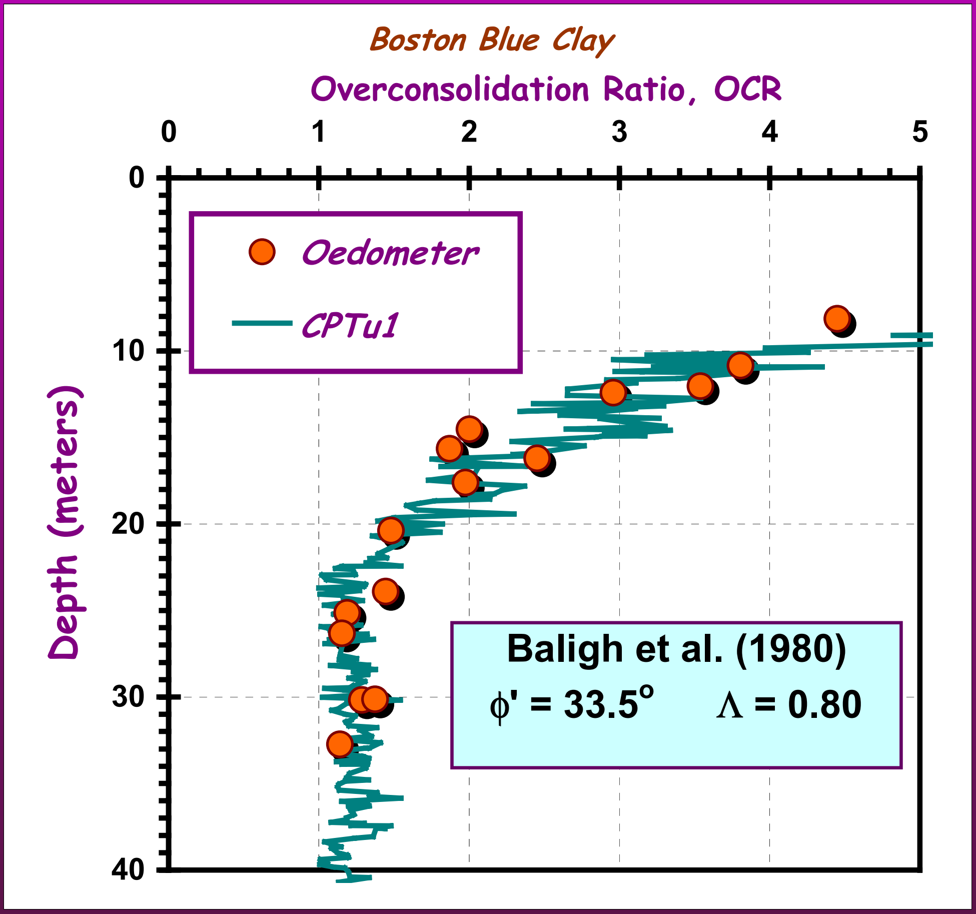
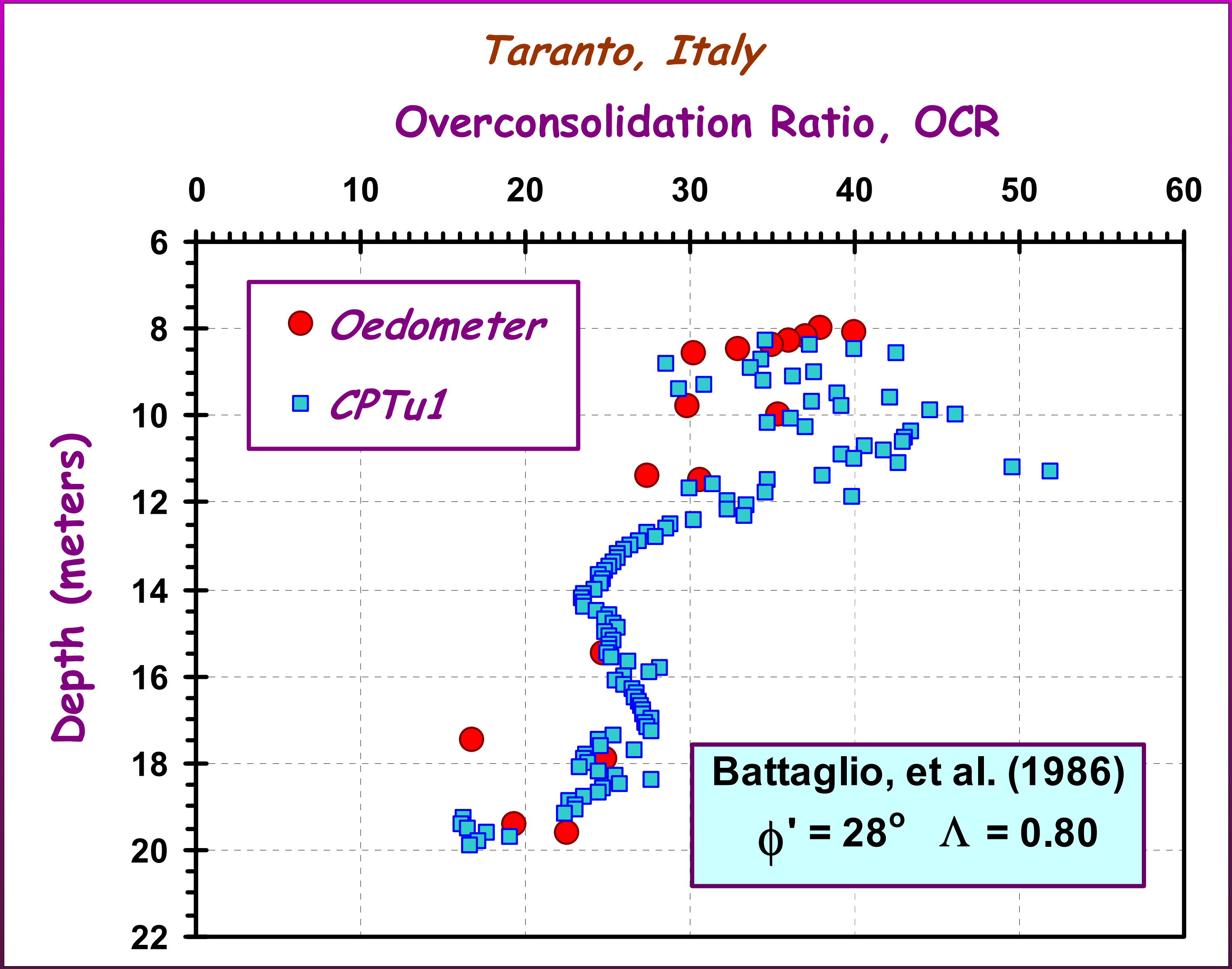

San Francisco Bay Mud, Muni Metro Station
Overconsolidation Ratio, OCR
0
1
2
3
4
0
5
10
15
20
25
30
35
40
Depth (meters)
CPTu1
Oedometer
Koutsoftas (1989)
φ' = 29°
Λ = 0.75

Boston Blue Clay, Massachusetts





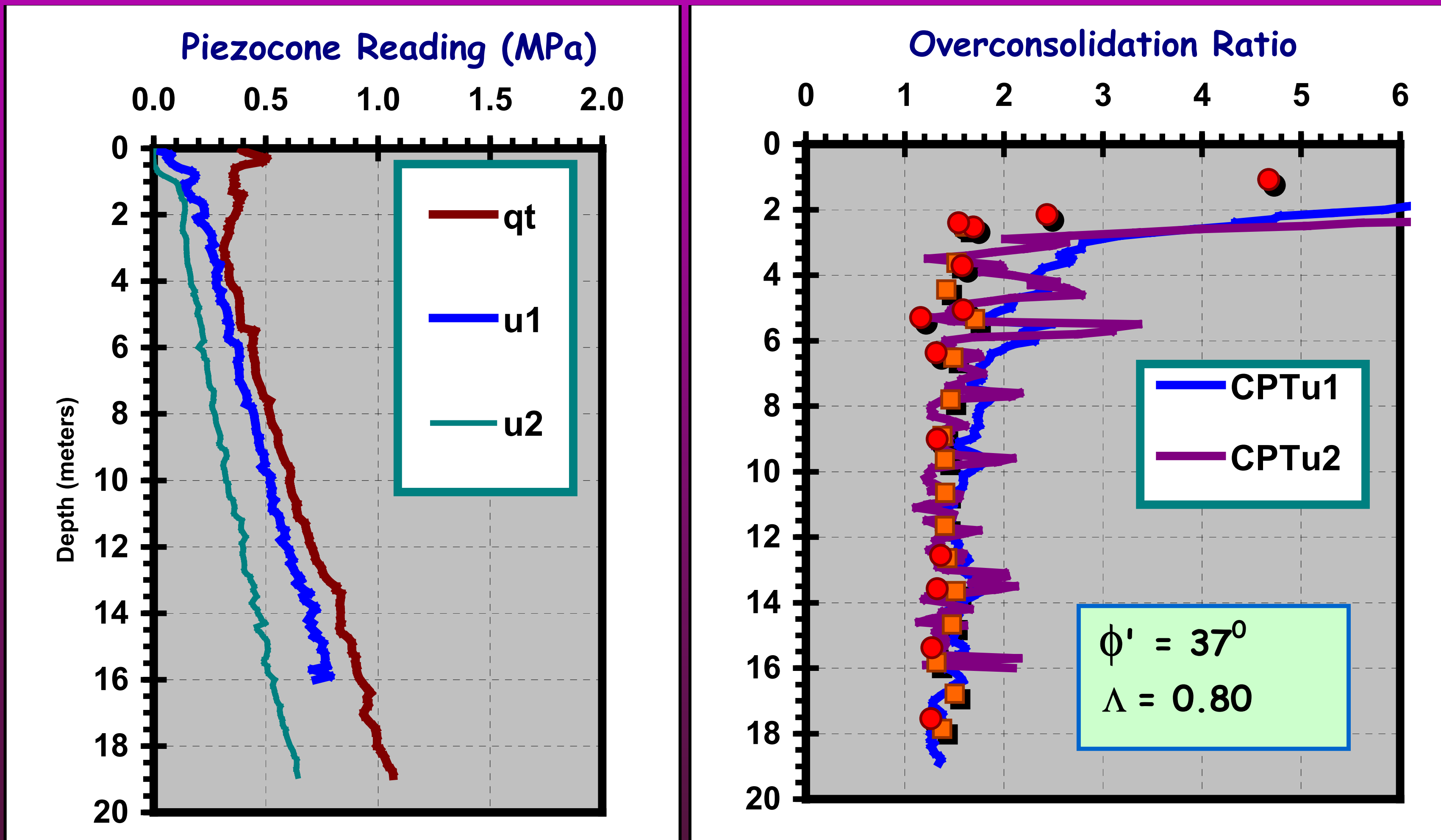


Taranto, Italy
Overconsolidation Ratio, OCR
0
10
20
30
40
50
60
6
8
10
12
14
16
18
20
22
Depth (meters)
Oedometer
CPTu1
Battaglio, et al. (1986)
φ' = 28° Λ = 0.80

Dual-Element Piezocones and Paired Sets of u_1 and u_2 Soundings

Bothkennar, UK Test Site

(Powell, et al., 1988)



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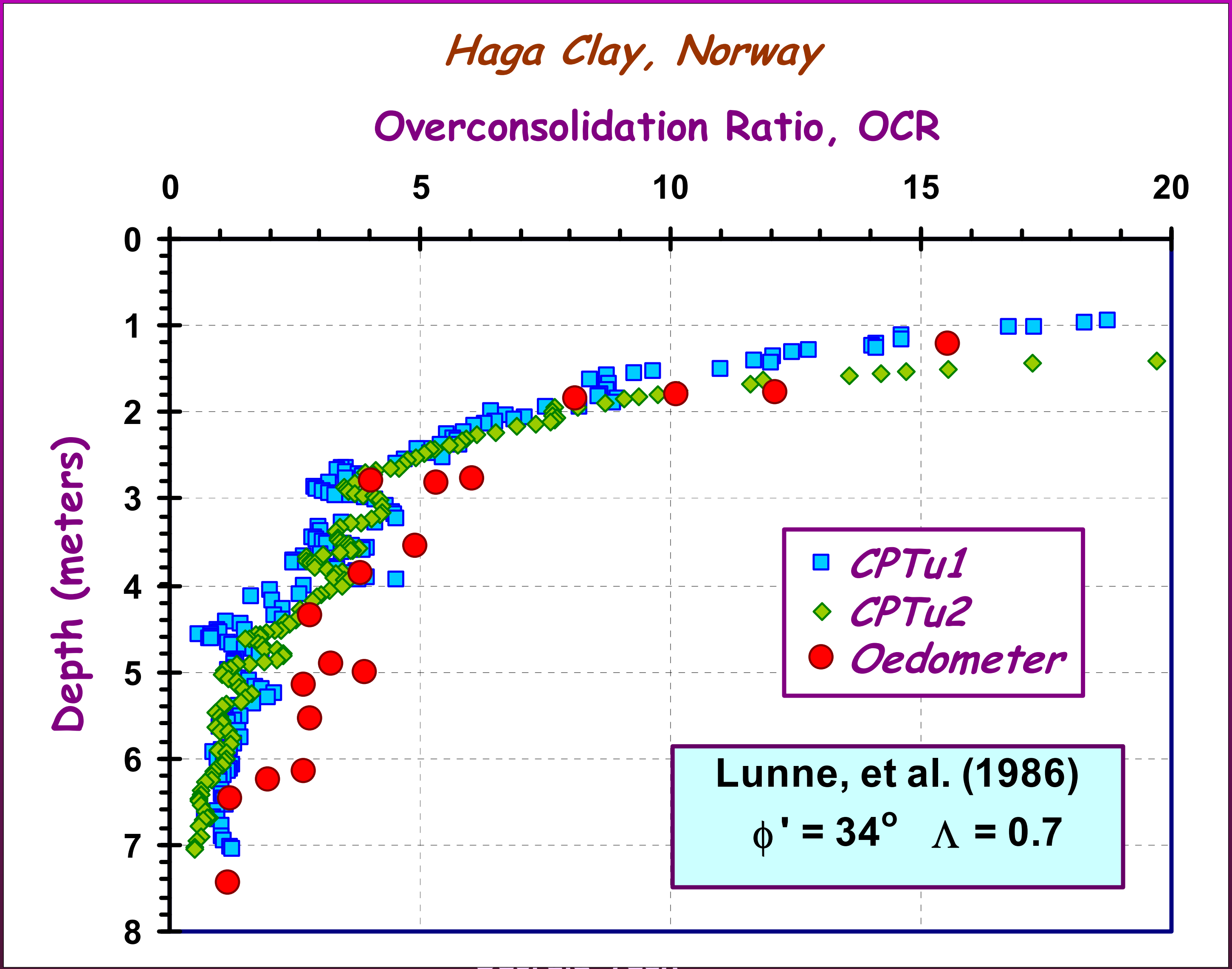
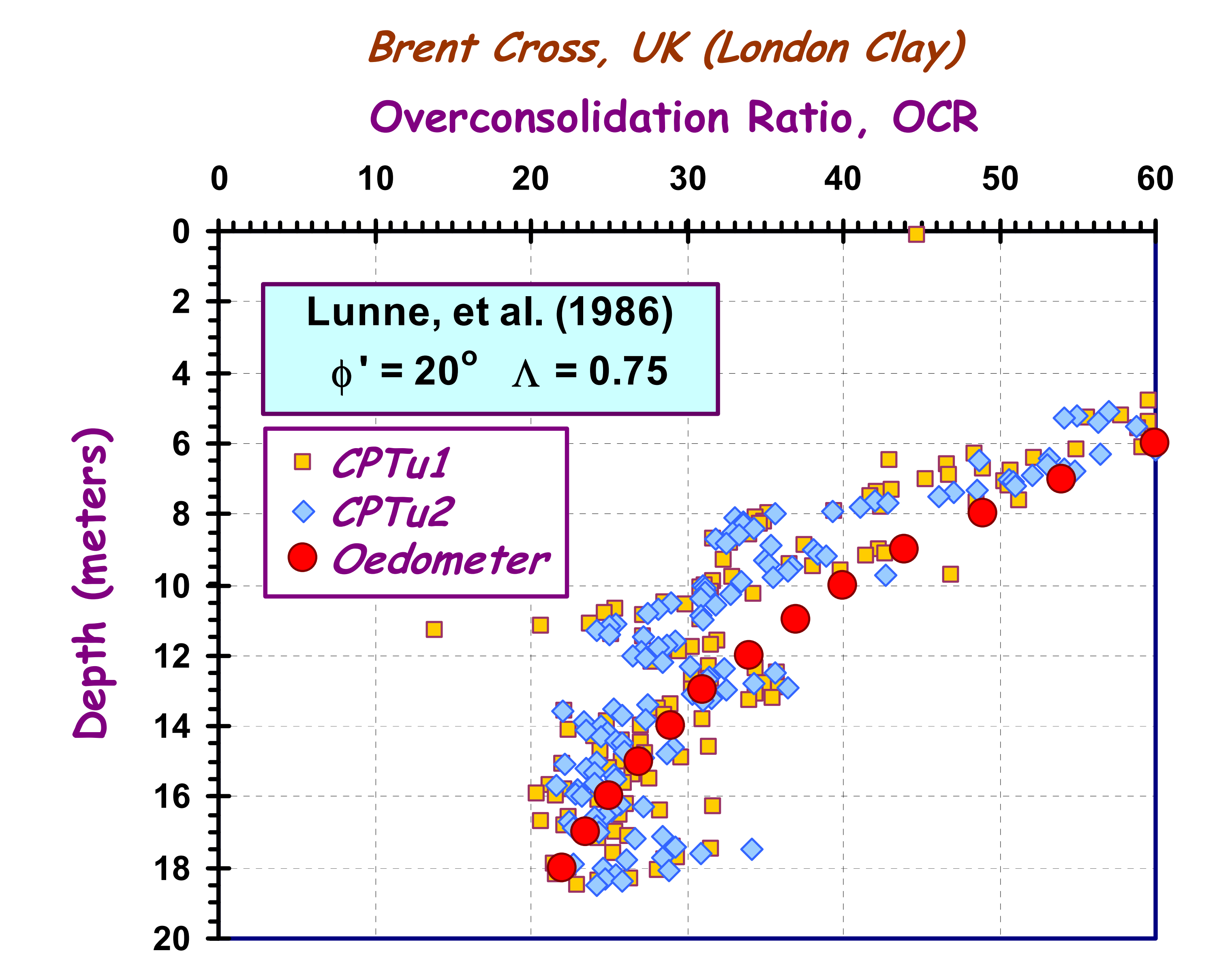
Dual CPTu - Haga Norway





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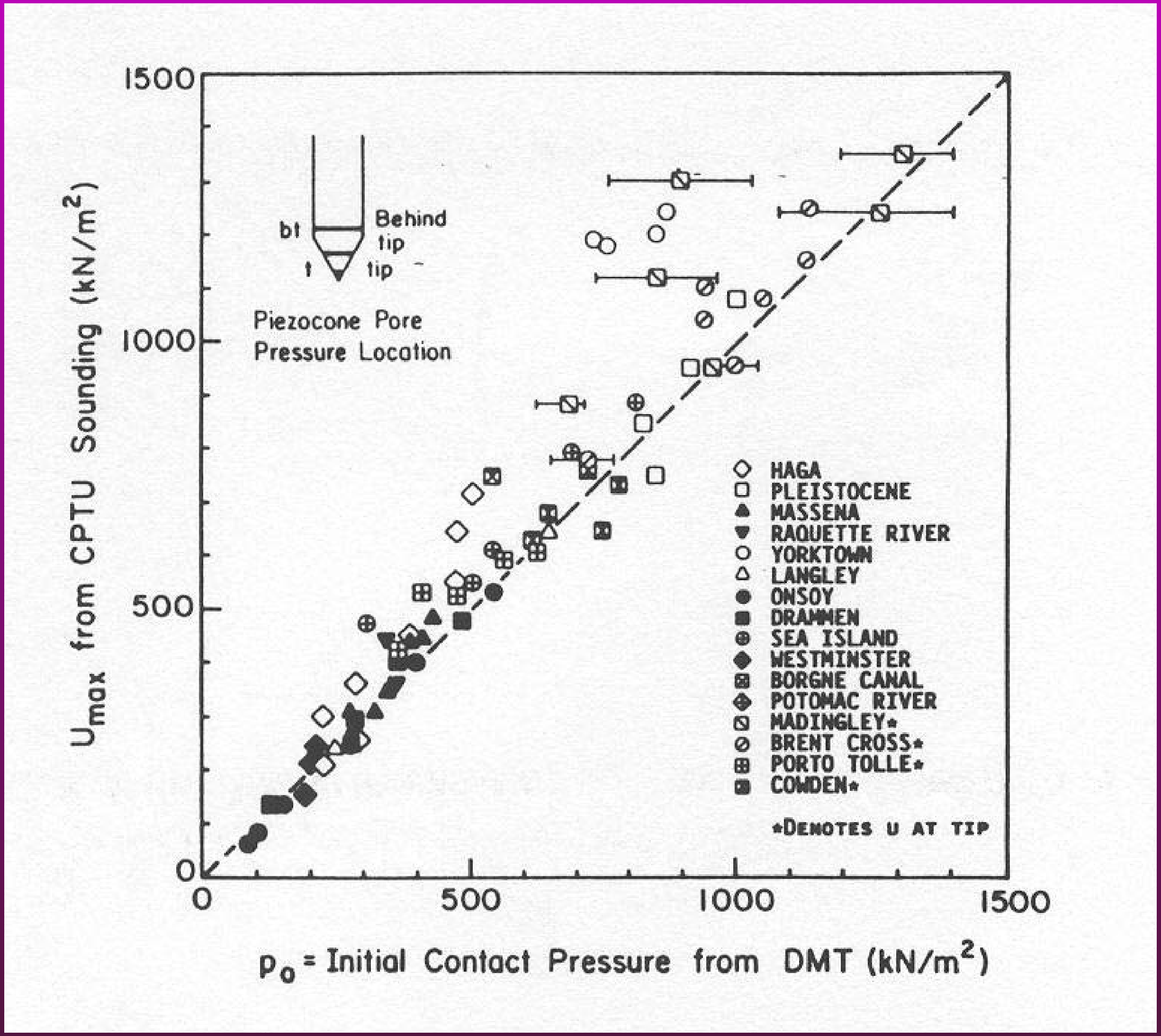
Cavity Expansion-Critical State Method for Flat Dilatometer in Clays

Essentially, the lift-off pressure
is dominated by porewater effects
induced during penetration

$$p_0 \approx u_{max}$$

CPTu-DMT Database: $p_0 \approx u_{meas}$



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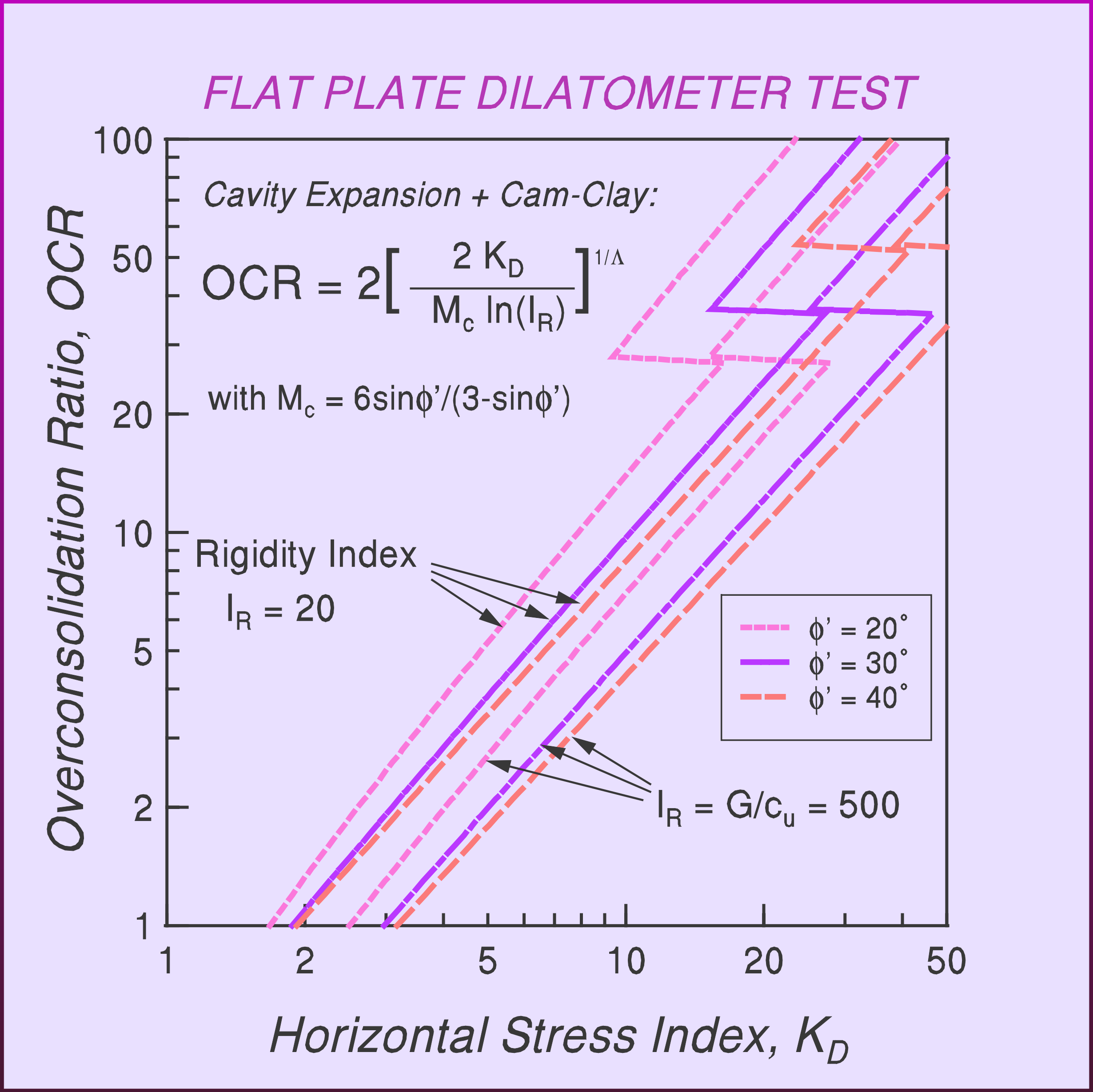
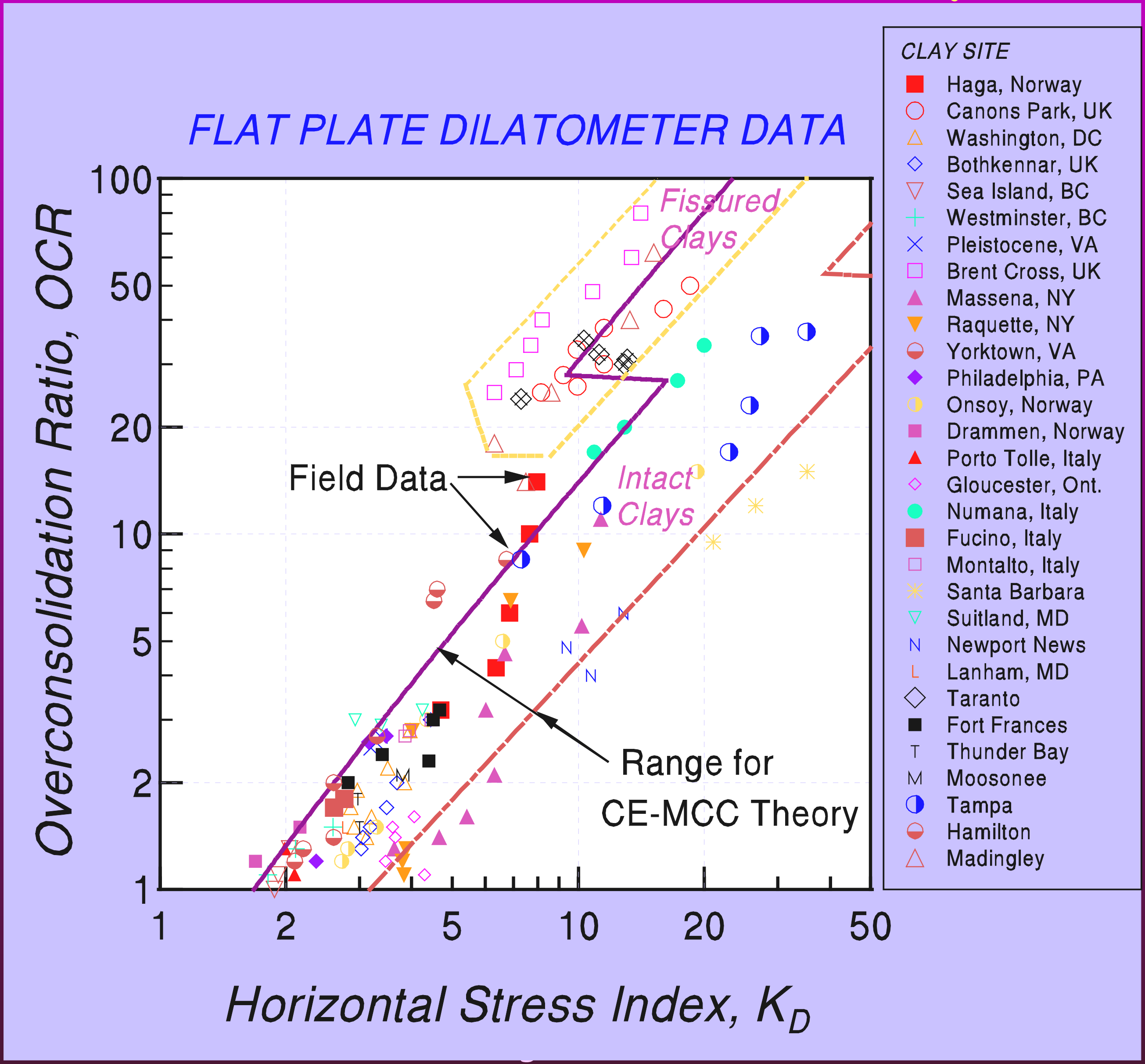
CE-CSSM for DMT in Clays



CE-CSSM for DMT in Clays



Conclusions

- Theoretical Basis for relating OCR to normalized CPTu parameter $(q_t - u_m)/\sigma_{vo}'$ and DMT parameter, K_D.
- Cavity Expansion + Critical State Soil Mechanics indicates importance of ϕ', $\Lambda = 1 - C_s/C_c$, and Rigidity Index, I_R
- Calibration with Well-Documented Sites