2023 Terzaghi Lecture at 55th KU Geotechnical Engrg. Conference

Contributions towards Geoparameter Evaluation Using the Cone Penetration Test

Paul W. Mayne, PhD, P.E., Life M. ASCE

Georgia Institute of Technology

Terzaghi Lecturers

1963: Ralph B. Peck
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1967: H. Bolton Seed
1968: Philip C. Rutledge
1969: Stanley D. Wilson
1970: T. William Lambe
1971: John Lowe, III
1972: Bramlette McClelland
1974: F.E. Richart, Jr
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1977: Robert F. Legget
1978: Nathan M. Newmark
1979: George F. Sowers
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1981: Robert V. Whitman
1982: J. Barry Cooke
1983: Ronald F. Scott
1984: James K. Mitchell
1985: Jorg O. Osterberg
1986: Charles C. Ladd
1987: Leonardo E. Zeevaert (Wiechers)
1988: Elio D'Appolonia
1989: John H. Schmertmann
1990: James P. Gould
1991: James M. Duncan
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1996: Robert M. Koerner
1997: Richard D. Woods
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2002: Victor Milligan
2003: John T. Christian
2004: Harry Poulos
2005: Delwyn G. Fredlund
2006: Raymond J. Krizek
2007: George G. Goble
2008: Jean-Pierre Giroud
2009: Clyde N. Baker, Jr
2010: Robert D. Holtz
2011: Kenneth H. Stokoe
2012: David E. Daniel
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2015: Donald A. Bruce
2016: Thomas D. O'Rourke
2017: R. Kerry Rowe
2018: Rudolph Bonaparte
2019: Eddie Idriss
2020: Edward J. Cording
2021: Gregory B. Baecher
2022: Edward Kavazanjian
2023: Paul W. Mayne

Terzaghi Lecturers

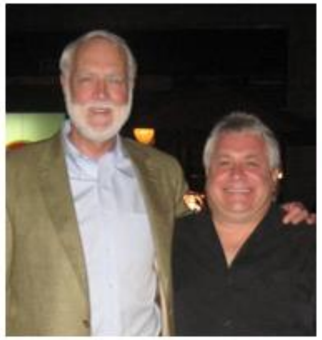


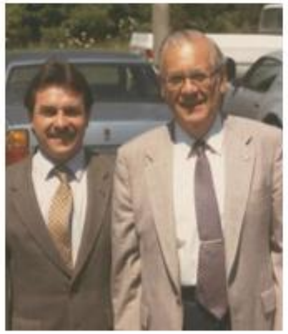
2023 2001 1963














Principle of Effective Stress

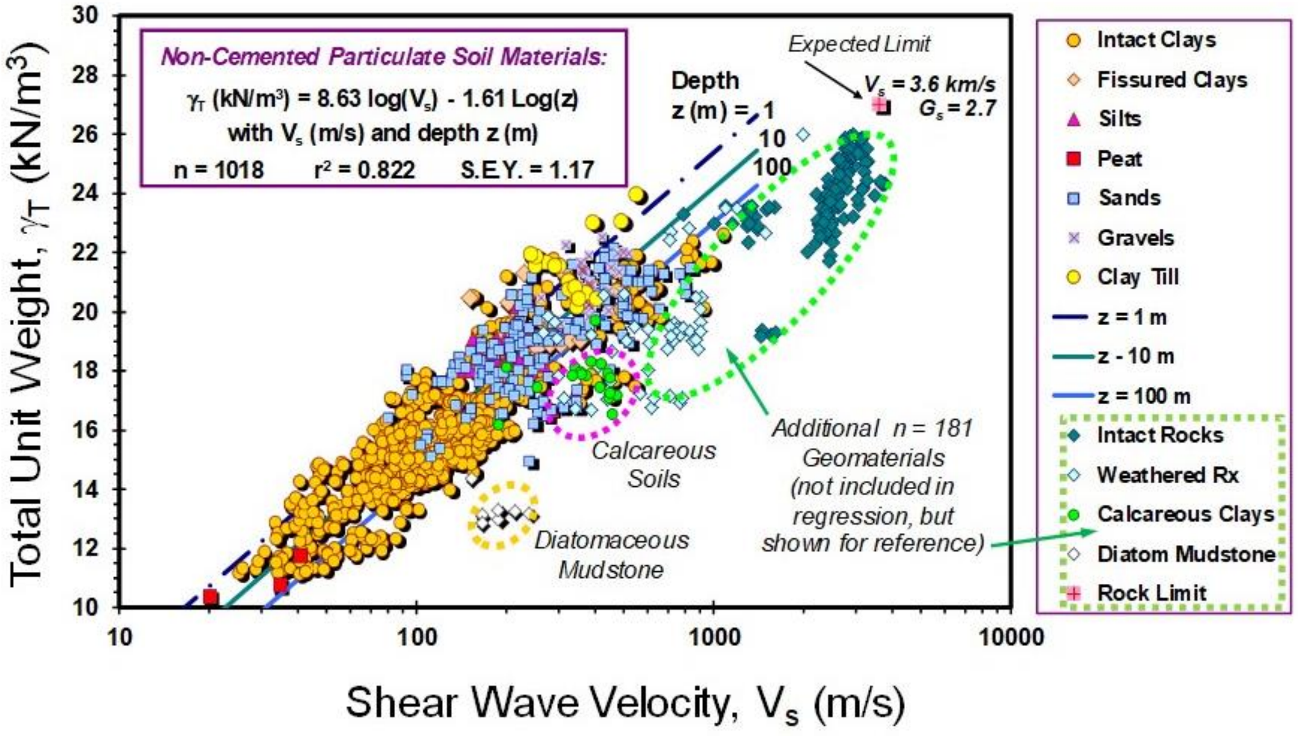
$$\sigma' = \sigma - u$$

(Karl von Terzaghi, 1947)

The name is Mayne .... Dots are my game

Database compilations are useful for:

- Finding trends
- Verification of hypotheses
- Validation of theories
- Cross-check for anomalies
- Predicting performance
- Deciding boundaries
- Statistical analyses
- Sorting groups of data
- Developing correlations

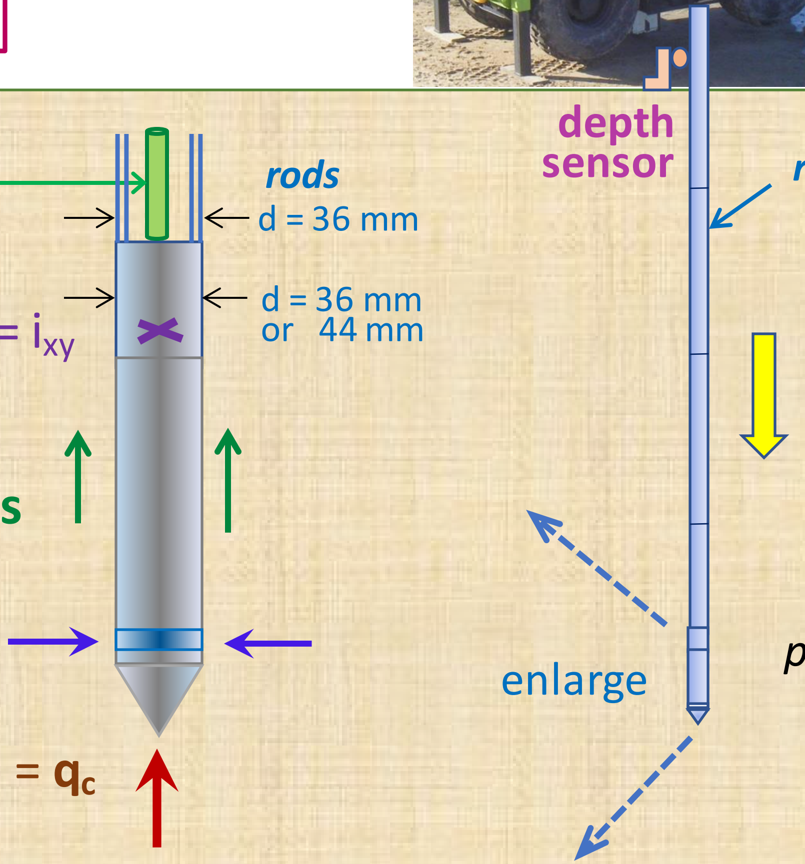


CONE PENETRATION TEST (CPT)
ASTM D 5778
ISO Standard 22476-1

CPT Rig
(20 tonnes)

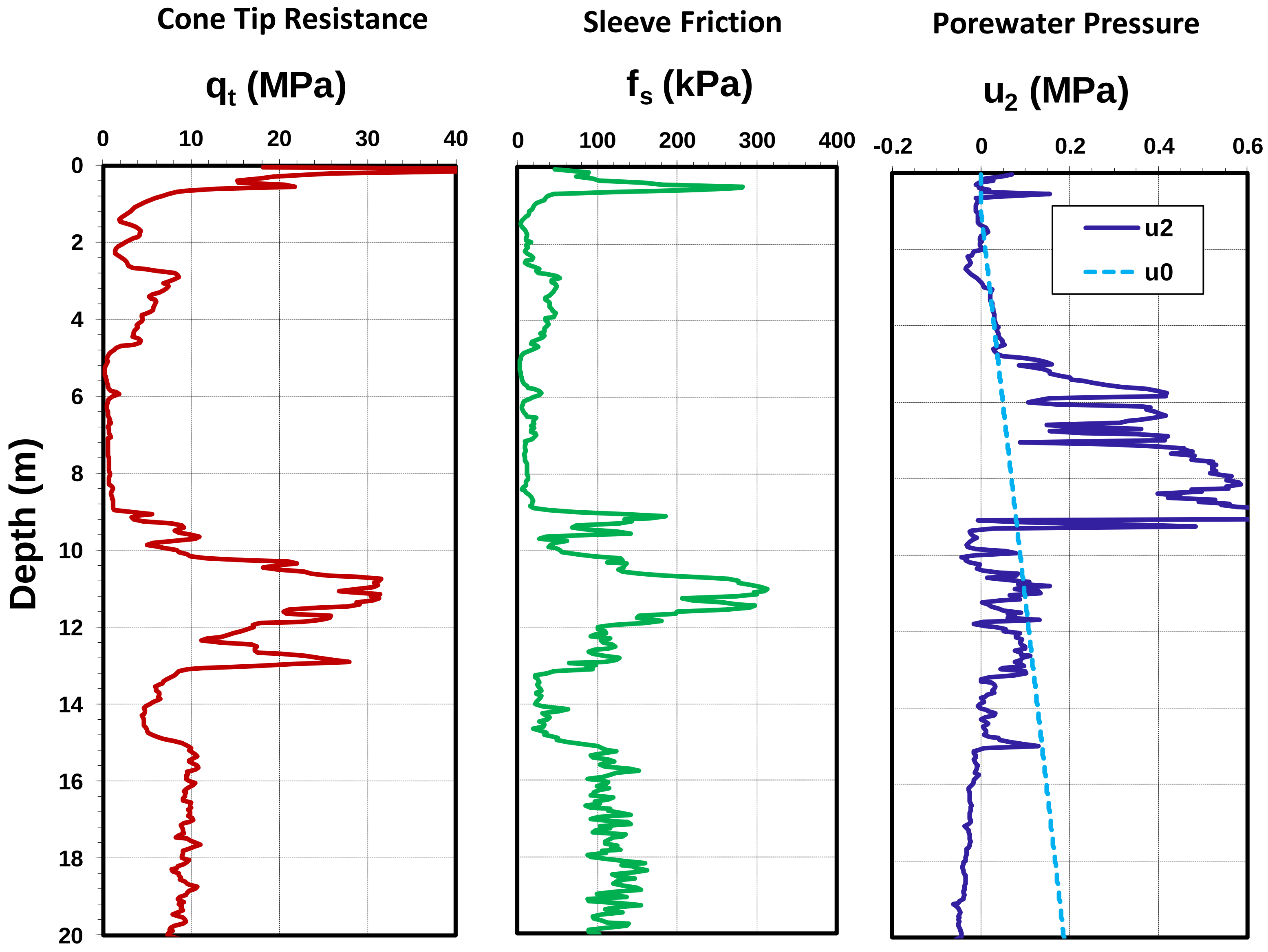
ground surface

electronic
piezocone
penetrometer



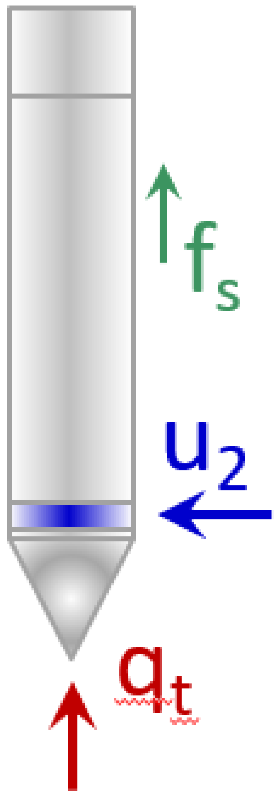
where $q_t = q_c + (1-a_{net})\cdot u_2$ and $0.35 \le a_{net} \le 0.90$ depends on equipment

CPT Sounding, Ghent District, Virginia

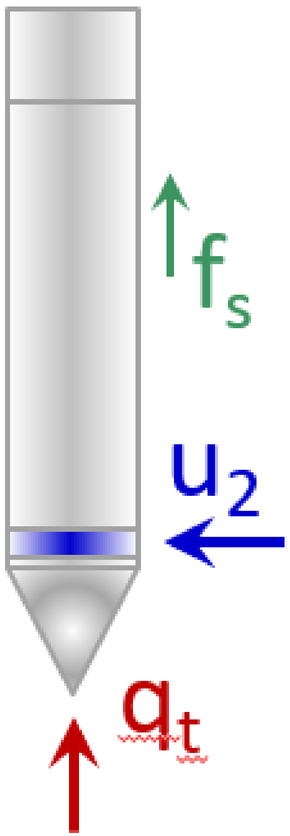


Data Courtesy of Ethan Cargill

CONETEC



Post Processing and Normalization of CPT Readings



$q_{net} = q_t - \sigma_{vo}$ = net cone tip resistance

$\Delta u_2 = u_2 - u_0$ = excess porewater pressure

$q_E = q_t - u_2$ = effective cone resistance

$Q = Q_t = Q_{t1} = q_{net}/\sigma_{vo}'$ = normalized cone resistance

$U = \Delta u_2/\sigma_{vo}'$ = normalized porewater pressure = $Q \cdot B_q$

$B_q = \Delta u_2/q_{net}$ = pore pressure ratio

$F_r = 100\ f_s/q_{net}$ = normalized friction ratio (%)

$Q_E = q_E/\sigma_{vo}'$ = normalized effective cone resistance

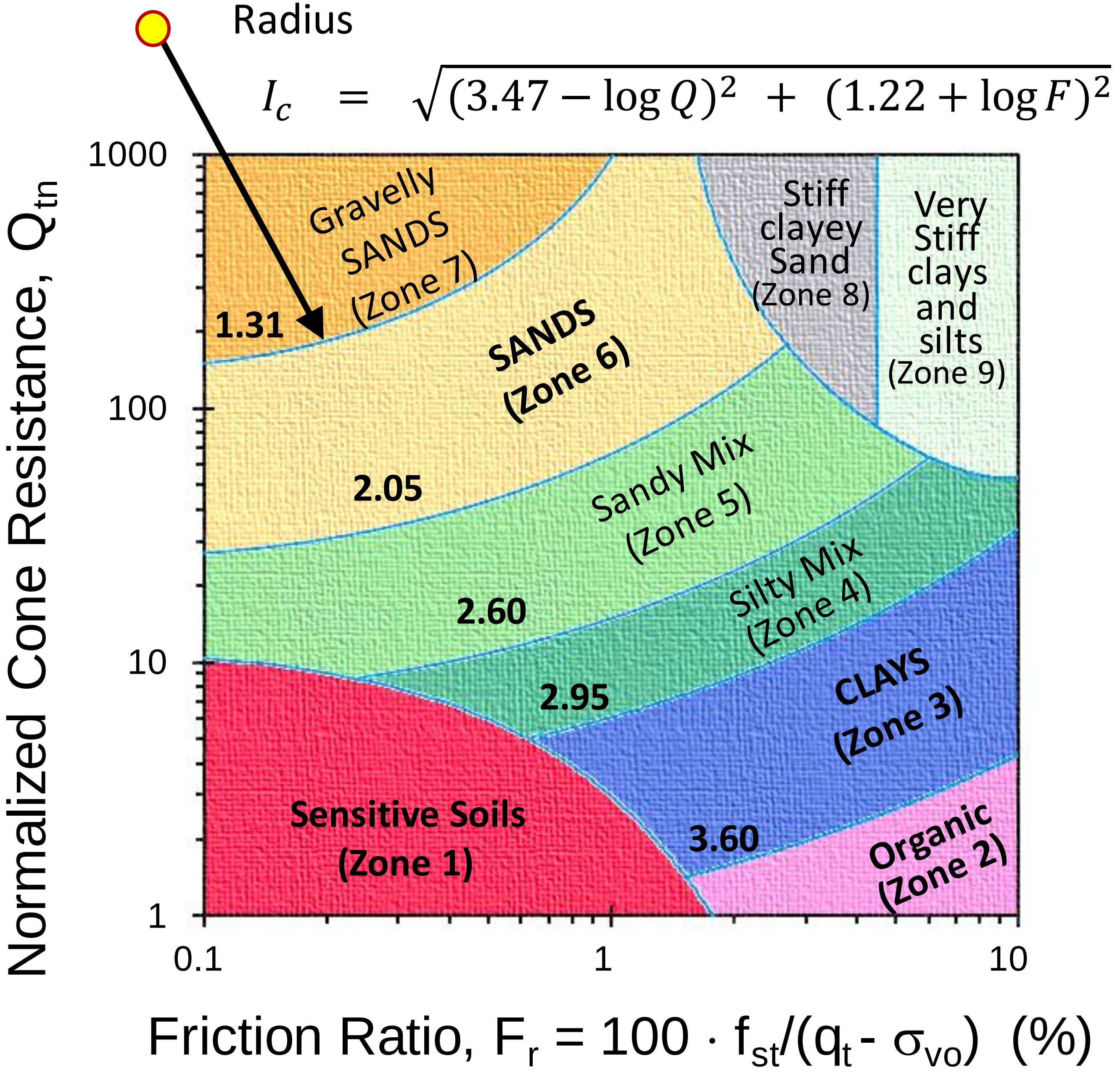
$Q_{tn} = q_{net}/(\sigma_{vo}')^n$ in bars where n = *fctn* (soil type and/or I_c)

[e.g., n = 1 clay; 0.75 silt; 0.5 sand]

CPT Soil Behavior Type (SBTn) Chart

(Robertson 1990, 2009)

CPT Material Index, I_c



Overview on CPT contributions

- Effective Stress Friction Angle, ϕ' — Sands, Silts, Clays
- Yield stress (preconsolidation), σ_p' — Sands, Silts, Clays
- Sensitivity and Remolded Strength — Clays
- State parameter, ψ — Sands, Silts, Clays
- Equipment and Innovations
- New directions for “ConeHeads”

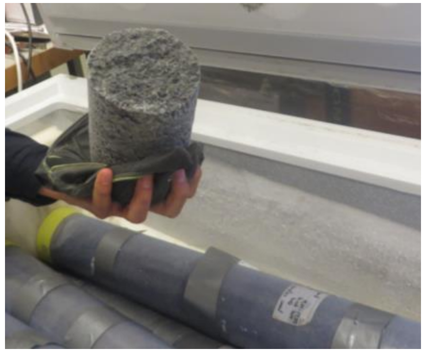
Undisturbed Sands to Silty Sands Database
(number of sites, N = 28; no. triaxial tests, n = 68)

Soil Number	*Site Name*	*Site Location*	*Reference Source*	*Type Sand*	*Method of Sampling*
1	Blessington	Ireland	Doherty & Gavin (2010, CPT'10, California)	Glacial fine Sand	Sonic
2	Charleston	South Carolina	Esposito et al. (2016, ASCE JGGE)	Pleistocene Sand	Frozen
3	Duncan Dam	British Columbia	Plewes et al. (1994, CGJ)	Glaciofluvial Sand	Frozen
4	Edo	Japan	Mimura (2003, C&EPNS, Singapore)	Natural Alluvial	Frozen
5	Ekofish	North Sea	Mitchell & Lunne (1972, JSMFD ASCE)	Marine	Samples
6	Gioia Tauro	Italy	Ghionna & Porcino (2004, ISC-2 Porto)	Natural Coarse Sand	Frozen
7	Hibernia	North Atlantic	Thompson & Long (1989, CGJ)	Marine Sand	Frozen
8	Highmont	British Columbia	Robertson, Wride, et al. (2000, CGJ)	Tailings	Frozen
9	Holmen	Norway	Lunne, et al (2003, C&EPNS, Singapore)	Natural Alluvial	Tube/Frozen
10	J-pit	Alberta	Robertson, Wride, et al. (2000, CGJ)	Hydraulic Fill	Frozen
11	Kao Hsiung	Taiwan	Huang (2016, ISC-5, Australia)	Alluvial Sands	Gel Sampler
12	Kidd	British Columbia	Robertson, Wride, et al. (2000, CGJ)	Natural Alluvial	Frozen
13	Kilmore	New Zealand	Taylor (2015, PhD - Univ. Canterbury)	Fluvial & Aeolian	Gel Sampler
14	LL Dam	British Columbia	Robertson, Wride, et al. (2000, CGJ)	Tailings	Frozen
15	Madras-Armagh	New Zealand	Taylor (2015, PhD - Univ. Canterbury)	Fluvial & Aeolian	Gel Sampler
16	Massey	British Columbia	Robertson, Wride, et al. (2000, CGJ)	Natural Alluvial	Frozen
17	McDonald Farm	British Columbia	Robertson (1983, Dissertation, UBC)	Fraser River Sands	Piston Tube
18	Mildred L.	Alberta	Robertson, Wride, et al. (2000, CGJ)	Hydraulic Fill	Frozen
19	Milford Dam	Illinois	Stark et al. (2011, ASCE JGGE)	Alluvial Sands	Tube/Frozen
20	Natori	Japan	Matsuo & Tsutsumi (1998, ISC-1, Atlanta)	Natural Alluvial	Frozen
21	Piedmont	Georgia	Harris & Mayne (1994, FHWA Orlando)	Residual silty Sands	Shelby Tube
22	Po River	Italy	Ghionna et al (1995, ISP-5, Quebec)	Alluvial Sands	Not Known
23	Tone	Japan	Matsuo & Tsutsumi (1998, ISC-1, Atlanta)	Natural Alluvial	Frozen
24	West Kowloon	Hong Kong	Lee, Shen, Leung, Mitchell (1999, JGGE)	Hydraulic Fill	Mazier Tube
25	Yodo	Japan	Mimura (2003, C&EPNS, Singapore)	Natural Alluvial	Frozen
26	Yuan Lin	Taiwan	Huang et al (2004, Soil Dyn & EQ Engrg)	Alluvial Sands	Gel Sampler
27	Zelany Most	Poland	Jamiolkowski (DMT 2015, Rome)	Silty fine Sand Tailings	Frozen
28	Øysand	Norway	Quinteros (2022), PhD Imperial College	Fluvial	Frozen

Notes:
JGGE = Journal of Geotechnical & Geoenvironmental Engineering
ISC = International Conference on Site Characterization (ISSMGE TC 102)
C&EPNS = Characterization & Engineering Properties of Natural Soils
ISP = International Symposium on Pressuremeter
JSMFE = Journal Soil Mechanics & Foundations Division (ASCE)
DMT = Intl. Conf. on Dilatometer Testing
CPT = Intl. Symp Cone Penetration Test
FHWA = Federal Highway Administration
CGJ = Canadian Geotechnical Journal

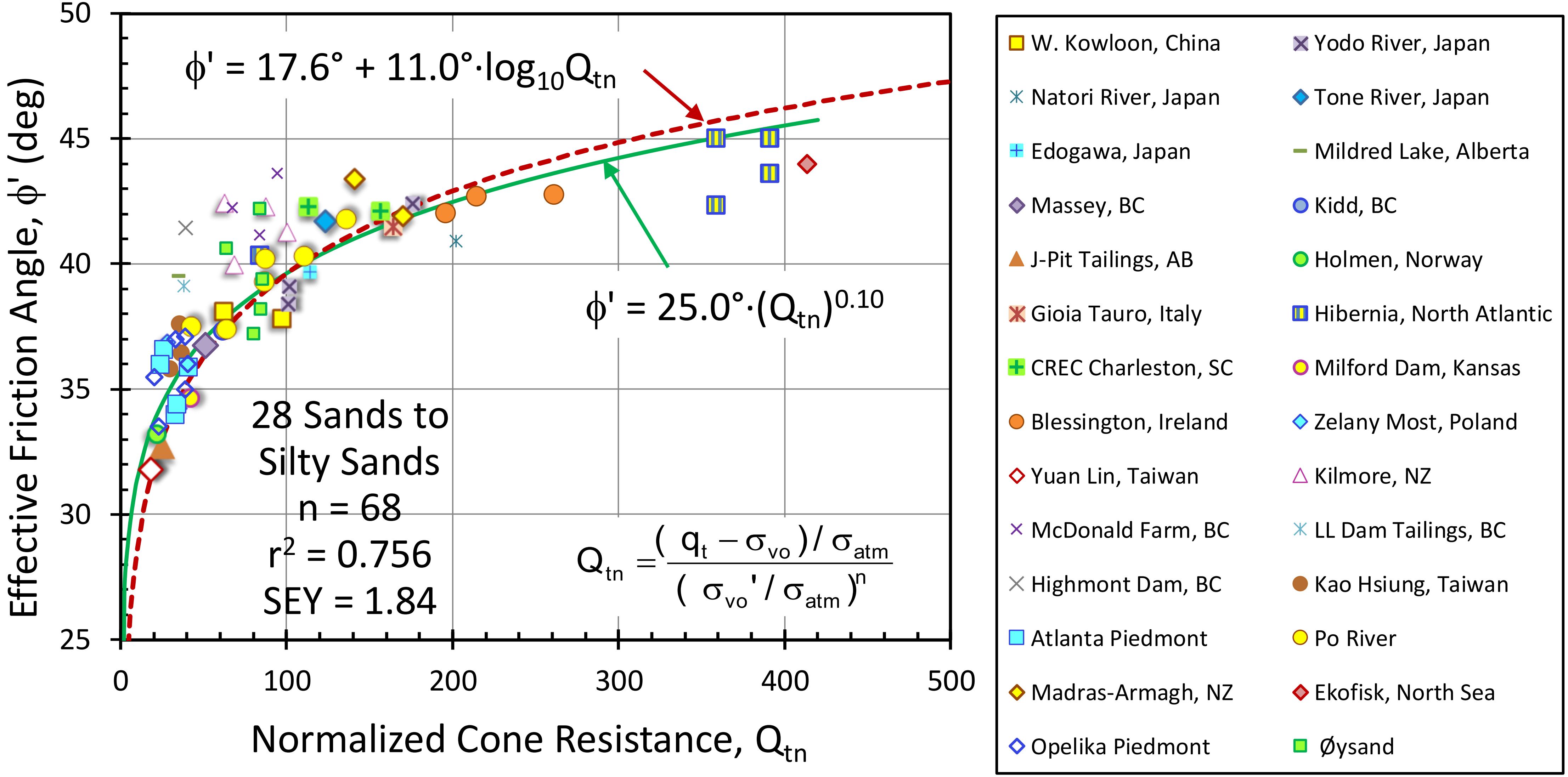
NGI Lab 2019

NGI Frozen Øysand

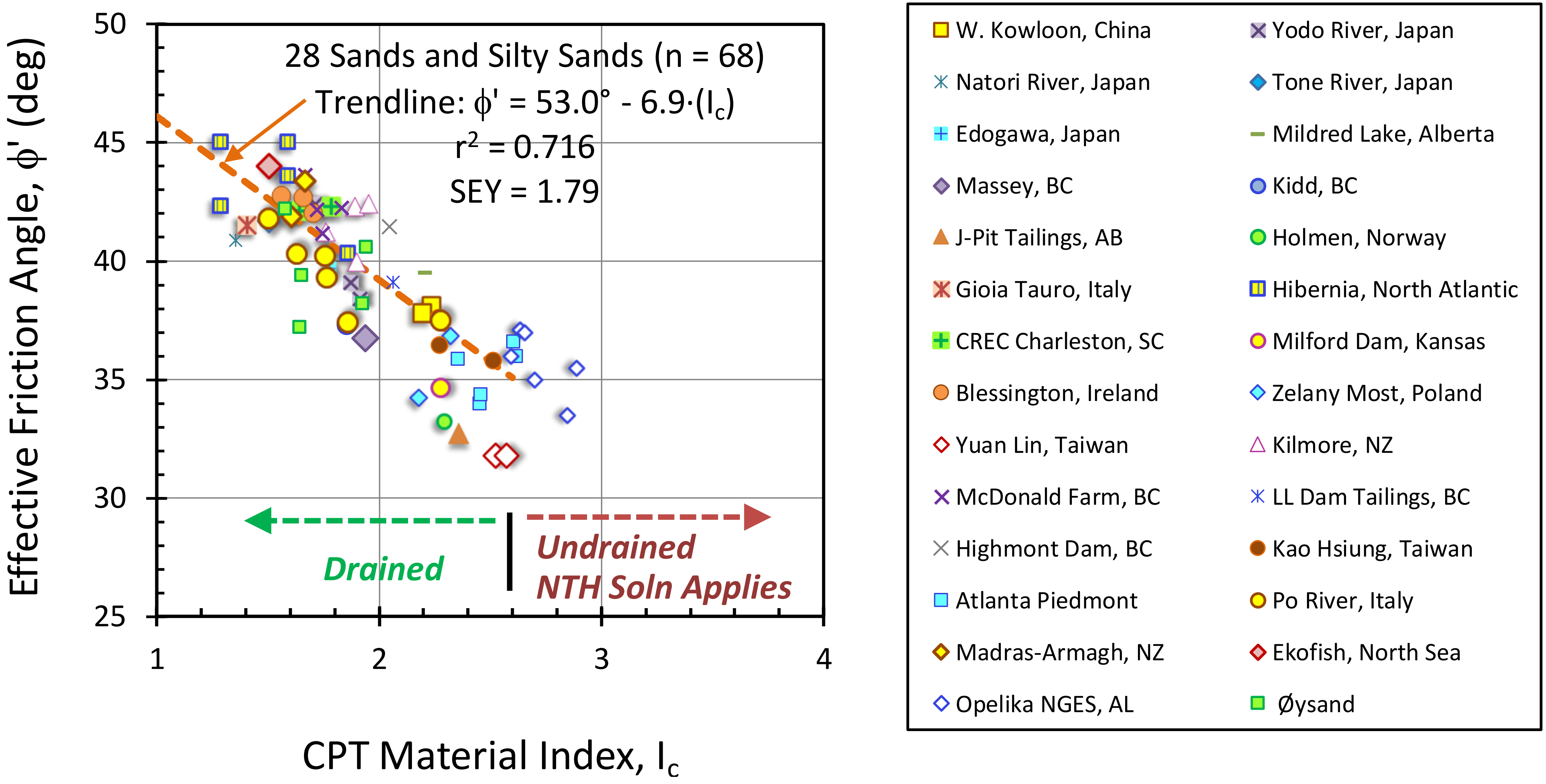


Gel-Push Sample

Effective Friction Angle of Sands and Silty Sands from CPT

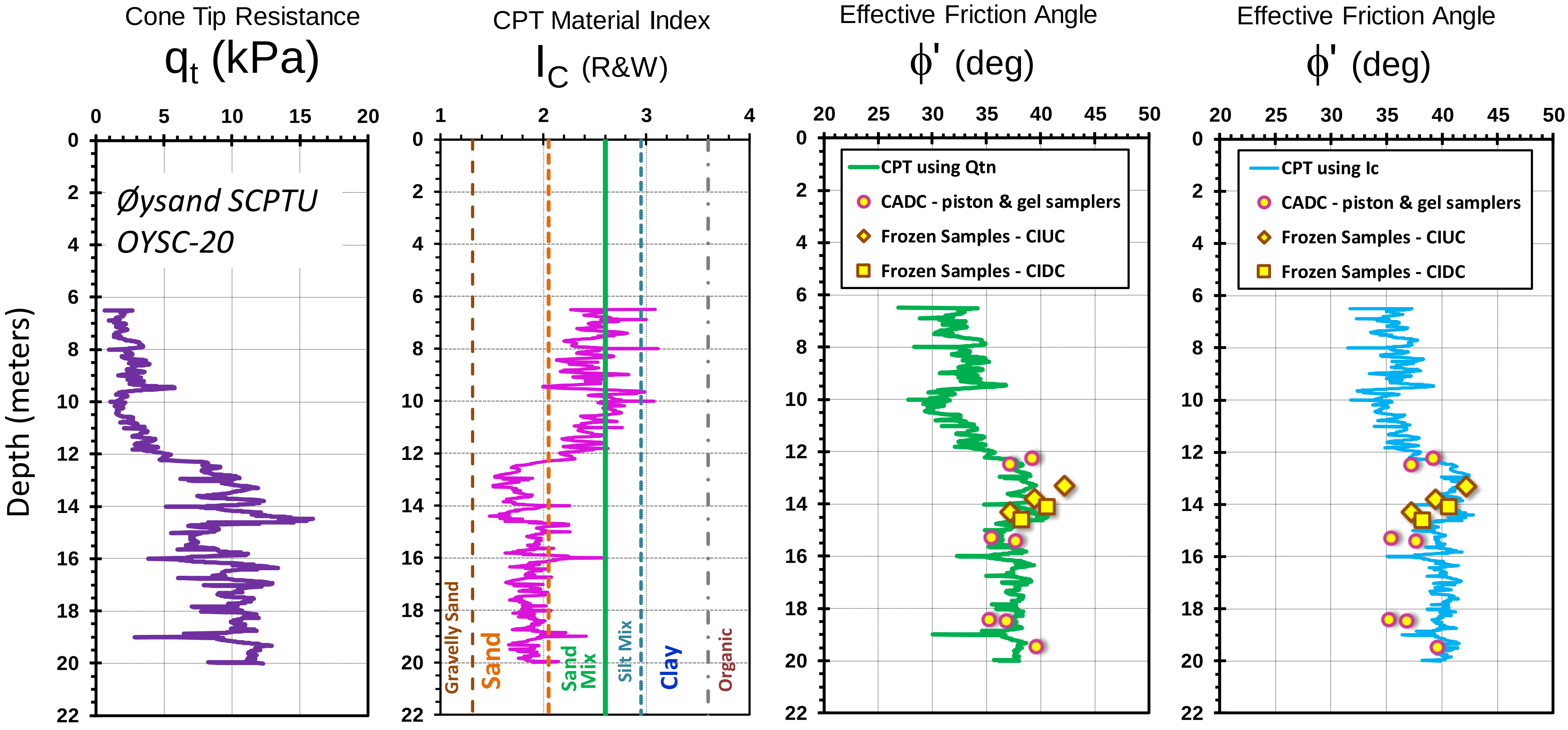


Effective Friction Angle of Sands and Silty Sands from CPT



Øysand International GeoTest Site, Norway

(Quinteros, et al. 2019; 2022 PhD – Imperial College)



NTH Solution for ϕ’ from CPTU for undrained penetration

NTH = Norwegian Institute of Technology, now NTNU, Trondheim)

Effective stress limit plasticity theory (c’=0):

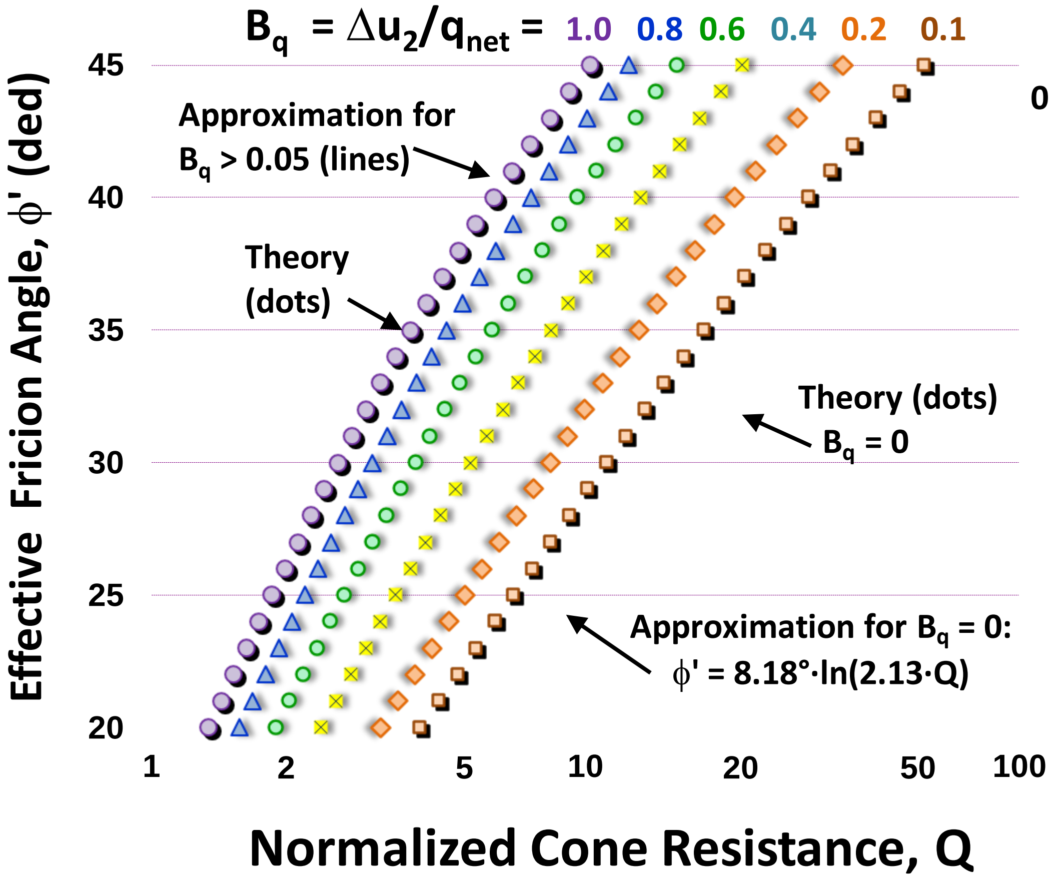
$$Q = \frac{\tan^2(45° + \phi'/2) \cdot \exp[(\pi - 2\beta) \cdot \tan\phi'] - 1}{1 + 6 \cdot \tan\phi' \cdot (1 + \tan\phi') \cdot B_q}$$

Approximation for undrained case (β = 0°):

$$\phi' \approx 29.5° \cdot B_q^{0.121} \cdot [0.256 + 0.336 \cdot B_q + \log Q]$$

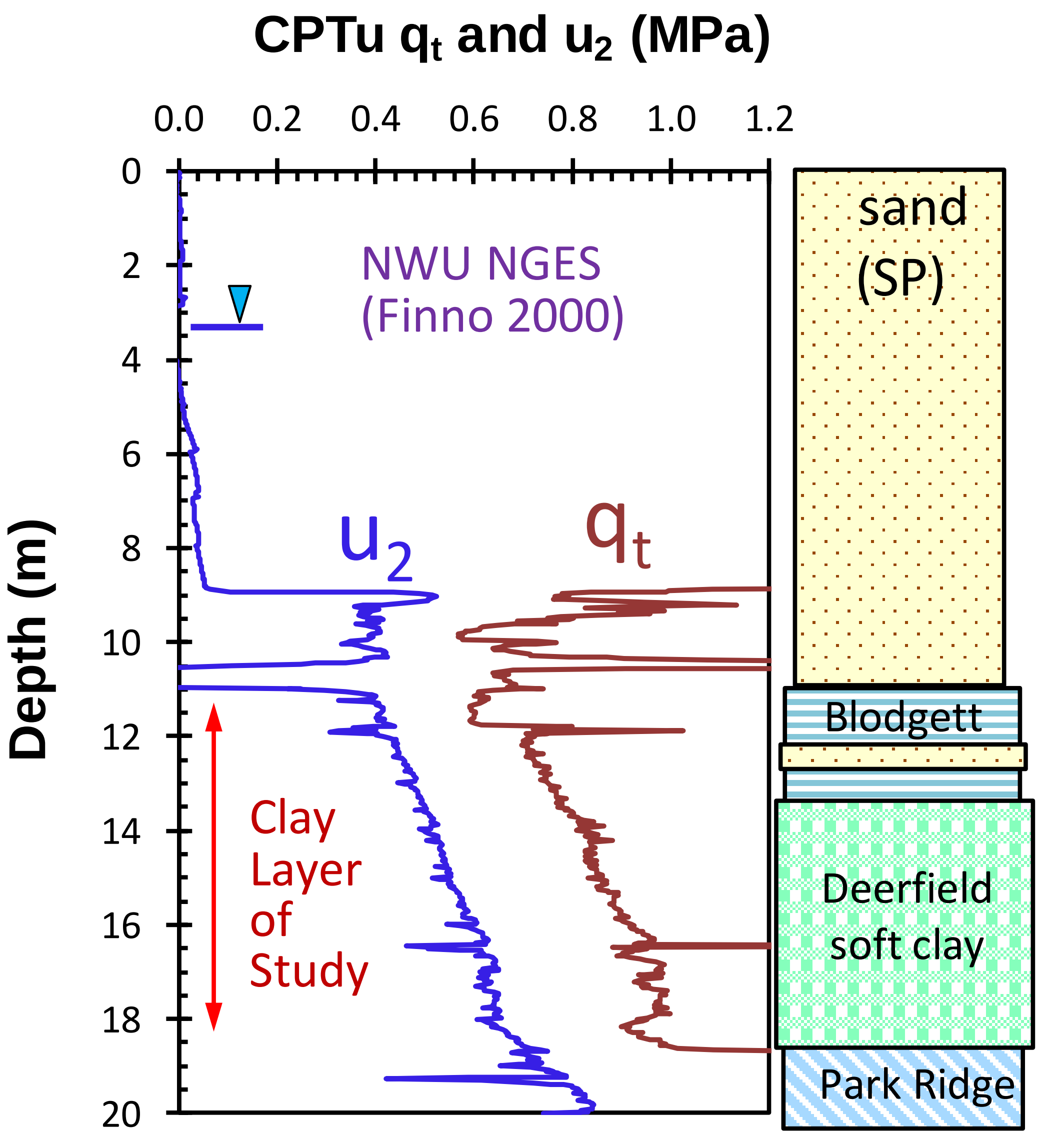
Applicable to clays for OCRs < 2.5 and ranges: $0.05 \leq B_q \leq 1$ and $18° \leq \phi' \leq 45°$

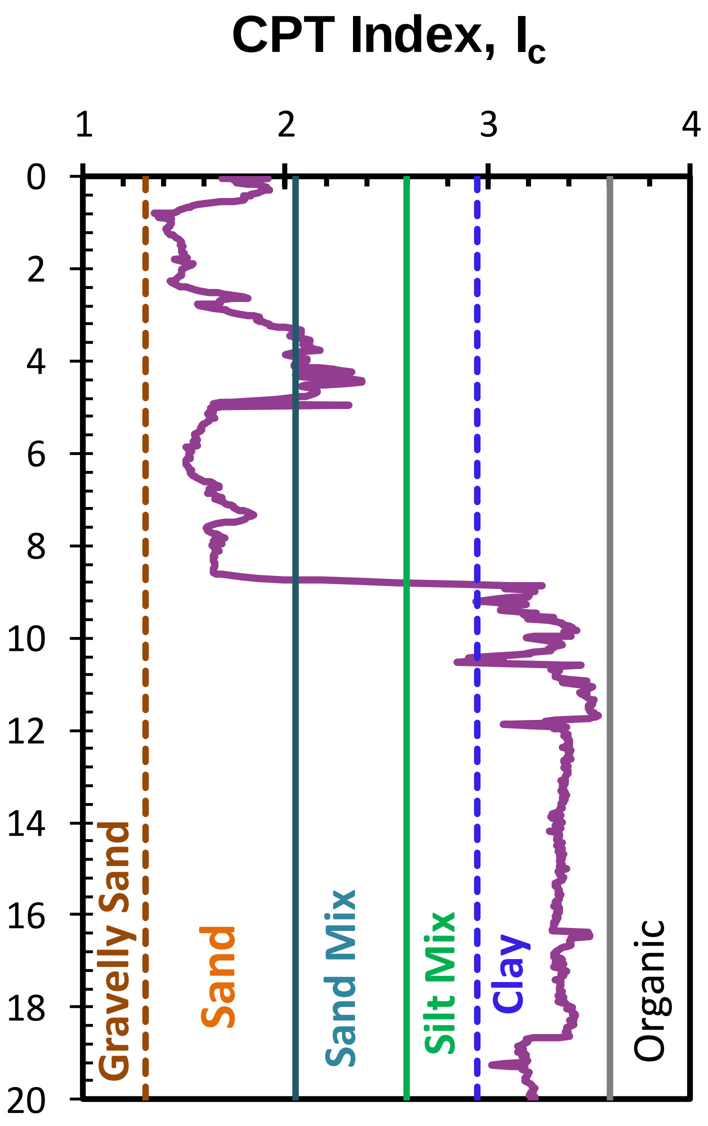
Note: for Modified NTH Solution (Sandven et al. 2016), substitute $Q' = Q \cdot OCR^{-\Lambda}$ in above equations



Janbu & Senneset (1974)
Senneset & Janbu (1985)
Senneset et al. (1989)
Sandven (1990)
Sandven & Watn (1995)
Sandven et al. (2015)
Sandven et al. (2016)
Ouyang & Mayne (2018)
Ouyang & Mayne (2019)
Ouyang & Mayne (2023)

Soft Chicago Clay at Northwestern University GeoTest Site



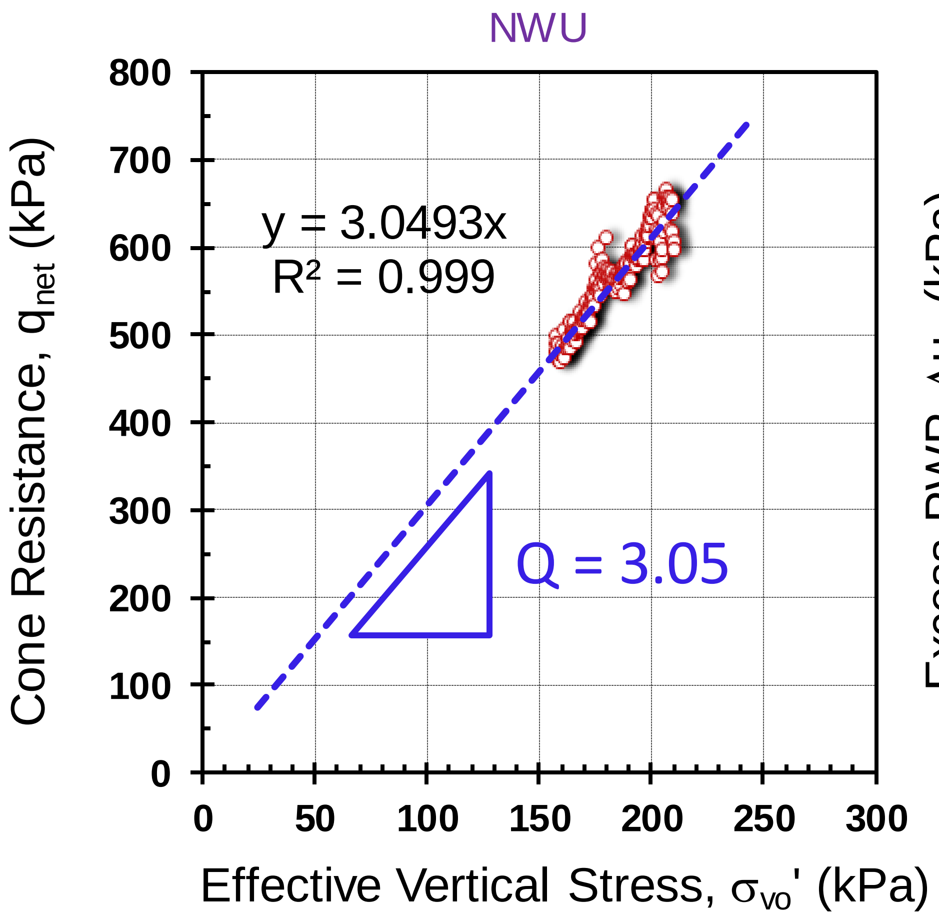


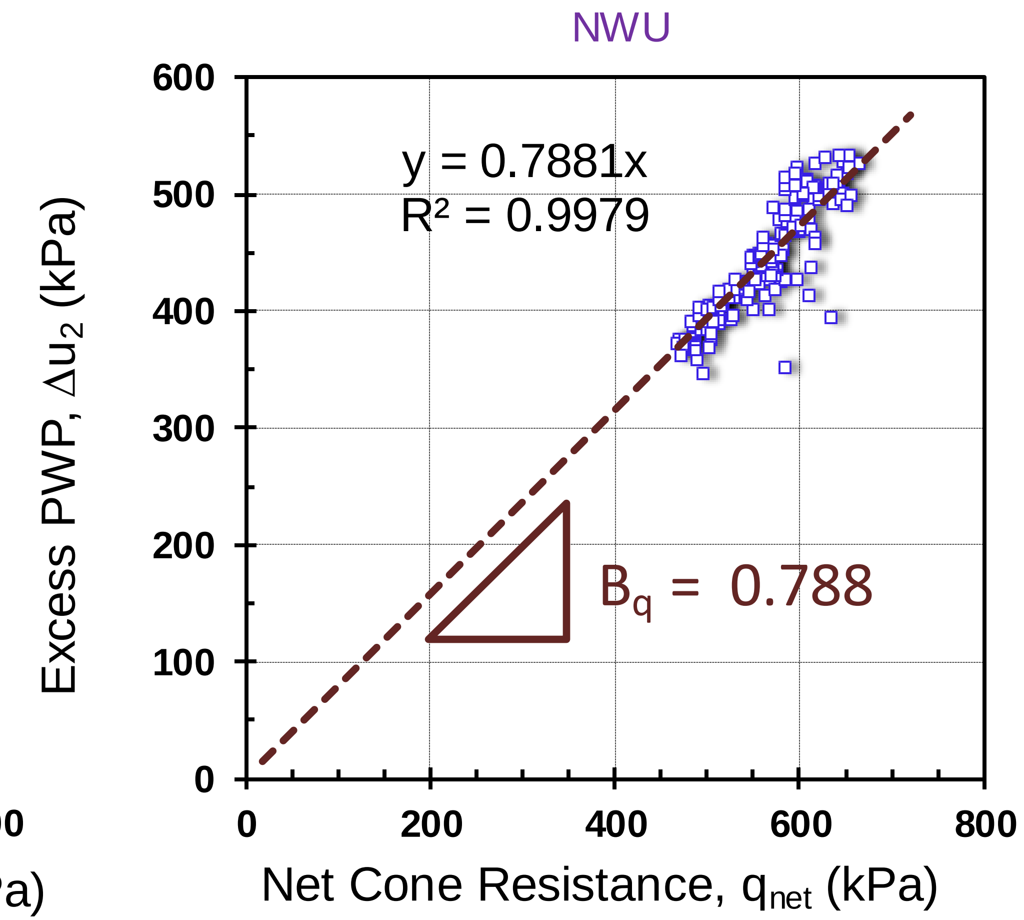
Clay Sensitivity
From VST:
$S_t \approx 2$

NGES - Northwestern University, Evanston, Illinois

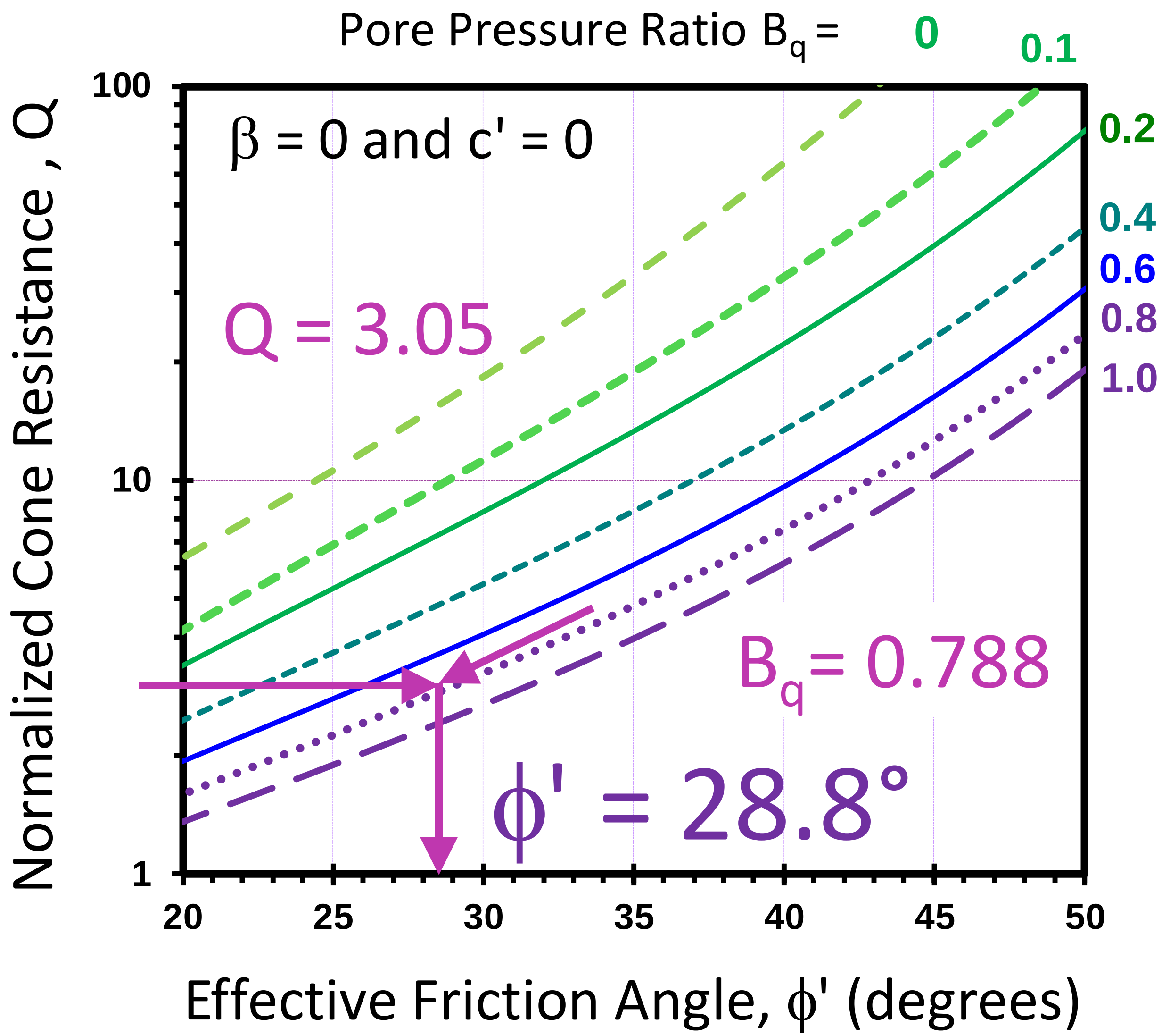
$$Q = \frac{\tan^2(45° + \phi'/2) \cdot \exp(\pi \cdot \tan\phi') - 1}{1 + 6 \cdot \tan\phi' \cdot (1 + \tan\phi') \cdot B_q}$$

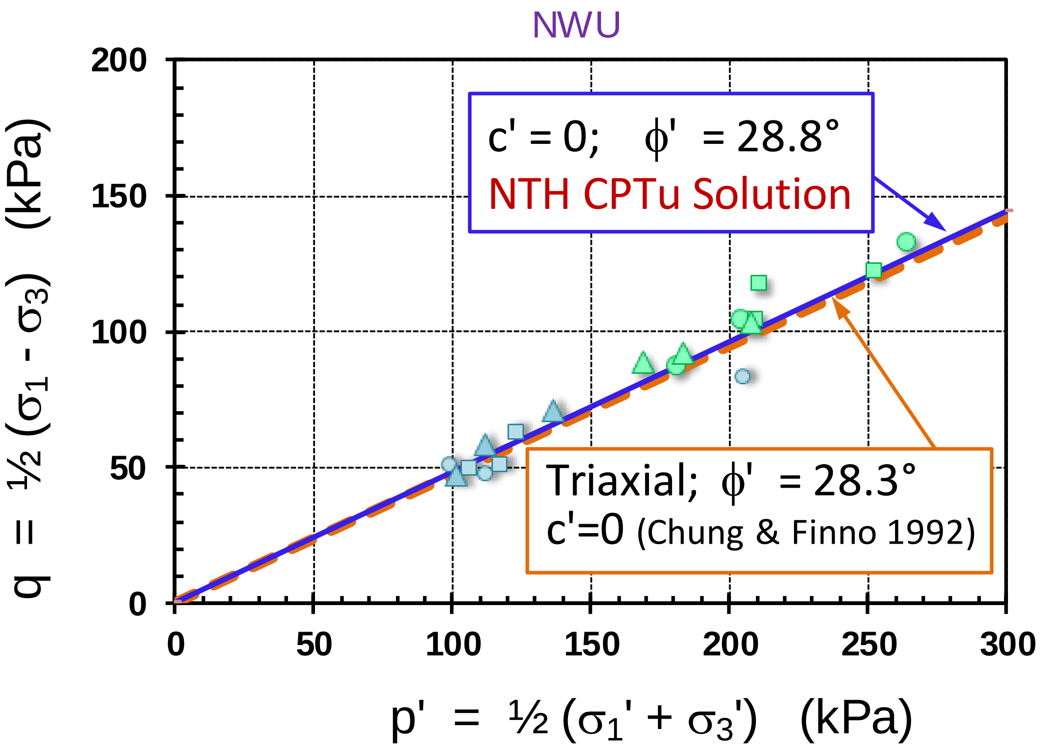
$\phi' = 28.8°$





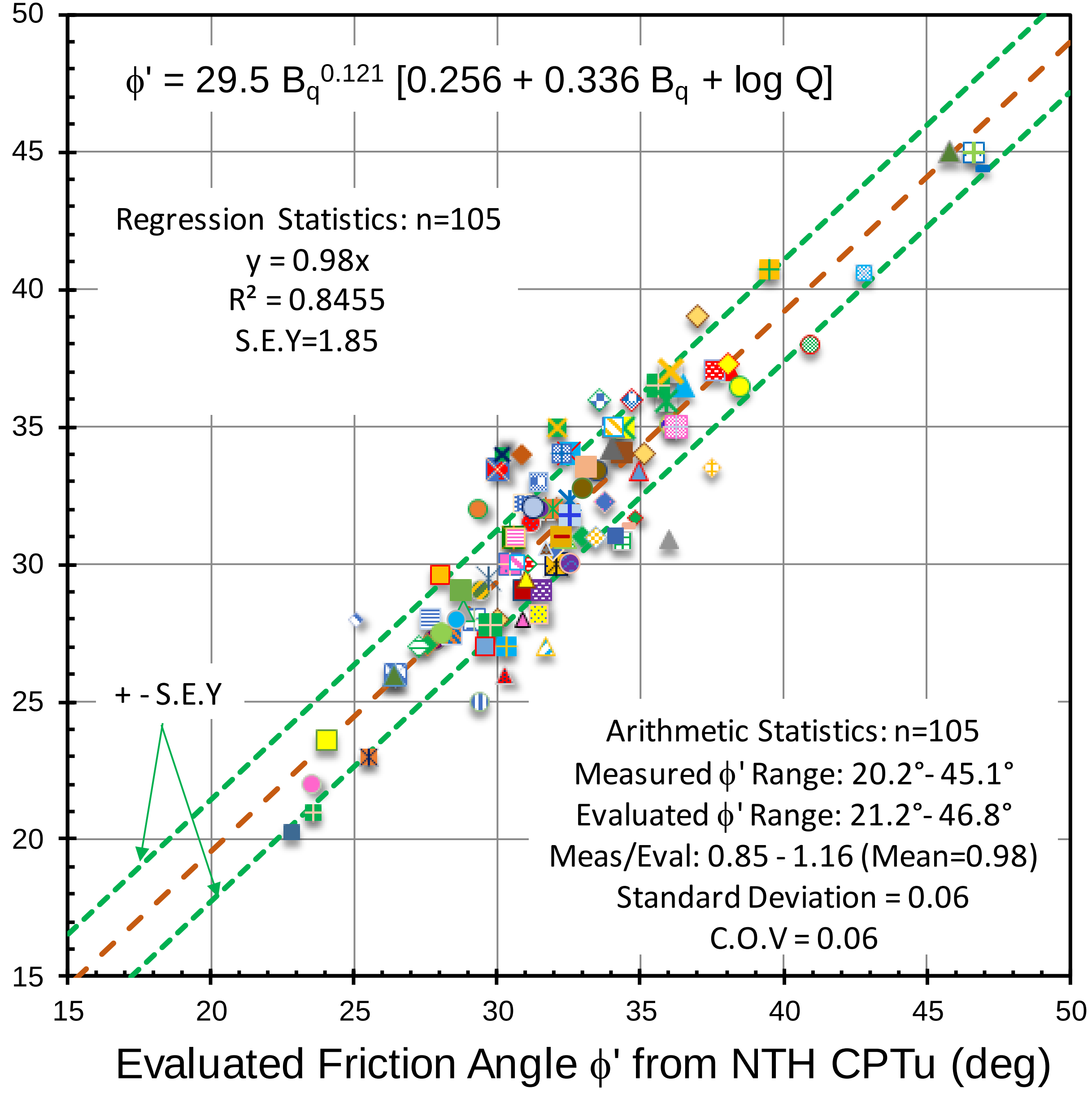
Evaluate ϕ' in Soft Chicago Clay from NTH Solution





Comparison of Triaxial ϕ’ and NTH ϕ’ from CPTu

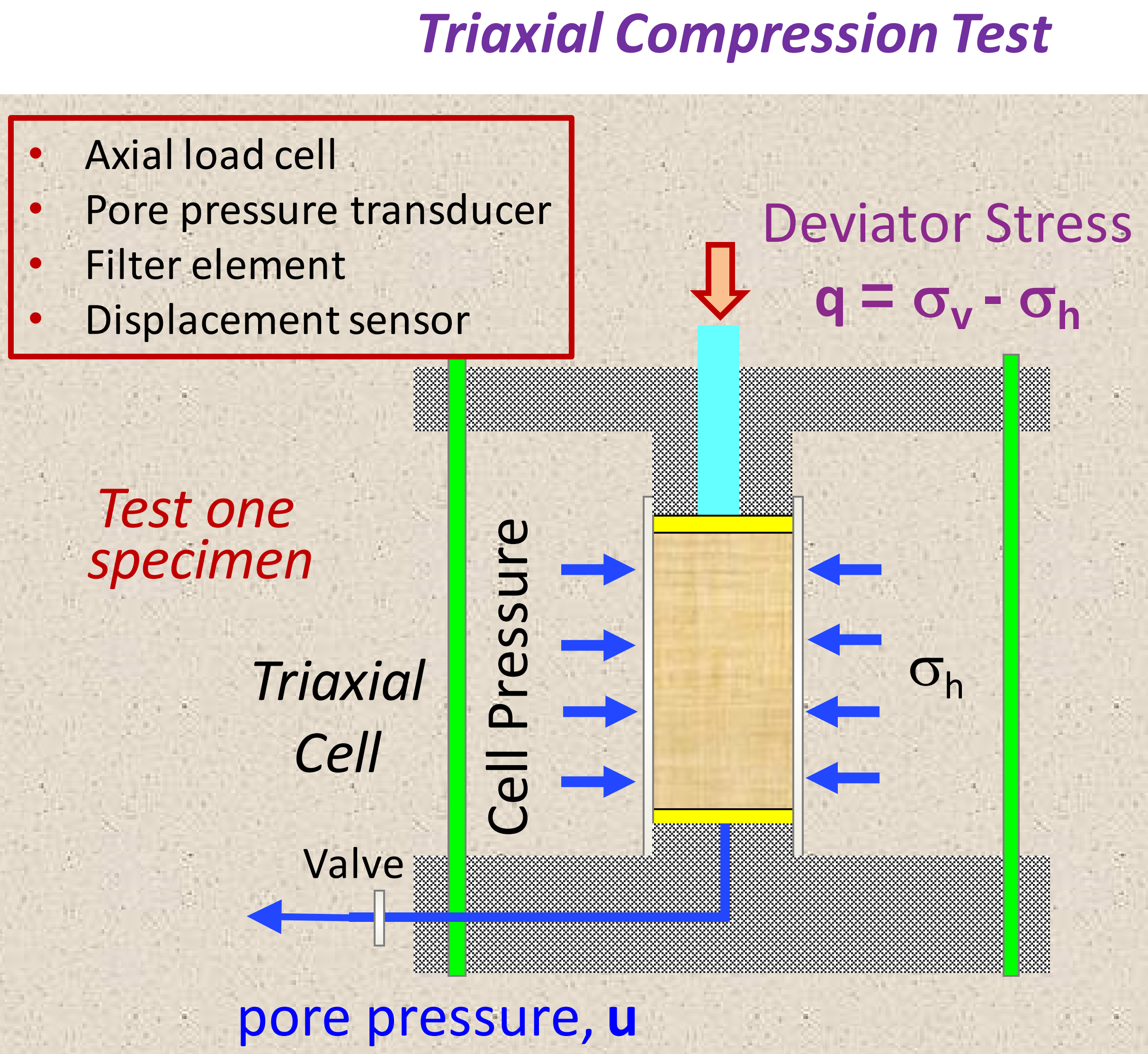
Triaxial Apparatus

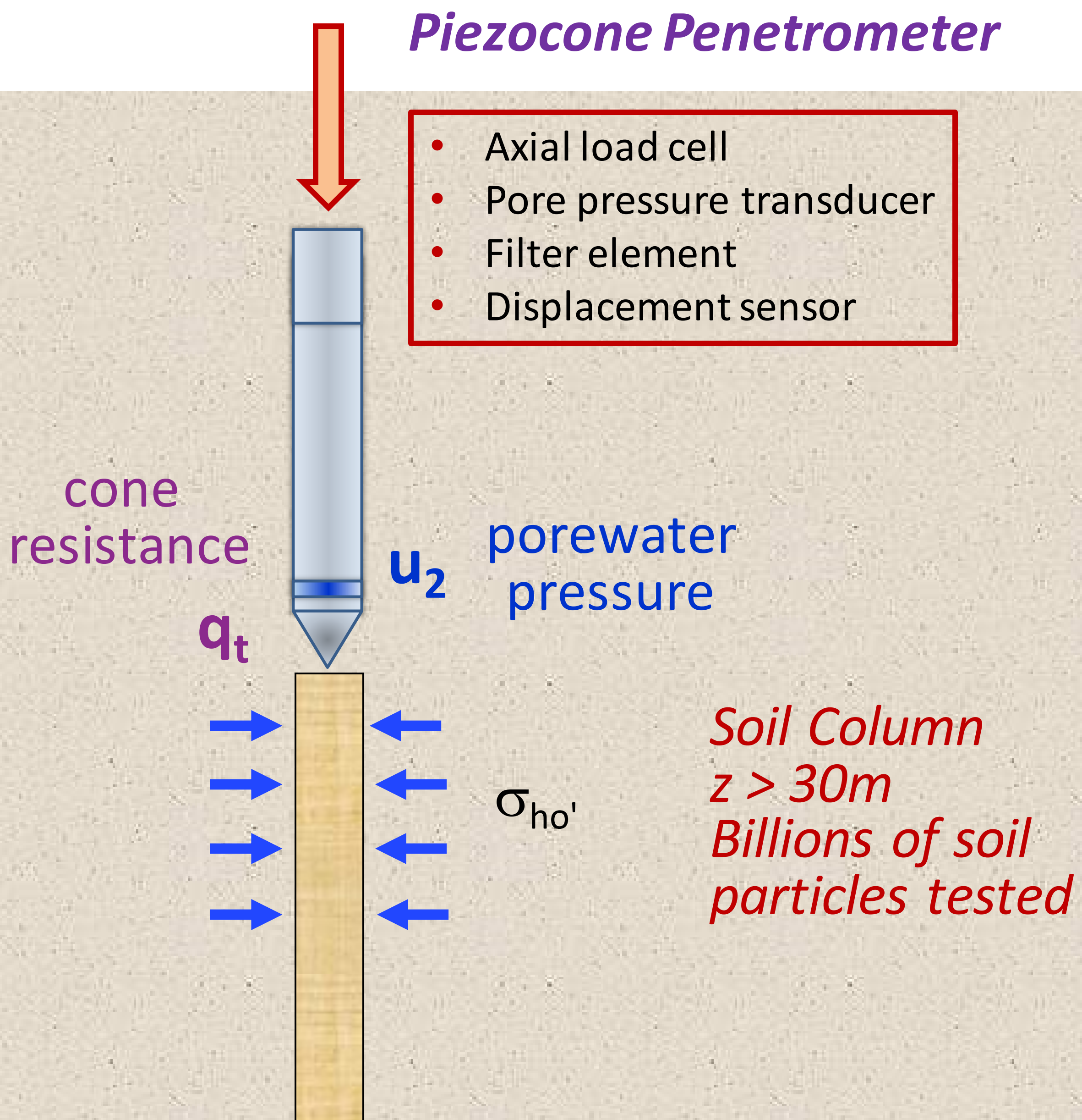


Database of 105 NC-LOC Natural Clays

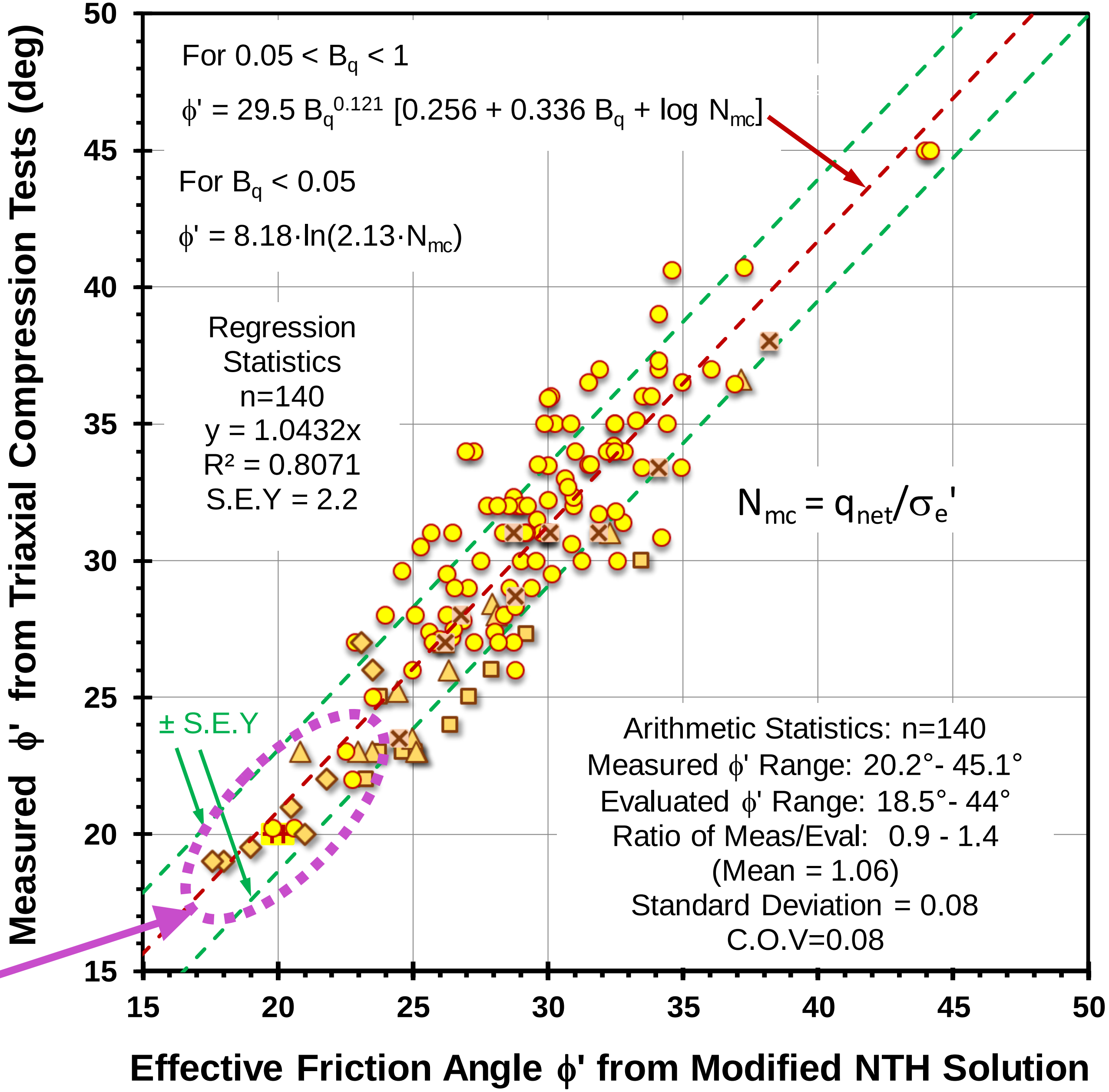
Electronic Piezocone Penetrometers

Principle of effective stress: $\sigma' = \sigma - u$ (Terzaghi 1925)





Comparison of Triaxial ϕ′ and Modified NTH ϕ′ from CPTu

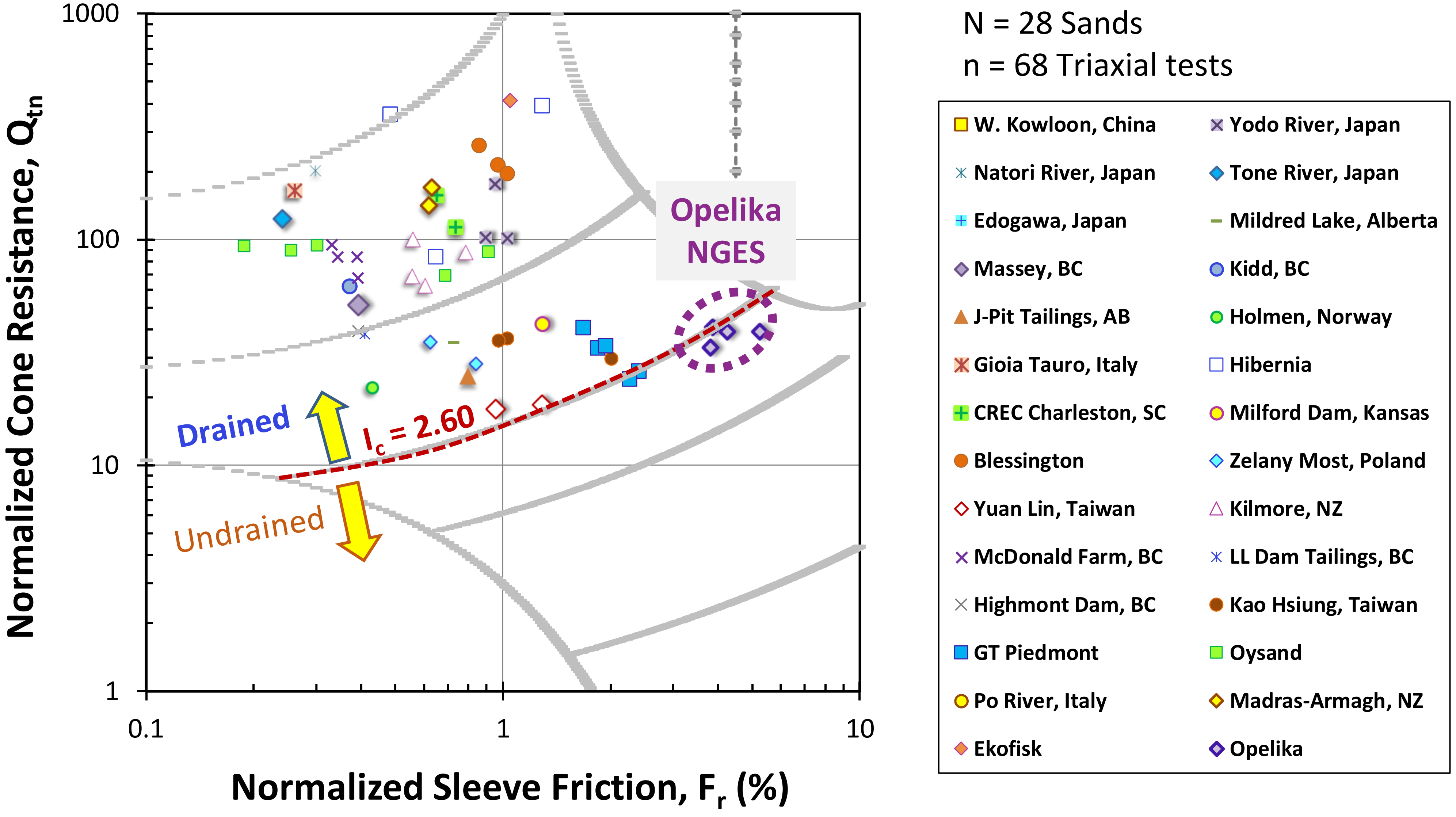


CPTU and TX Tests on 140 Clays

Low Friction Kaolin from Lab tests with ϕ' ≈ 20° to 23°

28 Undisturbed Sands to Silty Sands Database

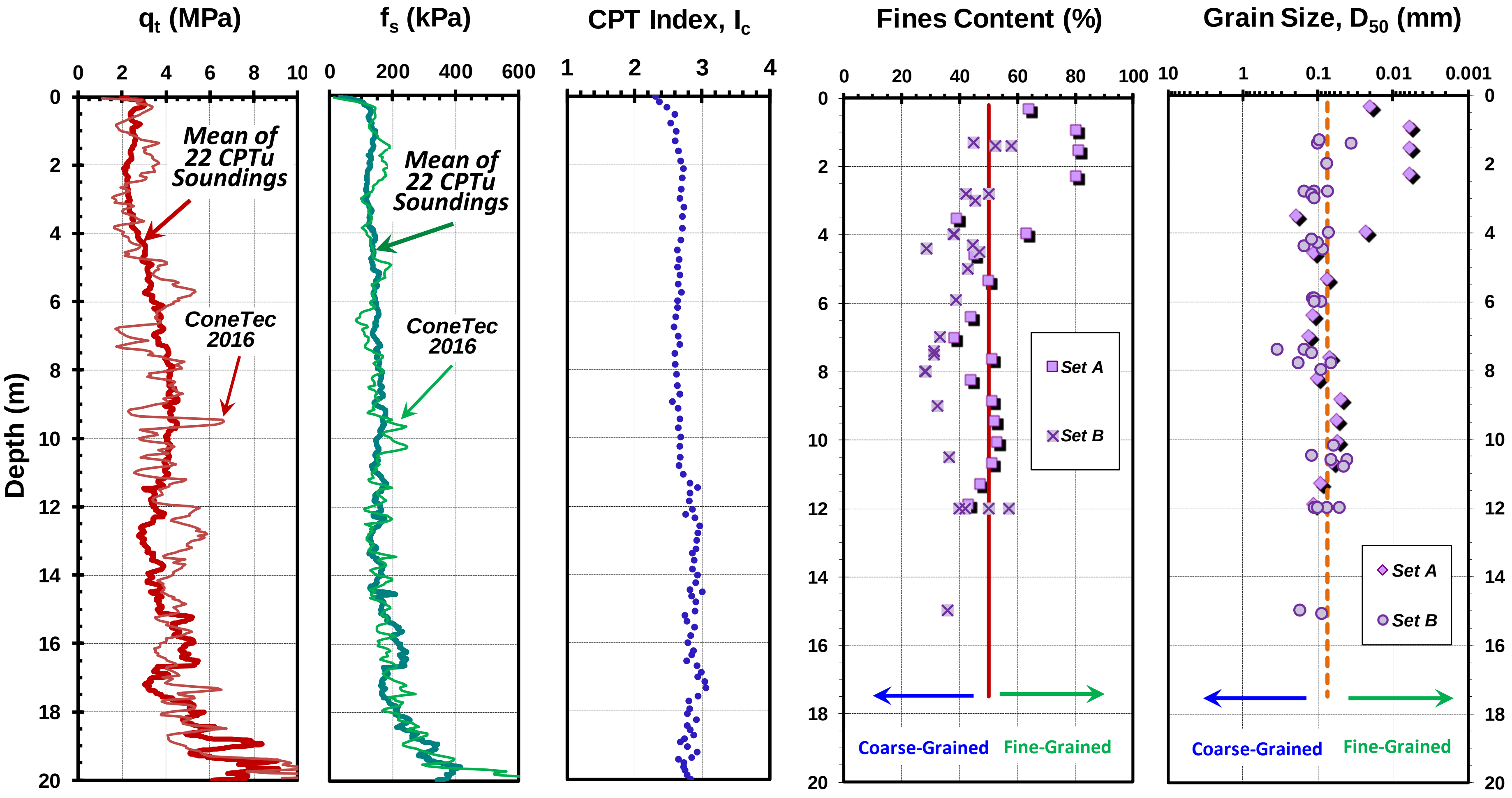
Drained Behavior: $-0.06 \leq B_q \leq +0.01$ Range (mean $B_q = -0.01$)



Opelika National Geotech Experimentation Site, Alabama

Fine sandy Silts to silty fine Sands (SM - ML)

$I_c \approx 2.60$ $FC \approx 50\%$ $D_{50} \approx 0.075$ mm



350 hectare site

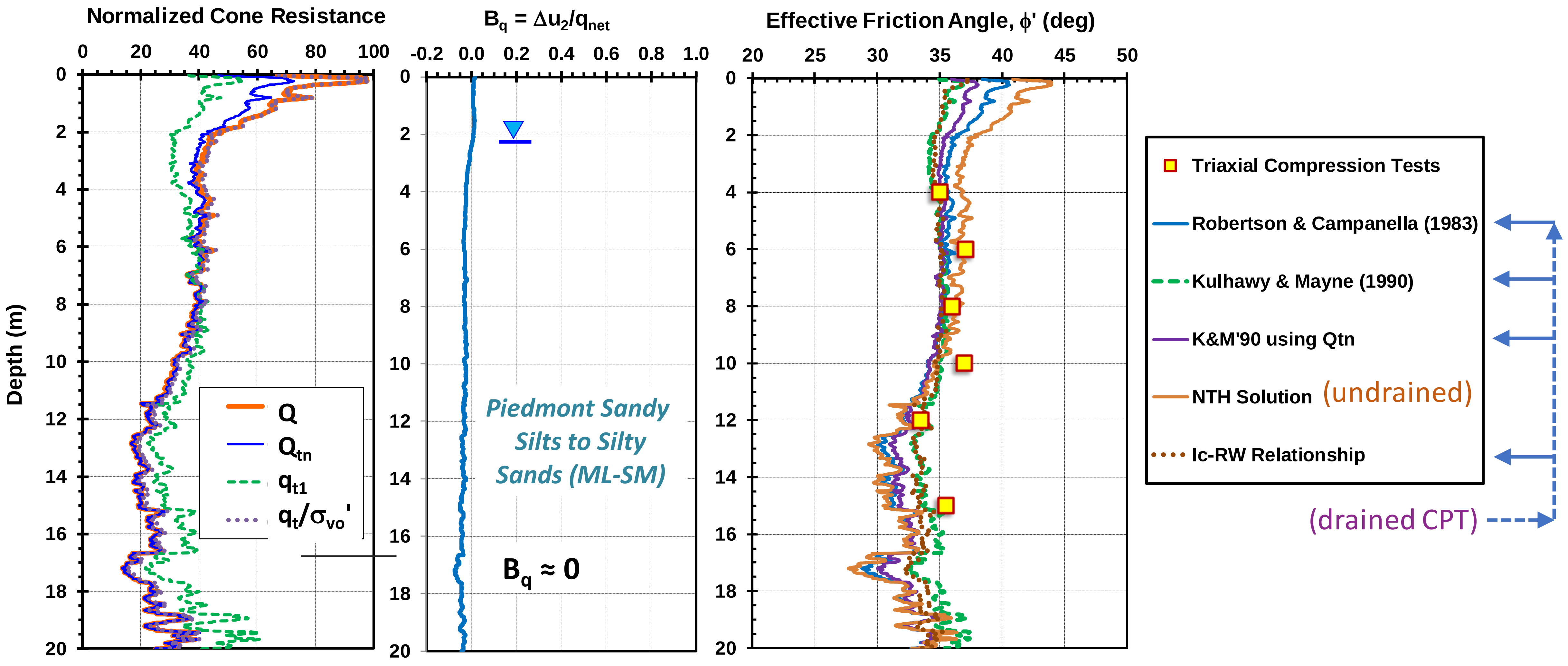
Owned by Alabama DOT

Managed by
Auburn University

- Dan Brown
- Brian Anderson
- Jack Montgomery

Opelika National Geotechnical Experimentation Site, Alabama

Fine sandy Silt to silty fine Sand (ML-SM) of the Appalachian Piedmont



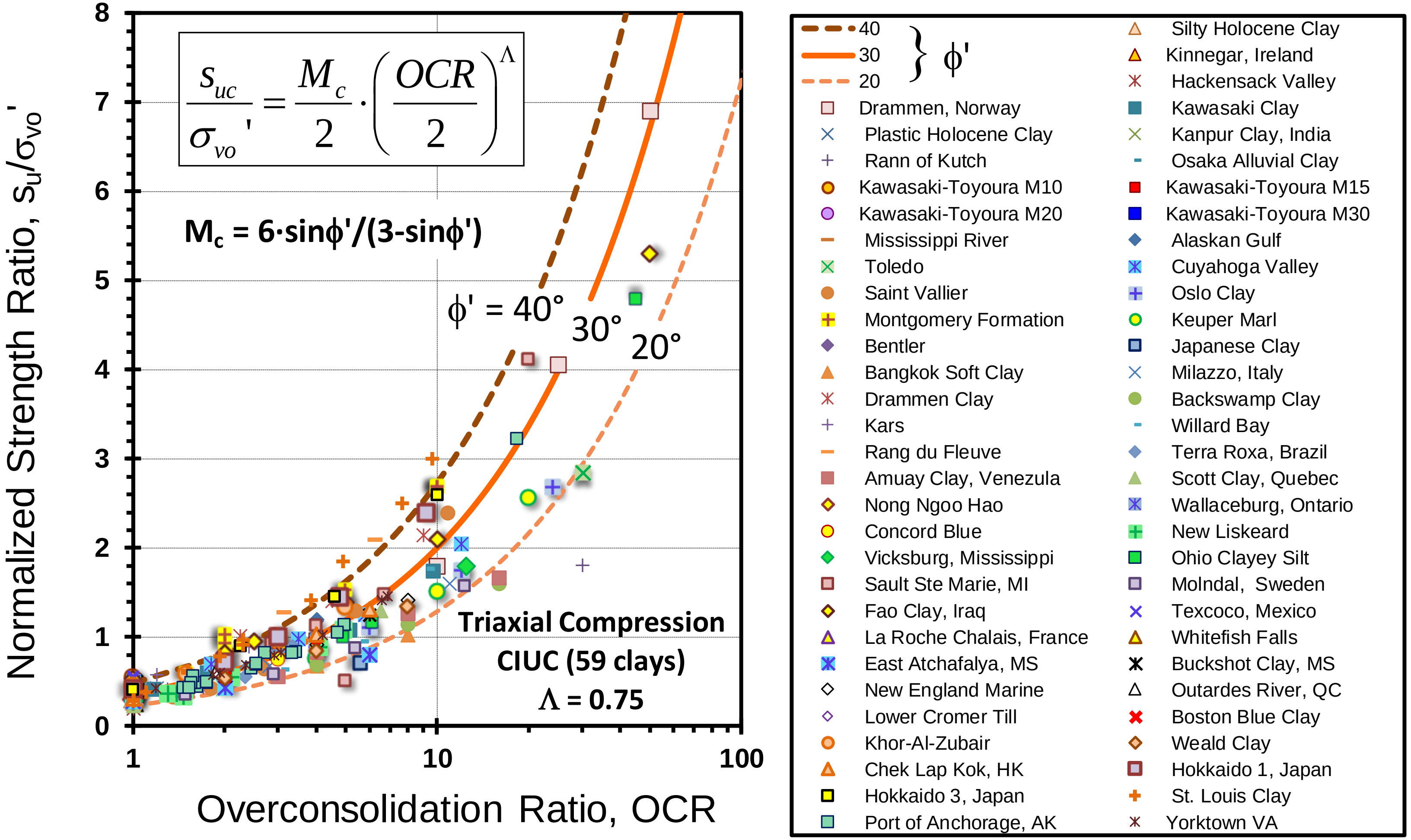
What is "Spruce Pine"
and why is it relevant to geotechnics ?

The Quartz Corporation

- Spruce Pine is the sand used in the Masters Tournaments
- Mined near Asheville, NC
- Purest quartz sand in the world (99.998% SiO_2)
- $20,000/ton (compared to $20/ton regular sand)

Cam-clay predictions of undrained strength (Mayne, JGE 1980)

- Triaxial series on clays
- Undrained shear strength, s_{uc}
- Effective friction angle, ϕ'
- Overconsolidation ratio, OCR
- Compressibility parameters
- $\Lambda \approx 1 - C_s/C_c$
- SHANSEP
- CSSM



SCE-CSSM Analytical Method for CPTu in clays

YSR = yield stress ratio = OCR

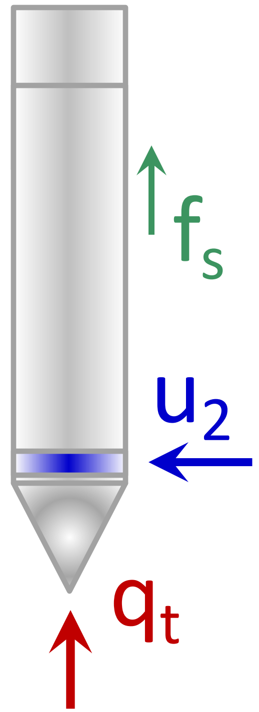
$$YSR = 2\left[\frac{(2/M_c)\cdot Q}{(4/3)(\ln I_R + 1) + \pi/2 + 1}\right]^{(1/\Lambda)}$$

$$YSR = 2\left[\frac{U - 1}{(2M_c/3)\cdot \ln(I_R) - 1}\right]^{(1/\Lambda)}$$

$$YSR = 2\cdot\left[\frac{Q_E}{1.95M_c + 1}\right]^{(1/\Lambda)}$$

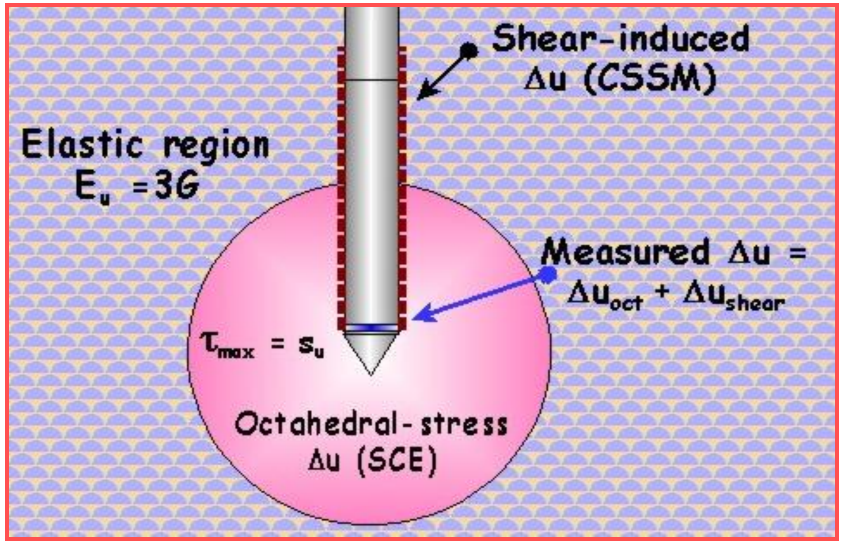
$$I_R = \exp\left[\frac{1.5/M_c + 2.925\cdot a_q}{1 - a_q}\right] \quad where\ a_q = \frac{(u_2 - \sigma_{vo})}{(q_t - \sigma_{vo})}$$

$$Vesic\ (1977):\quad s_{uc} = \frac{q_{net}}{N_{kt}} \quad where\ N_{kt} = \frac{4}{3}[\ln(I_R) + 1] + \frac{\pi}{2} + 1$$



SCE = spherical cavity expansion

CSSM = critical state soil mechanics



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

$I_R = G/s_u$ = rigidity index

$s_u = (M/2)(OCR/2)^{\Lambda}\,\sigma_{vo}'$

$\Lambda = 1 - C_s/C_c$

Soft Chicago Clay at Northwestern University

$$I_R = \exp\cdot\left(\frac{1.5 + 2.925 \cdot M_c \cdot a_q}{M_c \cdot (1 - a_q)}\right)$$

$$where \ \ a_q = \frac{(u_2 - \sigma_{vo})}{(q_t - \sigma_{vo})} = \frac{U-1}{Q}$$

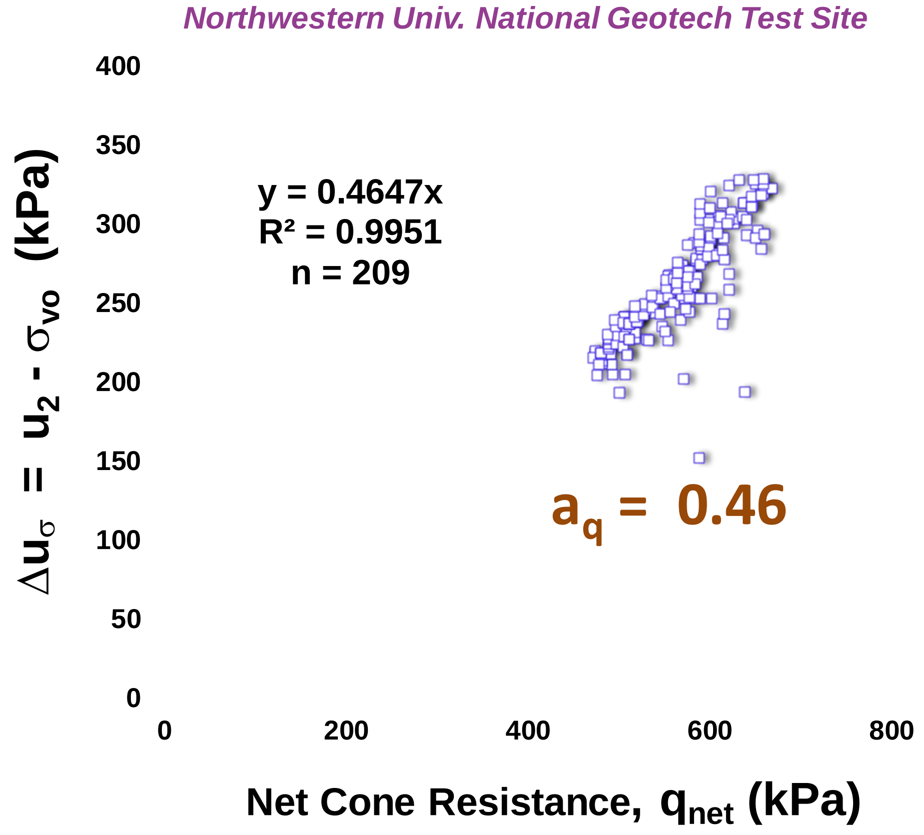
Parameter a_q = (U-1)/Q = 0.46

Effective Friction Angle, ϕ' = 28°

M_c = (6 sinϕ')/(3 - sinϕ') = 1.11

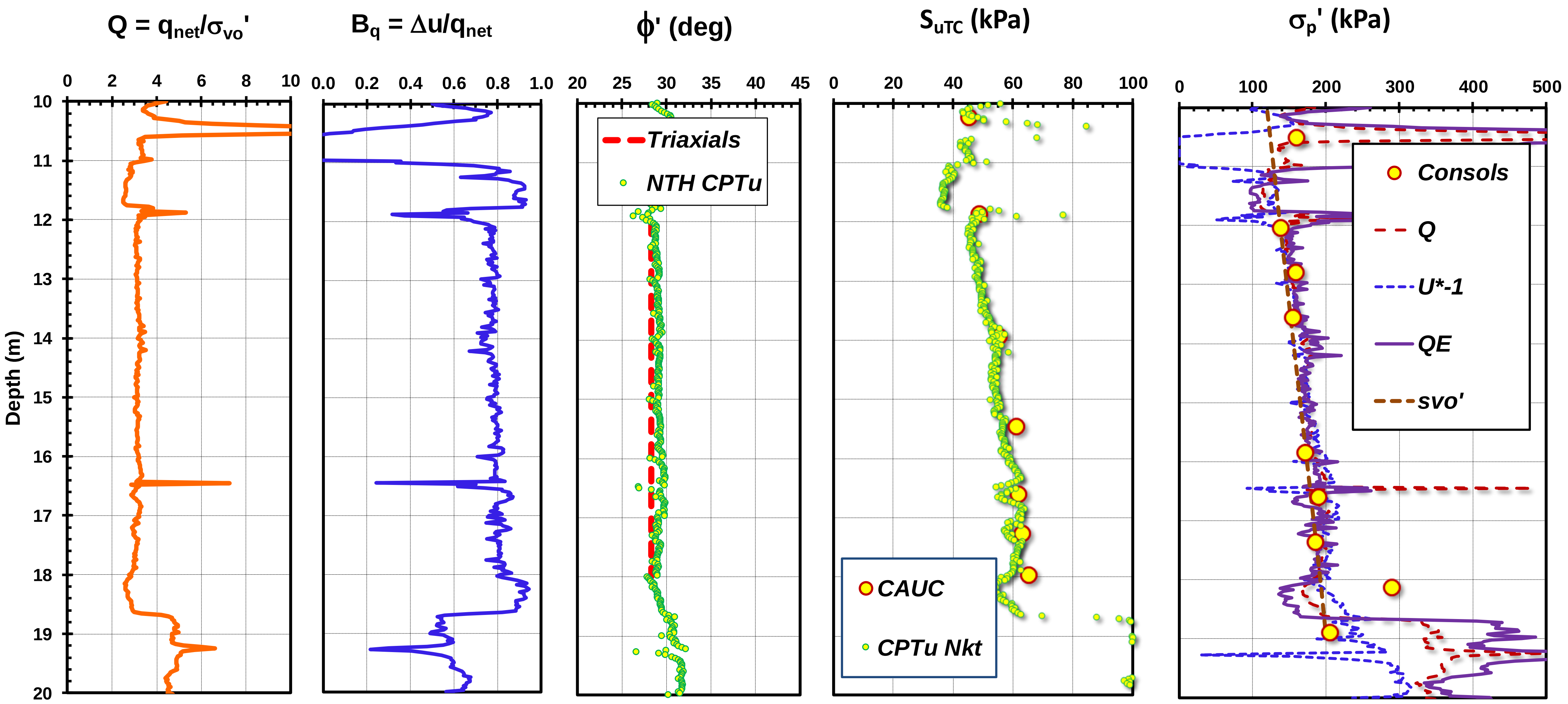
I_R = Rigidity Index = 147

N_{kt} = cone bearing factor = 10.6



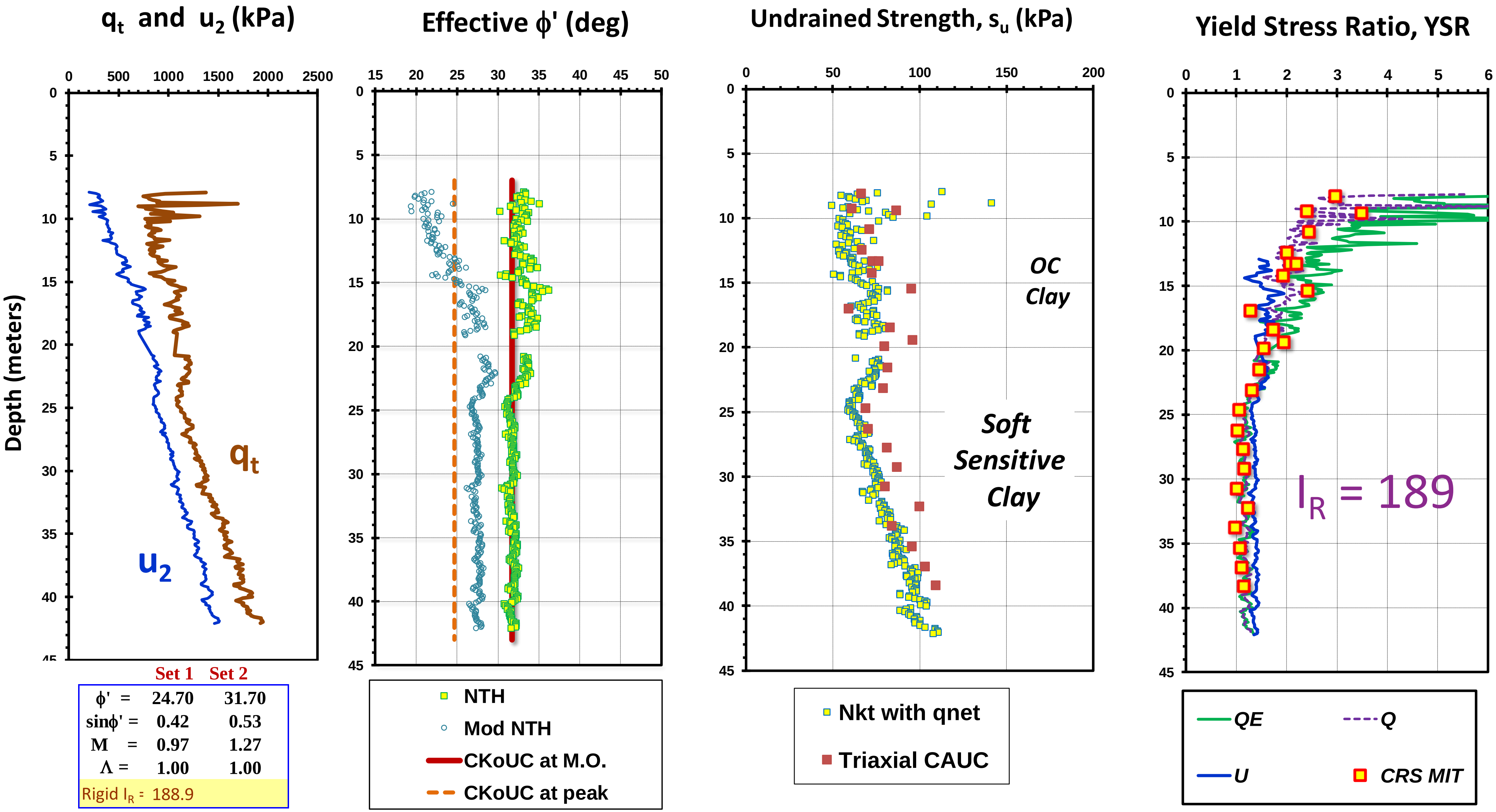
CPTU in soft Chicago clay at Northwestern Geotechnical Test Site

Parameter $a_q = 0.460$ Rigidity Index, $I_R = 147$



Boston Blue Clay, Saugus, Massachusetts

(Varner 1998; Sutabutr, et al. 2001; Whittle et al. 2001; Agaiby & Mayne 2022)



	Set 1	Set 2
ϕ' =	24.70	31.70
$\sin\phi'$ =	0.42	0.53
M =	0.97	1.27
Λ =	1.00	1.00
Rigid I_R = 188.9		

Simplified SCE-CSSM Solution for Monotonic Dissipation
(Burns 1998; Burns & Mayne 1998; Burns & Mayne 2002)

Measured time for 50% consolidation: t_{50}

SCE-CSSM Solution:

$$c_{vh} = \frac{T'_{50} \cdot (a_c)^2 \cdot (I_R)^{0.75}}{t_{50}}$$

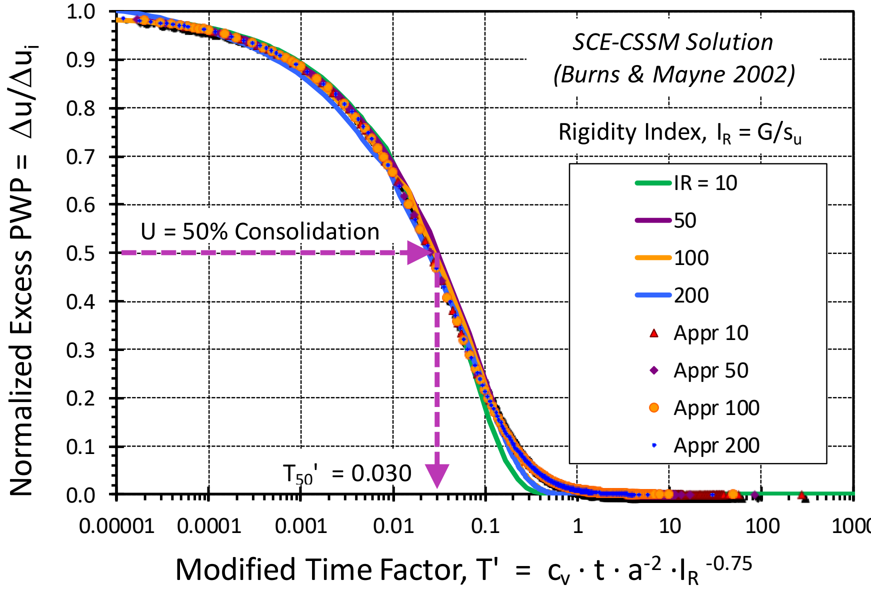
T_{50}' = 0.03 = time factor for 50% porewater dissipation

a_c = radius of penetrometer or probe or piling

I_R = undrained rigidity index of the clay

c_{vh} = coefficient of consolidation

$$\frac{\Delta u}{\Delta u_i} \approx [1-(0.13/T'+1)^{-0.45}] \cdot [1-\frac{1}{1+0.22/T'}]$$

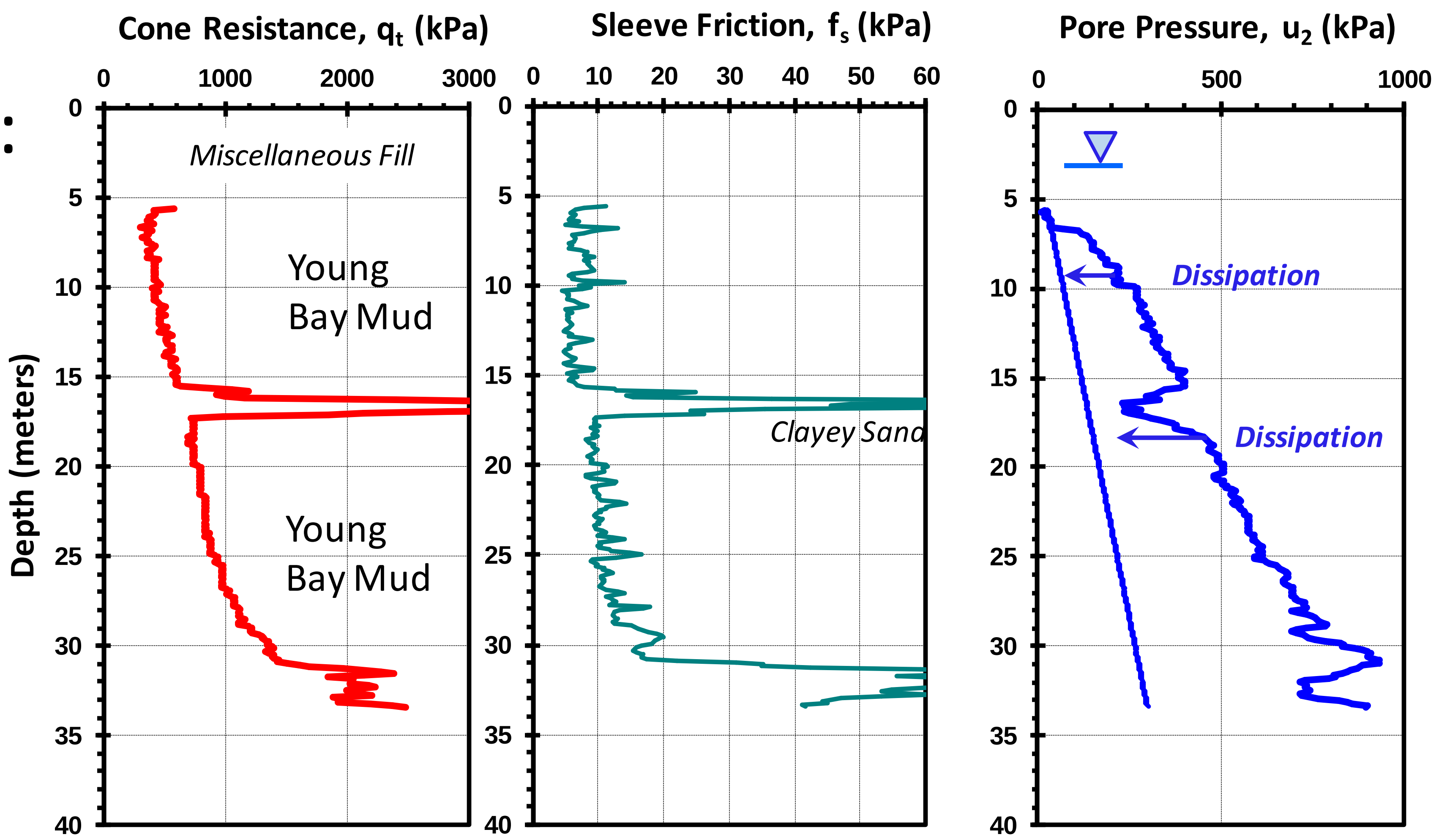


CPTU in San Francisco Bay Mud

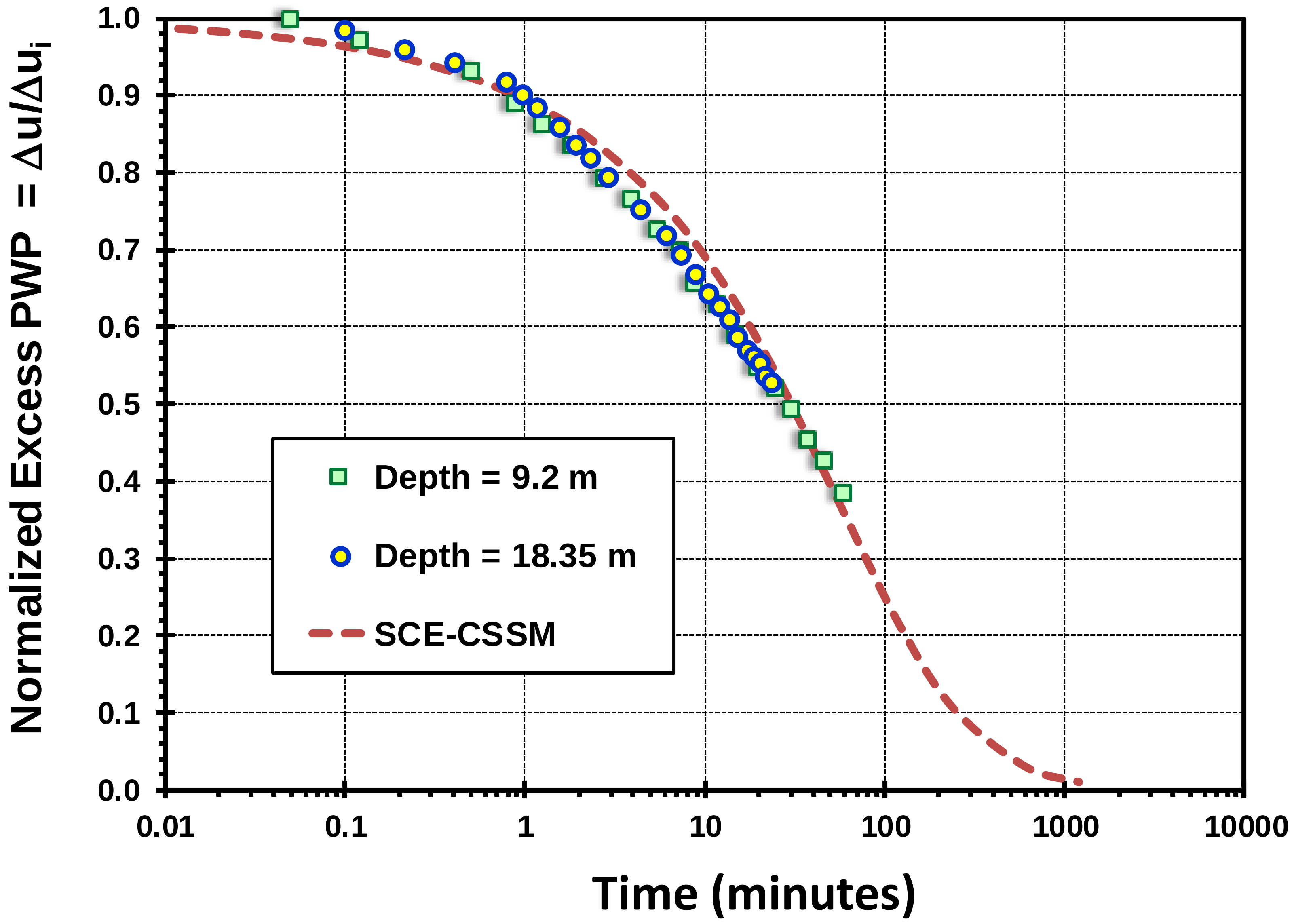
(Hunt, Pestana, and Bray 2001a, 2001b in JGGE)

CPTU Provides:

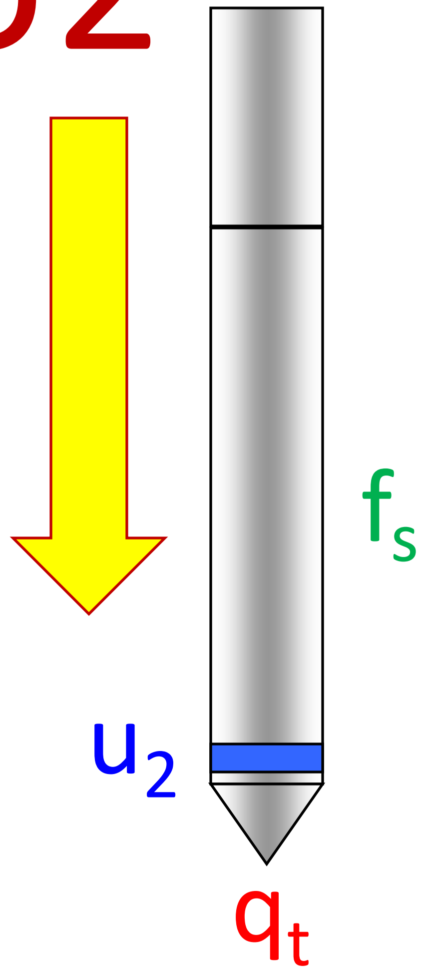
- ϕ'
- s_u
- I_R
- YSR
- c_{vh}



CPTU Dissipations in San Francisco Bay Mud



THIS U2



Professional Service

Pro Bono

Prof. Tim Stark

Geotech
And Lawyer

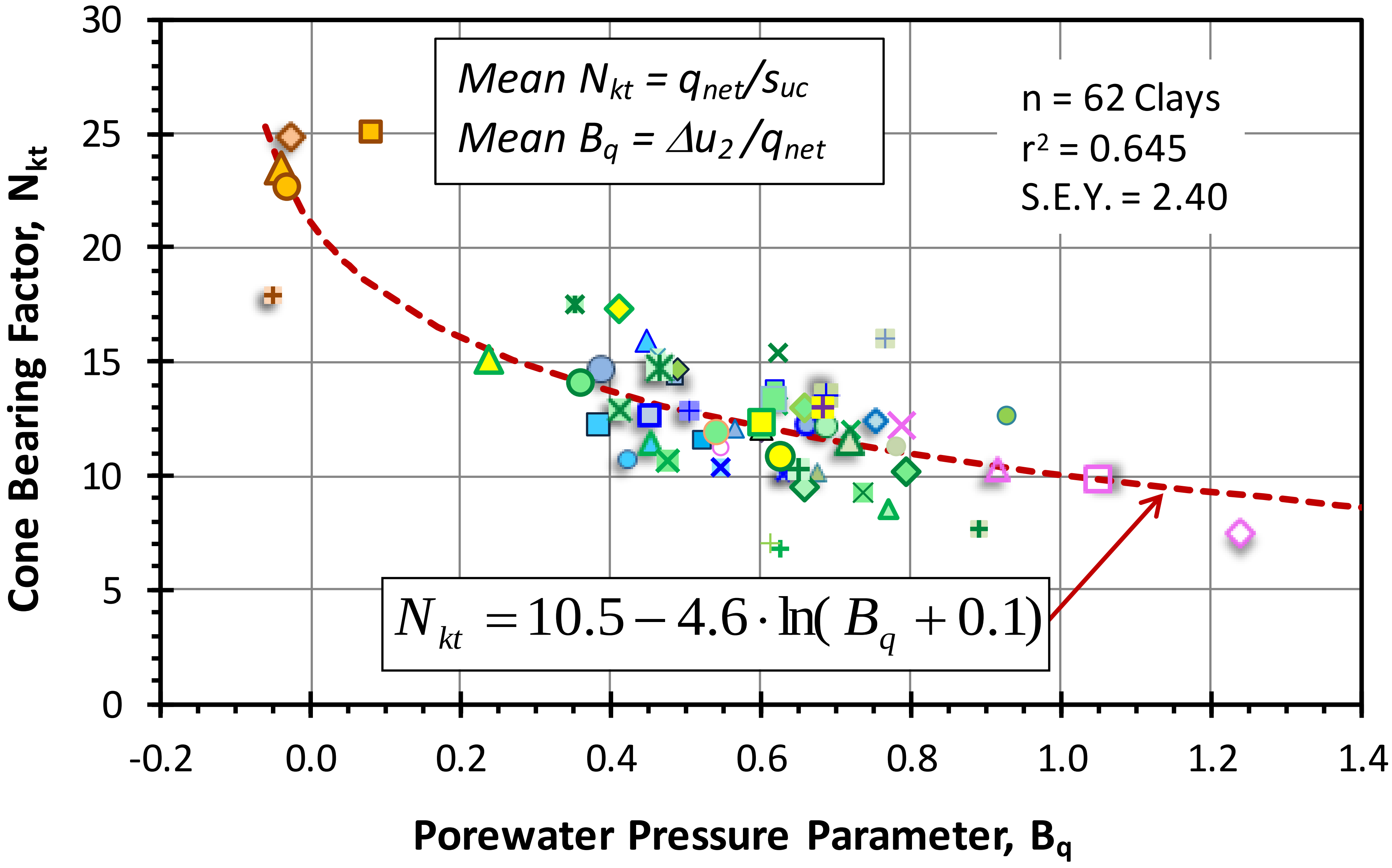
Prof. Rodrigo Salgado

Mike Jamiolkowski

James K. Mitchell

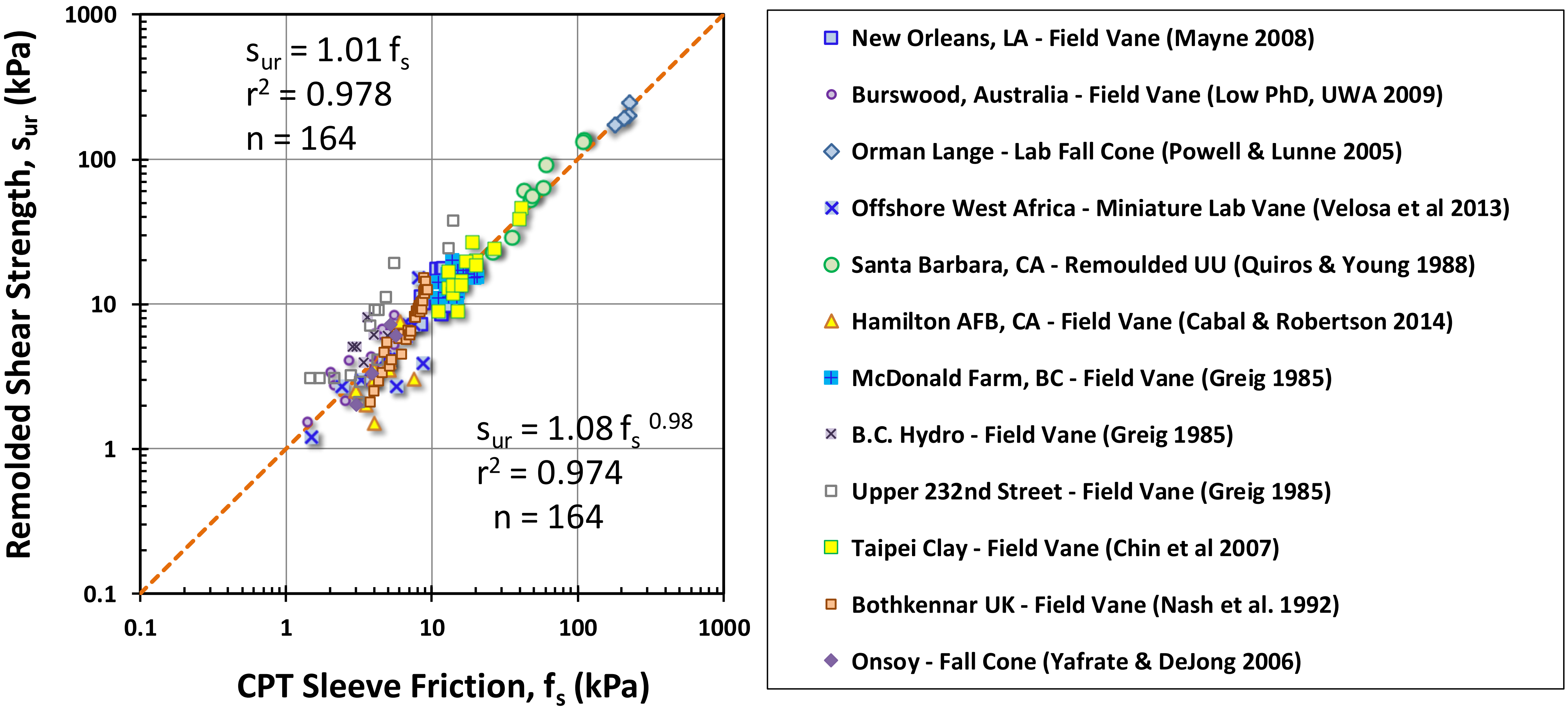
Pro Bono

Direct CPTU Method for s_u from 62 natural clays

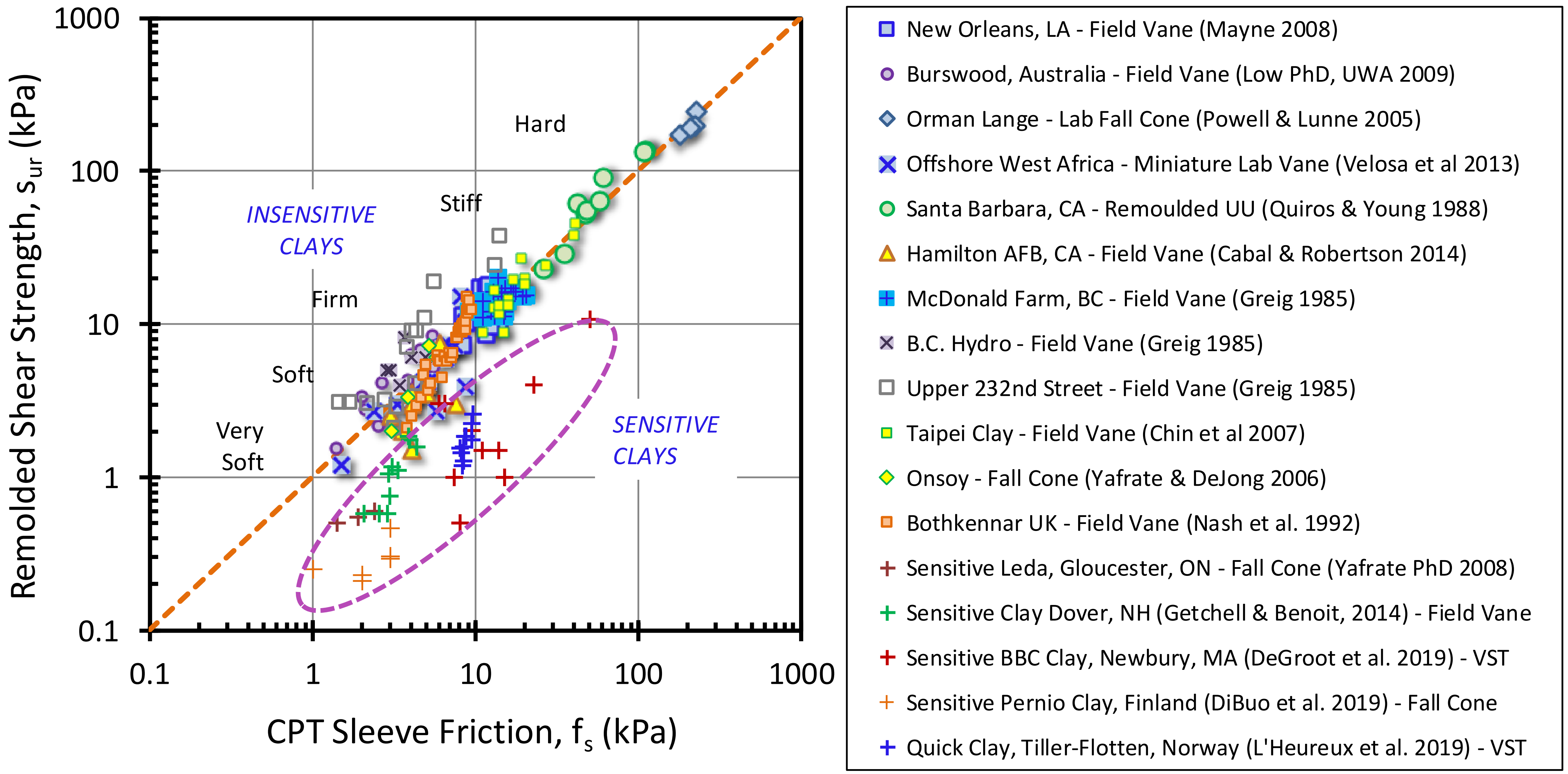


Remolded Undrained Shear Strength, s_{ur}

Dataset: s_{ur} and f_s for 12 Clays of low-medium sensitivity: $S_t < 10$

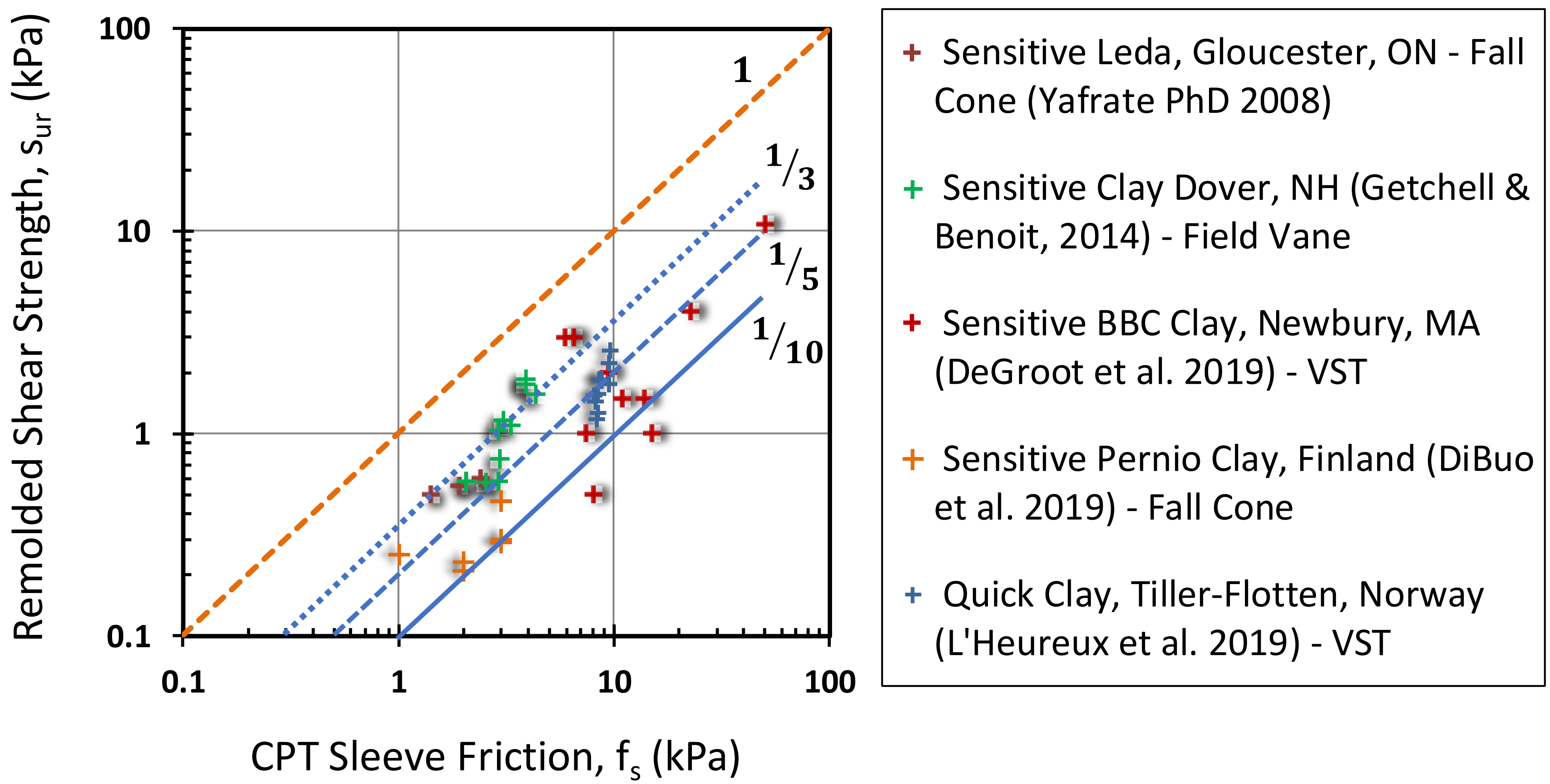


Remolded Undrained Shear Strength, s_{ur}



Remolded Undrained Shear Strength, s_{ur}

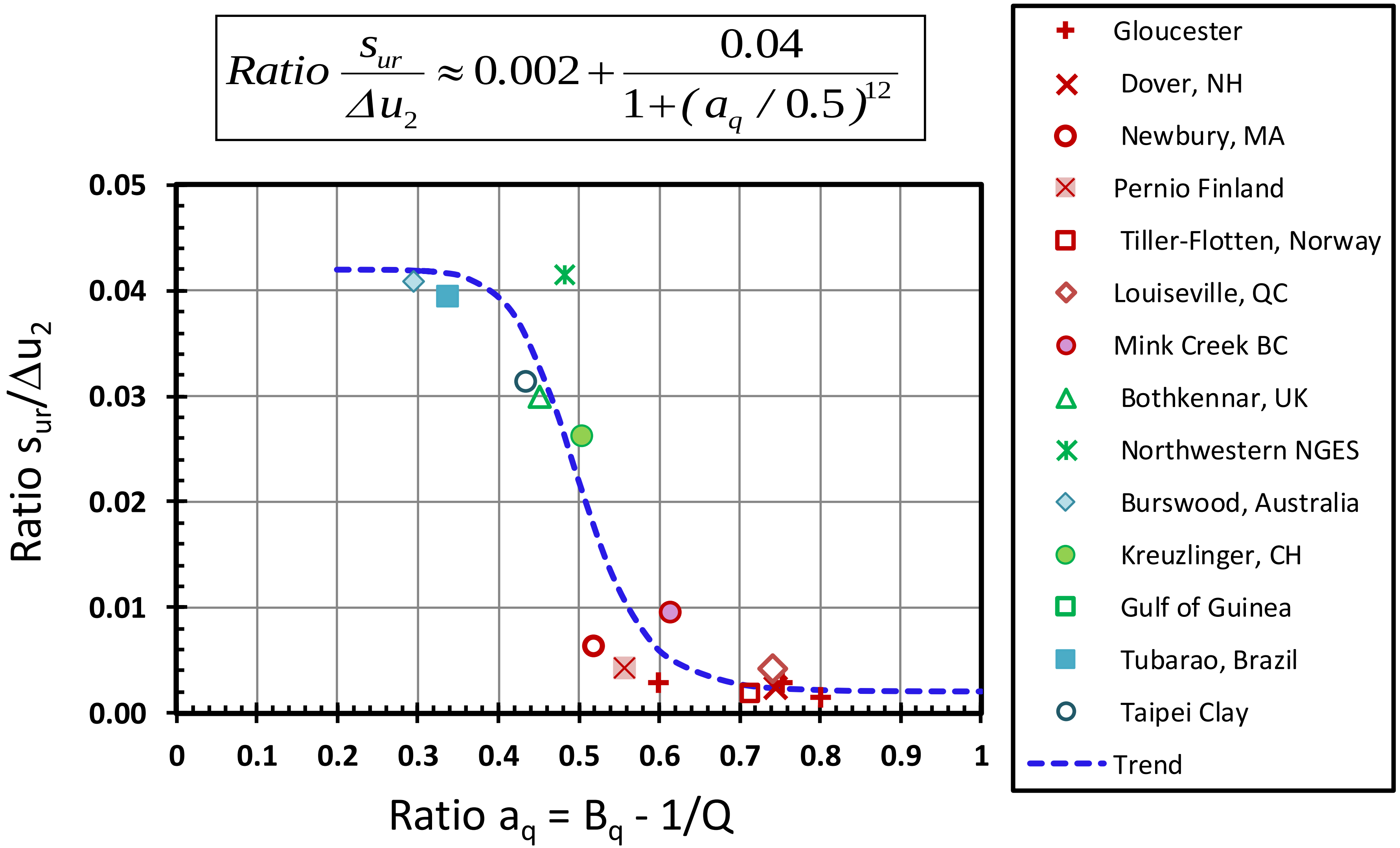
Dataset: s_{ur} and f_s for 5 Clays of high sensitivity: $S_t > 10$



Remolded Undrained Shear Strength, s_{ur}

New VST-CPTU database from 14 natural clays

$$Ratio\ \frac{s_{ur}}{\Delta u_2} \approx 0.002 + \frac{0.04}{1+(a_q/0.5)^{12}}$$



7 highly sensitive to quick clays ($15 < S_t < 100+$)

7 clays of low-medium sensitivity ($2 < S_t < 8$)

What famous geo-song did the

artist Sting perform?

Sting: You Don't Have to Put on the Red….

Simplified SCE-CSSM Solution for CPTU in Clays

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

For $\Lambda = 1 - C_s/C_c = 1$

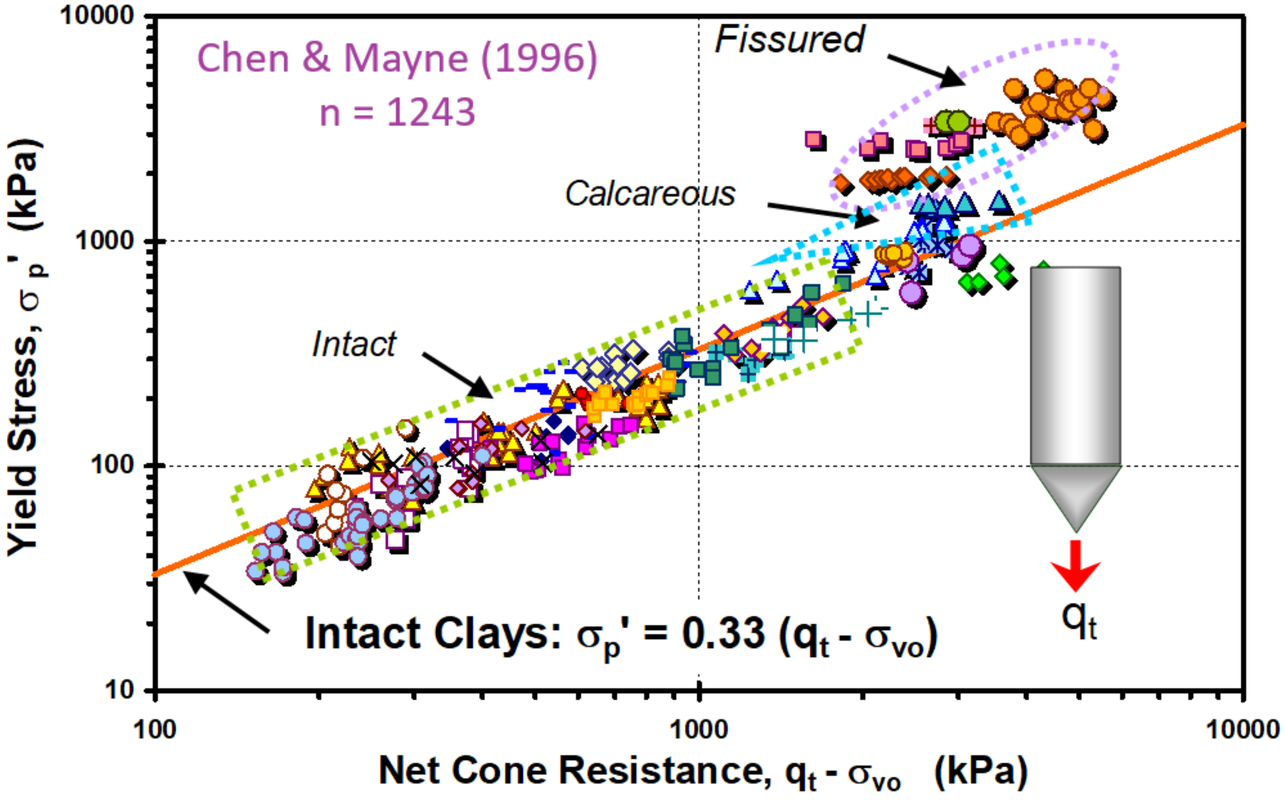
$$\sigma_P' = \frac{(q_t - \sigma_{vo})}{M \cdot [1 + \frac{1}{3}\ln(I_R)]}$$

$\phi' = 30^o$

$I_R = G/s_u = 100$

$$\sigma_P' = 0.33 \cdot (q_t - \sigma_{vo})$$

First-Order Approximation



Evaluating Yield Stresses in Sands by CPT

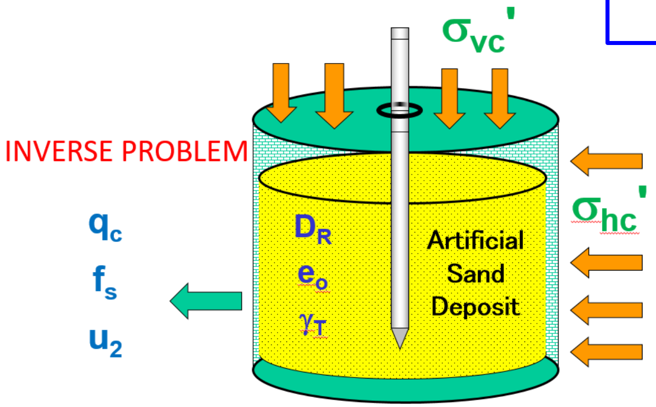
Calibration Chamber Data

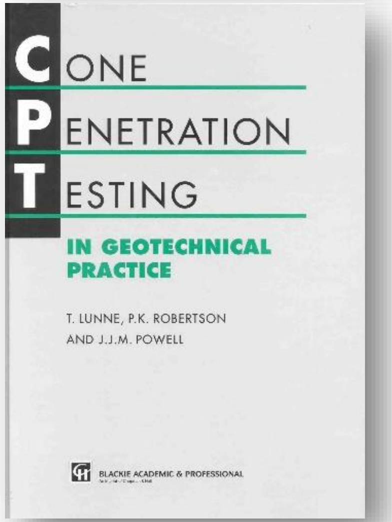
Oxford University

Virginia Tech

- Flexible Wall Chambers
- Essentially large triaxial test
- 706 tests from 26 sands

$$YSR = \left[\frac{0.192 \cdot (q_{net}/\sigma_{atm})^{0.22}}{(1-\sin\phi') \cdot (\sigma_{vo}'/\sigma_{atm})^{0.31}} \right]^{\frac{1}{\sin\phi' - 0.27}}$$





Generalized yield stress evaluation from CPT

26 SANDS (n = 706 chamber tests)

$$YSR = \left[\frac{0.192 \cdot (q_{net}/\sigma_{atm})^{0.22}}{(1-\sin\varphi') \cdot (\sigma_{vo}'/\sigma_{atm})^{0.31}}\right]^{\frac{1}{\sin\varphi' - 0.27}}$$

where σ_{atm} = atmospheric pressure (1 atm ≈ 1 bar = 100 kPa).

$$YSR \approx \left[\frac{(q_{net}/\sigma_{atm})^{0.72}}{13.8 \cdot (\sigma_{vo}'/\sigma_{atm})^{1.02}}\right]$$

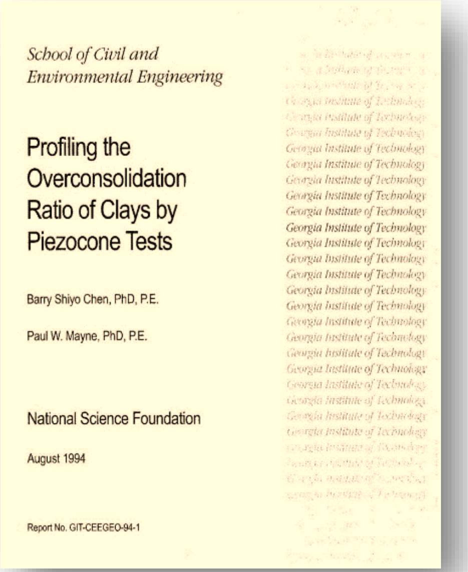
For ϕ' = 35°

$$\sigma_p' \approx 0.32 \cdot (q_{net})^{0.72}$$

First-Order Approximation

Units of kPa

206 CLAY SITES (n = 1234)


School of Civil and Environmental Engineering

Profiling the Overconsolidation Ratio of Clays by Piezocone Tests

Barry Shiyo Chen, PhD, P.E.

Paul W. Mayne, PhD, P.E.

National Science Foundation

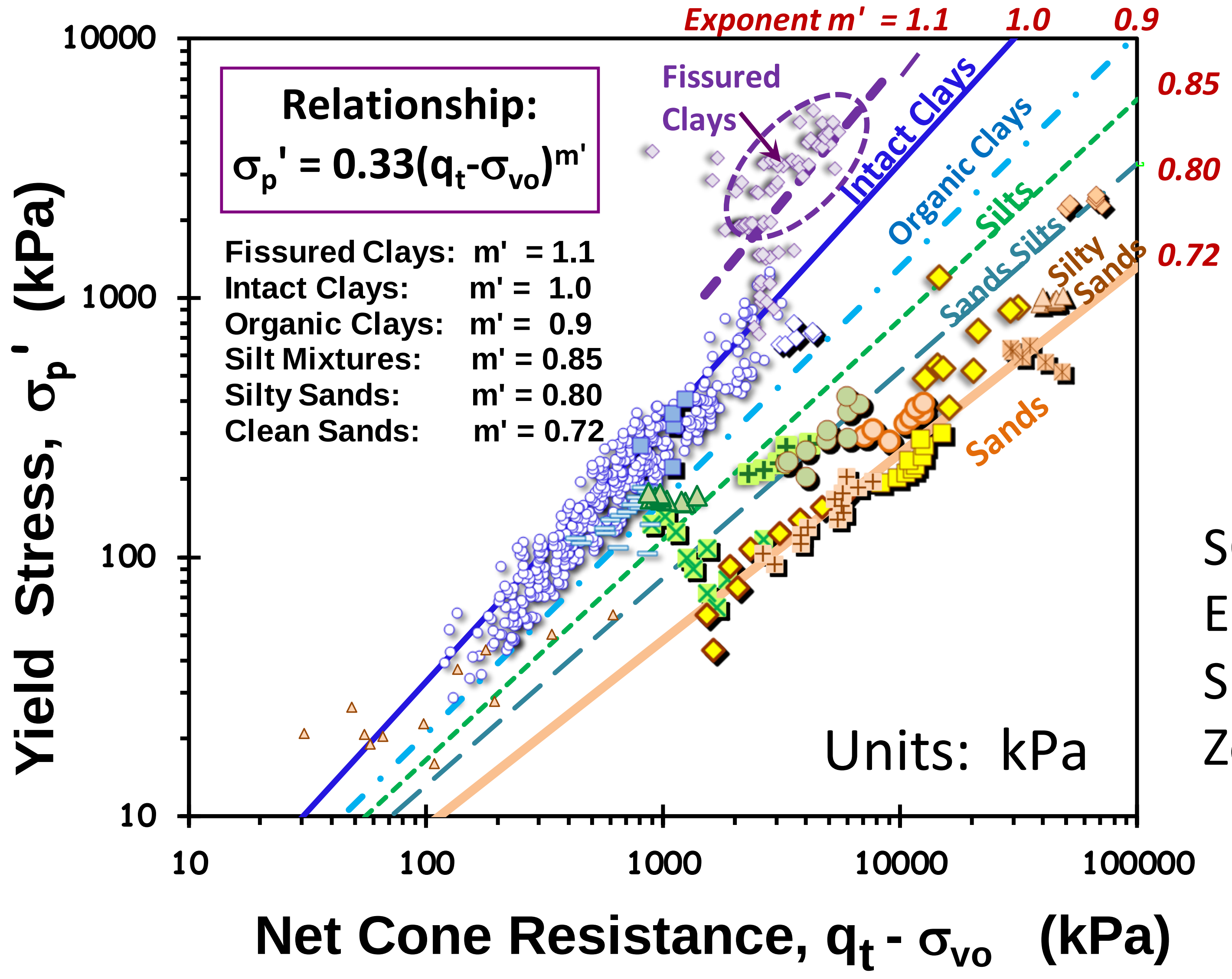
August 1994

Report No. GIT-CEEGEO-94-1

$$\sigma_p' \approx 0.33 \cdot (q_{net})$$

$$\sigma_p'(kPa) = 0.33 \cdot (q_t - \sigma_{vo})^{m'}$$

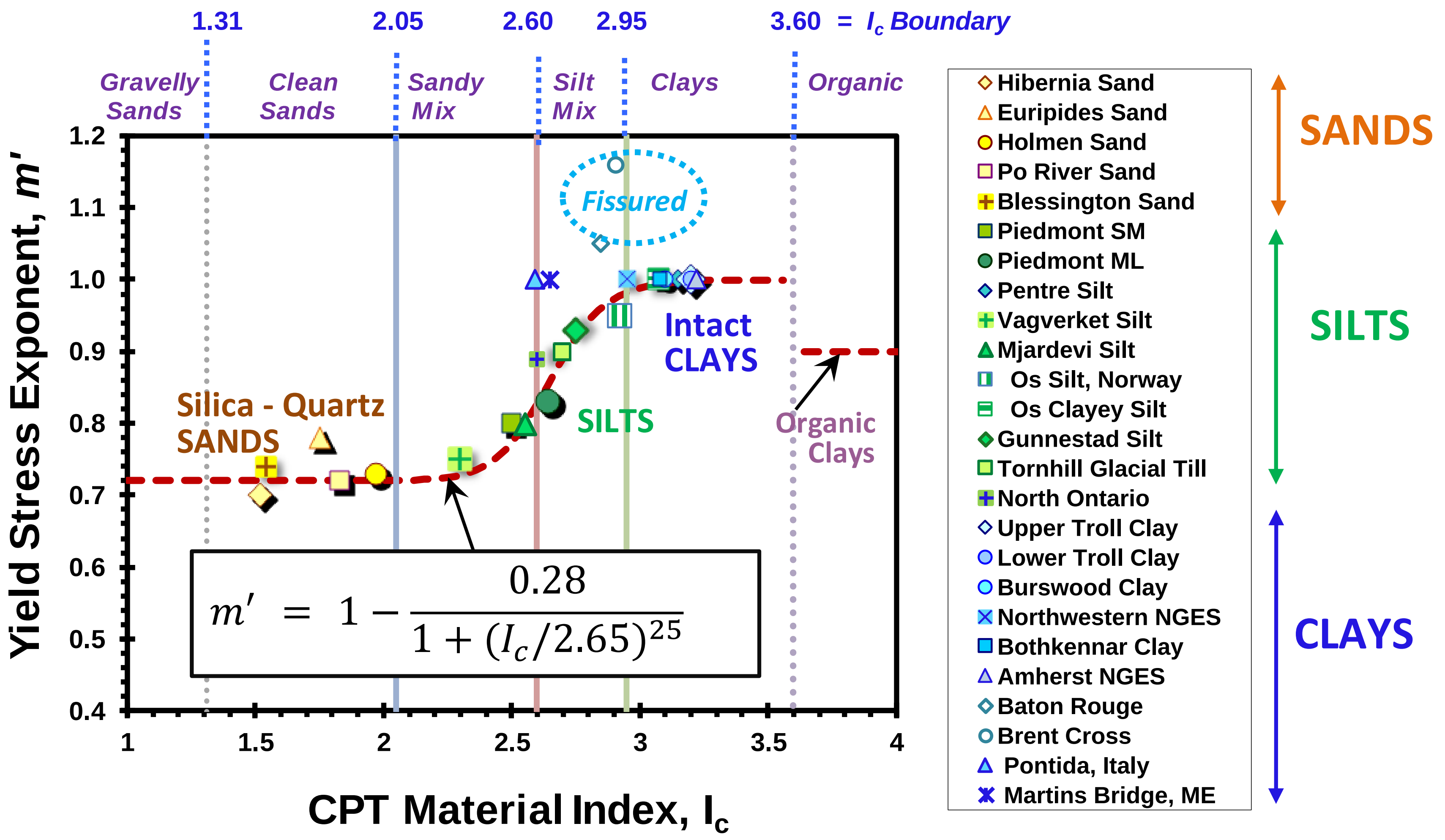
Generalized yield stress evaluation from CPT



SOA-1 at ICSMGE (2009, Egypt): Mayne, Coop, Springman, Huang, and Zornberg

Trend of Exponent m' with CPT Material Index, I_c

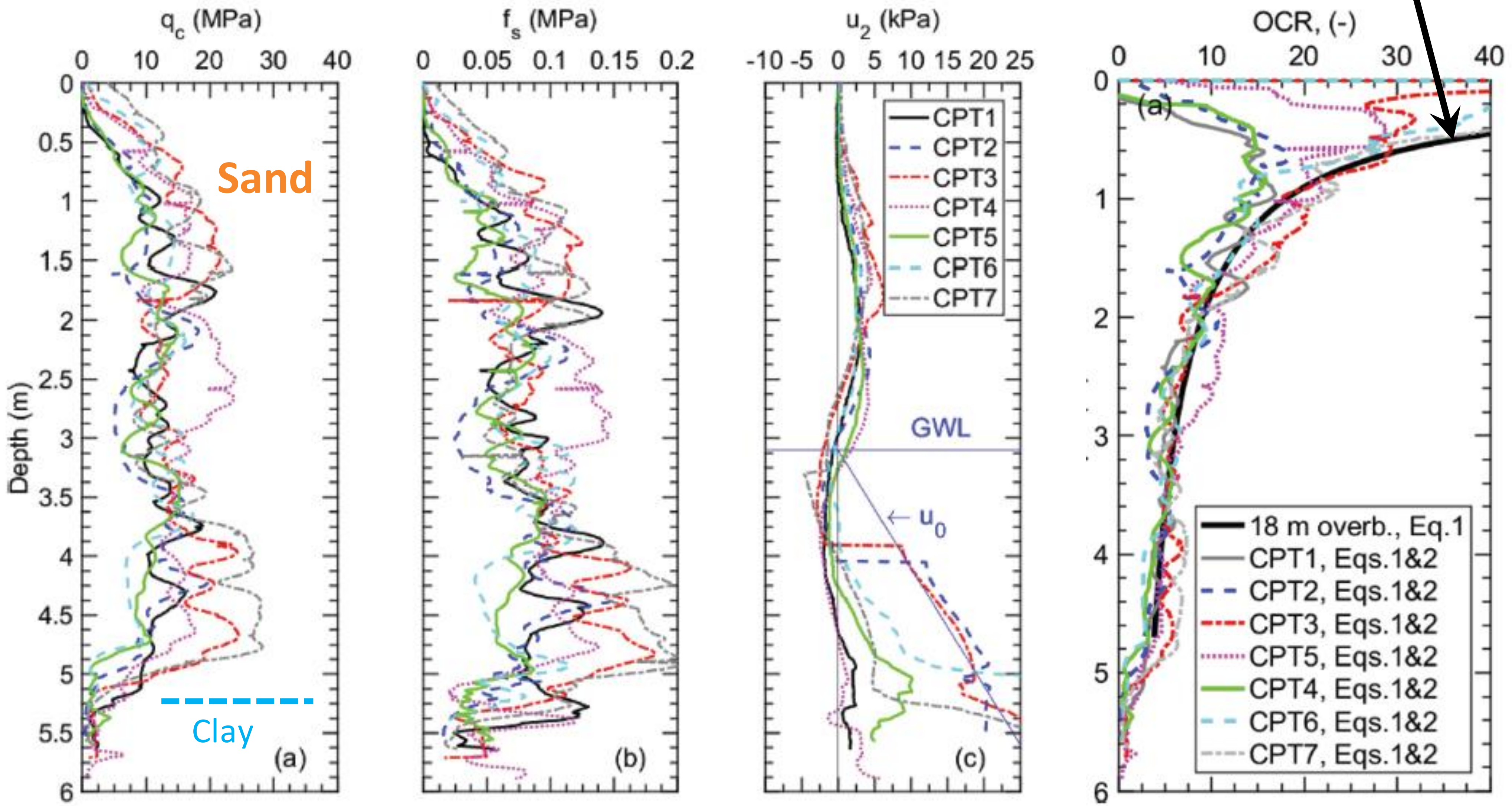
$$\sigma_p' = 0.33 \cdot (q_t - \sigma_{vo})^{m'} \cdot (\sigma_{atm}/100)^{1-m'}$$



OC Sand at Cuxhaven, Germany

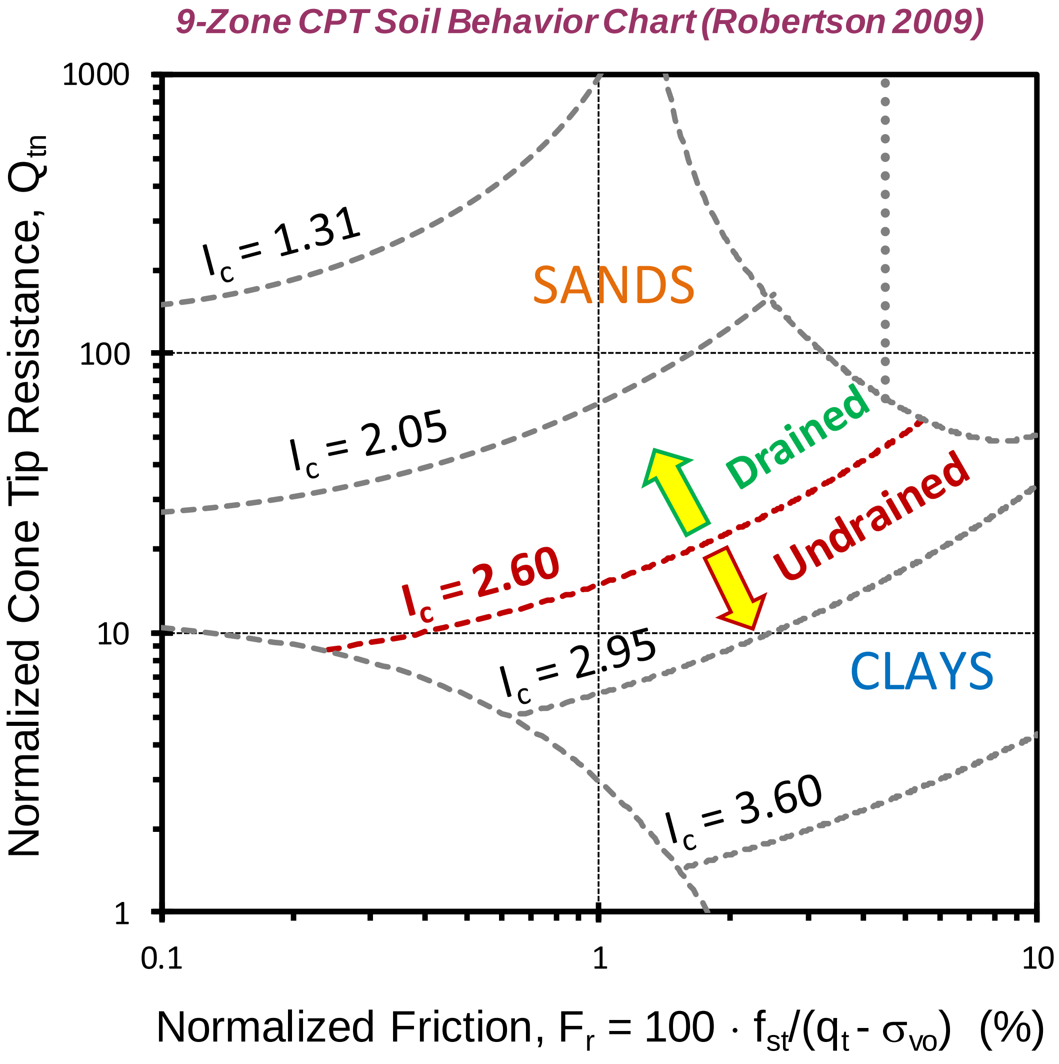
(Quinteros, Lunne, Krogh, et al. CPT'18)

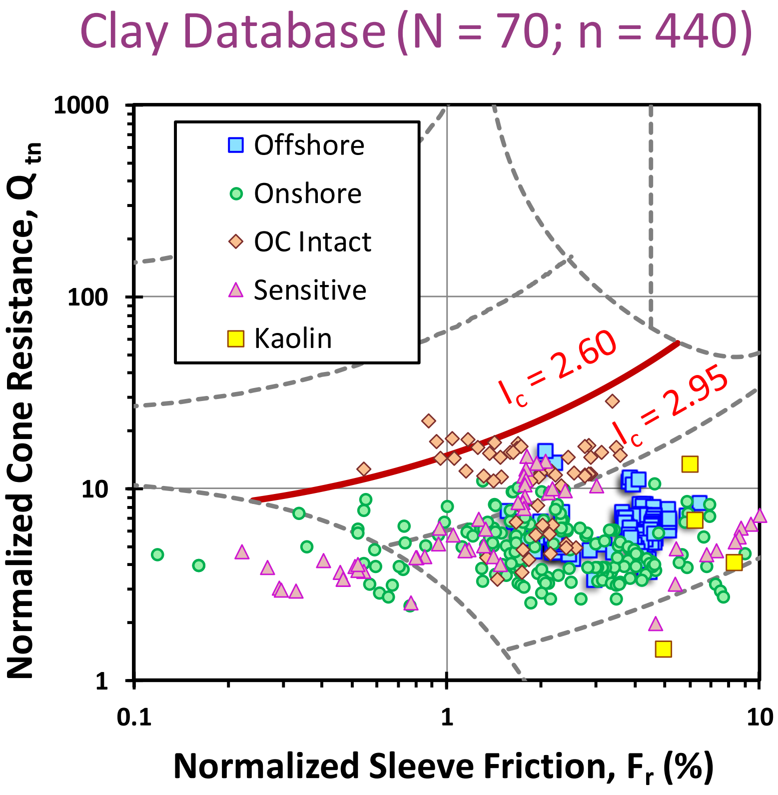
Calculated OCR due to 18 m of overburden removal



Undrained-Drained Threshold on Q_{tn}-F_r Chart (Robertson 2009)

Conventional Definition: Undrained when $I_c > 2.60$; Drained when $I_c < 2.60$



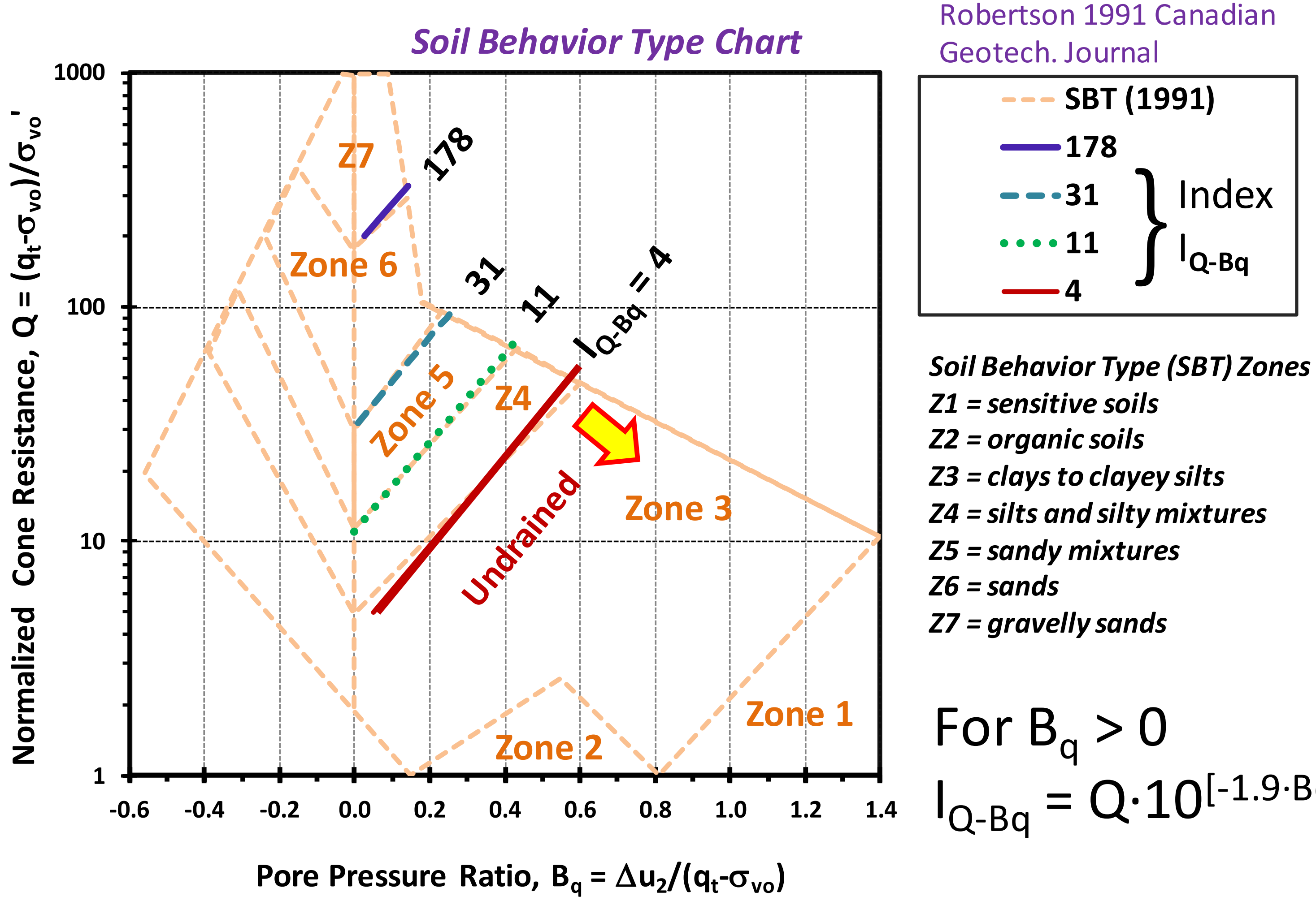


Defining undrained behavior on Q – B_q Chart

Index defined by Torrez-Cruz (2015 PCSMGE, Buenos Aires)

Undrained when $I_{Q\text{-}Bq} < 4$

$$I_{Q-Bq} = Q \cdot 10^{(-1.9\,B_q)}$$



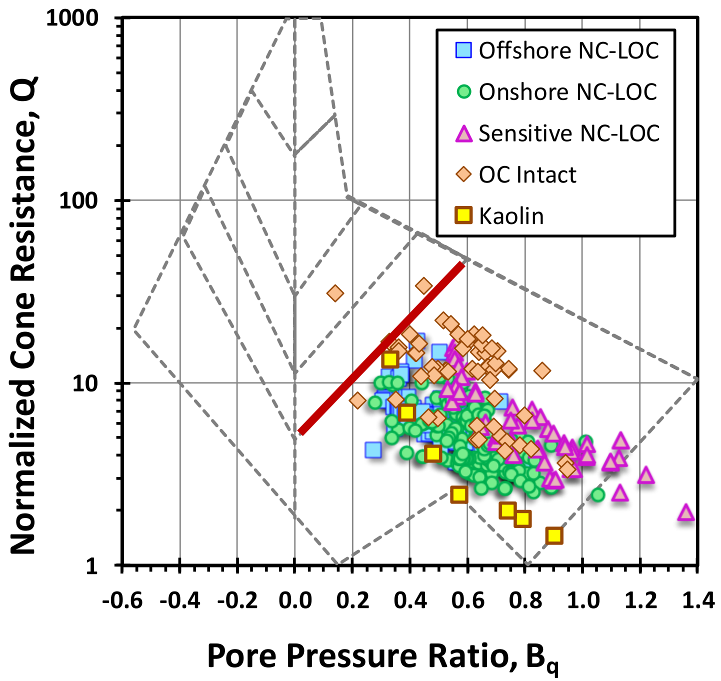
Soil Behavior Type (SBT) Zones

Z1 = sensitive soils
Z2 = organic soils
Z3 = clays to clayey silts
Z4 = silts and silty mixtures
Z5 = sandy mixtures
Z6 = sands
Z7 = gravelly sands

For $B_q > 0$

$I_{Q\text{-}Bq} = Q \cdot 10^{[-1.9 \cdot Bq]}$

Clay Database (N = 70; n = 440)



Caveat: Generalized Method: Yield Stress of Soils from CPT

$$\sigma_p' \approx 0.33\ (q_{net})^{m'} \qquad \text{(units of kPa)}$$

A. If undrained, use simplified method with m' = 1

B. Otherwise, evaluate exponent m' from I_c expressions:

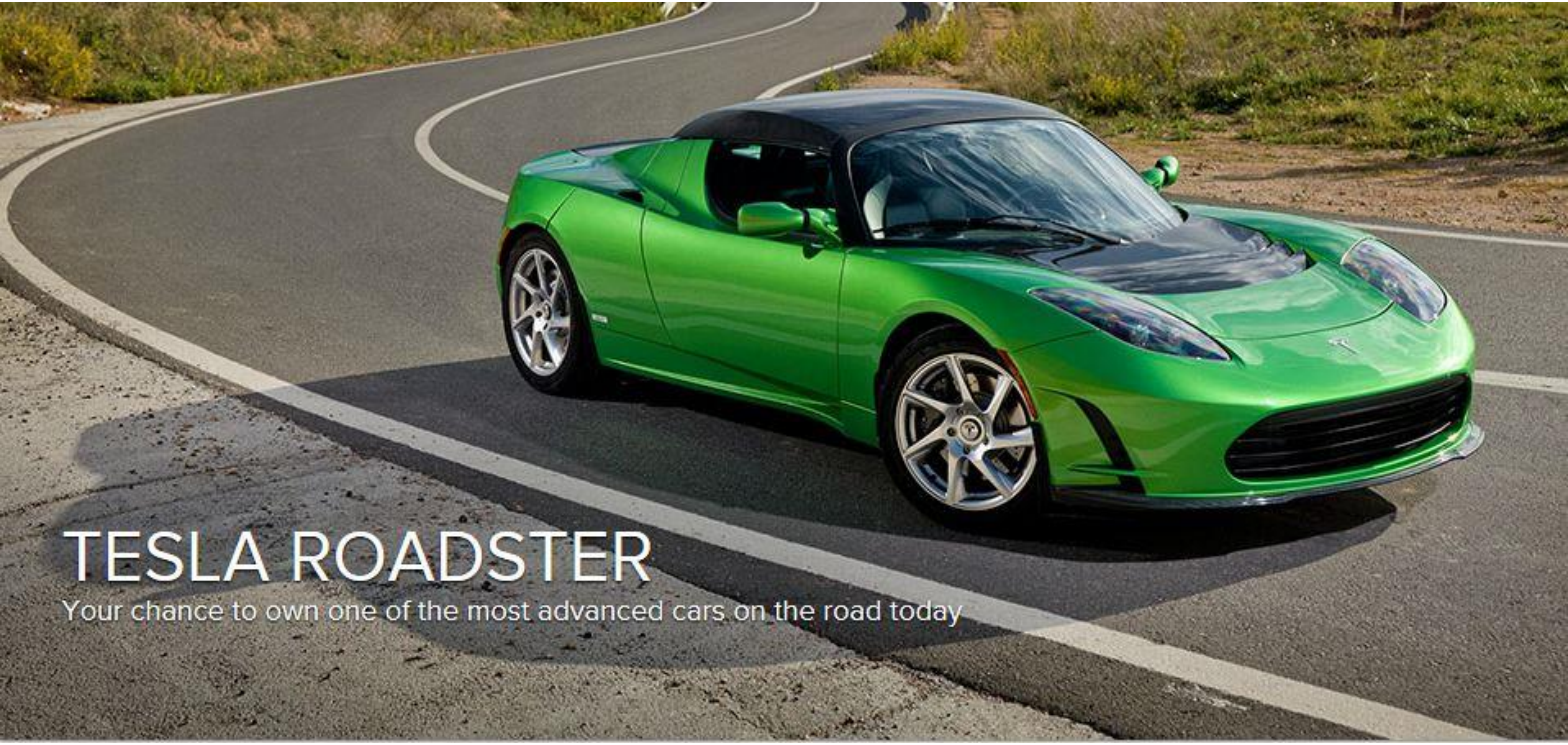
- $m' \approx 1 - 0.28/[\ 1 + (I_c/2.65)^{25}\ ]$ (Agaiby & Mayne, 2019)
- $m' \approx 1 = 0.28/[\ 1 + (I_c/2.6)^{15}\ ]$ (Robertson & Cabal 2022)

Geotechnical Site Investigations

“Soils are made by Nature, and not by man, ….

[thus] the products of Nature are always complex”

Karl von Terzaghi - 1936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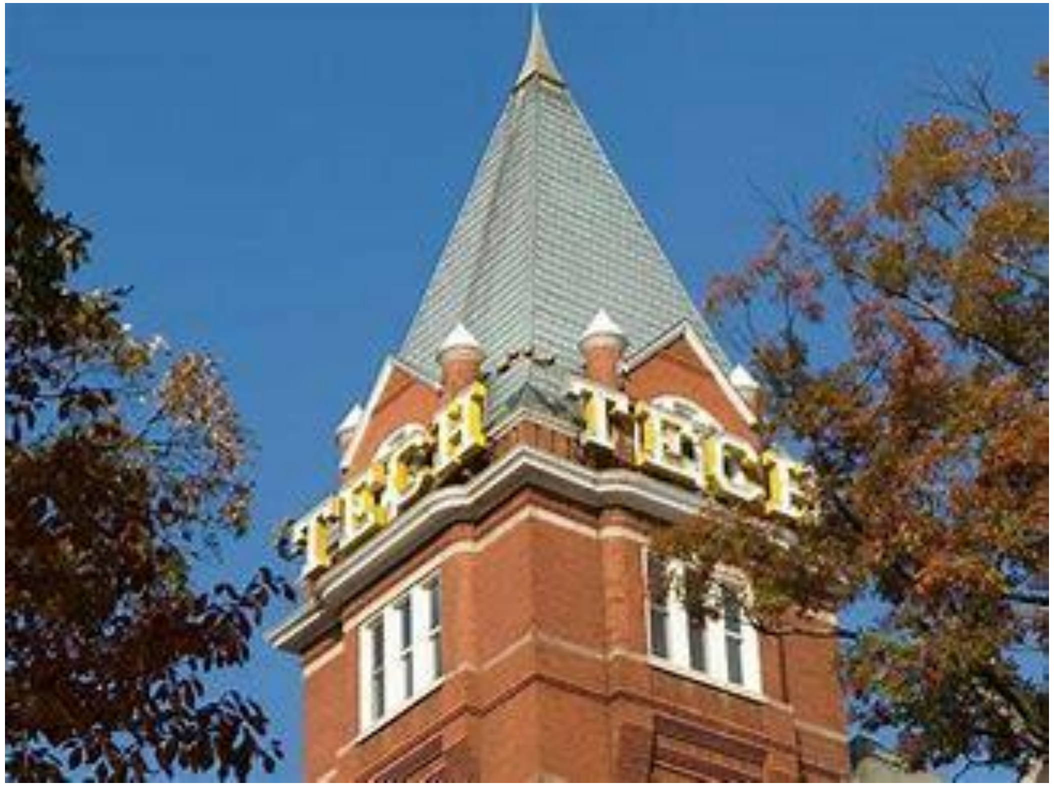
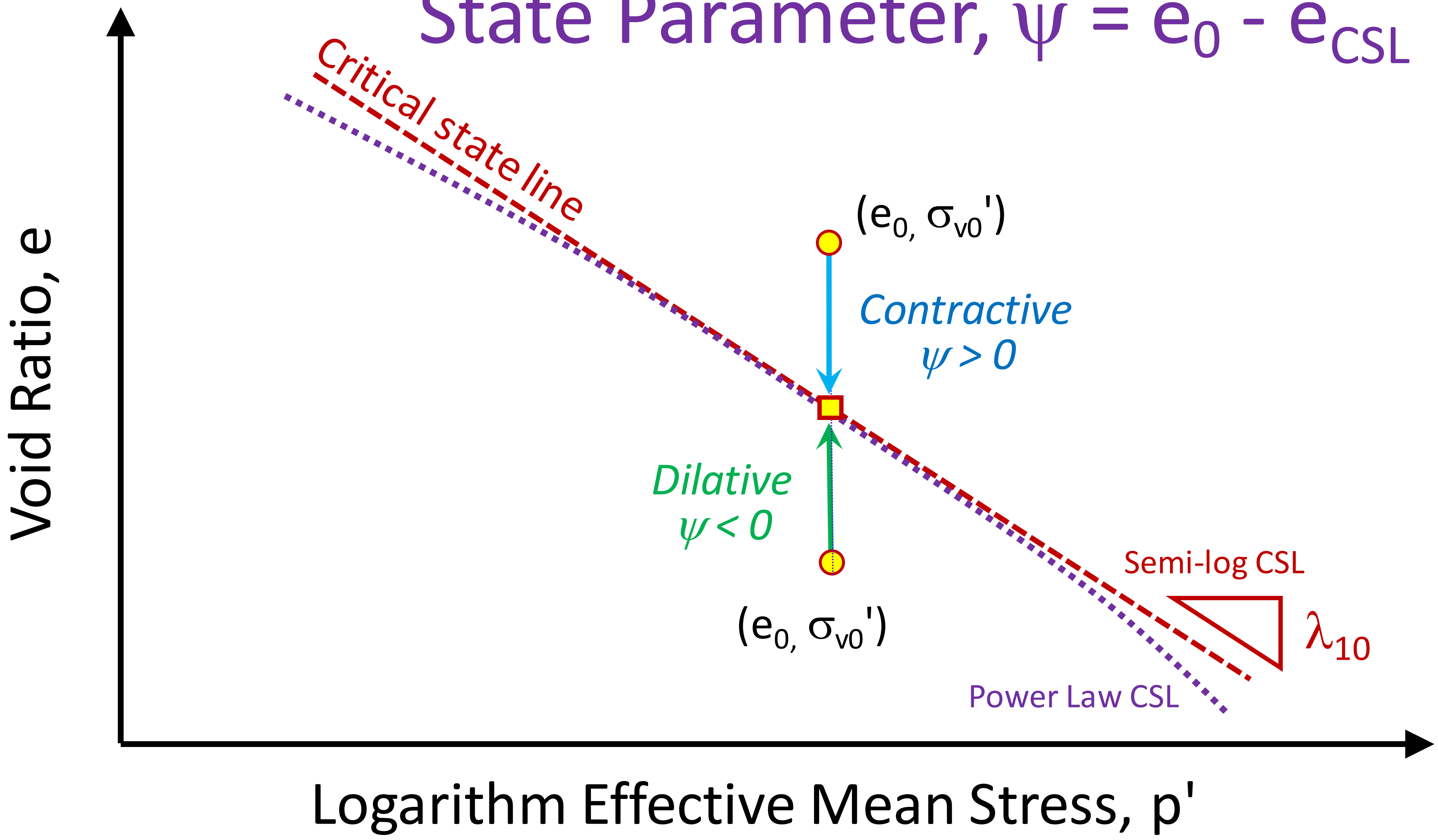


Georgia
Tech

Toyota Colors

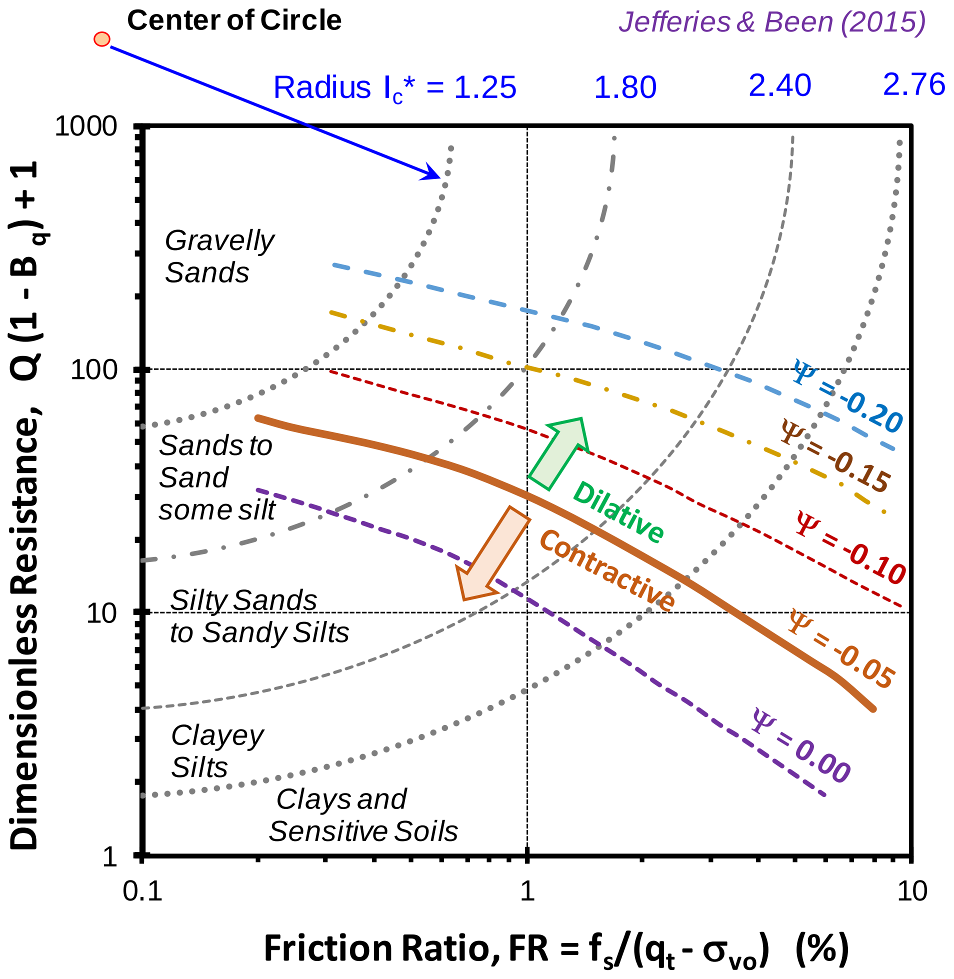
State Parameter, $\psi = e_0 - e_{CSL}$



Methods for Screening State Parameter by CPTU

Jefferies and Been (2006, 2015)

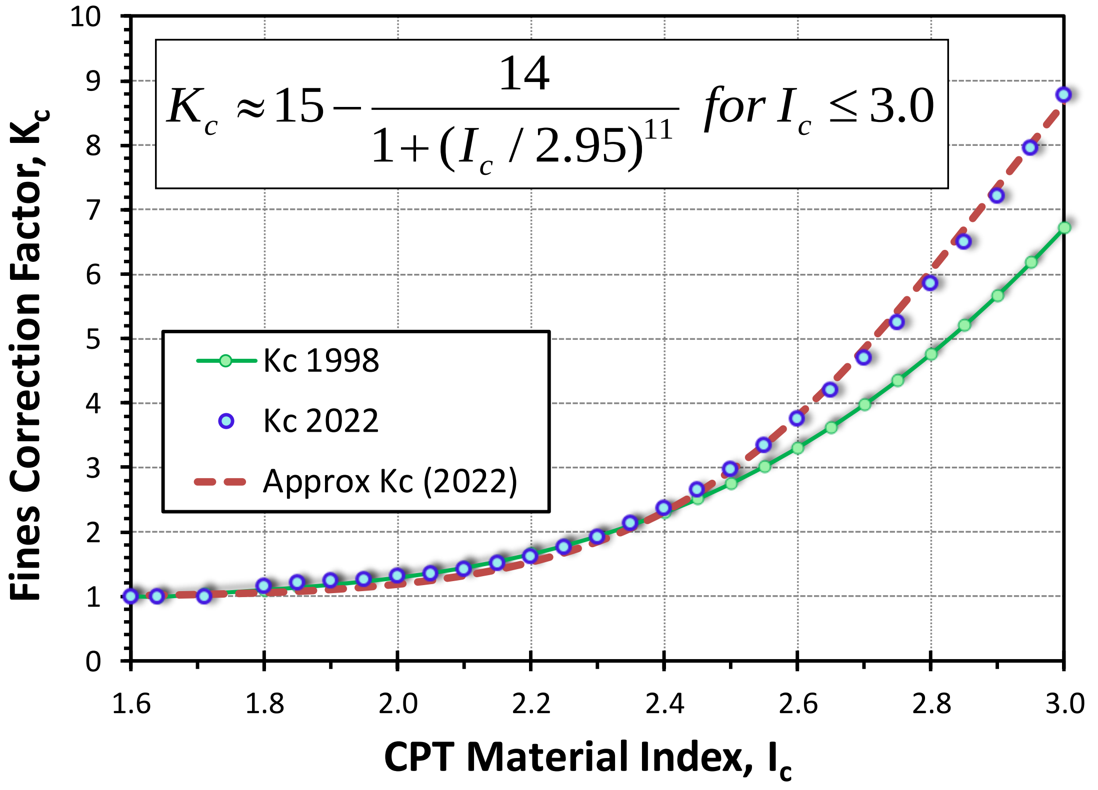
$$I'_c = \sqrt{\{3 - log_{10}[Q(1 - B_q)]\}^2 + \{1.5 + 1.3 log_{10}(F_r)\}^2}$$

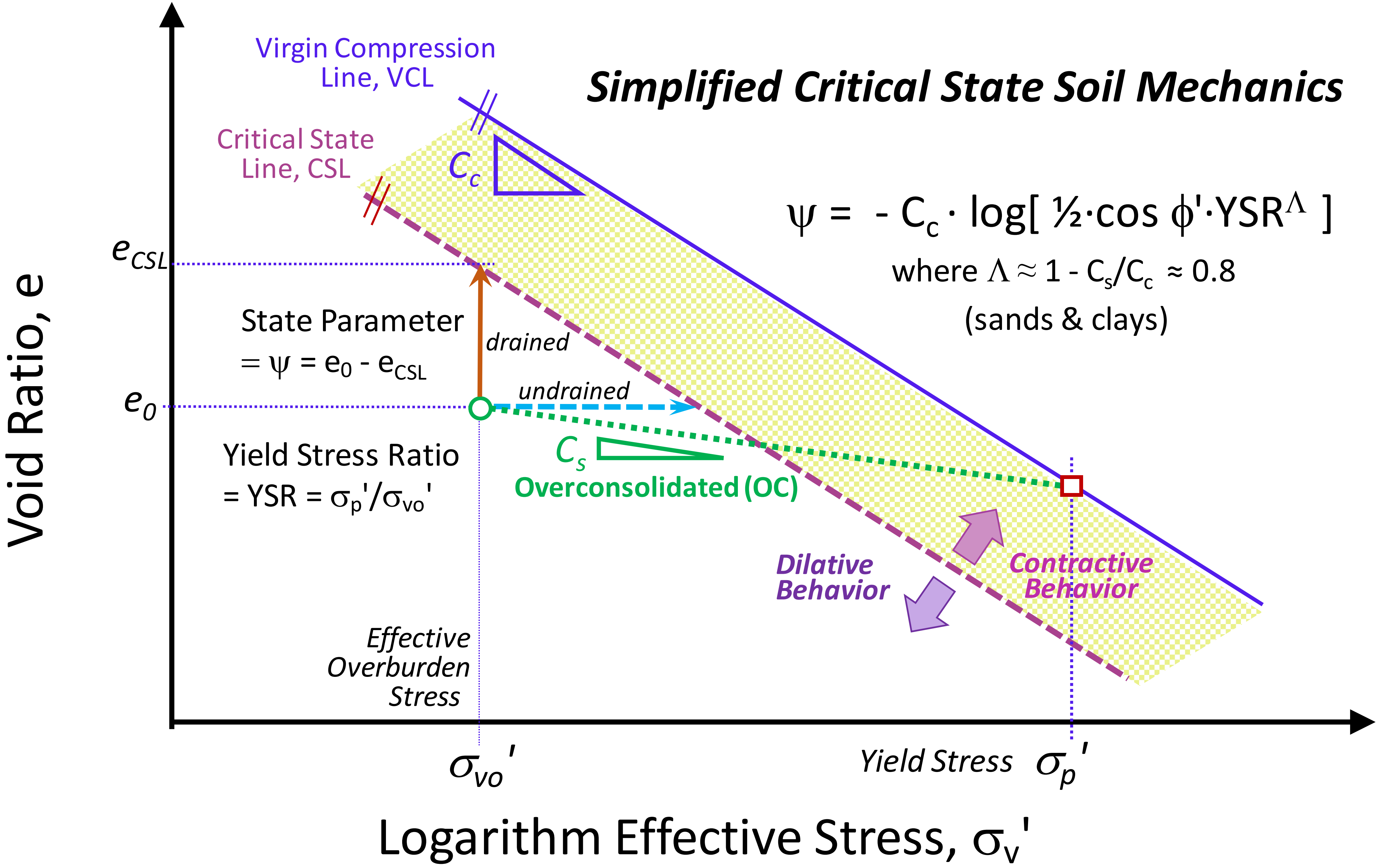


Robertson (2010, 2022)

$$\psi = 0.56 - 0.33 \cdot Q_{tn-cs}$$

$$Q_{tn-cs} = K_c \cdot Q_{tn}$$

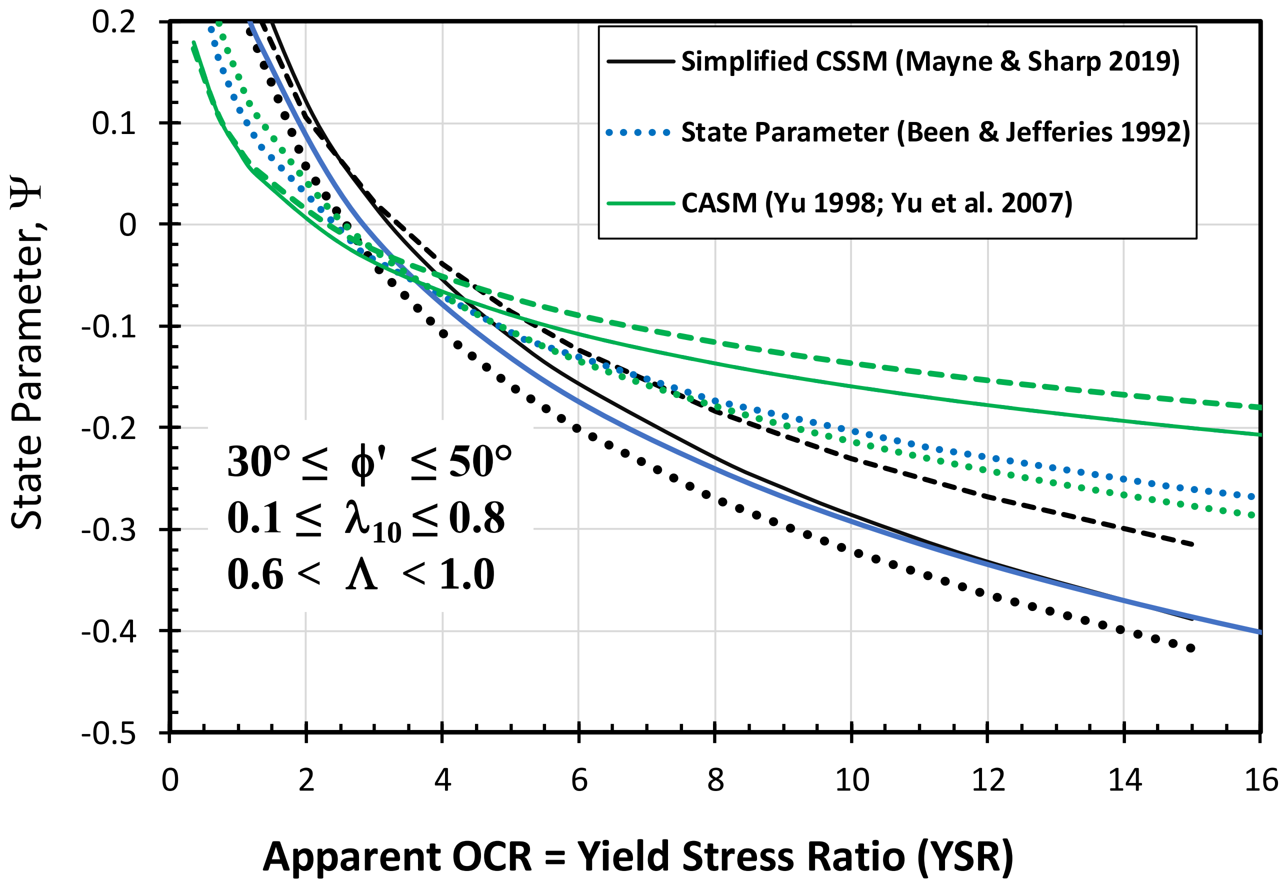




Simplified Critical State Soil Mechanics
Virgin Compression Line, VCL
Critical State Line, CSL
C_c
$\psi = -C_c \cdot \log[\, ½ \cdot \cos\phi' \cdot YSR^{\Lambda}\,]$
where $\Lambda \approx 1 - C_s/C_c \approx 0.8$
(sands & clays)
e_{CSL}
e_0
State Parameter
$= \psi = e_0 - e_{CSL}$
drained
undrained
Yield Stress Ratio
$= YSR = \sigma_p'/\sigma_{vo}'$
C_s
Overconsolidated (OC)
Dilative Behavior
Contractive Behavior
Effective Overburden Stress
σ_{vo}'
Yield Stress σ_p'
Void Ratio, e
Logarithm Effective Stress, σ_v'

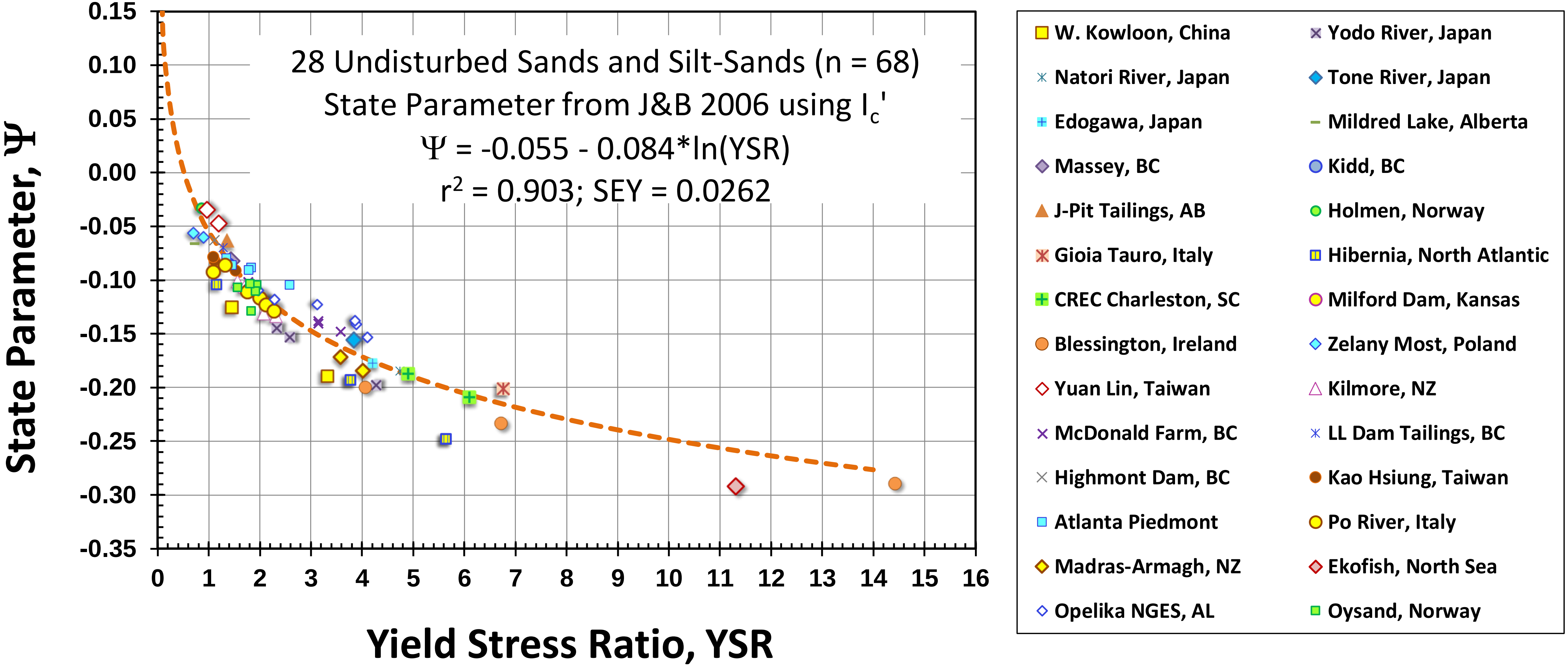
Interrelationships between State Parameter ψ and YSR

- Been et al. (1989)
- Plewes et al. (1992)
- Been & Jefferies (1992)
- Yu (1998, 2006)
- Mayne & Sharp (2019)



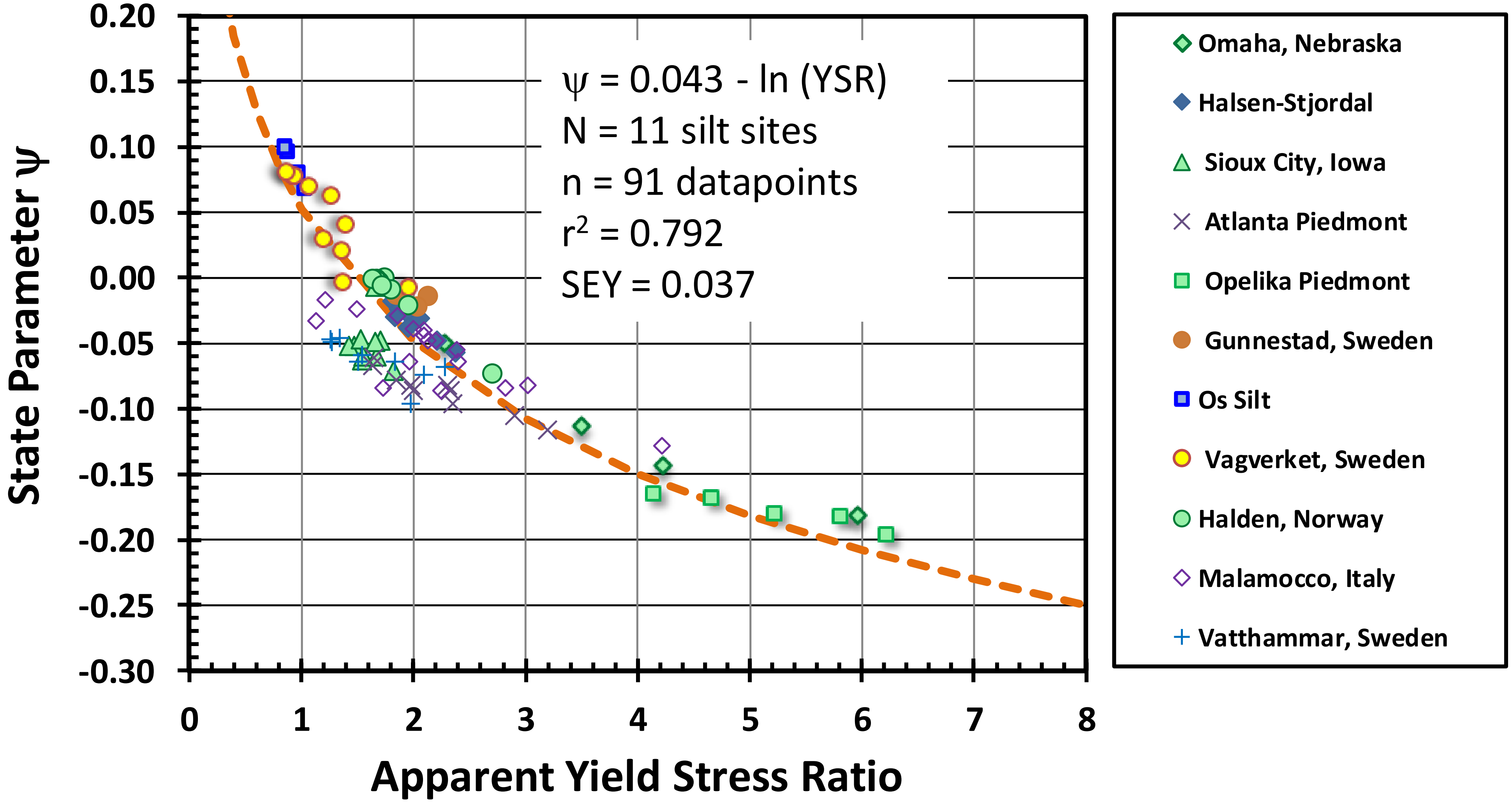
Nexus between State Parameter ψ and YSR for Sands

Jefferies & Been (2006, 2015): $I'_c = \sqrt{\{3 - log_{10}[Q(1 - B_q) + 1]\}^2 + \{1.5 + 1.3log_{10}(F_r)\}^2}$



State Parameter ψ and YSR for Silt Database

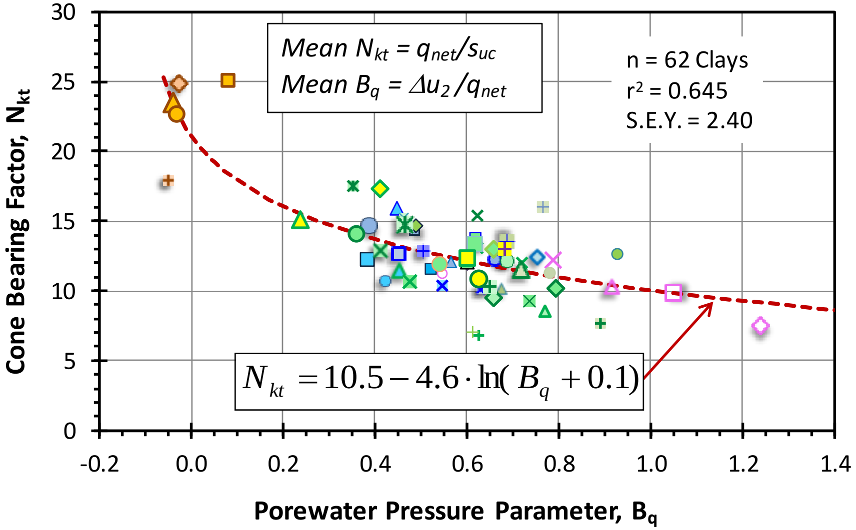
Silt Database Using PKR (2022) and R&C (2022) *11 SILTS*



CPTU Clay Database

Focus on CAUC s_{uc} from 70 natural clays (n = 501)

(Mayne & Peuchen, CPT'18; CPT'22)



CPTu Methodology for s_{uCAUC}

GoG 2	Brage 2
China	Chinguetti
East India	Gullfaks C
Laminaria	GoG 1
GoG 3	GoG 4
GoG 5	GoG 6
Lower Troll	Norwegian Sea
Osaka Bay	Upper Troll
Snorre	South Gloucester Upper
South Gloucester Lower	Hilleren
Tiller	Oz (lower)
Oz (Upper)	Amherst
Ariake	Ballina
Bangkok NNH	Boston Blue Clay 246
Belfast	Bothkennar
Busan	Goteborg 1-470b
Hamilton AFB	Kurihama
Lake Bonneville	Liayungang
Lierstranda	Lilla Mellosa
Louiseville	Newbury
Nile River Delta	Northwestern Univ.
Onsoy	Pisa
Porto Tolle	Recife
San Francisco	Sarapui
Saro Road 6/900	Singapore
Taipei Clay K1	Torp
Anchorage	Cooper Marl
Haltenbanken	Haga
Taranto	Baytown
Baton Rouge	Brent Cross
Dublin Boulder Clay	Beaufort Sea

Offshore NC-LOC Clays

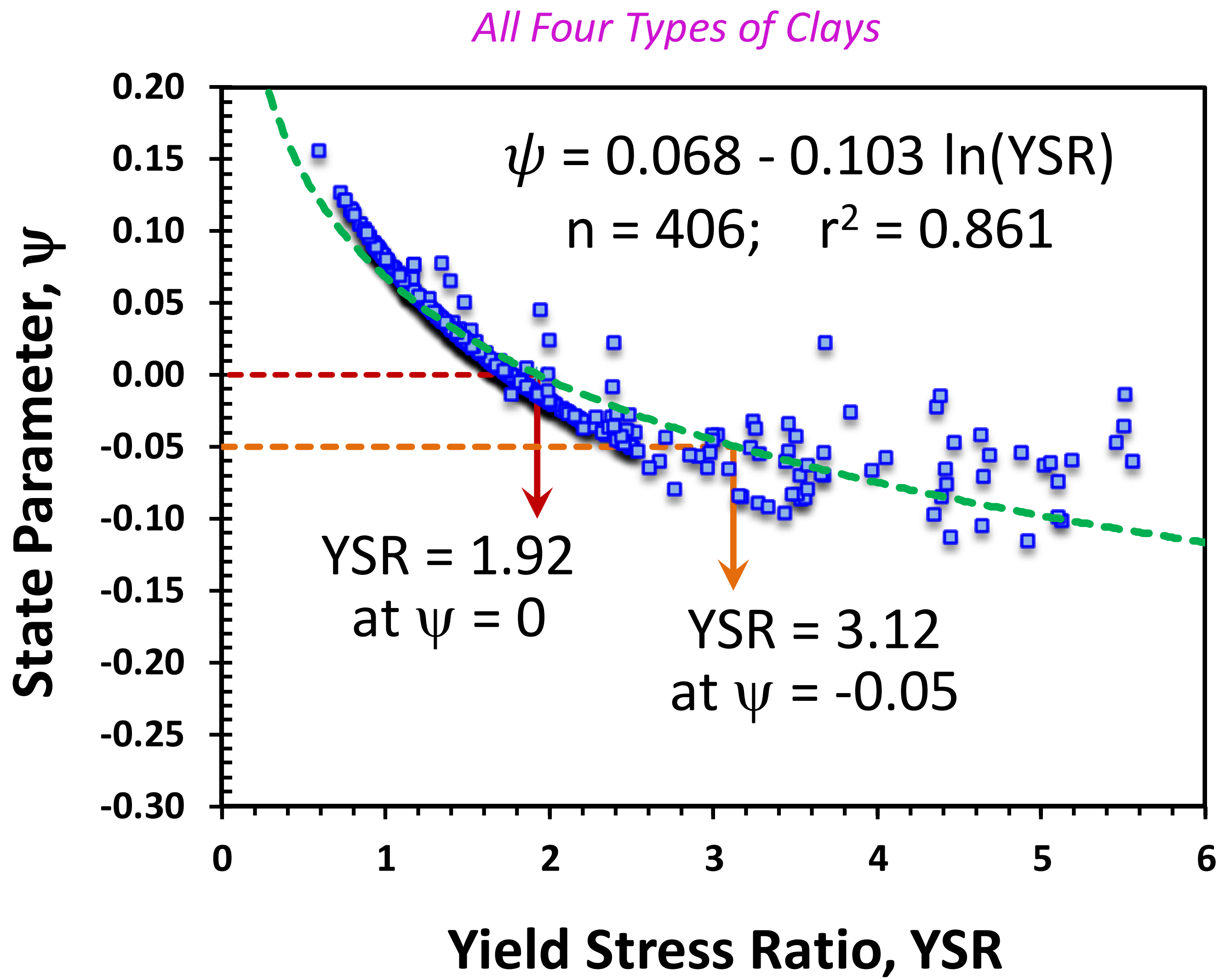
Sensitive Clays

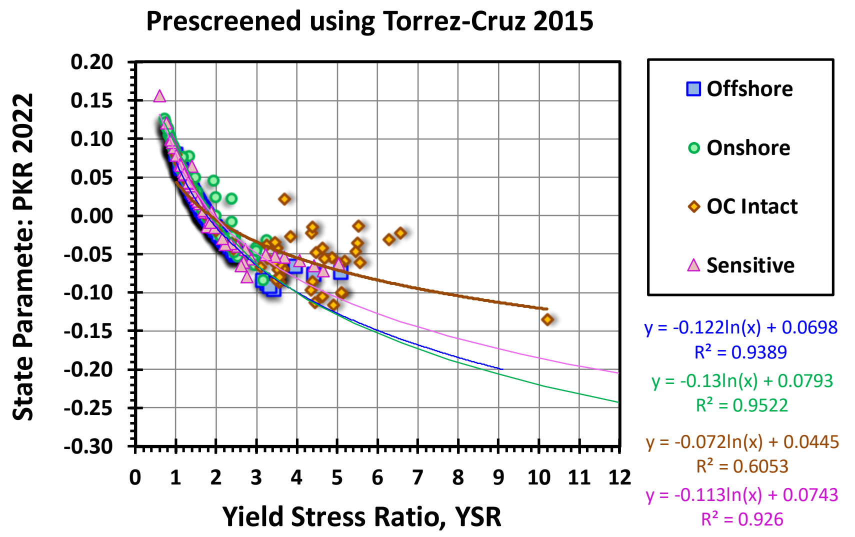
Onshore NC-LOC Clays

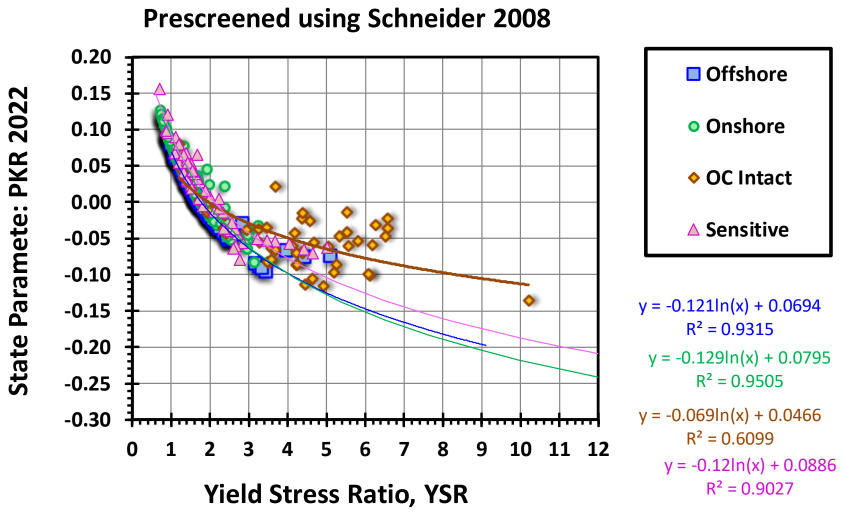
OC Intact

OC Fissured

Nexus between State Parameter ψ and YSR in clays







State Parameter ψ and YSR in sands, silts, and clays

Contractive-Dilative Threshold at $\psi = -0.05$

Clays: $\psi \approx +0.06 - 0.1 \cdot \ln(\text{YSR})$

Silts: $\psi \approx +0.02 - 0.1 \cdot \ln(\text{YSR})$

Sands: $\psi \approx -0.02 - 0.1 \cdot \ln(\text{YSR})$

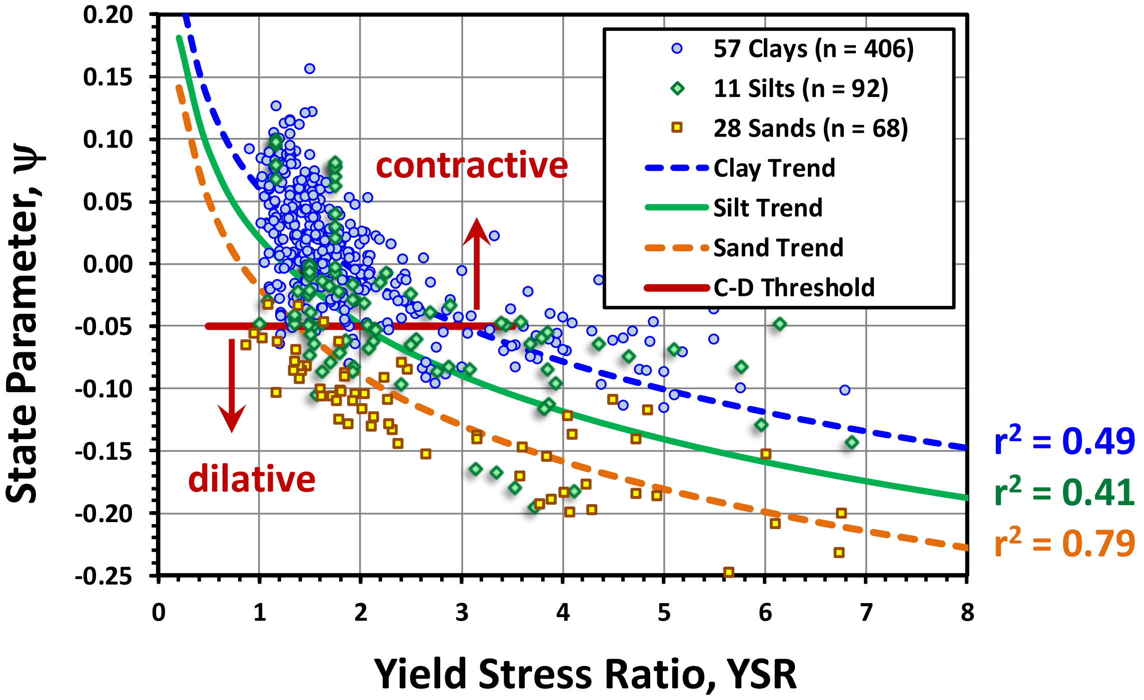
Contractive Behavior

Clays: YSR < 3

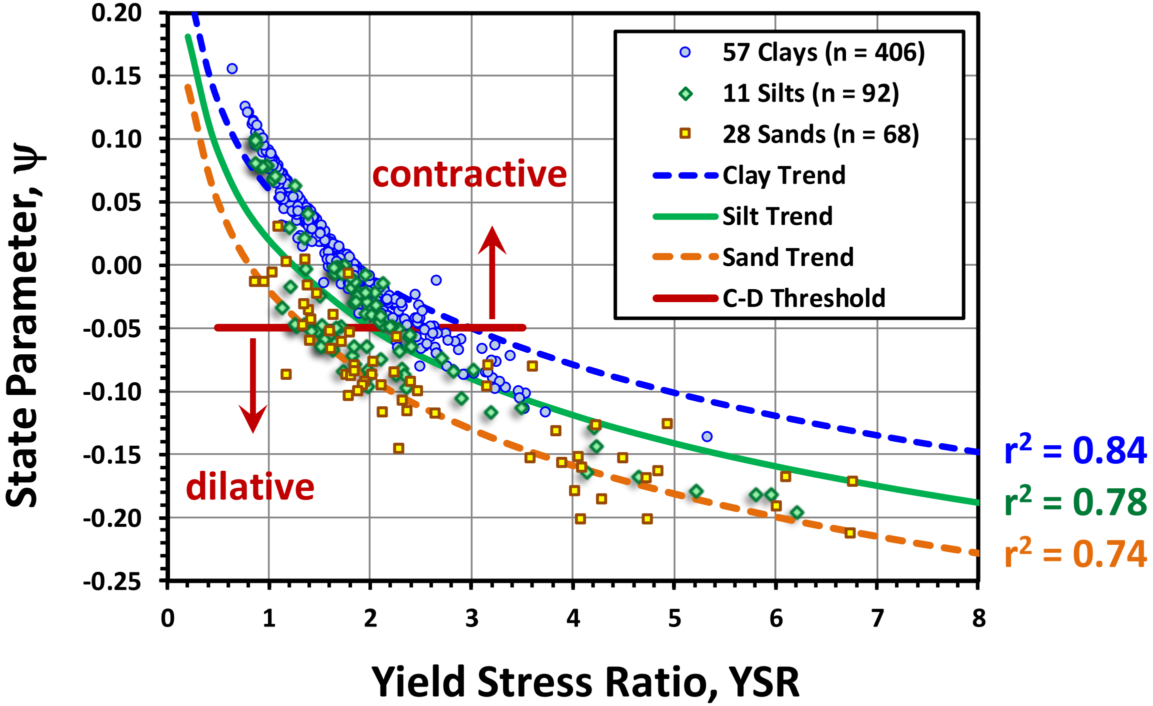
Silts: YSR < 2

Sands: YSR < 1.35

Sand ψ from J&B'06; YSR of clays & silts from consols



YSR from P&C 2022 and ψ from PKR 2022



CASM = clay and sand model (Yu et al. 2019)

Constitutive Soil Model Based on Critical State Soil Mechanics

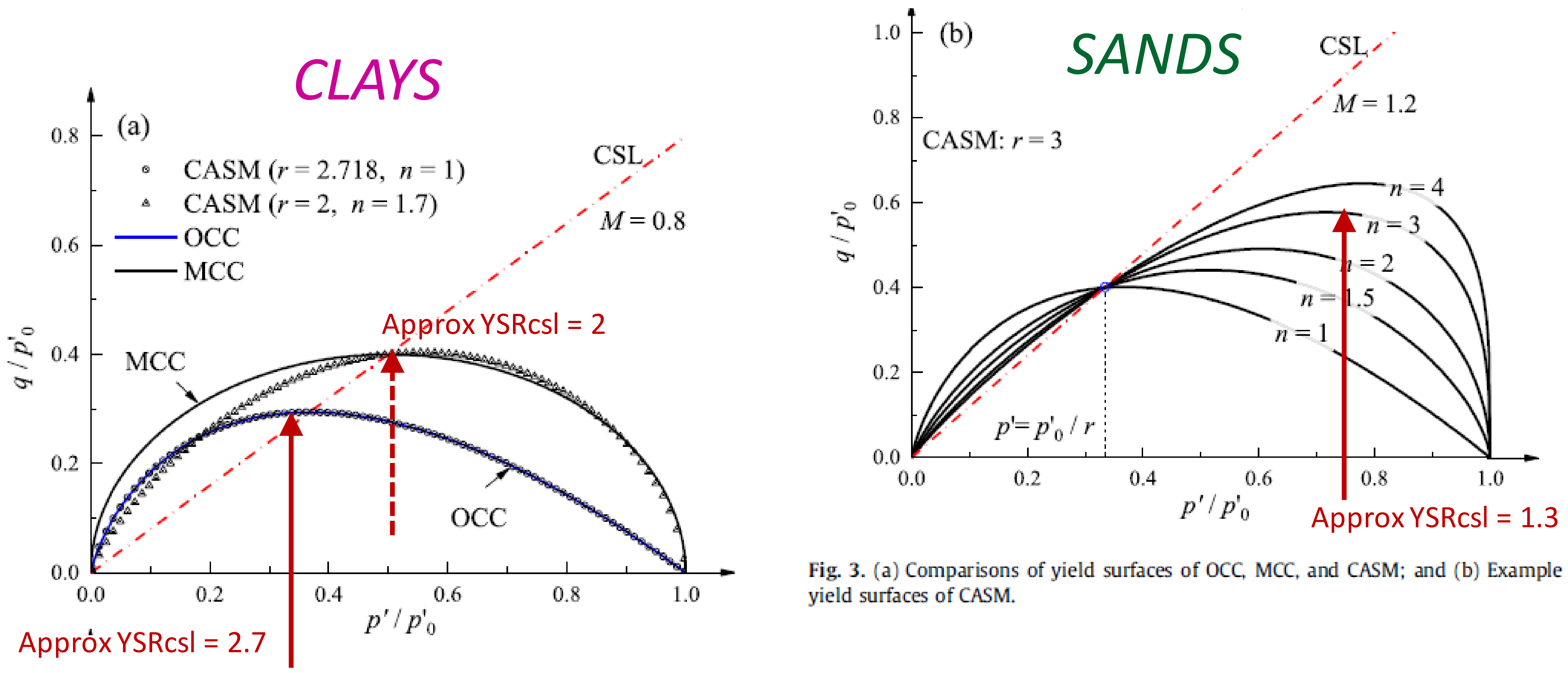
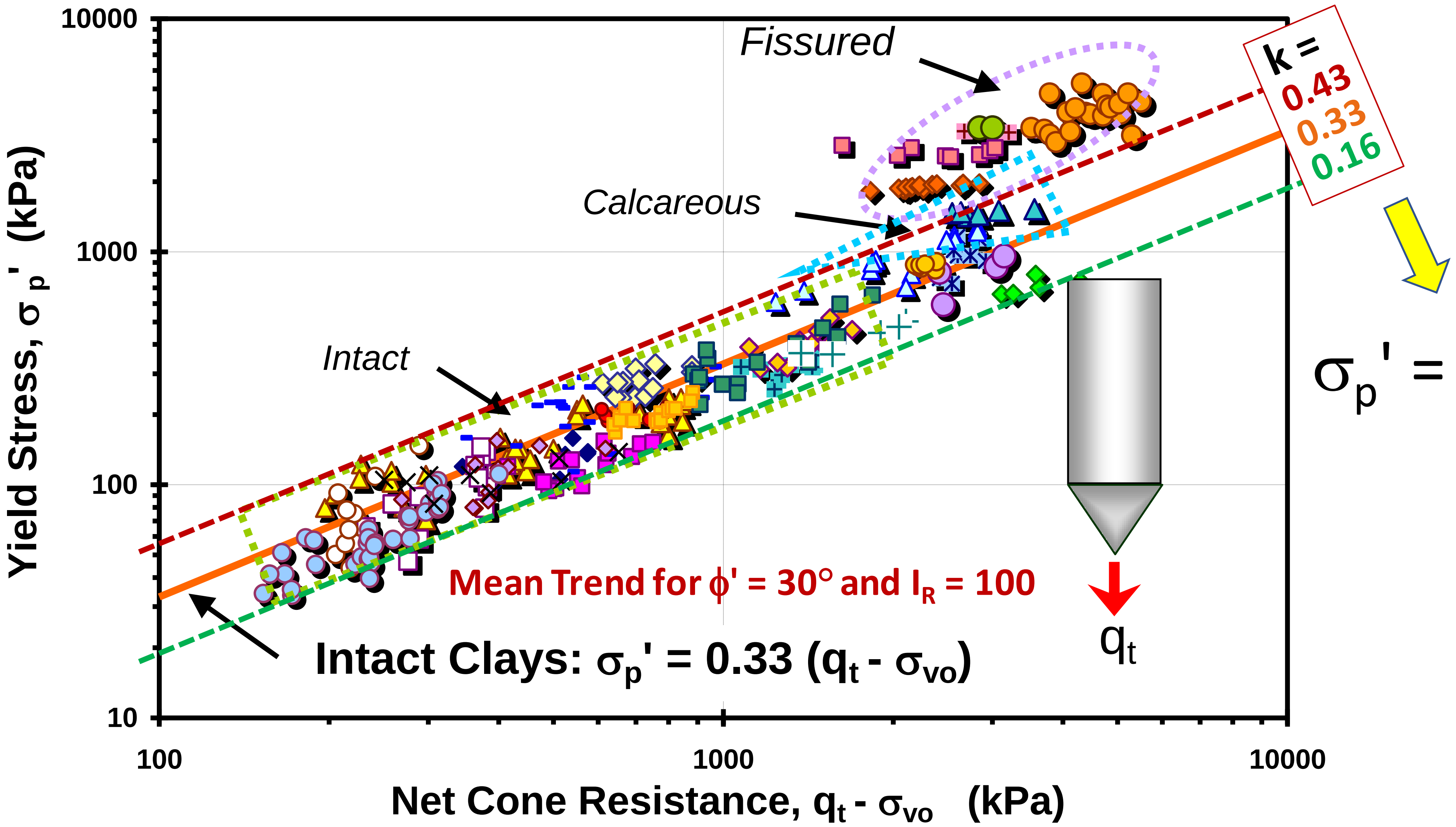


Fig. 3. (a) Comparisons of yield surfaces of OCC, MCC, and CASM; and (b) Example yield surfaces of CASM.

Profiling Yield Stress in Clays by CPT



$$\sigma_p' = k \cdot q_{net}$$

SCE-CSSM Solutions for YSR

First-order approximations for insensitive, inorganic clays

$$YSR = 2\left[\frac{(2/M)Q}{(4/3)(\ln I_R + 1) + \frac{\pi}{2} + 1}\right]^{(1/\Lambda)}$$

For $\Lambda = 1$

$\phi' = 30^o$
$I_R = 100$

$$\sigma_P{}' = \frac{(q_t - \sigma_{vo})}{M \cdot [1 + \frac{1}{3}\ln(I_R)]}$$

$$\sigma_P{}' \approx 0.3(q_{net})$$

$$YSR = 2\left[\frac{U - 1}{2/3\, M \cdot \ln(I_R) - 1}\right]^{(1/\Lambda)} \approx 2\left[\frac{U}{2/3\, M \cdot \ln(I_R)}\right]^{(1/\Lambda)}$$

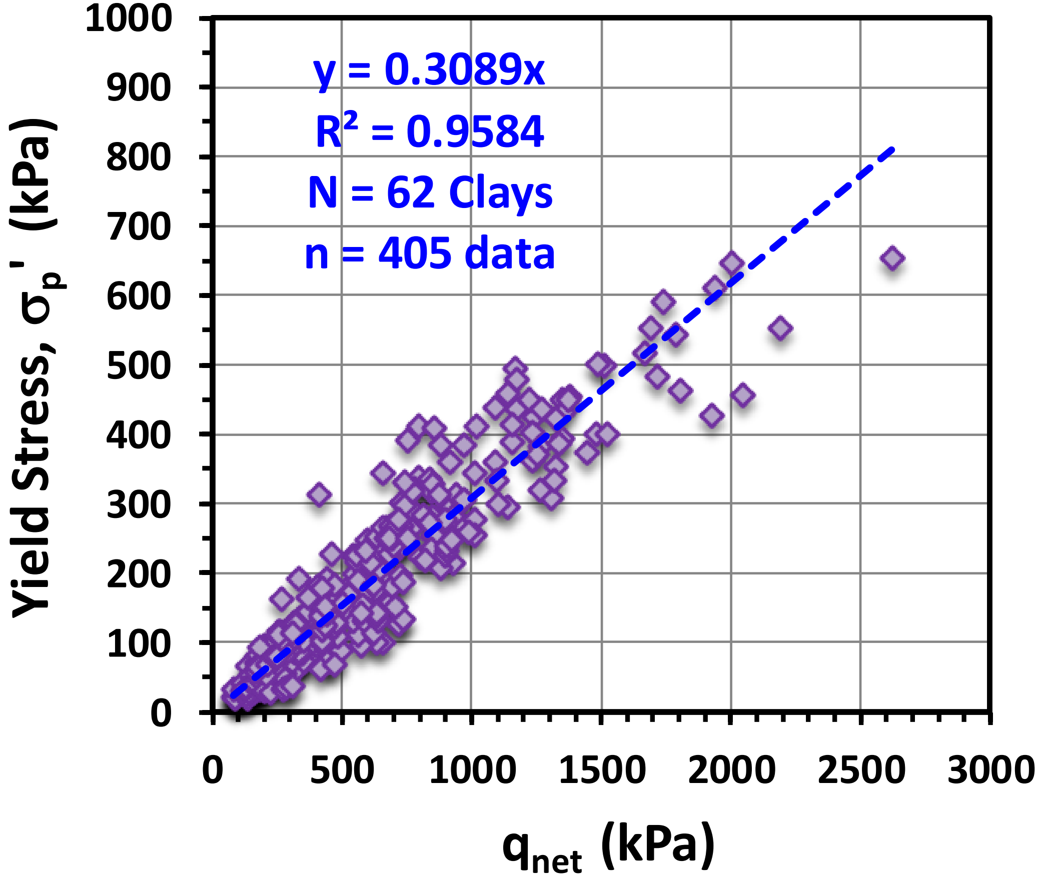
$$\sigma_P{}' = \frac{3 \cdot (u_2 - u_o)}{M \cdot \ln(I_R)}$$

$$\sigma_P{}' \approx 0.5(\Delta u_2)$$

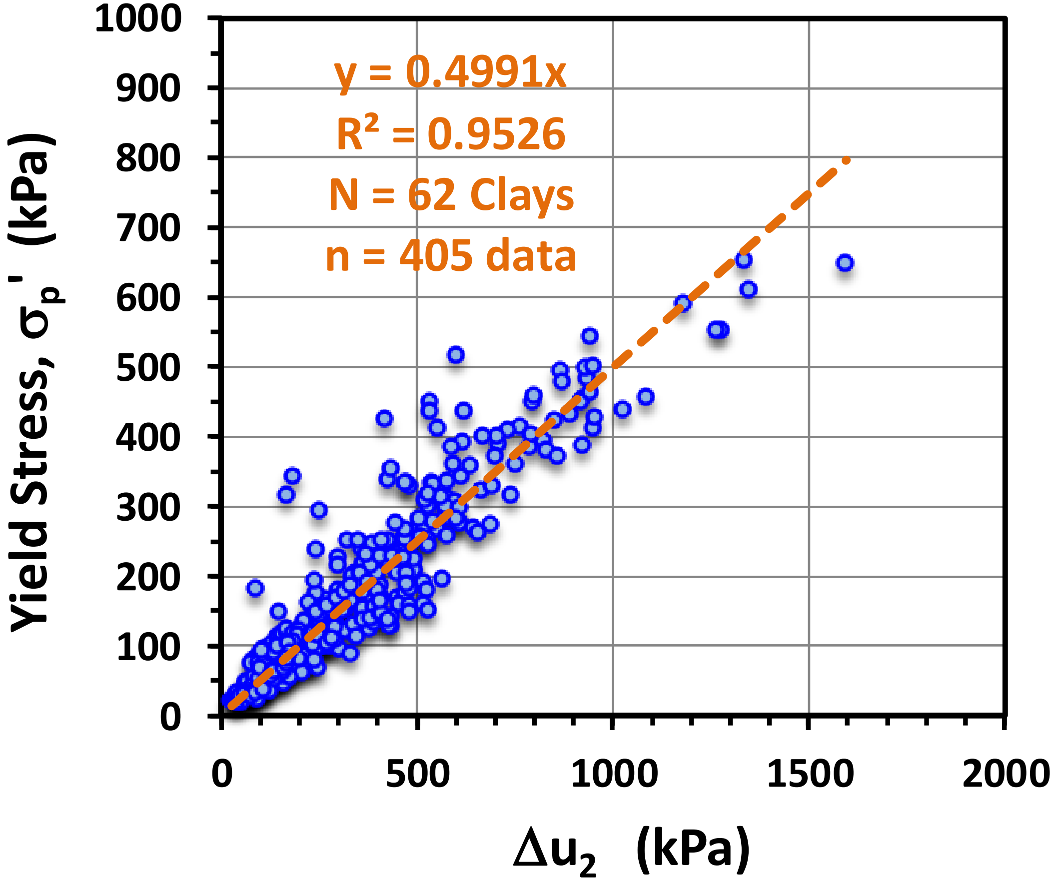
Yield stress of clays from CPTU (2023)

Regression lines from best fit lines (b = 0)

$$\sigma_p' = 0.3\, q_{net}$$



$$\sigma_p' = 0.5\, \Delta u_2$$



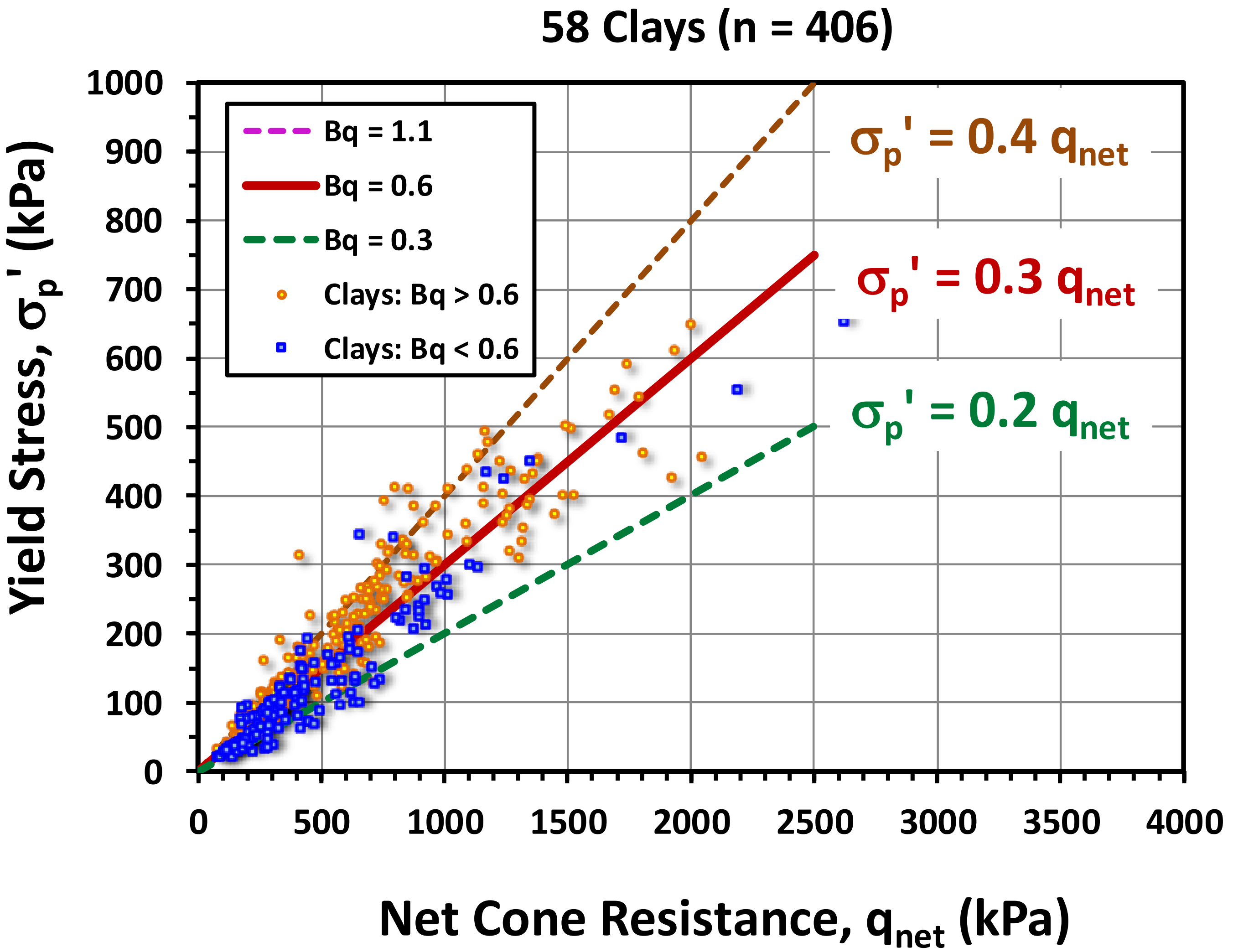
Yield stress of clays from CPTU (2023)

$$\sigma'_p = \sqrt{(\sigma_p{}')^2}$$

$$\sigma'_p = \sqrt{(0.3\, q_{net}) \cdot (0.5\, \Delta u_2)}$$

$$For\ B_q = \frac{\Delta u_2}{q_{net}} > 0.3$$

$$\sigma'_p = 0.3\, q_{net} \sqrt{\frac{B_q}{0.6}}$$

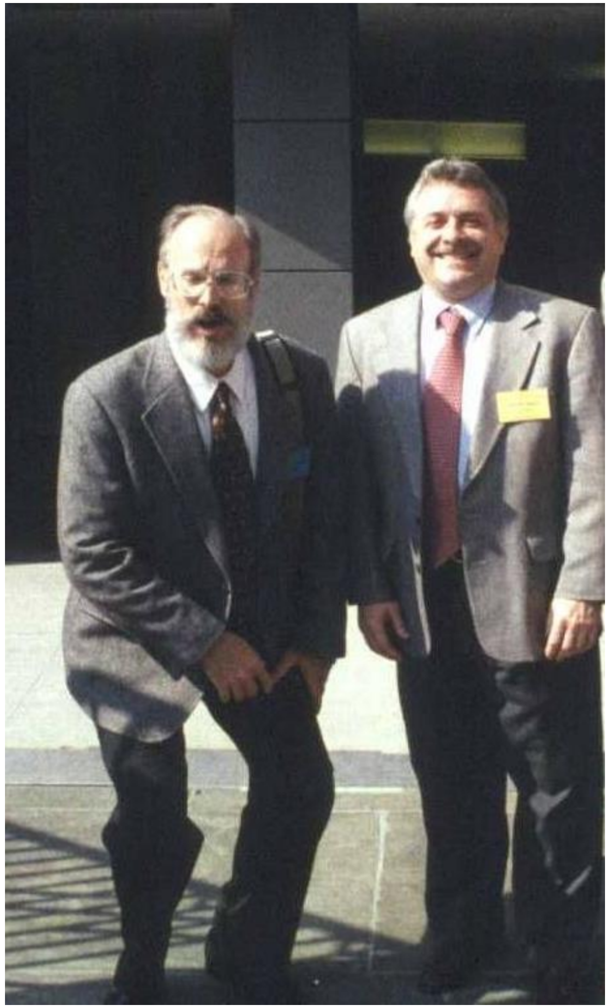


Legacy - Terzaghi Lecturers

Music with
James K. Mitchell
TL 1984

Music with
Harry Poulos
TL 2004

The Shortest TL



Ken Stokoe II
TL 2011

Beer for CPT Users

ELSEVIER

Developments in Geotechnical Engineering

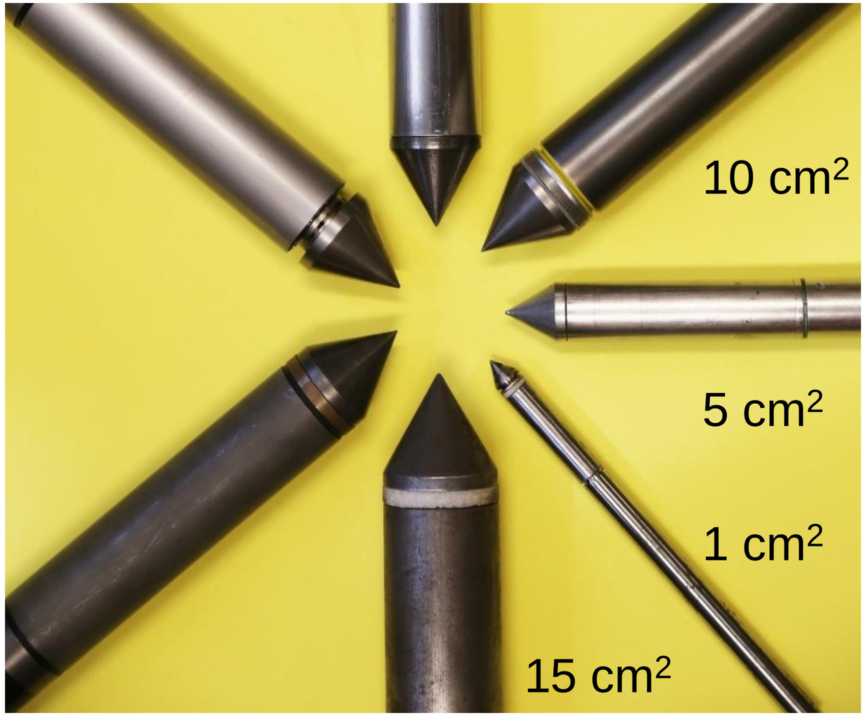
Volume 1, 1972, Pages 121-142

Chapter 3 - The De Beer Theory for the Interpretation of Penetrometer Test Data

Cone Penetrometer Sizes

10 cm^2 10 cm^2 15 cm^2 15 cm^2

2 cm^2 10 cm^2



Cone Penetrometer Sizes

10 cm^2 15 cm^2 40 cm^2

ConeTec Penetrometers

Fugro Penetrometers

33 cm^2 15 cm^2 10 cm^2

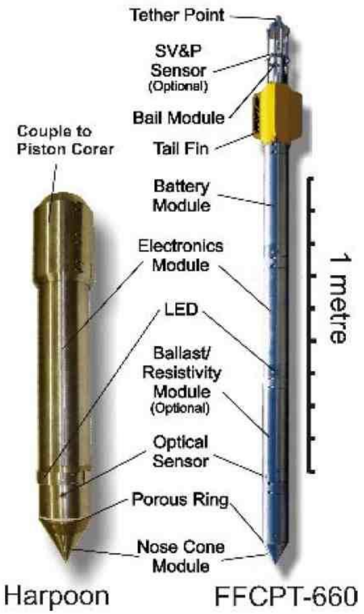
Free Fall Cone Penetrometers

For investigating rivers and waterways

Harpoon Penetrometers

44 mm < d < 250 mm

- US Navy XDP
- Canadian FFCPT
- German MARUM
- Australian FFP
- Brasil COPPE

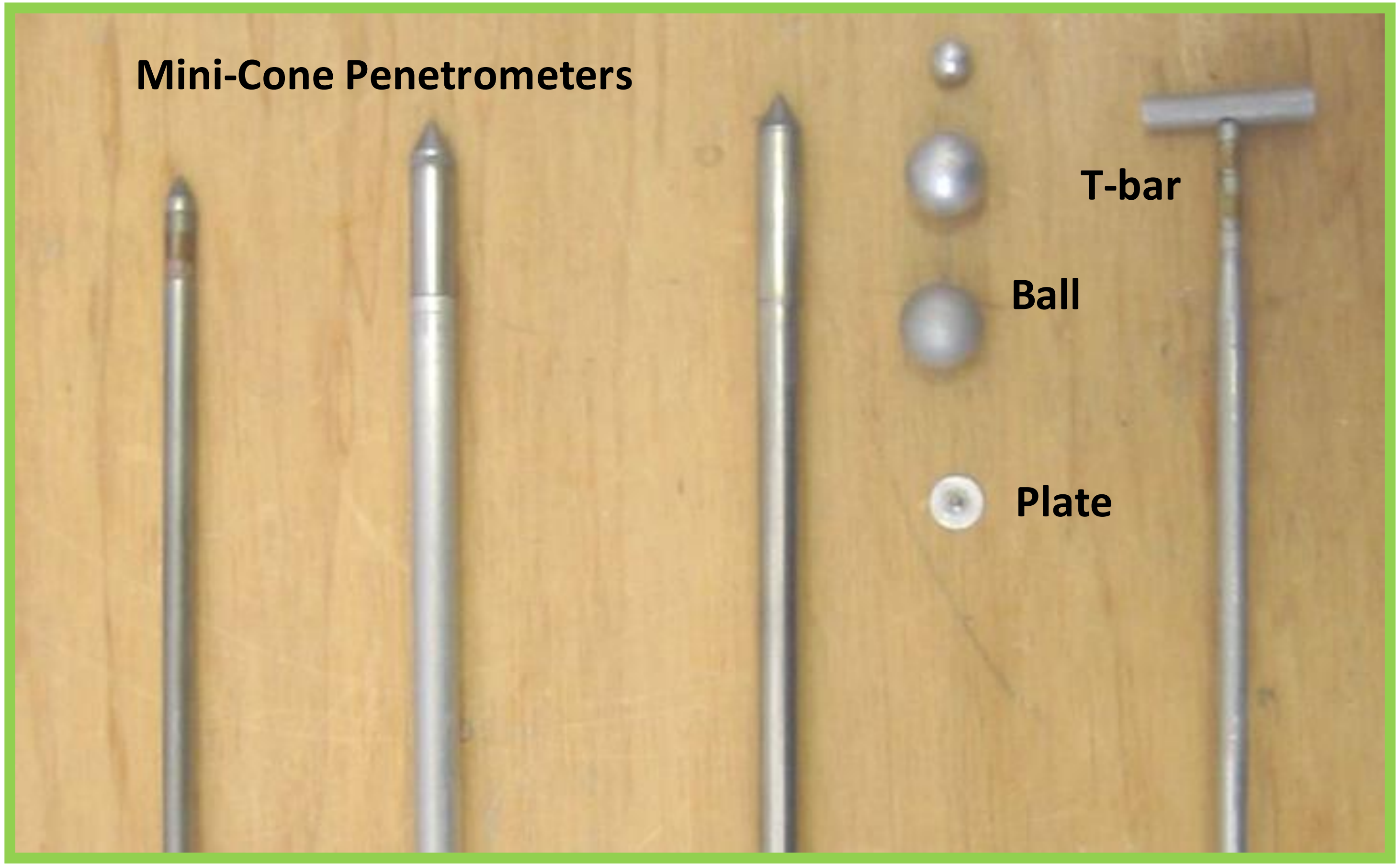


Mini-Cone Penetrometers

CPT Piezocones for Centrifuge - University of Western Australia

d = 10 and 12 mm

0 50 mm



Main Centrifuge

Drum Centrifuge

Micro-Cone Penetrometers

Kim, Choi, Lee & Lee: Korea University (GeoFlorida 2010)

- **Developed FBG Cone Penetrometers**

- Diameter : 1~7mm
- FBG +S/G sensors
- Temperature transducer
- Dual stainless steel tube

FBG = Fibre Bragg Grating sensor

Vaccination Shots and Booster Jabs Using CPT

1-mm diameter cone penetrometer

Robotic CPT - AutoCoson

by A.P. van den Berg, Holland

Onshore

Offshore

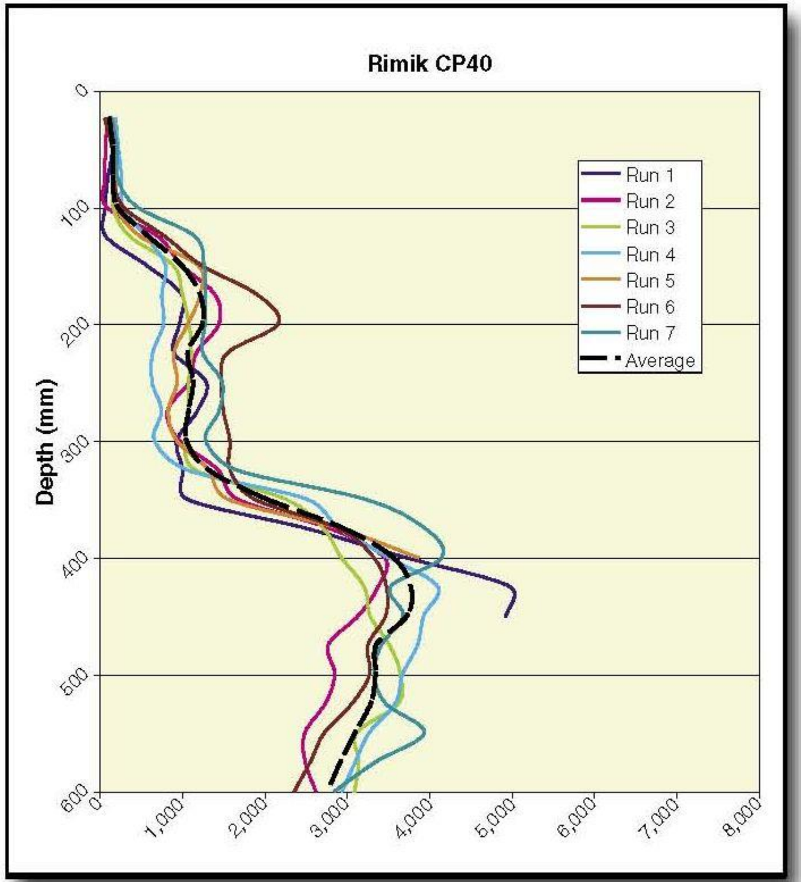
PROD = Portable Remotely Operated Drill

by Benthic Geotech Australia

Cone Penetrometer Testing

Hand-held electronic cone penetrometers

Measured Penetration Resistance



Excellent Repeatability

Spectrum Scout SC 900

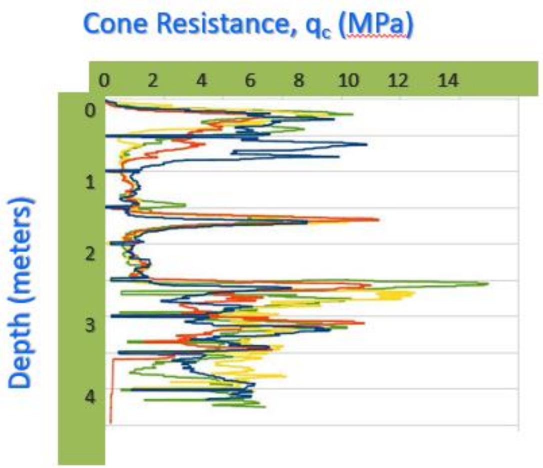
Rimik CP40

Eijkelcamp

CPTs in Antarctica

Adrian McCallum
Scott Polar Research Institute (SPRI)
Lankelma, UK

Halley Research Station



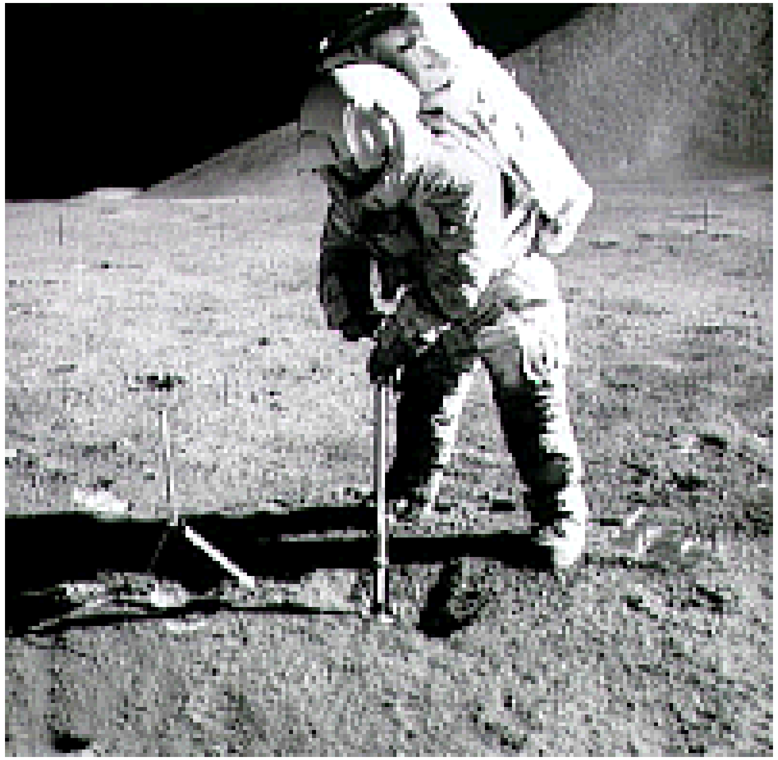
CPTs

- all 7 continents
- all 5 oceans

Earth

Lunar Cone Penetrometer

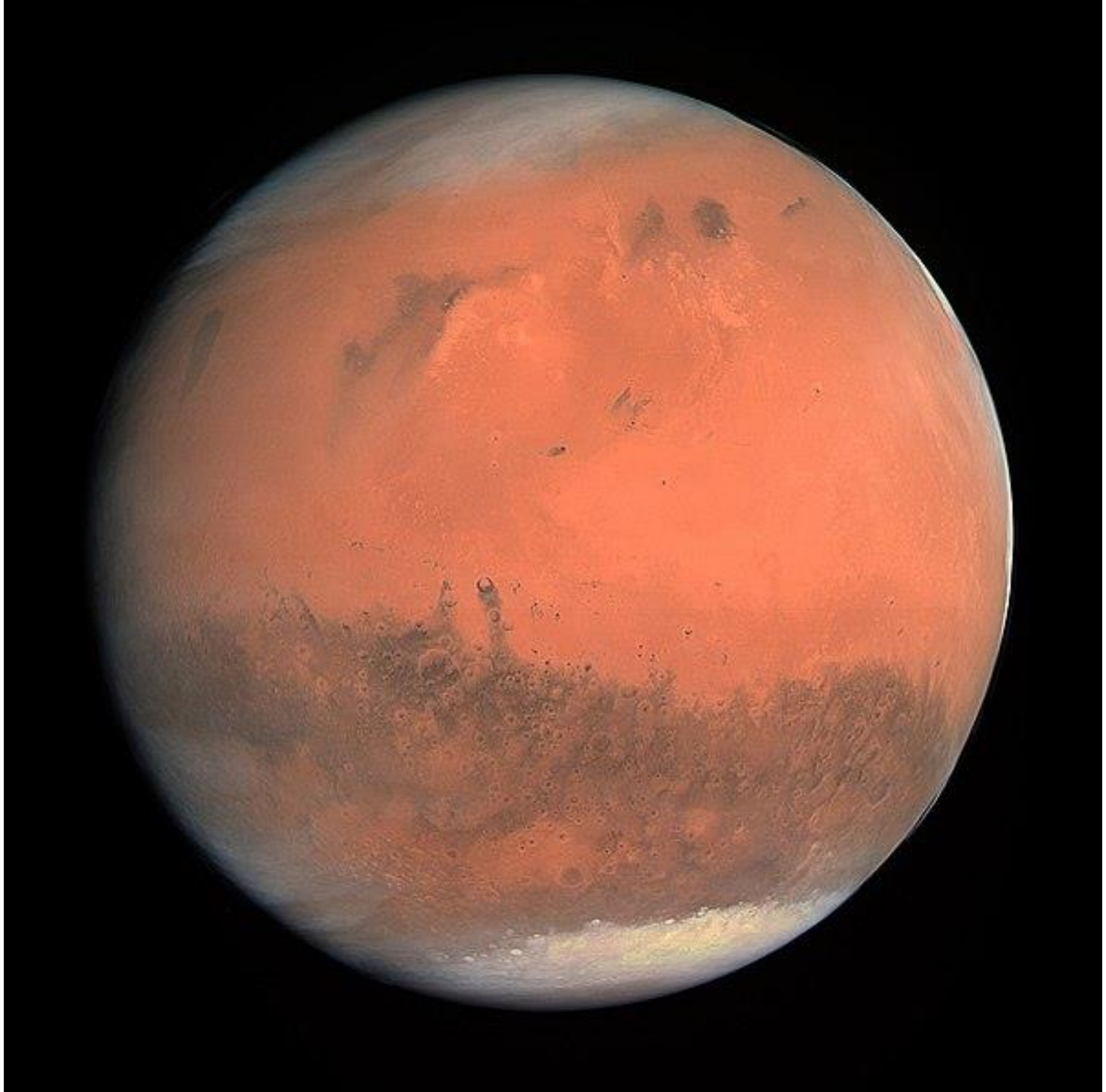
Carrier, W.D., Mitchell, J.K. and Mahmood, A. "The Nature of Lunar Soil," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 99, No. SM 10, 1973, pp. 813-832.



The Moon

Mars

In-Sight Mission by NASA

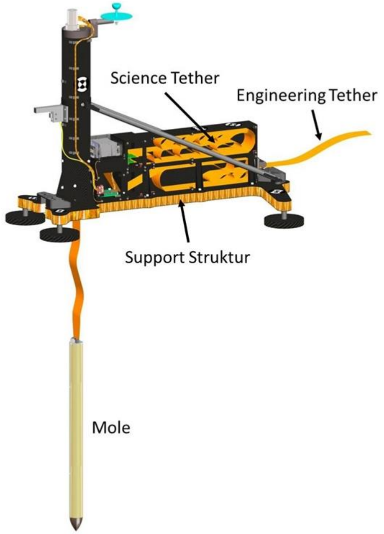


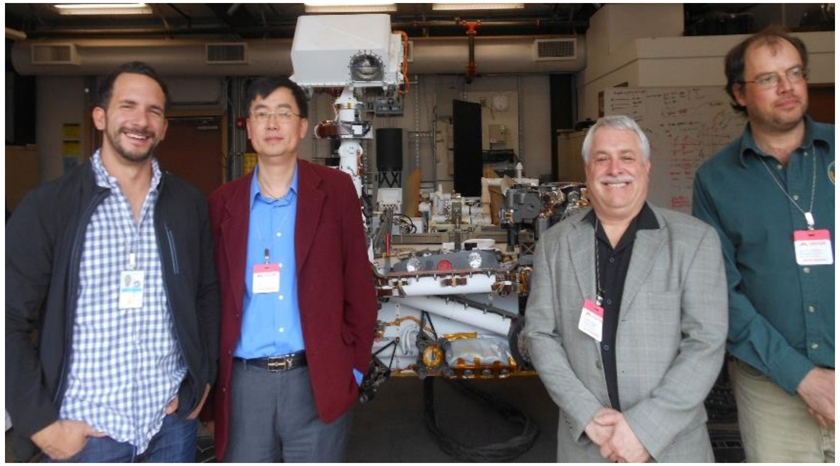

Mars InSight Mission
Launched May 2018
Landed November 2018

INSIGHT MISSION: External Geotechnical Review Team at JPL

Jose Andrade, Caltech, Professor, Dept. of Mechanical & Civil Engineering
Paul Mayne, Georgia Tech, Professor, School of Civil & Environmental Engineering
David Zeng, Case Western Reserve, Professor and Chairman, Dept of Civil Engineering
Ralph Lorenz, John Hopkins Applied Physics Lab, Planetary In-Situ instrumentation

Martian Penetrometer





Proceedings ICSMGE 2022 - Sydney

Special Lecture: Planetary Geotechnics

Pierre Delage, Ėcole des Ponts Paris Tech

INSIGHT MISSION

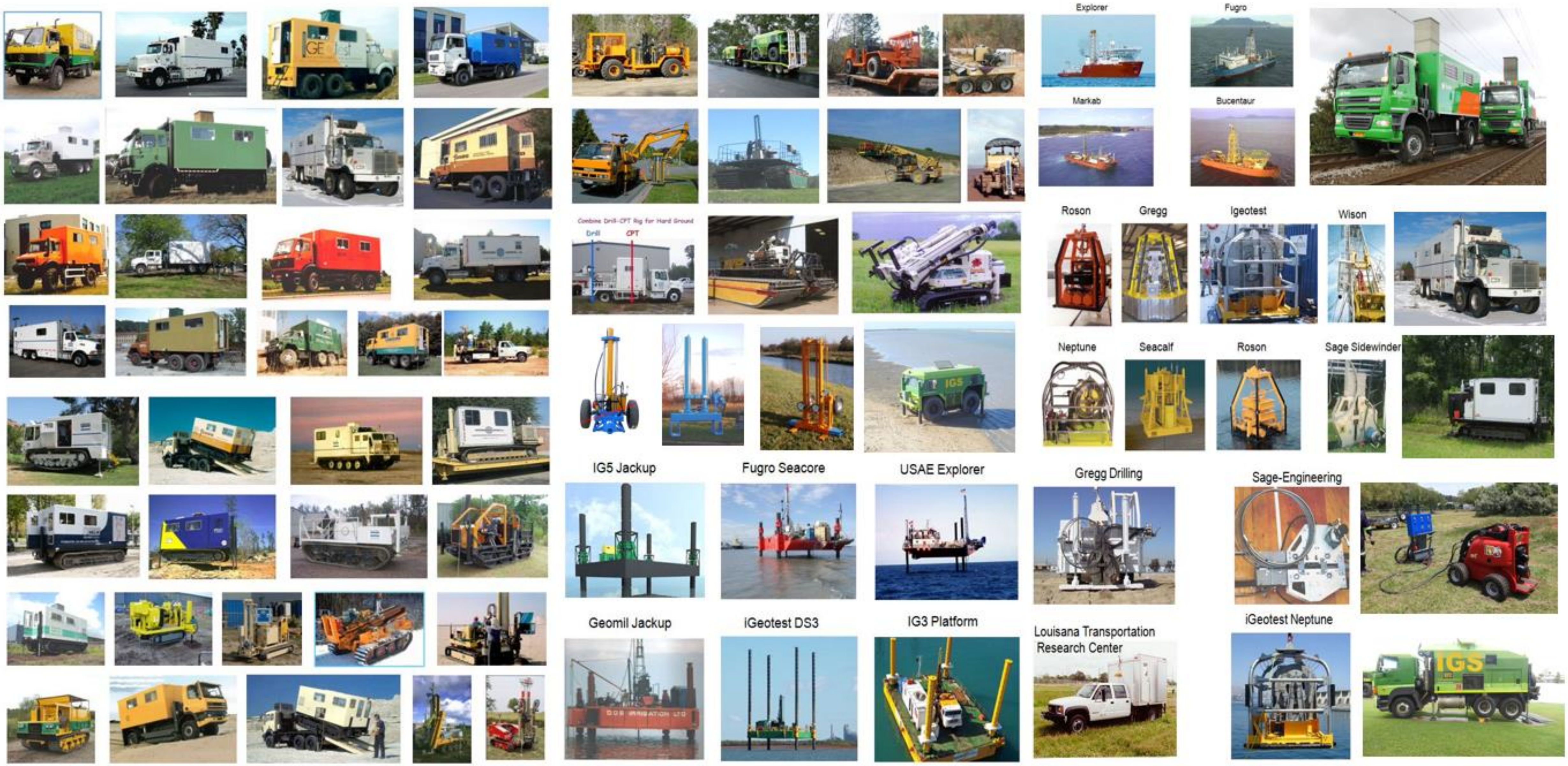
Mars Penetrometer

(inadvertently inclined CPT)

IPGP NASA InSight cnes DLR ETH MPS isae Imperial College London LOCKHEED MARTIN

Cone Penetration Rig

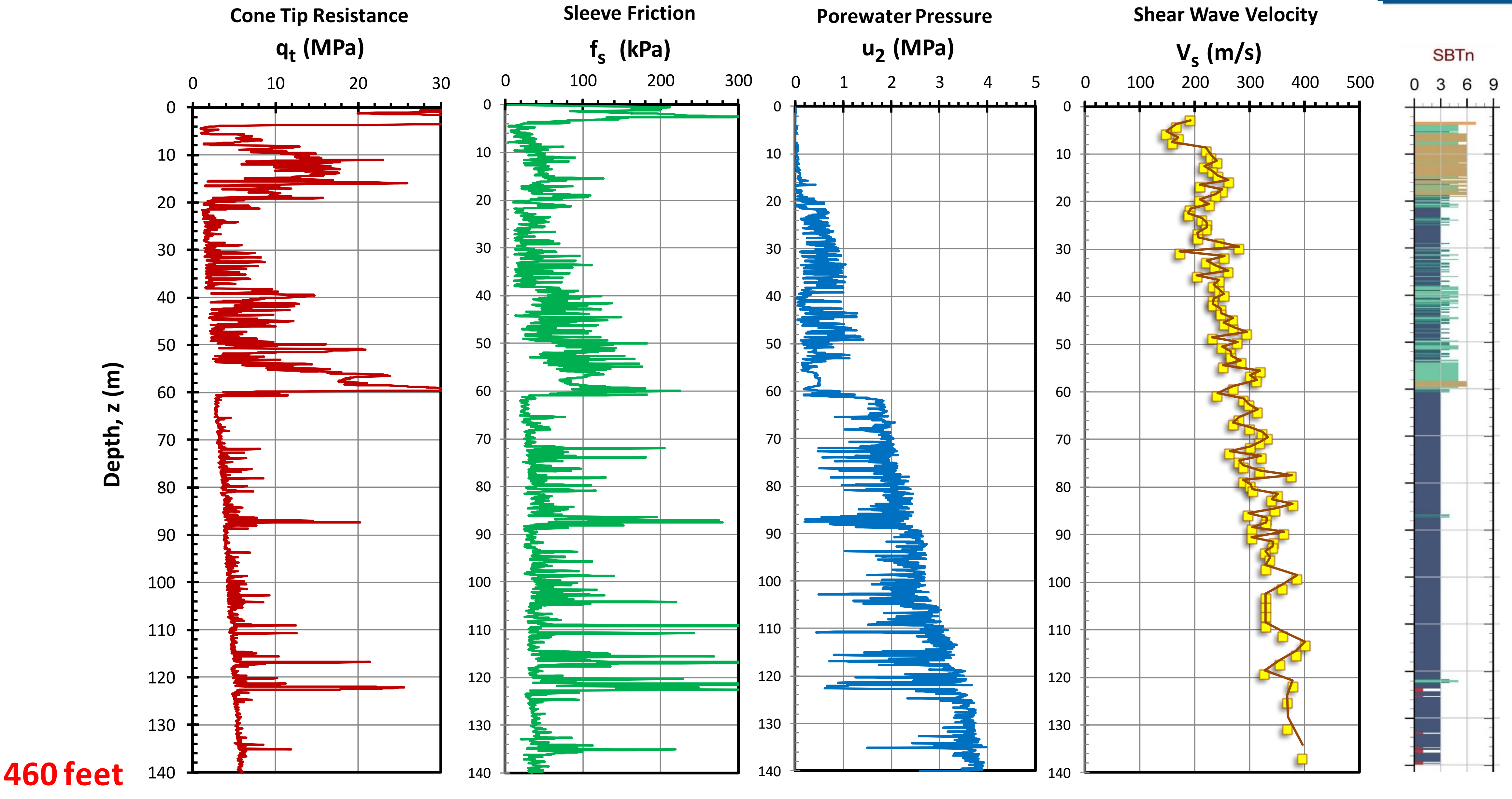
Cone Penetration Rigs and Vehicles



New Electric-Diesel Hybrid CPT Rig

Hybrid-EV Powered CPT Site Characterization

140-m deep SCPTU - Fraser River Delta, BC



Arizona State University | Georgia Tech | NM State University | UC Davis University of California

CBBG Self-Burrowing Robotic Integrated Sensor System

Courtesy:
Chloe Arson - GT

CBBG
Center for Bio-mediated & Bio-inspired Geotechnics

NSF

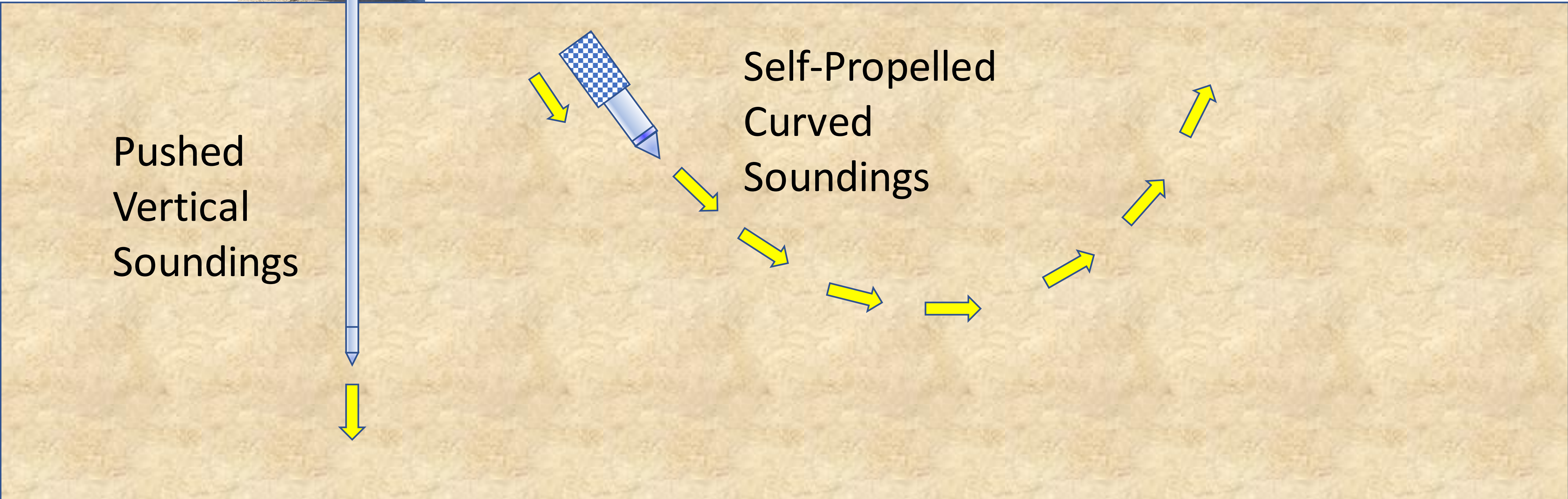
Center for Bio-mediated & Bio-inspired Geotechnics

CBBG Self-Burrowing Robotic Integrated Sensor System

NOW in 2023

BACK TO THE FUTURE - 1,000,000 years of evolution by plants and self-propelling animals (earthworms)

Researchers: Chloe Arson/GT, Alexandro Martinez/UCD
Jason DeJong/UCD; J. David Frost/GT



Specialized CPTs

- Resistivity Cones
- Seismic CPT
- Cone Pressuremeter
- Conductivity CPT
- Gamma CPT
- pH CPTu
- Vision CPT (VisCPT)
- Dielectric CPTu
- Acoustic CPT
- Radio-isotope CPT
- Vibrocone (VCPT)
- Thermal (TCPT)

Any unanswered Questions ?   Please see……

ChatCPT

Open AI

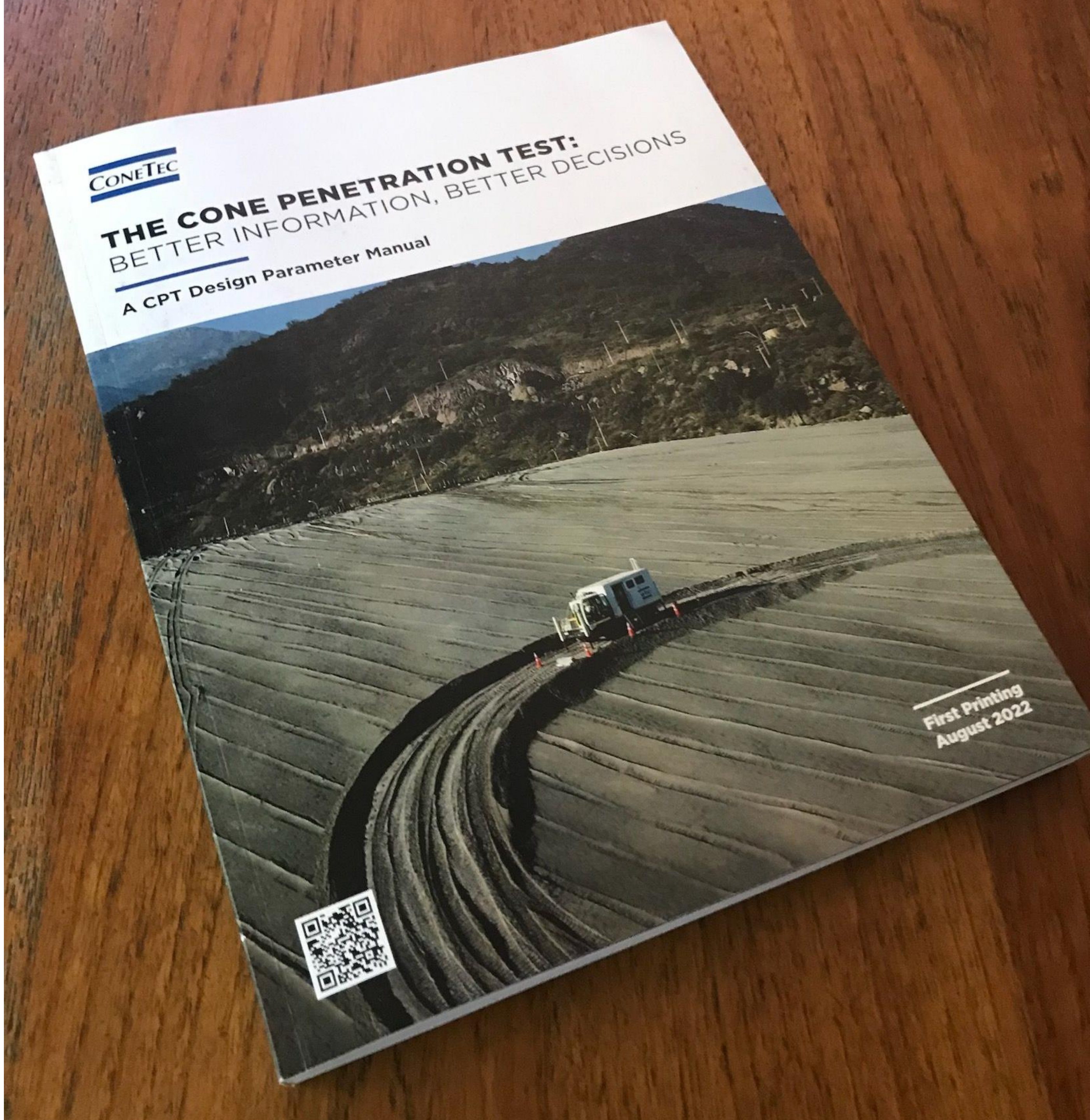
ConeTec CPT Manual (2023)

Paul W. Mayne
Ethan Cargill
Jim Greig

Free PDF download from:

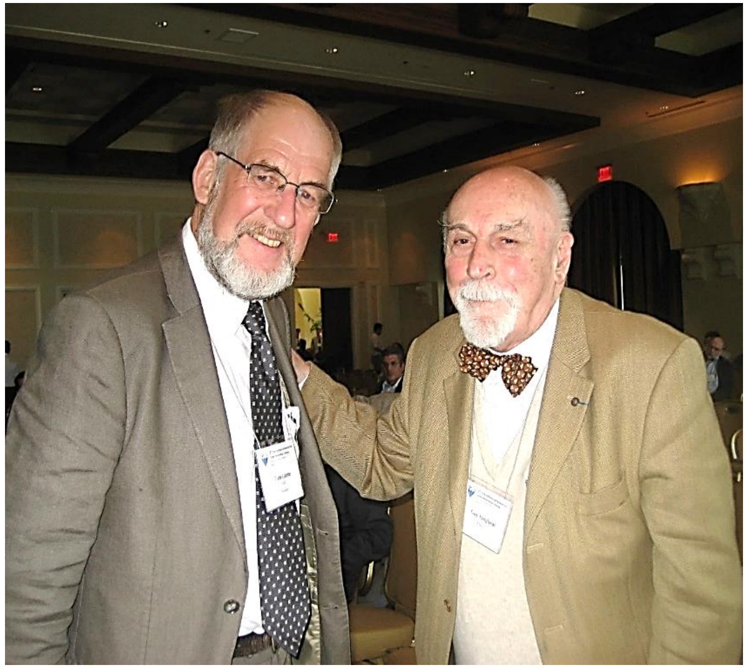
www.conetec.com

257 pages

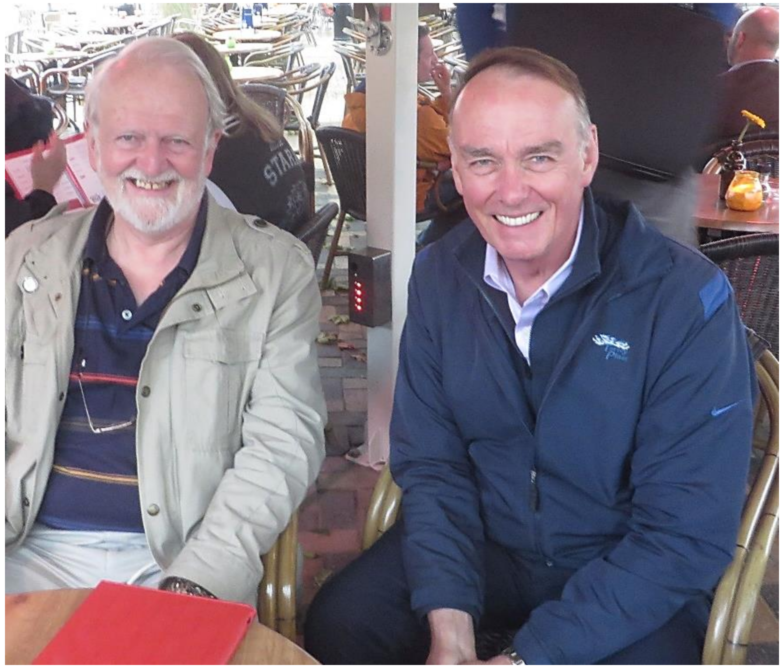


Some Famous ConeHeads

Tom Lunne and
Guy Sanglerat

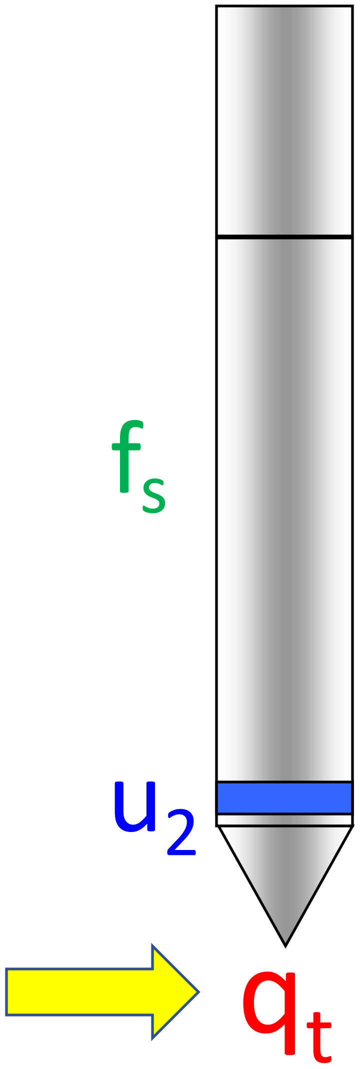


John Powell and
Peter Robertson



Band U2 formed in 1976

New Musical Band "qt"



Lead Vocalist:
Inger Sofie Senneset

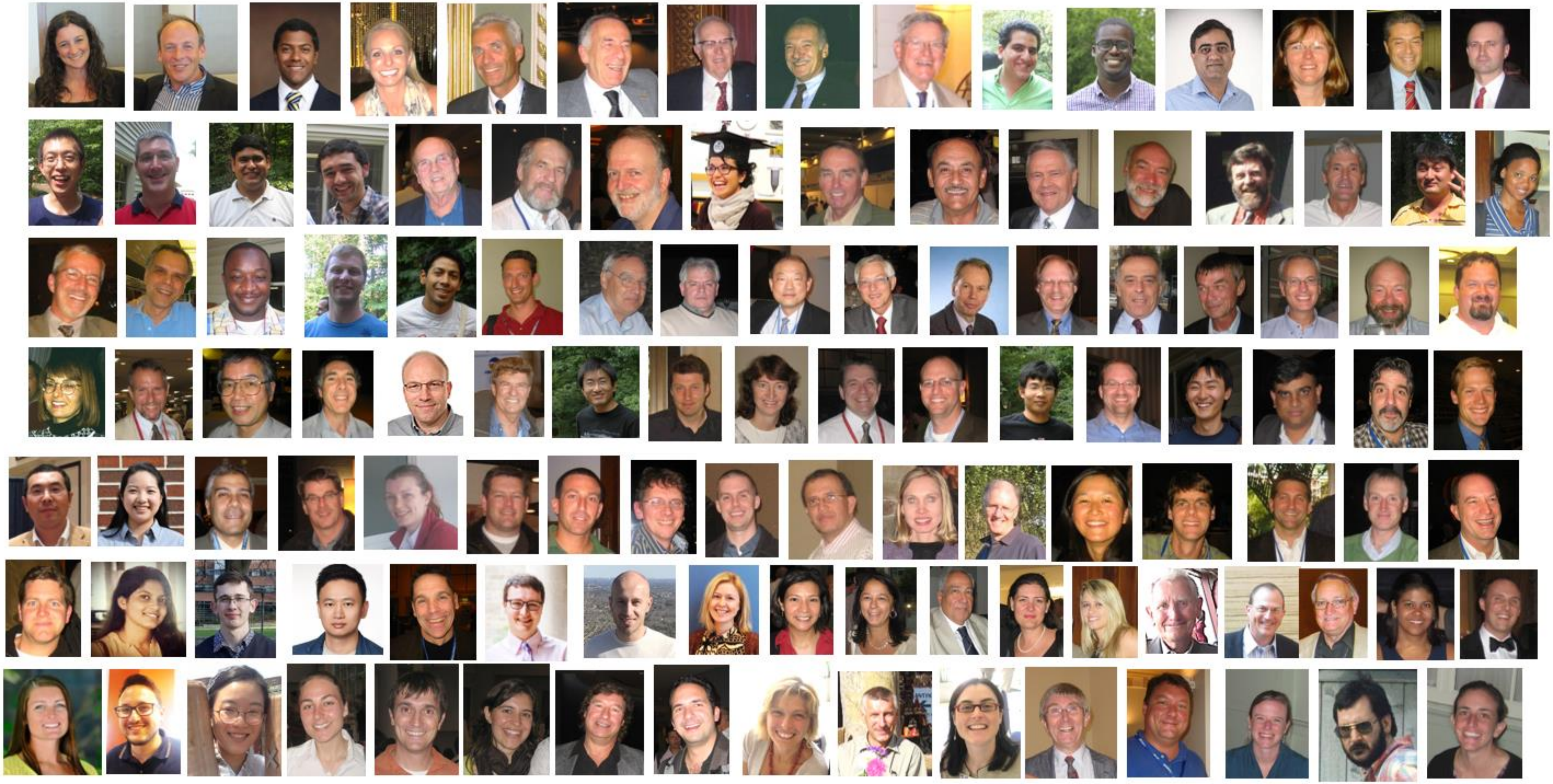
A real "**Cutie**"
pronounced "qu-tee"

(Also a beer drinker)

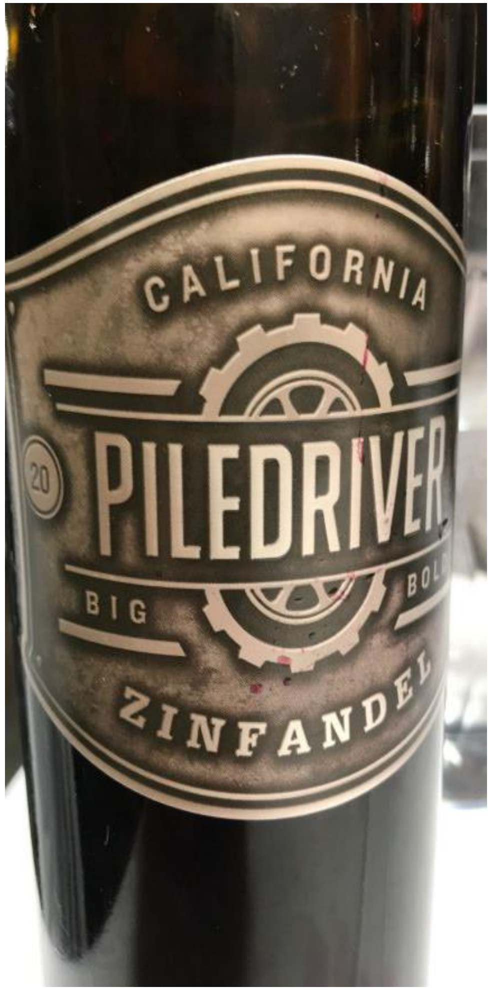
Lead
Guitarist
for the band **qt**

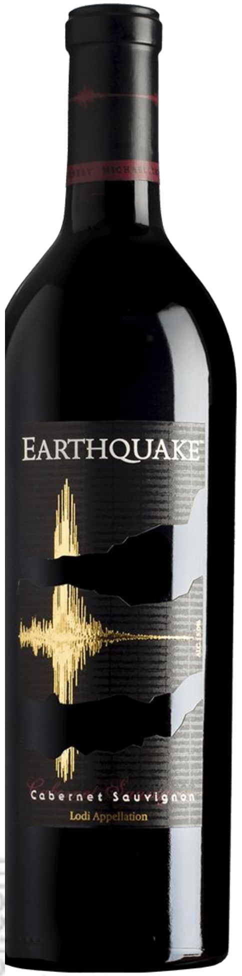
Kaare
Senneset

ConeHeads from Around the World



Wines for ConeHeads





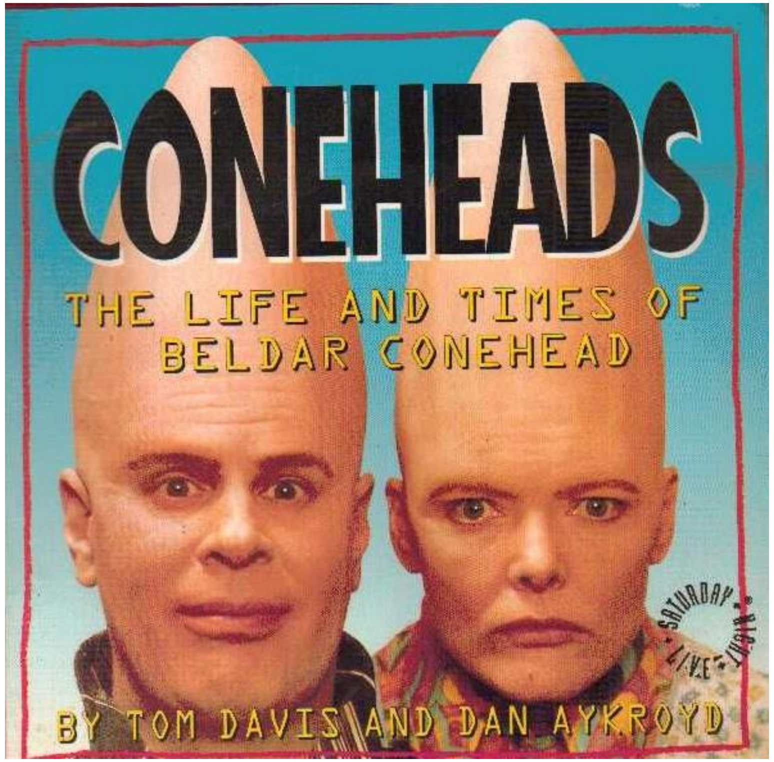
The Geotech Mascot is the Groundhog

Groundhog = Marmot = Woodchuck = Whistlepig

Whiskey

$4369/bottle

What is the preferred alcoholic beverage by ConeHeads?



Cognac

KU THE UNIVERSITY OF KANSAS

CONETEC

MDOT
Michigan Department of Transportation

G-I ASCE
60TH ANNIVERSARY
KARL TERZAGHI LECTURE
EST. 1963

GT

ICT ILLINOIS CENTER FOR TRANSPORTATION

mn DEPARTMENT OF TRANSPORTATION

G-I ASCE