



2014 Hoover Distinguished Lecture

38th ASCE IOWA SECTION GEOTECHNICAL CONFERENCE

**GeoCharacterization for Shallow and
Deep Foundations Using Hybrid
Geotechnical-Geophysical In-Situ Tests**

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Purposes: Geotechnical Site Investigation

- Required for all geotechnical projects
- Determine geostratigraphy for site development
- Information for foundation design
- Data for geotechnical parameter evaluation
- Input to analytical models and numerical FEM
- Minimize problems during construction
- Mitigate potential for legal involvement

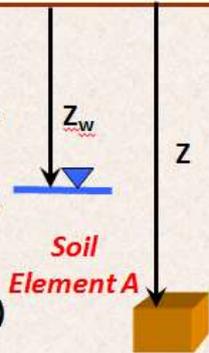
GeoCharacterization



Initial Conditions

INDICES

- Geologic Origin
- Age, A_G
- Grain Sizes, D_{50}
- Mineralogy
- Plasticity, PI
- Shape (fractals)
- Sphericity, S_{ph}
- Roundness, R_n
- Angularity, A_{ng}
- Packing limits: e_{max} and e_{min}
- Specific Surface, S_s
- Particle characteristics for DEM:
 - crushing strength
 - modulus
 - roughness
 - friction



STATE

- Void Ratio, e_0
- Unit Weight, γ_T
- Relative Density, D_R
- State Parameter, Ψ
- Vertical Stress, σ_{vo}
- Hydrostatic Pressure, u_0
- Yield Stress Ratio, YSR
- Saturation, S (%)
- Geostatic $K_0 = \sigma_{ho}' / \sigma_{vo}'$
- Stiffness, $G_0 = G_{max}$
- State Parameter, ψ
- Degree of cementation
- Fabric and void index, I_{vo}
- Continuity
 - intact
 - fissured

Geoengineering Parameters

CONDUCTIVITY

- Hydraulic: k_v, k_h
- Thermal: k_e
- Electrical: Ω, ζ
- Chemical: D_f
- Transmissivity, T_m
- Permittivity, P_m

COMPRESSIBILITY

- Recompression index, C_r
- Yield Stress, σ_v' (and YSR)
- Preconsolidation, σ_p' (and OCR)
- Coefficient of Consolidation, c_v
- Virgin Compression index, C_c
- Swelling index, C_s

RHEOLOGICAL

- Strain rate, $\delta\varepsilon/\delta t$
- Time since consolidation (T)
- Secondary compression, $C_{\alpha\varepsilon}$
- Creep rate, α_R
- Time to failure, t_f

STIFFNESS

- Stiffness: $G_0 = G_{max}$
- Shear Modulus, G' and G_u
- Elastic Modulus, E' and E_u
- Bulk Modulus, K'
- Constrained Modulus, D'
- Tensile Stiffness, K_T
- Poisson's Ratio, ν
- Effects of Anisotropy (G_{vh}/G_{hh})
- Nonlinearity (G/G_{max} vs γ_s)
- Subgrade Modulus, k_s
- Spring Constants, k_z, k_x, k_w, k_θ

STRENGTH

- Drained and Undrained, τ_{max}
- Peak (s_u, c', ϕ')
- Post-peak, τ'
- Remolded strength
- Softened or critical state, s_u (rem)
- Residual (c_r', ϕ_r')
- Cyclic Behavior (τ_{cyc}/σ_{vo}')

Quote from Lord Kelvin (1883):

"...when you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind"

Jaksa (2005)

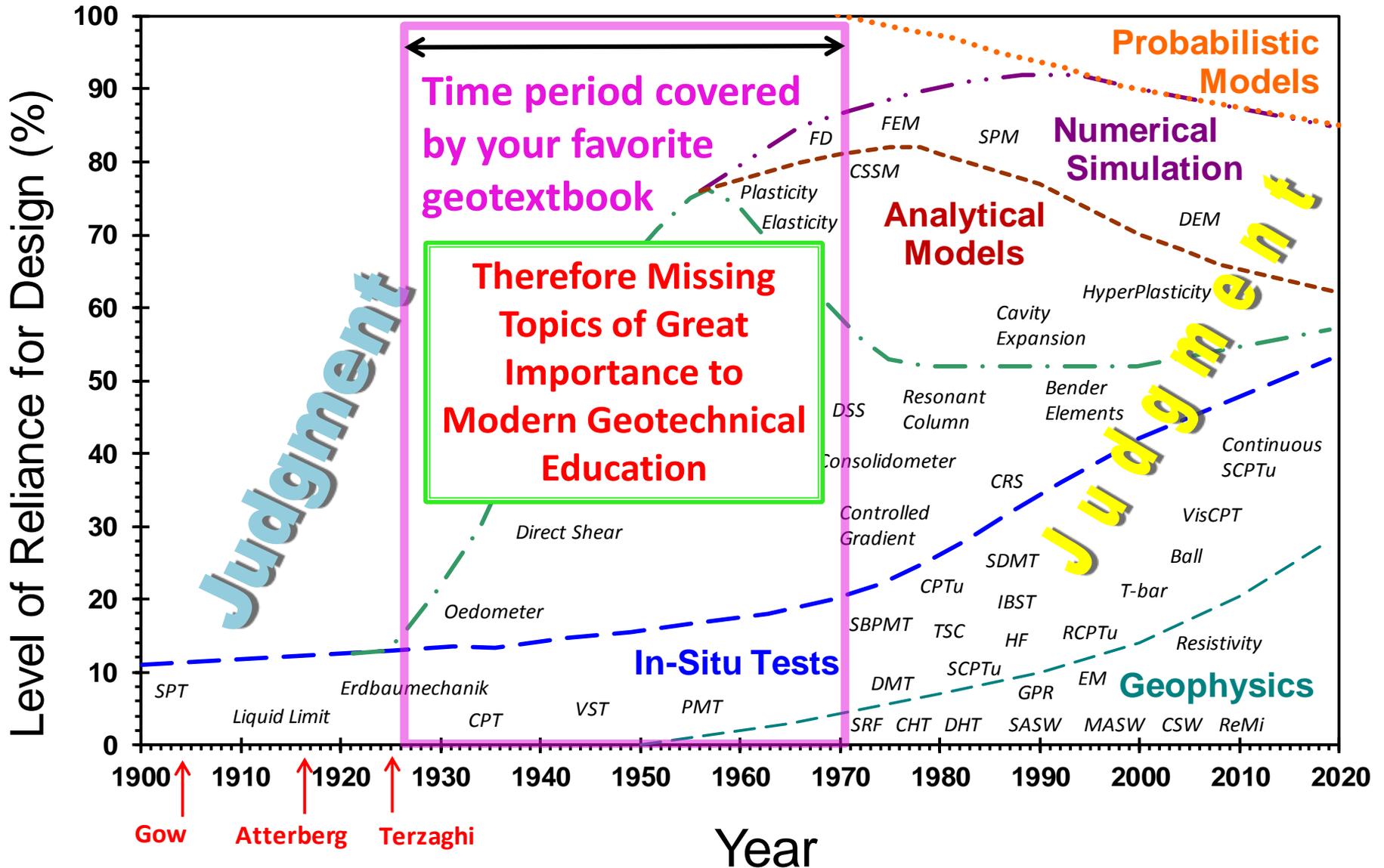
GeoCharacterization in 2014

- This talk is part **State-of-the-Art (SOA)**
= What we COULD be doing
- This talk also part **State-of-the-Practice (SOP)**
= What we ARE doing
- Limited time, so focus on *geocharacterization*
- Intro GeoCourse needs more balance of geophysics + in-situ + lab testing
- This talk = part **SOA** + part **SOP** → betterment

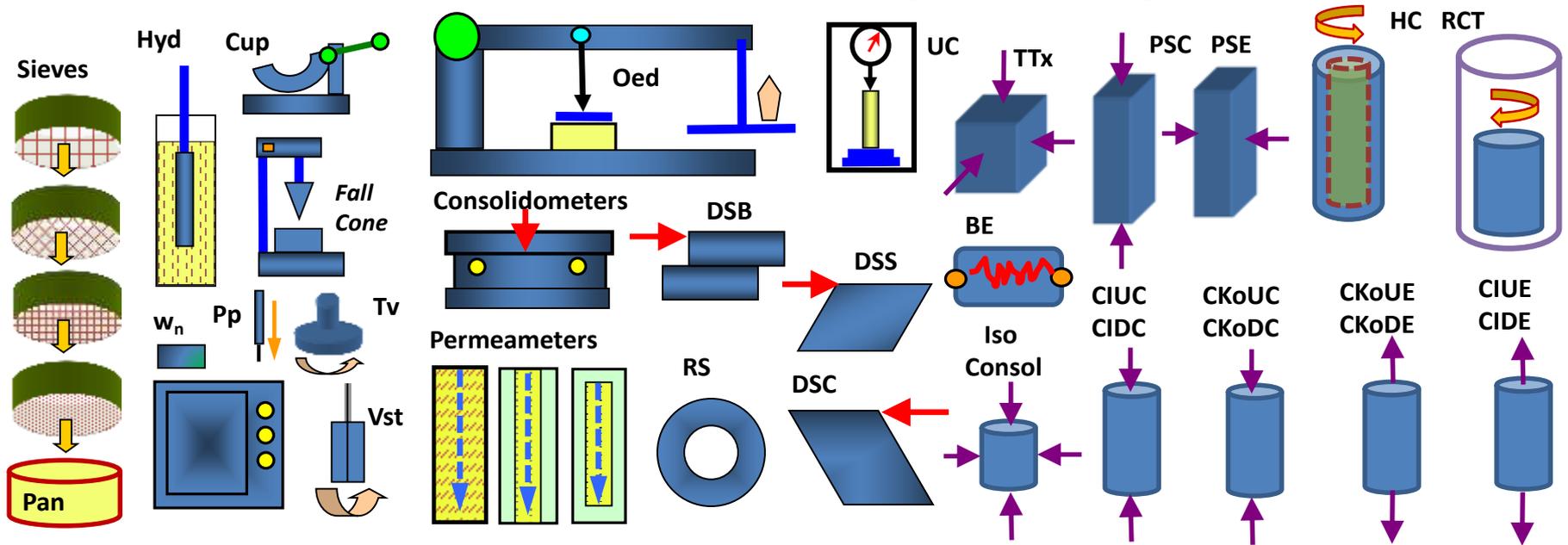
Mayne ≠ SOB

Evolution of Geotechnical Site Characterization

Modified after Lacasse (1985)



Geotechnical Laboratory Testing Devices



Grain size analyses
Hydrometer
Water content by oven
Liquid limit cup
Electron microscopy
Plastic limit thread
Fall cone device
Pocket penetrometer
Torvane
Unconfined compression
Miniature vane
Digital image analysis

Mechanical oedometer
Consolidometer
Constant rate of shear (CRS)
Falling-head permeameter
Constant-head permeameter
Flow permeameter
Direct shear box
X-ray diffraction
Ring shear
Unconsolidated undrained Tx
Simple shear
Directional shear cell

Triaxial apparatus (iso-consols, CIUC, CKoUC, CAUC, CIUE, CAUE, CKoUE, stress path, CIDC, CKoDC, CIDE, CKoDE, constant P')
Plane strain apparatus (PSC, PSE)
True triaxial (cuboidal)
Hollow cylinder
Torsional Shear
Resonant Column Test device
Non-resonant column
Bender elements

Methods for Geomaterial Characterization

Soils Laboratory

Lab Rat



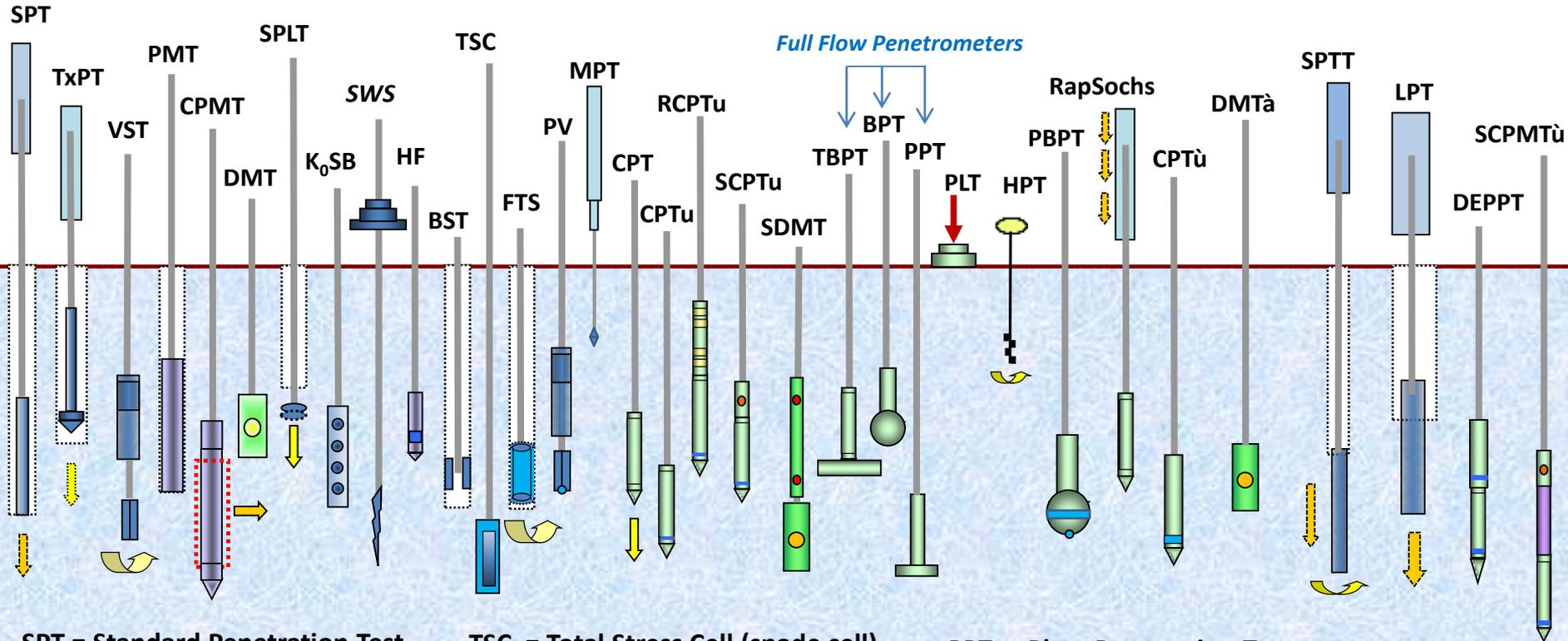
Laboratory Soils Testing

Varved Clay

- ❑ Limited number (discrete points)
- ❑ Lengthy test durations
- ❑ Affected by sample disturbance
- ❑ Expensive: Cost per specimen:
 - Oedometer = \$600 (2 weeks)
 - Automated Consolidation = \$800 (2-3 days)
 - CIUC Triaxial = \$600 (2 to 3 days)
 - CK_0 UC Triaxial = \$1500 ea (5 days)
 - Resonant Column = \$2000 ea (1 week)
 - Permeability = \$800 (1 to 2 weeks)



Field In-Situ Geotechnical Test Methods



SPT = Standard Penetration Test
TxPT = Texas Penetration Test
VST = Vane Shear Test
PMT = Pressuremeter Test
CPMT = Cone Pressuremeter
DMT = Dilatometer Test
SPLT = Screw Plate Load Test
ISB = Iowa K_0 Stepped Blade
SWS = Swedish Weight Sounding
HF = Hydraulic Fracture
BST = Borehole Shear Test

TSC = Total Stress Cell (spade cell)
FTS = Freestand Torsional Shear
PV = Piezovane
MPT = Macintosh Probe Test
CPT = Cone Penetration Test
CPTu = Piezocone Penetration
RCPTu = Resistivity Piezocone
SCPTu = Seismic Cone
SDMT = Seismic Flat Dilatometer
TBPT = T-Bar Penetrometer Test
BPT = Ball Penetrometer

PPT = Plate Penetration Test
PLT = plate load test
HPT = Helical Probe Test
PBPT = piezoball penetration test
RapSochs = Rapid soil characterization system
CPTu = piezodissipation test
DMT_a = Dilatometer with A-reading dissipations
SPTT = Standard Penetration Test with Torque
LPT = Large Penetration Test
DEPPT = Dual Element PiezoProbe Test
SCPMTu = Seismic Piezocone Pressuremeter

Geotechnical Methods for Site Investigation

Soils Laboratory

Lab Rat



In-Situ Testing

Field Mouse



Ball penetrometer testing

Home Appliances

1902

Office Equipment

Telegraph



Stove



Sewing Machine



Horse & Buggy



Casagrande Cup



Split-Spoon



Abacus



Note: Not to scale

Home Appliances

Telephone



Refridgerator



Gas Automobile



Television



Washer



1950

Office Equipment

Casagrande Cup



Split-Spoon



Slide Rule



Note: Not to scale

Home Appliances

2014

Office Equipment

smartphone



3-d LED Television



Refridgerator



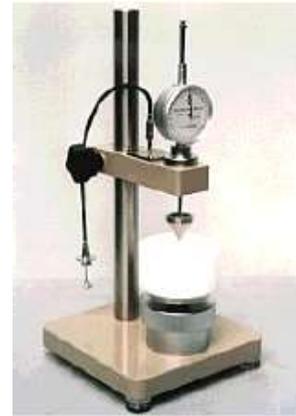
Washer



Electric Automobile



Liquid Limit



Split-Spoon



Tablet



Note: Not to scale

Calibration of SPT Energy - Auto Hammers

Manufacturer Type	ID No.	Mean Energy Ratio (%)	Reference
Diedrich D-120	ID 26	46	UDOT
Diedrich D-50	321870551	56	GRL
CME 850	ID 21	62.7	UDOT
BK-81 w/ AW-J rods	B2	68.6	ASCE
Mobile B-80	ID 18	70.4	UDOT
SK w/ CME hammer	B6	72.9	ASCE
Diedrich D50	UF5	76	UF
CME 55	UF2	78.4	FDOT
CME 850	296002	79	GRL
CME 45	UF1	80.7	UF
CME 85	UF4	81.2	UF
CME 75 w/ AW-J rods	A3	81.4	ASCE
CME 75	UF3	83.1	UF
CME 750	ID 4	86.6	UDOT
Mobile B-57	DR-35	93	GRL
CME 75 rig	ID 10	94.6	UDOT

Factor
of 2.1

Is One Number Enough???

c_u = undrained strength

γ_T = unit weight

I_R = rigidity index

ϕ' = friction angle

OCR = overconsolidation

K_0 = lateral stress state

e_o = void ratio

V_s = shear wave

E' = Young's modulus

C_c = compression index

q_b = pile end bearing

f_s = pile skin friction

k = permeability

q_a = bearing stress

D_R = relative density

γ_T = unit weight

LI = liquefaction index

ϕ' = friction angle

c' = cohesion intercept

e_o = void ratio

q_a = bearing capacity

σ_p' = preconsolidation

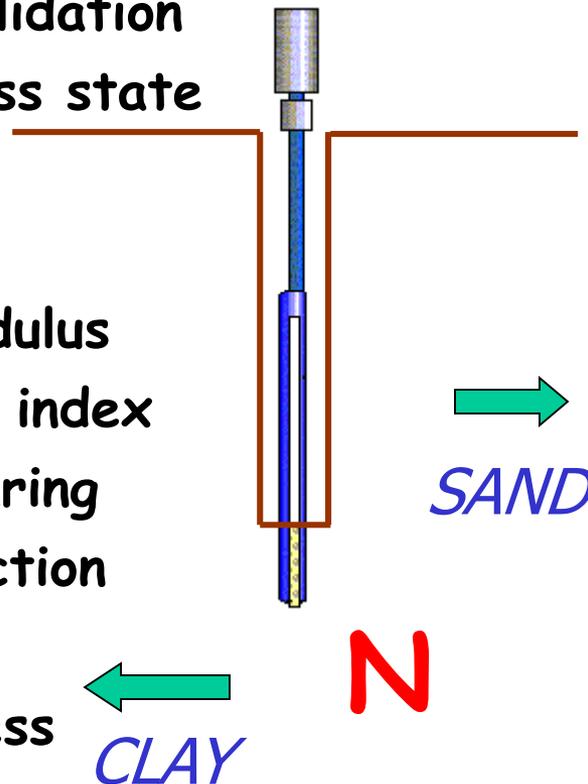
V_s = shear wave

E' = Young's modulus

Ψ = dilatancy angle

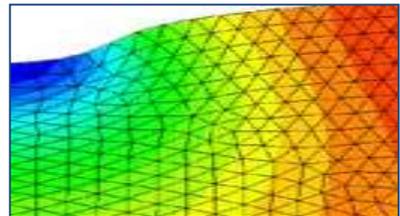
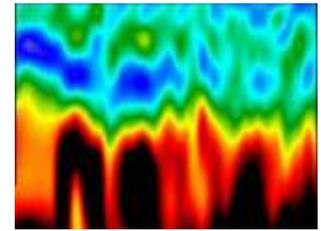
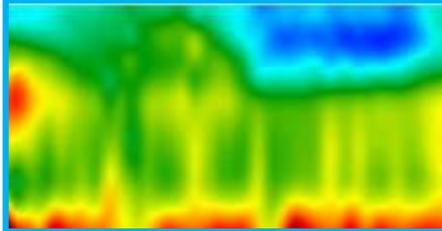
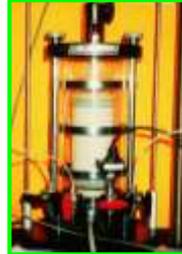
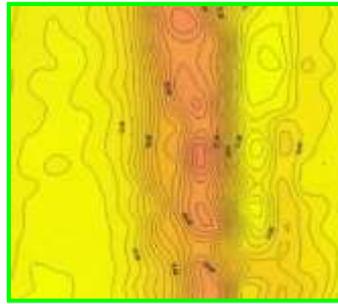
q_b = pile end bearing

f_s = pile skin friction



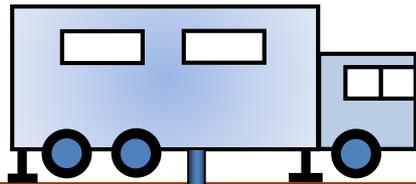
Geomaterial Characterization 2014

Need a Variety of Different Methods to Truly and Fully Ascertain Soil Parameters

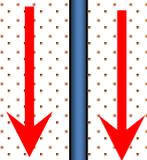


Cone rig with hydraulic pushing system

Cone Penetration Test (CPT)



- ASTM D-5778 Field Test Procedures
- Continuous push at 20 mm/s
- Add rods at 1-m vertical intervals



f_s
 u_2
 q_t

Readings taken every 1 or 5 cm

Electronic Penetrometer

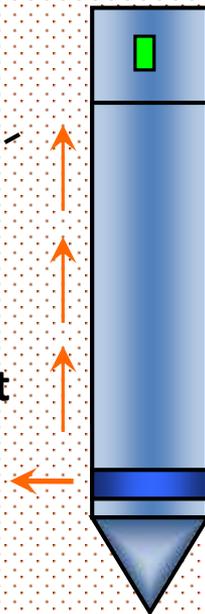
i_c = inclination

f_s = sleeve friction resistance

u_m = porewater pressure

q_c = measured tip resistance

q_t = total cone tip resistance



enlargement



CPT

- Current Phase Tranformer
- Cross Product Team
- Cellular Paging Teleservice
- Chest Percussion Therapy
- Crisis Planning Team
- Consumer Protection Trends
- Computer Placement Test
- Current Procedural Terminolgy
- Cost Per Treatment
- Choroid Plexus Tumor
- Cardiopulmonary Physical Therapy
- Corrugated Plastic Tubing
- Cumulative Price Threshold
- Cell Prepartion Tube
- Central Payment Tool
- Certified Proctology Technologist 
- Cockpit Procedures Trainer
- Cone Penetration Test 
- Color Picture Tube
- Critical Pitting Temperature
- Certified Phelbotomy Technician
- Control Power Transformer
- Cost Production Team
- Channel Product Table
- Conditional Probability Table
- Command Post Terminal

Cone Penetrometer Testing



- **Electronic Steel Probes with 60° Apex Tip**
- **ASTM D 5778 Procedures**
- **Hydraulic Push at 20 mm/s**
- **No Boring, No Samples, No Cuttings, No Spoil**
- **Continuous readings of stress, friction, pressure**

Cone Penetration Vehicles

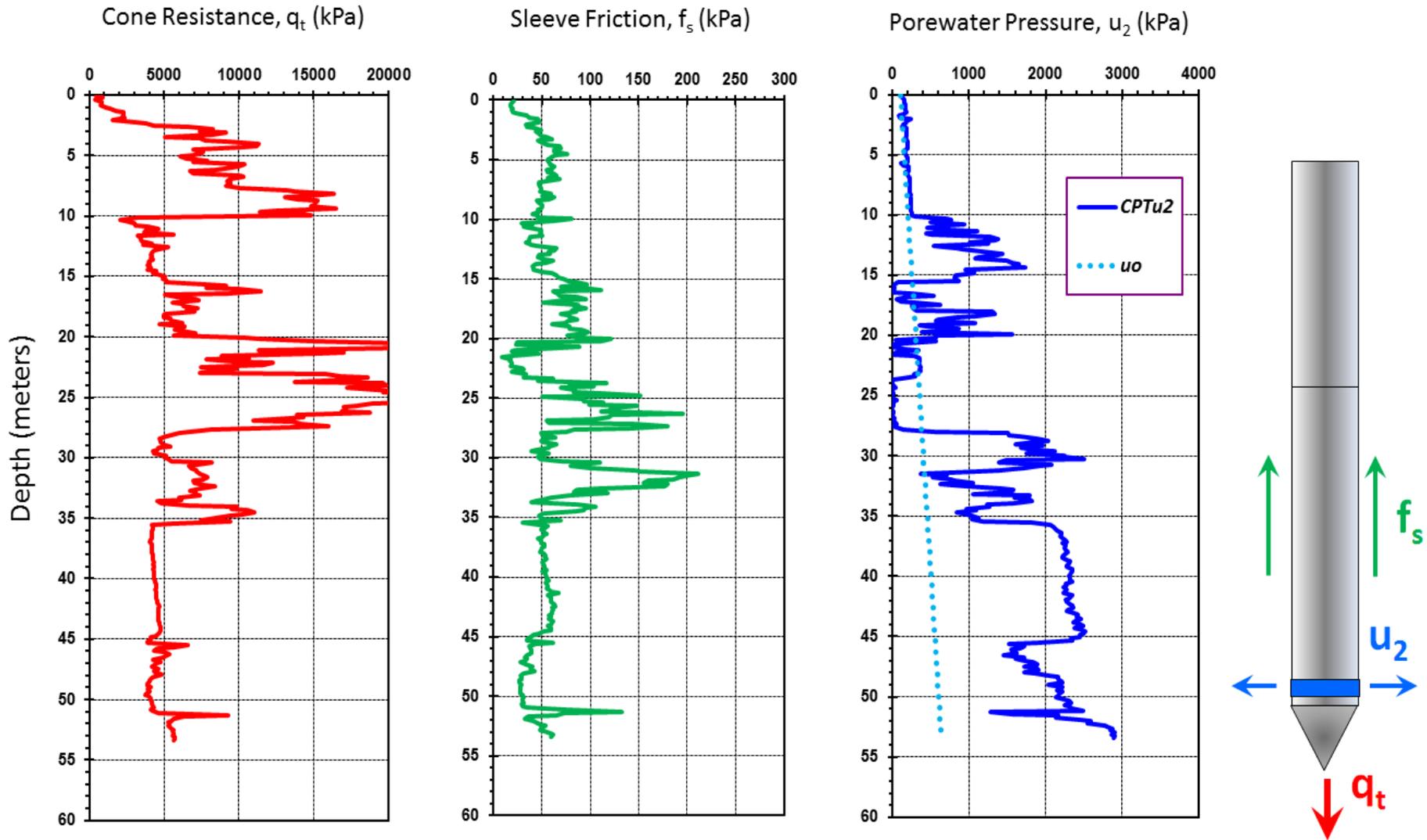
InDOT



Cone Penetration Vehicles



Geostratigraphy by CPTu in Portsmouth, Virginia



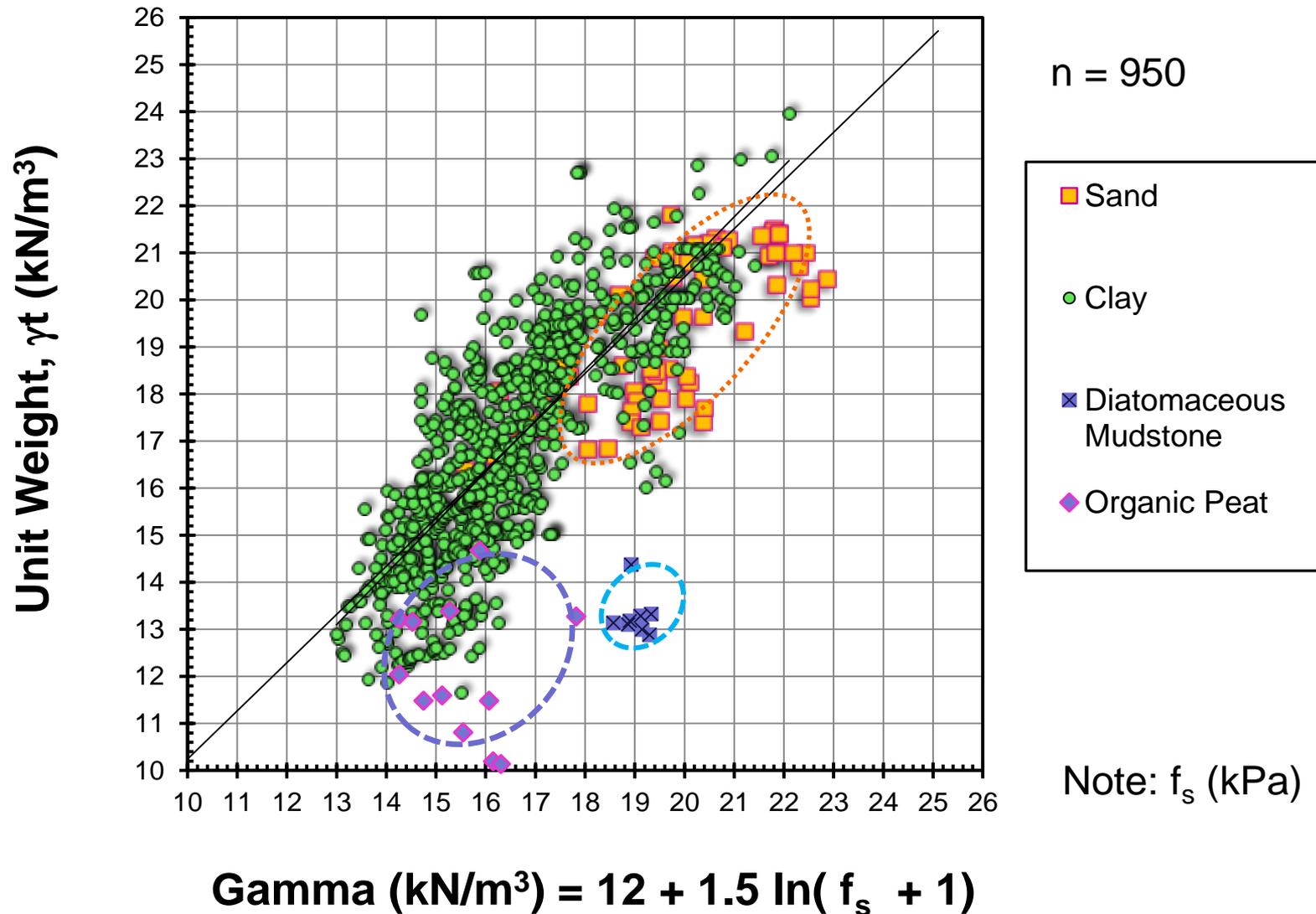
Georgia Tech Anchored Cone Rig



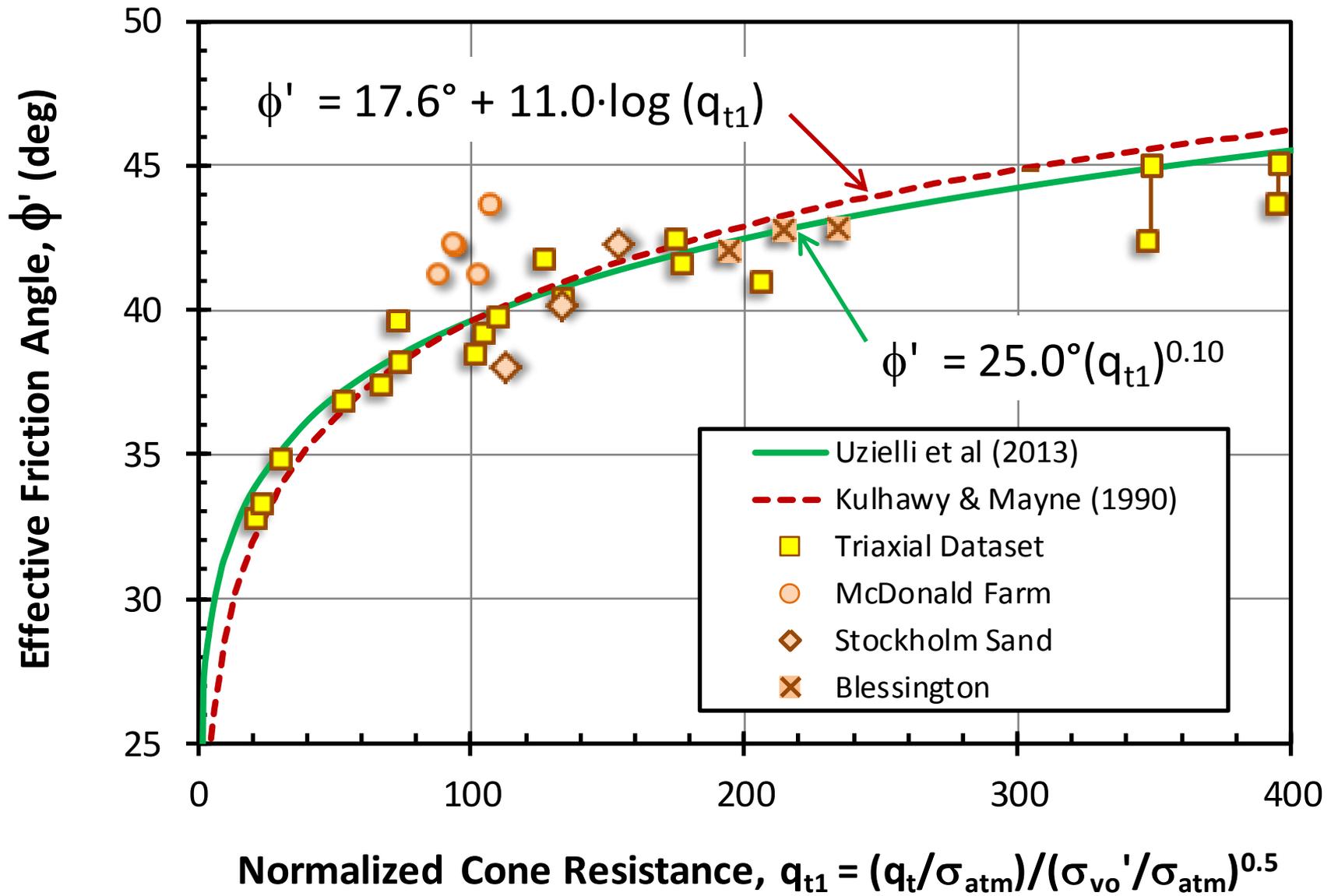
Downtown Atlanta, Georgia

- ❑ 6-tonne CPT truck with 20-tonne hydraulic pushing system
- ❑ No special license
- ❑ Twin earth anchors
- ❑ Has been used at sites in GA, VA, NC, SC, IL, FL, AR, MO, TN, KY, and AL

Quick Estimate of Unit Weight by CPTu



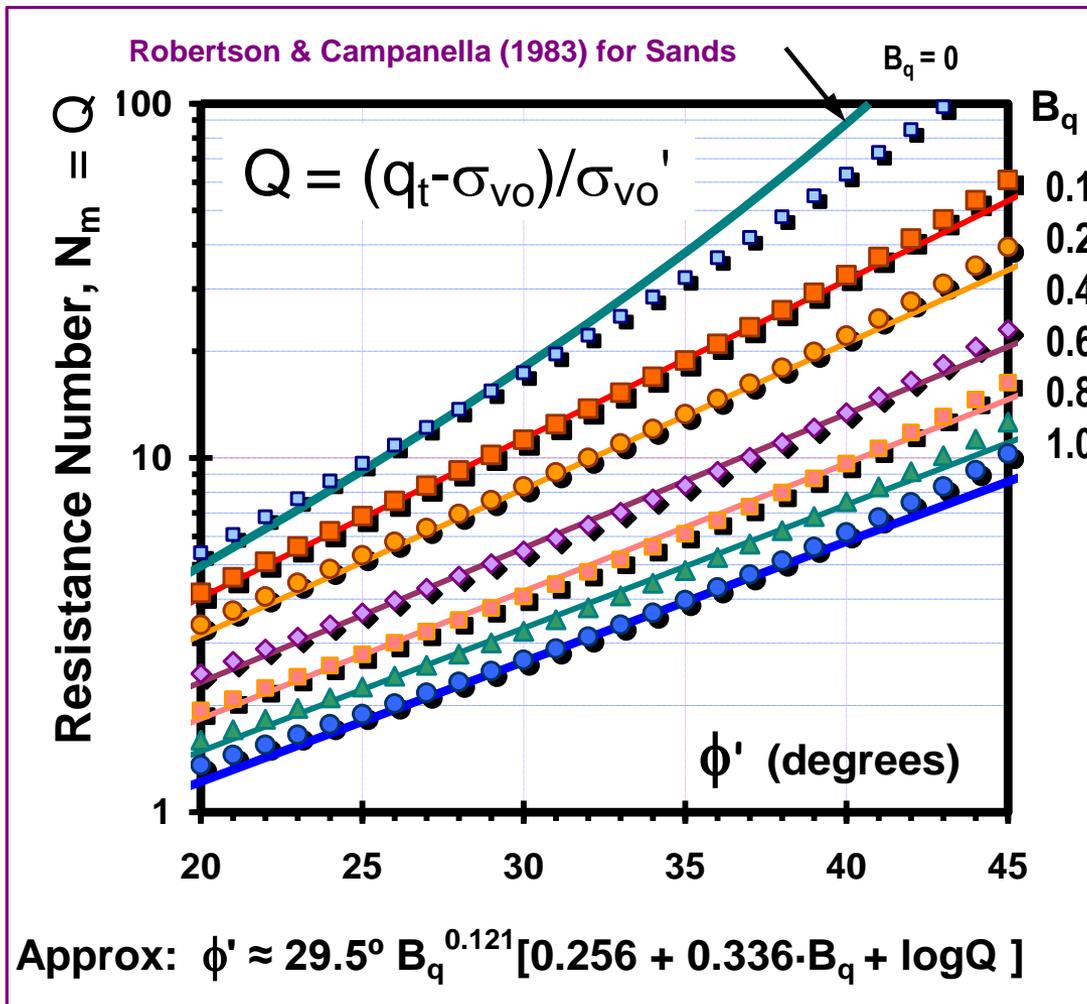
Friction Angle of Undisturbed Sands



Friction Angle ϕ' from CPTU for clays & silts (OCR < 2)

Norwegian Institute of Technology: Senneset et al (1989); Sandven (CPT'95)

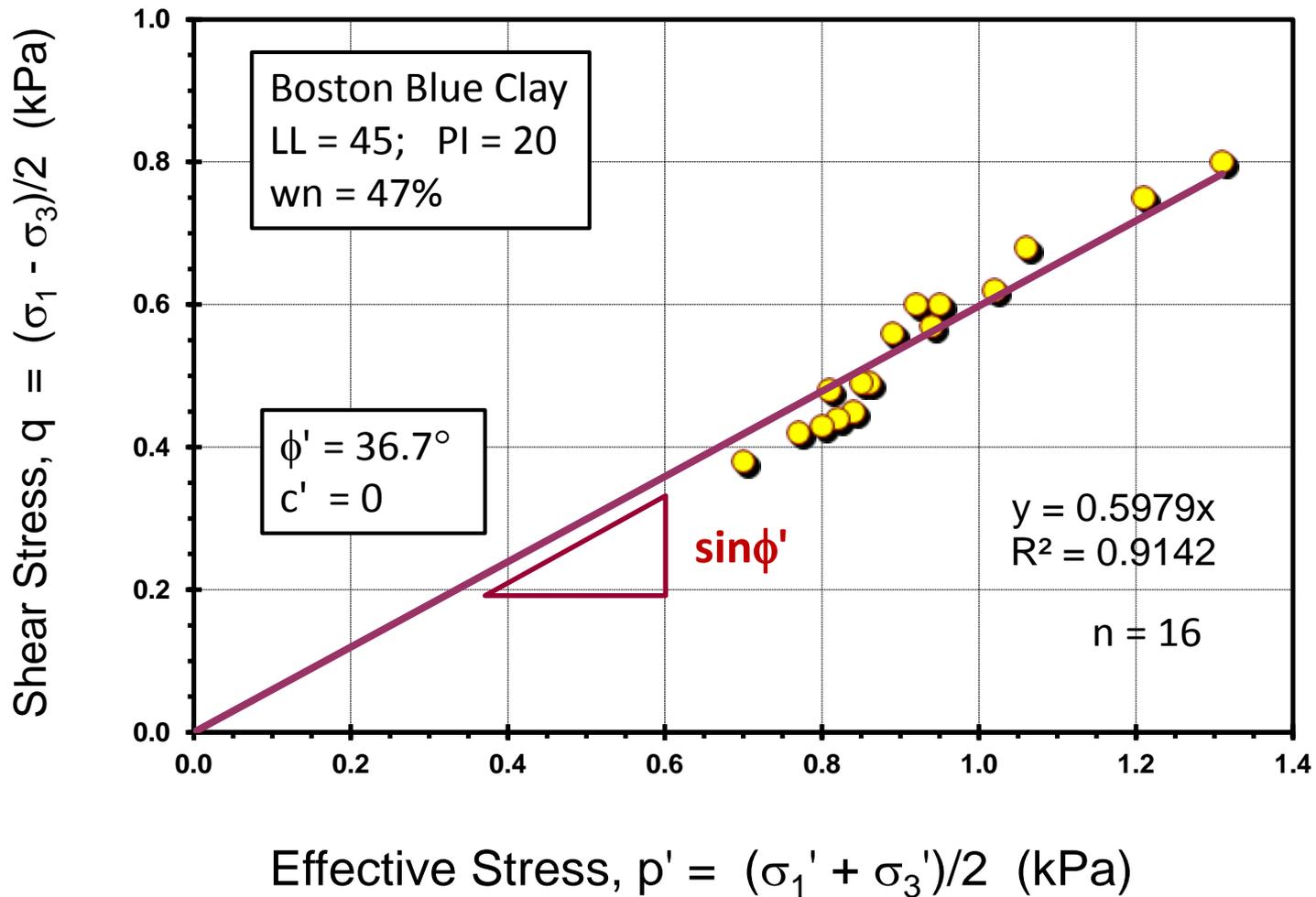
$$\phi' = 29.5 B_q^{0.121} [0.256 + 0.336 B_q + \log Q] \quad \text{where } B_q = (u_2 - u_0)/(q_t - \sigma_{vo})$$



Notes for NTNU Method:

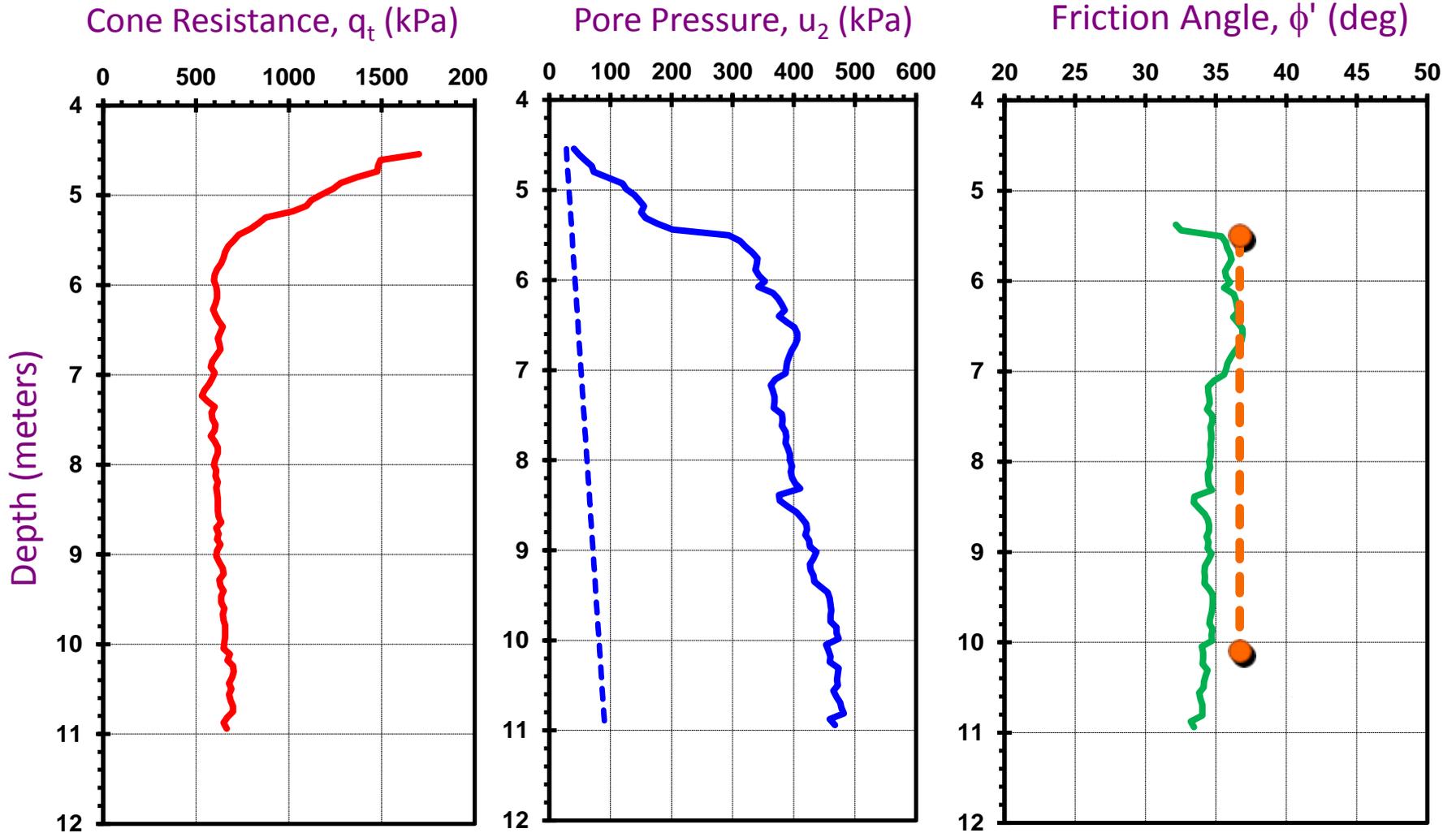
1. Define Cone Resistance Number: $N_m = (q_t - \sigma_{vo}) / (\sigma_{vo}' + a')$
2. Attraction: $a' = c' \cot \phi'$ where ϕ' = effective friction angle and c' = effective cohesion intercept.
3. For case where $a' = c' = 0$:
 $N_M = Q = (q_t - \sigma_{vo}) / \sigma_{vo}'$
4. Define Porewater Pressure Parameter: $B_q = \Delta u_2 / (q_t - \sigma_{vo})$
5. Approximate Expression Given for Ranges: $0.1 < B_q < 1.0$ and $20^\circ < \phi' < 45^\circ$
6. Plastification angle, $\beta_p = 0$

CK₀UC Triaxial Tests, Newbury, Massachusetts (Landon, 2007, U-Mass-Amherst)

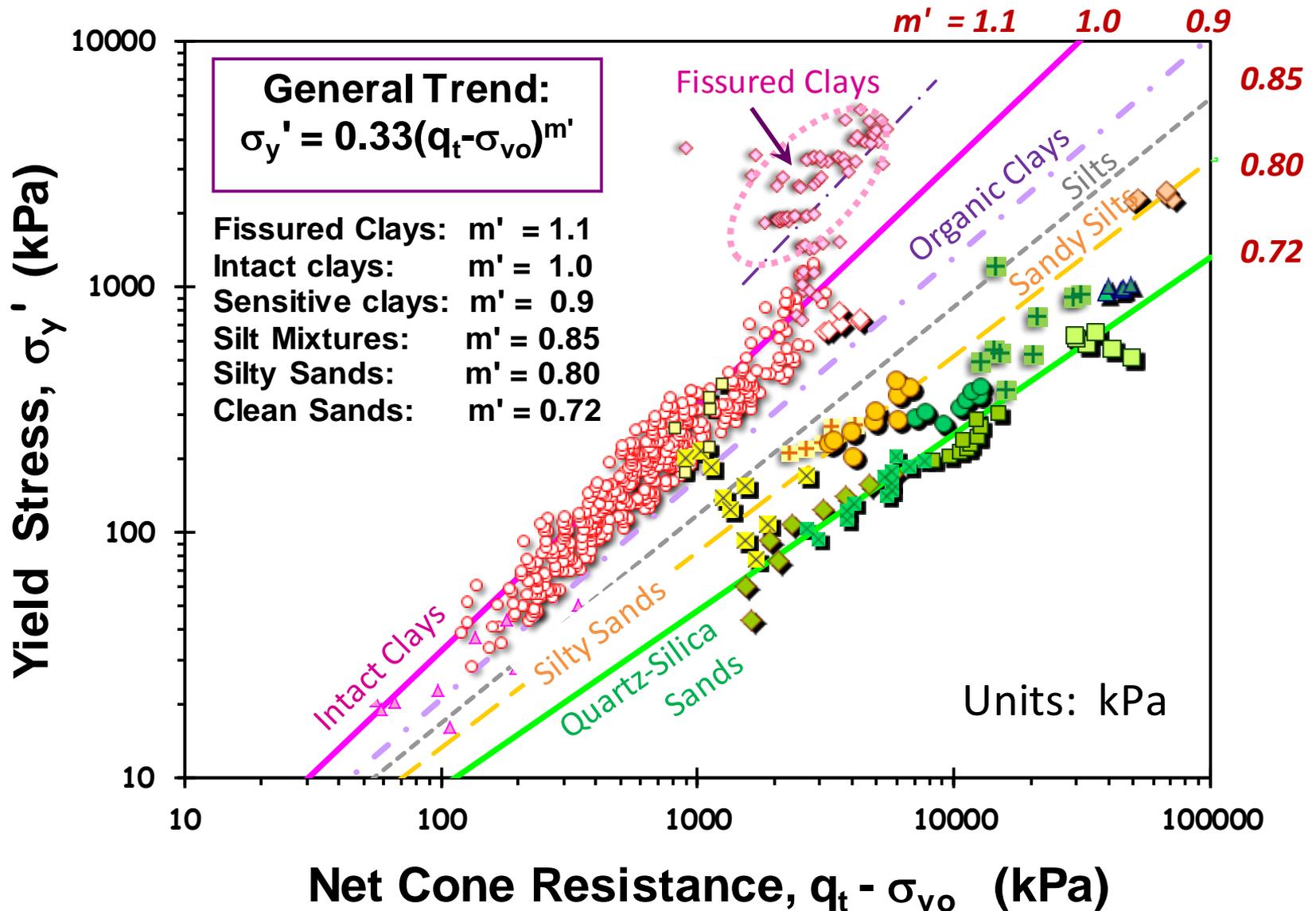


Newbury, Massachusetts

(Landon, 2007, U-Mass-Amherst)



Yield stress in soils from CPT



Blessington Sand Site

University of College Dublin (UCD)

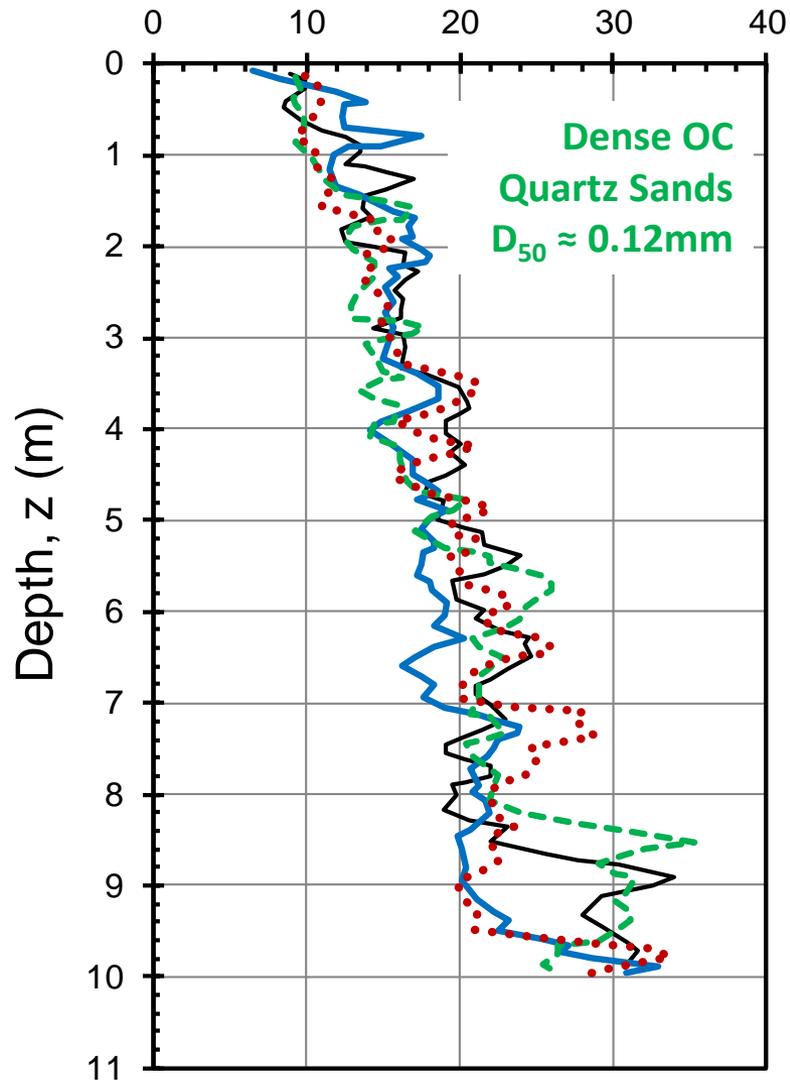
Doherty et al. (2012)

Tolooiyan & Gavin (2011)

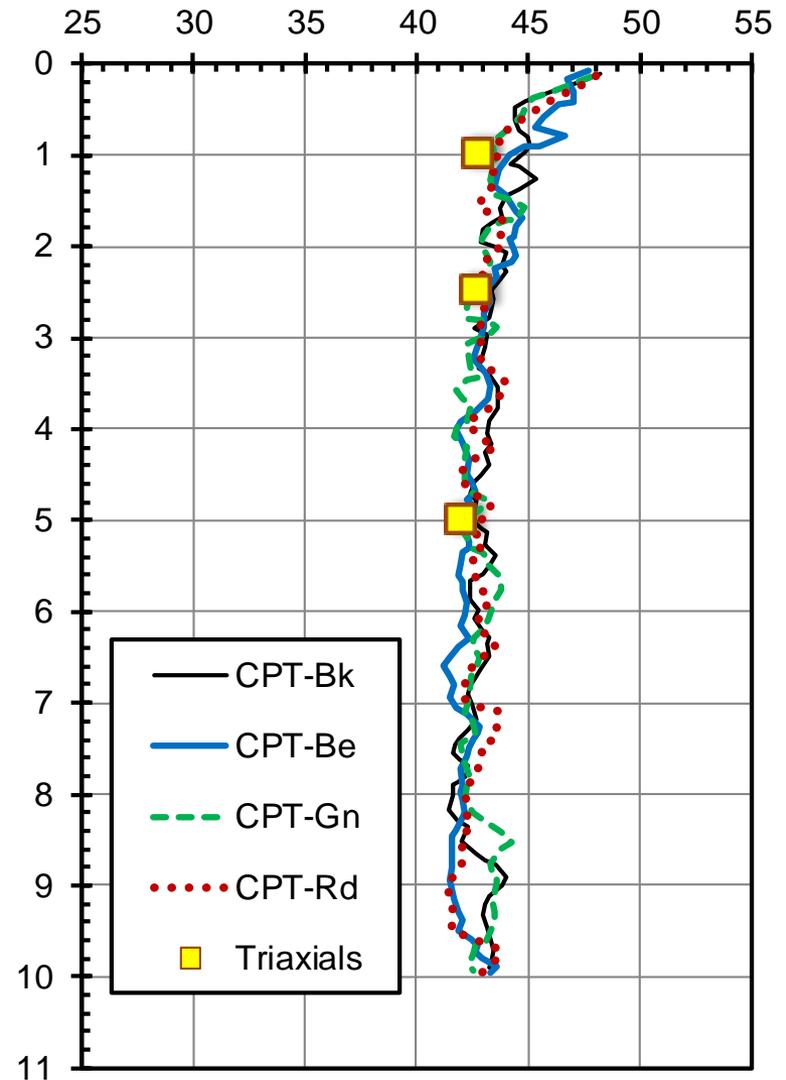


Blessington Sands, Ireland (Doherty et al 2012)

Cone Resistance, q_t (MPa)

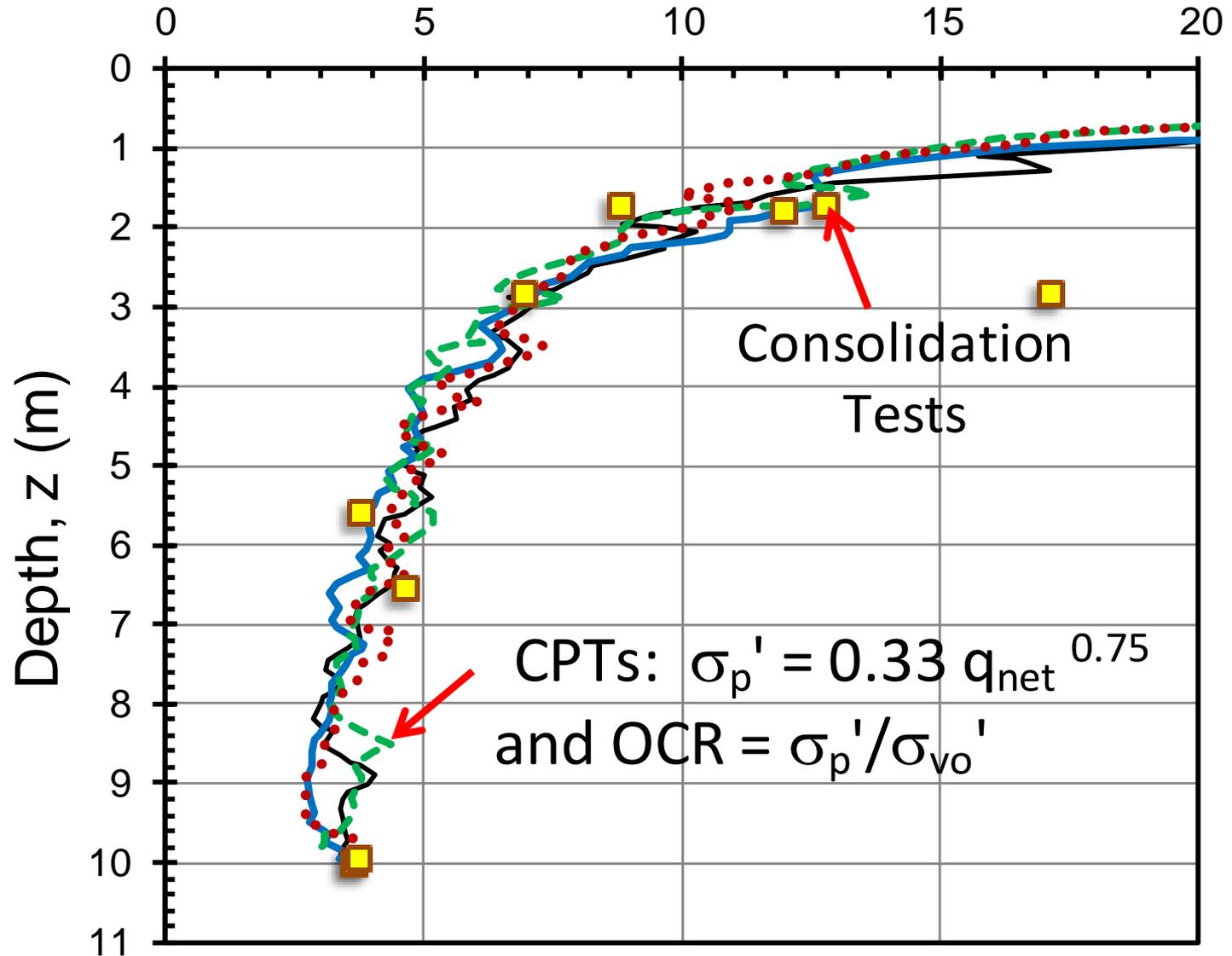


Friction Angle, ϕ' (deg)

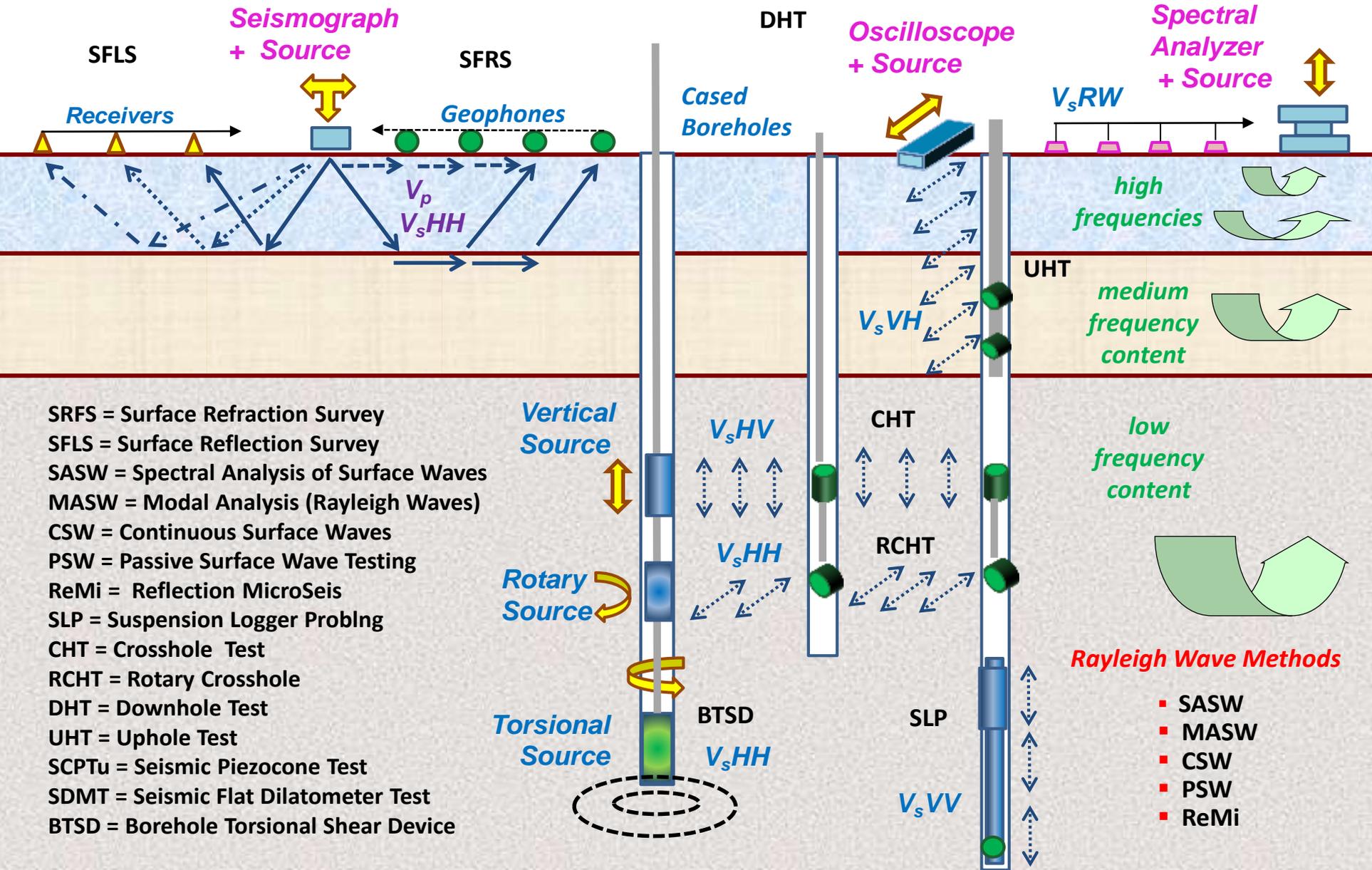


Blessington Sands, Ireland (Doherty et al 2012)

Overconsolidation Ratio, OCR



Field Geophysics - Mechanical Wave Methods



Shear Wave Velocity, V_s

- Fundamental measurement in all solids (steel, concrete, wood, soils, rocks)
- Initial stiffness represented by the small-strain shear modulus ($G_{\text{dyn}} = G_{\text{max}} = G_0$):

$$G_0 = \rho_t V_s^2 \quad \text{where total mass density } \rho_t = \gamma_t/g_a$$

- Applies to all static & dynamic problems at small strains ($\gamma_s < 10^{-6}$)
- Applicable to both undrained & drained loading cases in geotechnical engineering

Geotechnical Methods for Site Investigation

Soils Laboratory

In-Situ Testing

Geophysics

Lab Rat

Field Mouse

Fruit Bat

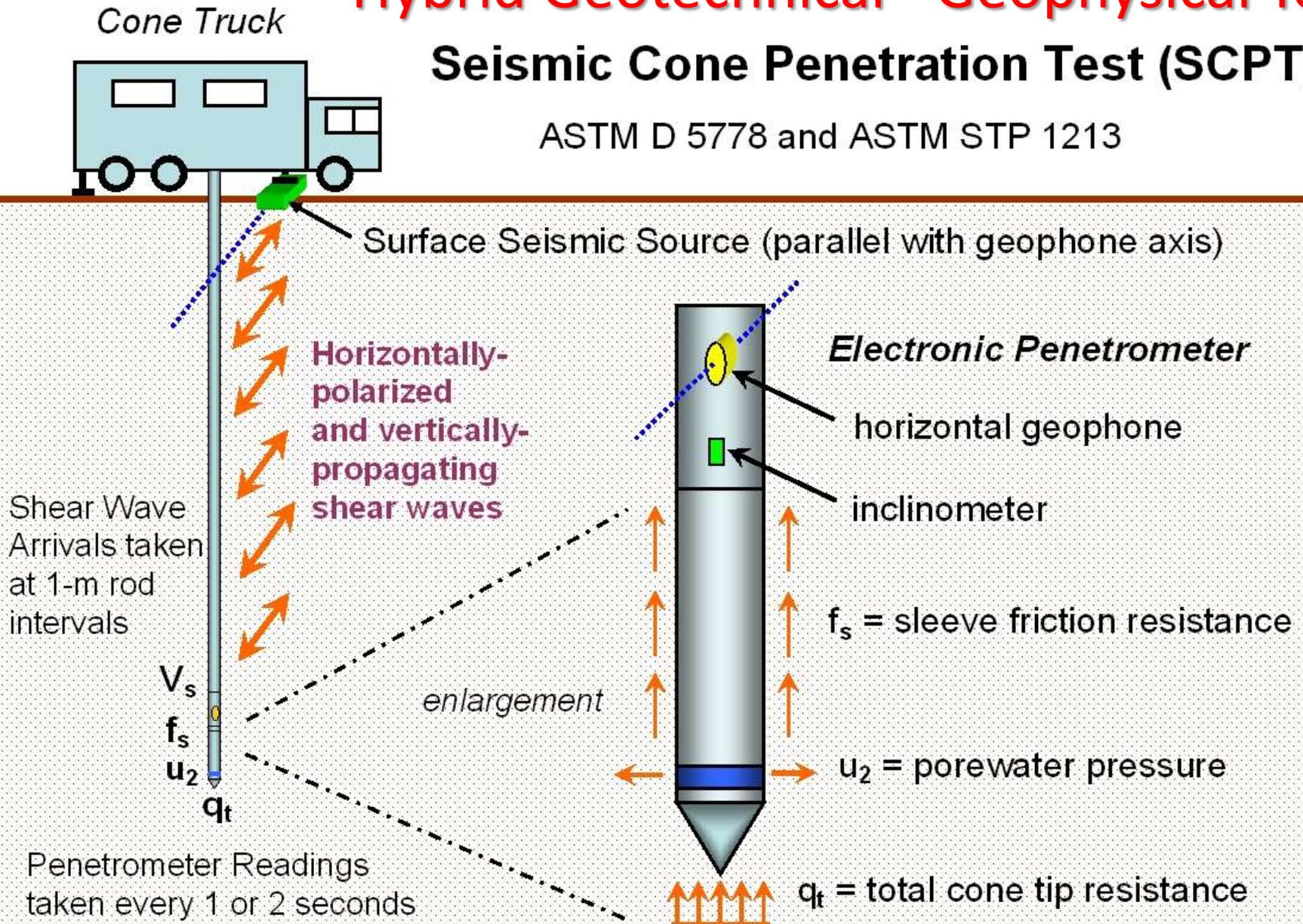


Field mouse with
ball penetrometer

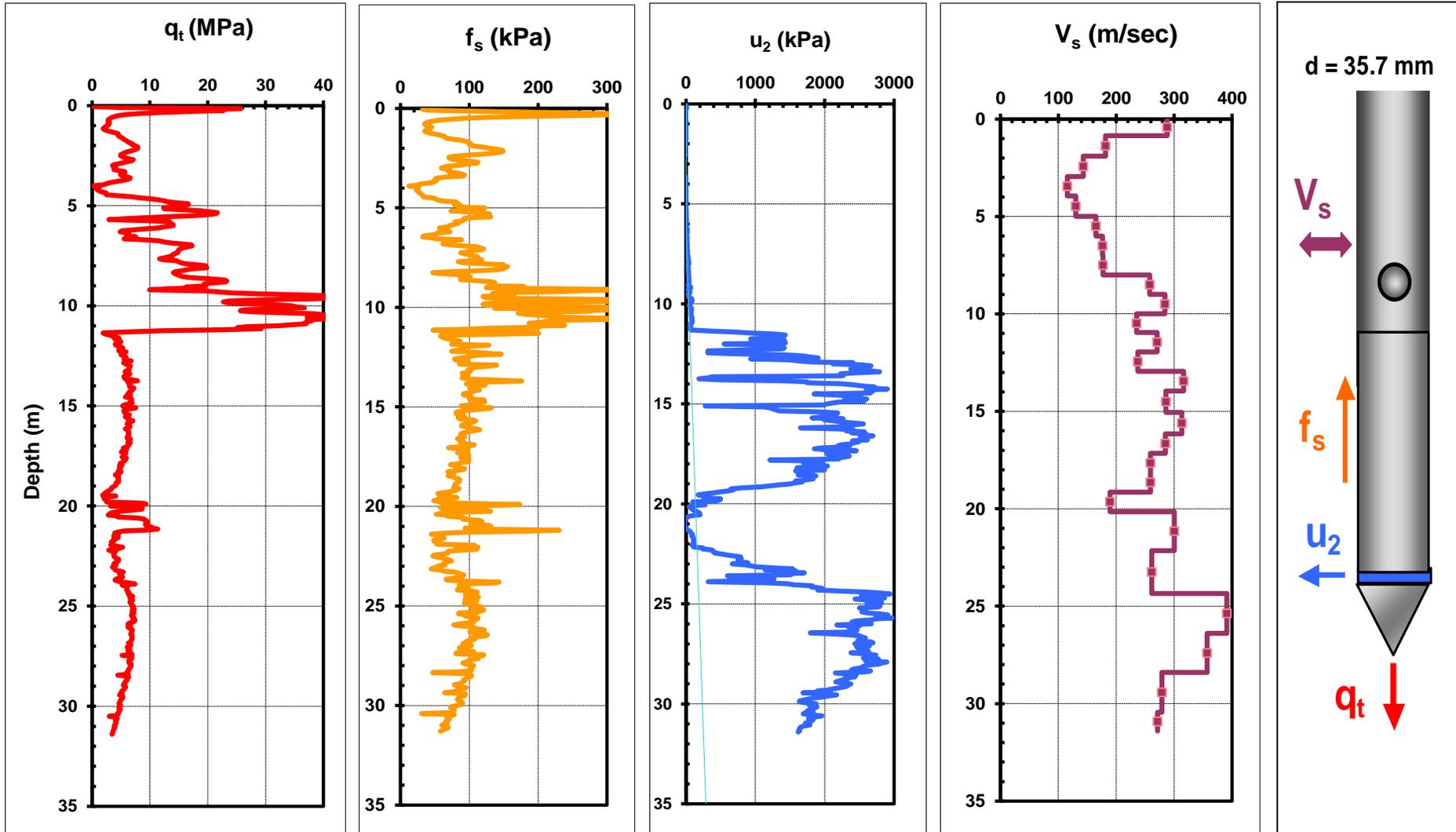
Hybrid Geotechnical - Geophysical Test

Seismic Cone Penetration Test (SCPT)

ASTM D 5778 and ASTM STP 1213



Hybrid Geotechnical - Geophysical Test SCPTu Sounding – Memphis, TN



Costs of Methods to profile V_s to 30 m

METHOD	TYPICAL COST
Suspension Logging (PSSL)	\$ 35,000 [#]
Crosshole Testing (CHT)	\$ 20,000
Downhole Testing (DHT)	\$ 9,000
Surface Waves (SASW, MASW)	\$ 4,500
ReMi Passive Surface Waves	\$ 2,500
Seismic Piezocone*	\$ 2,000

NOTE:

Typically only economical for profiling $z > 60$ m

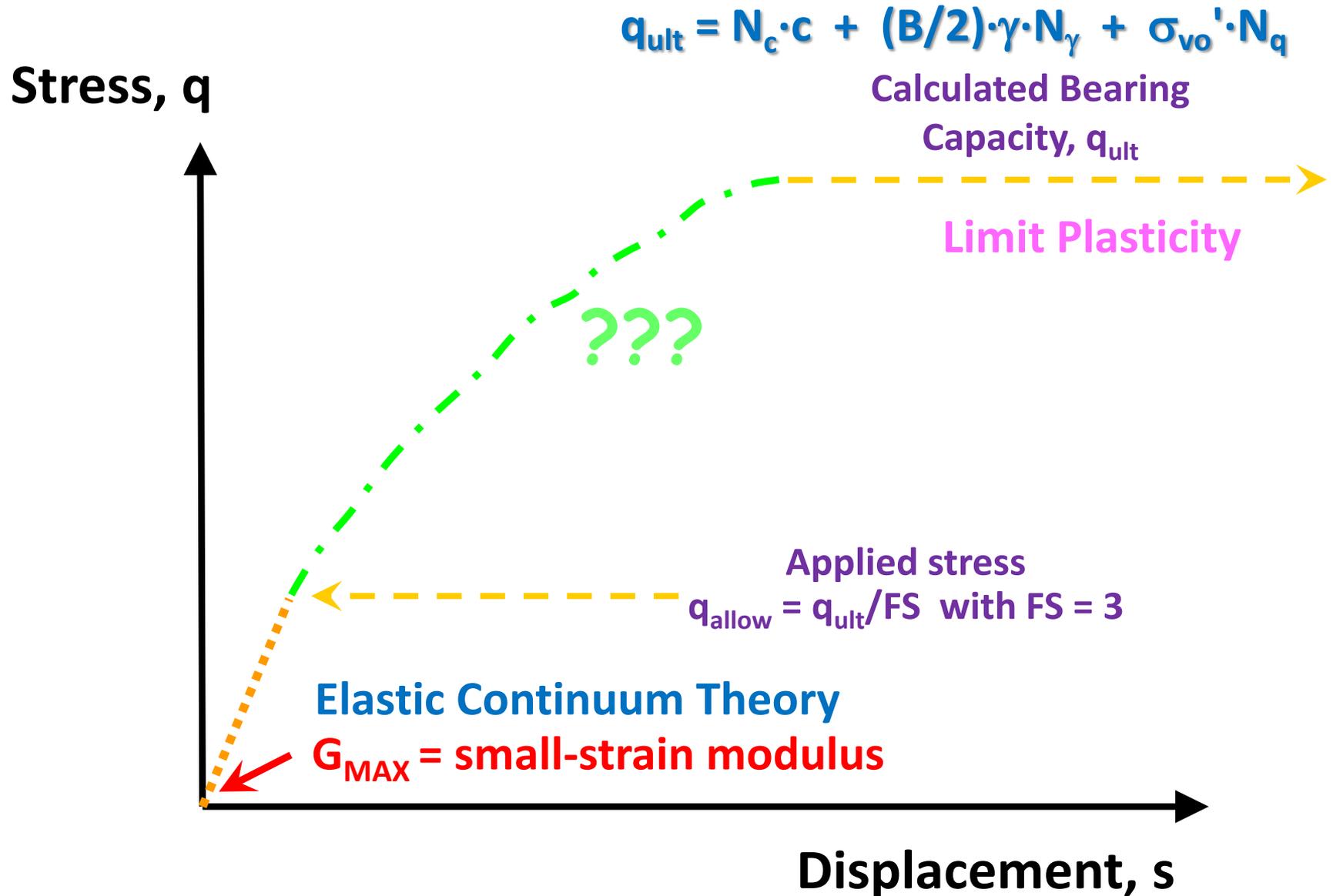
* Includes 4 separate readings with depth: q_t , f_s , u_2 , and V_s

SCPTu for Foundation Analyses

- Shallow Foundations
 - spread footings
 - mats or rafts
- Deep Foundations:
 - augered piles
 - driven pilings
 - drilled shafts
 - bored piles



Shallow Foundation Response



Displacement Influence Factors

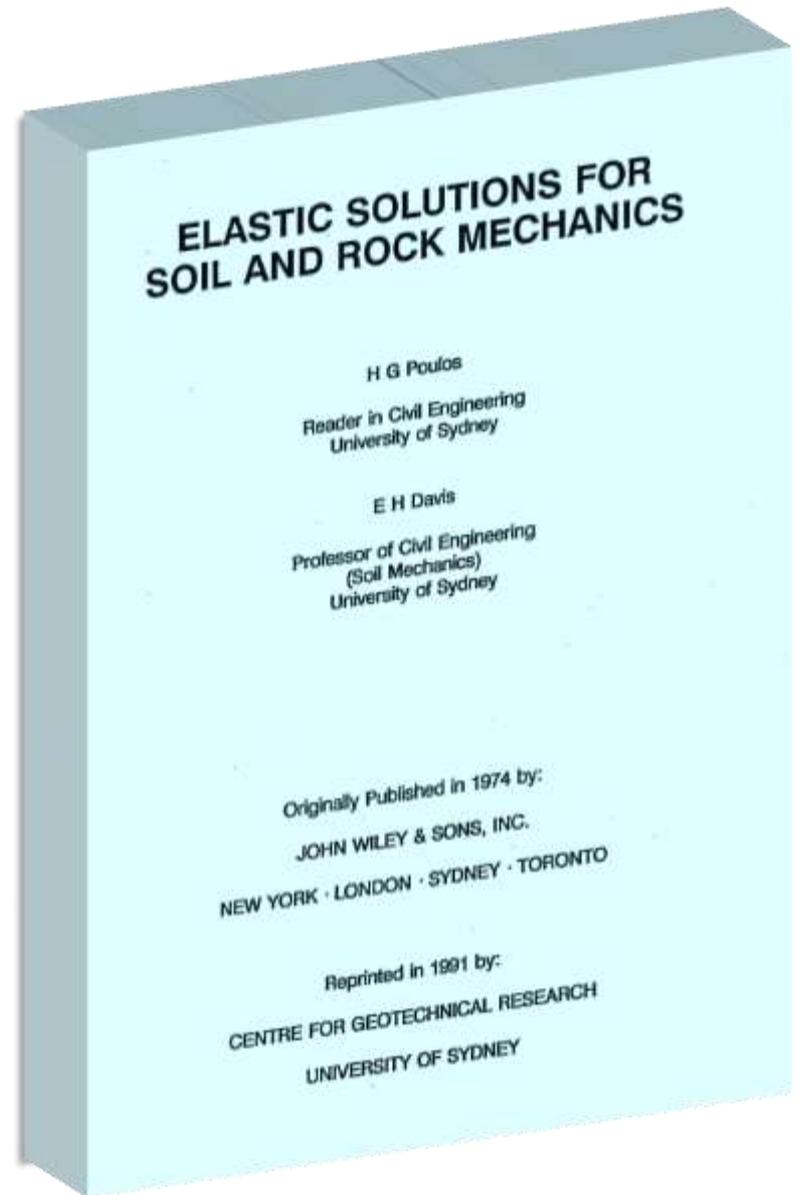
- Homogeneous Case: Soil Modulus constant with depth
- Uniform Flexible Loading
- Footing resting on a semi-infinite elastic half-space

$$\text{Displacement : } s = \frac{q \cdot B \cdot I}{E_s}$$

- q = applied surface stress
- B = foundation width (smaller dimension)
- E_s = equivalent elastic soil modulus
- I = displacement influence factor from elastic theory (Poulos & Davis 1974)

**Download PDF of 411
page book:
*Elastic Solutions for Soil
and Rock Mechanics*
(Poulos & Davis, 1974):**

www.usucger.org

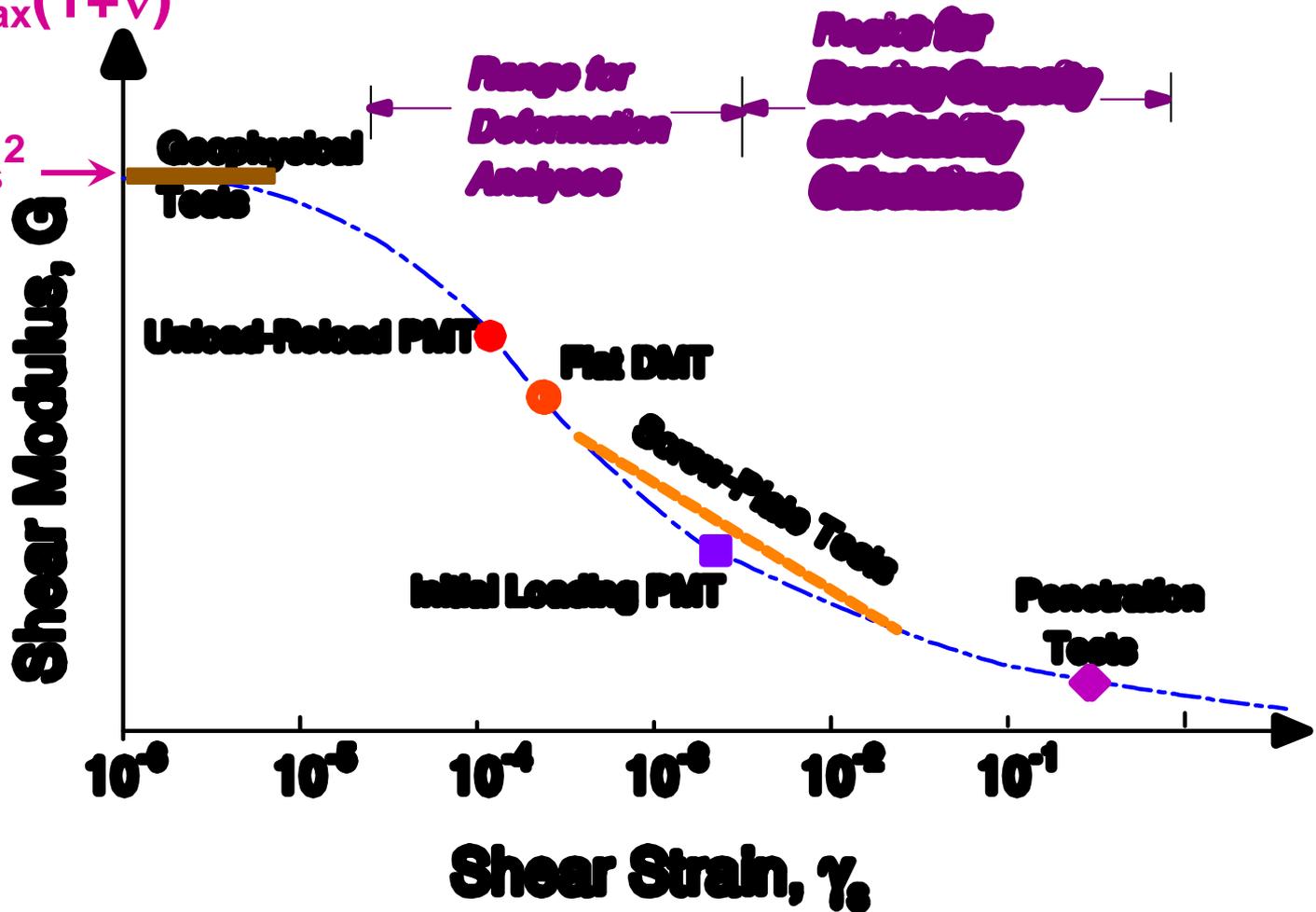


Equivalent Modulus for Monotonic Load Response

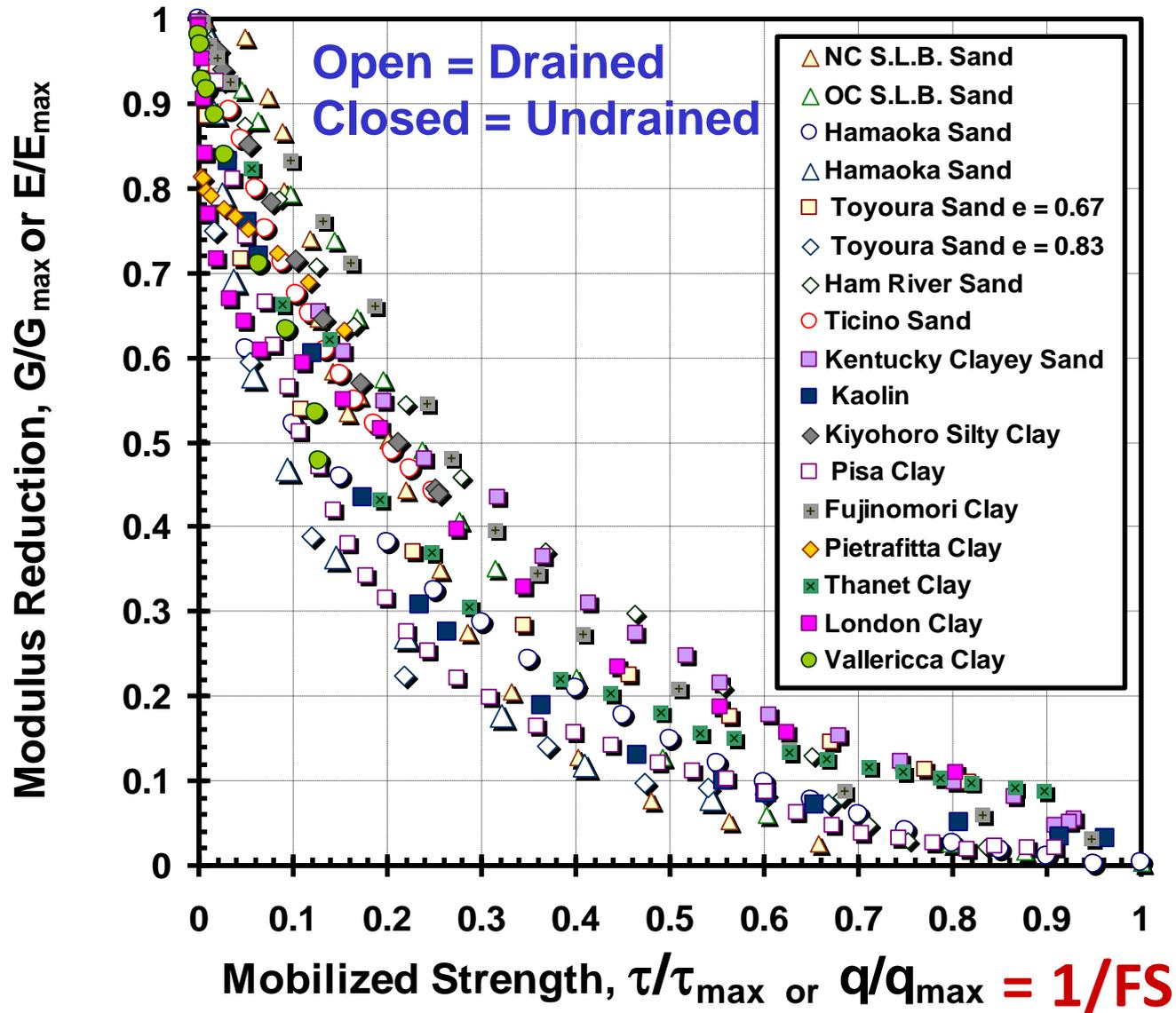
$$E_{\max} = 2G_{\max}(1+\nu)$$

$$G_{\max} = \rho_t V_s^2$$

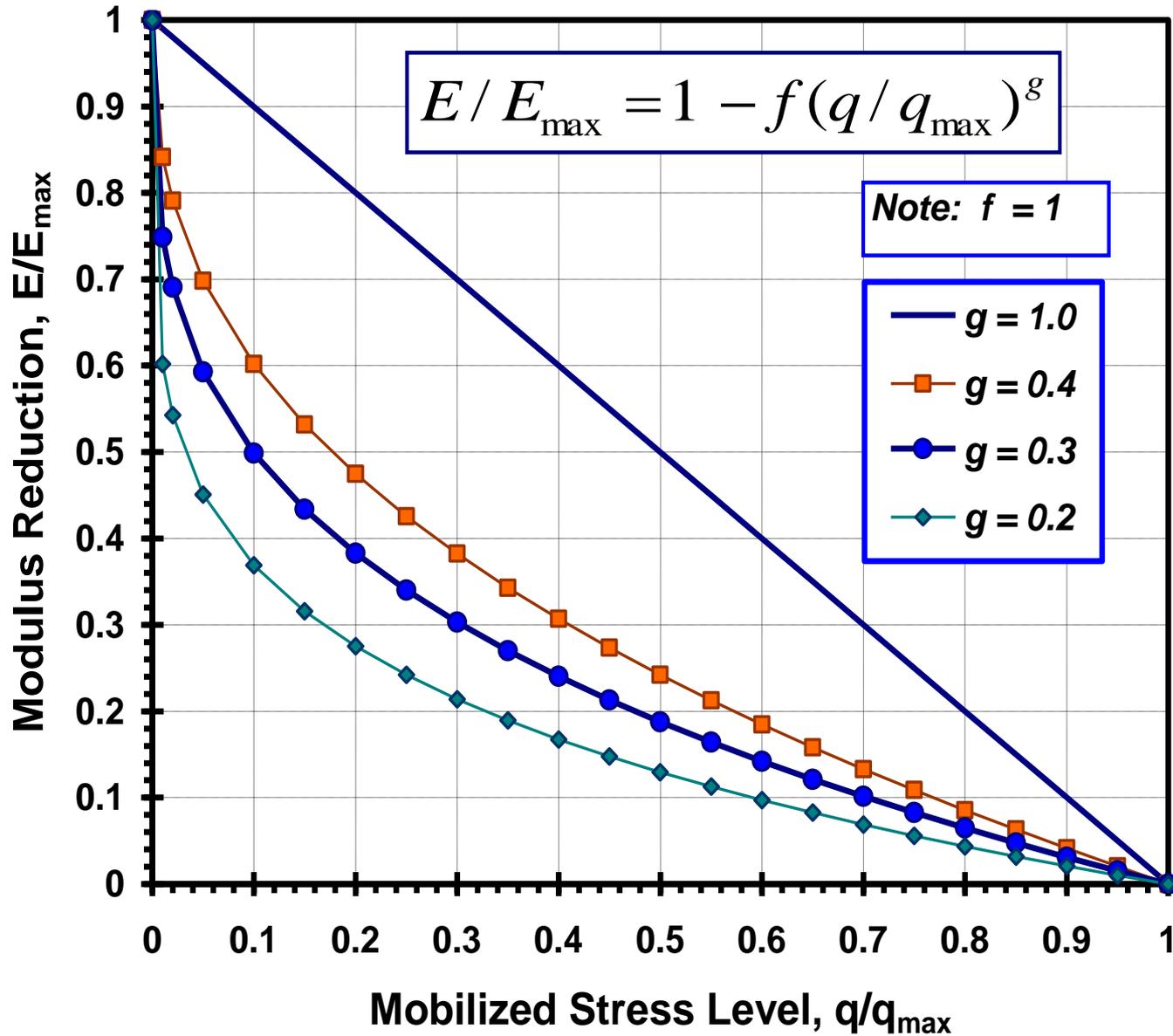
$$\rho_t = \gamma_t/g$$



Modulus Reduction from TS and TX Data



Modulus Reduction Scheme (Fahey & Carter 1993)



Equivalent Modulus for Foundation Response

- **Initial stiffness from small-strain shear modulus**
 - $G_{\max} = \rho V_s^2$
 - $E_{\max} = 2G_{\max} (1+\nu)$
- **Modulus reduction factor (Fahey & Carter 1993):**
 - $E/E_{\max} = 1 - f (Q/Q_{\text{ult}})^g = 1 - (\text{FS})^{-g}$
 - where $\text{FS} = Q_{\text{ult}}/Q$
 - Operational $E = (E/E_{\max}) \cdot E_{\max}$
 - for "well-behaved" soils: $f = 1$ and $g \approx 0.3$
i.e., "vanilla clay" and "hourglass sand"

Nonlinear Foundation Displacement Analyses

$$s_{center} = \frac{q \cdot B \cdot (1 - \nu^2)}{E_{MAX} [1 - (q / q_{ult})^{0.3}]}$$

where

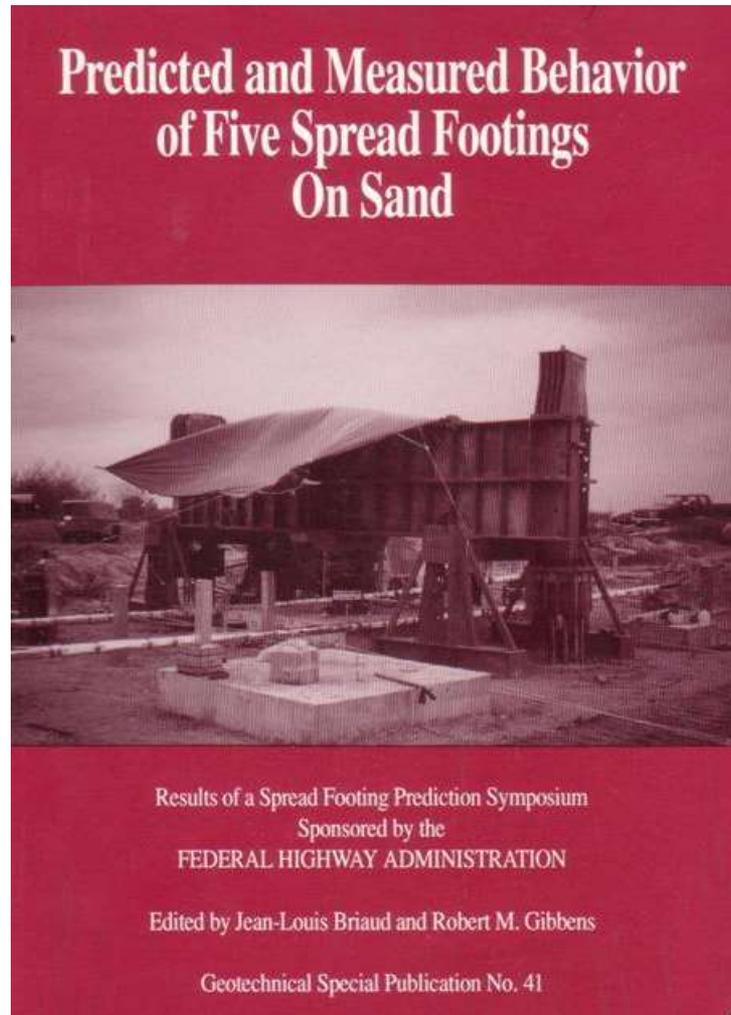
- ❑ s = centerpoint displacement
- ❑ q = applied surface stress;
- ❑ q_{ult} = ultimate bearing stress;
- ❑ B = footing width
- ❑ ν = Poisson's ratio
- ❑ E_{max} = initial elastic modulus = $2G_{max} (1 + \nu)$
- ❑ See Mayne & Poulos (ASCE J. Geot. Engrg. - Jan 2001)

Class “A” Prediction – Texas A&M

ASCE and FHWA Symposium (1994)

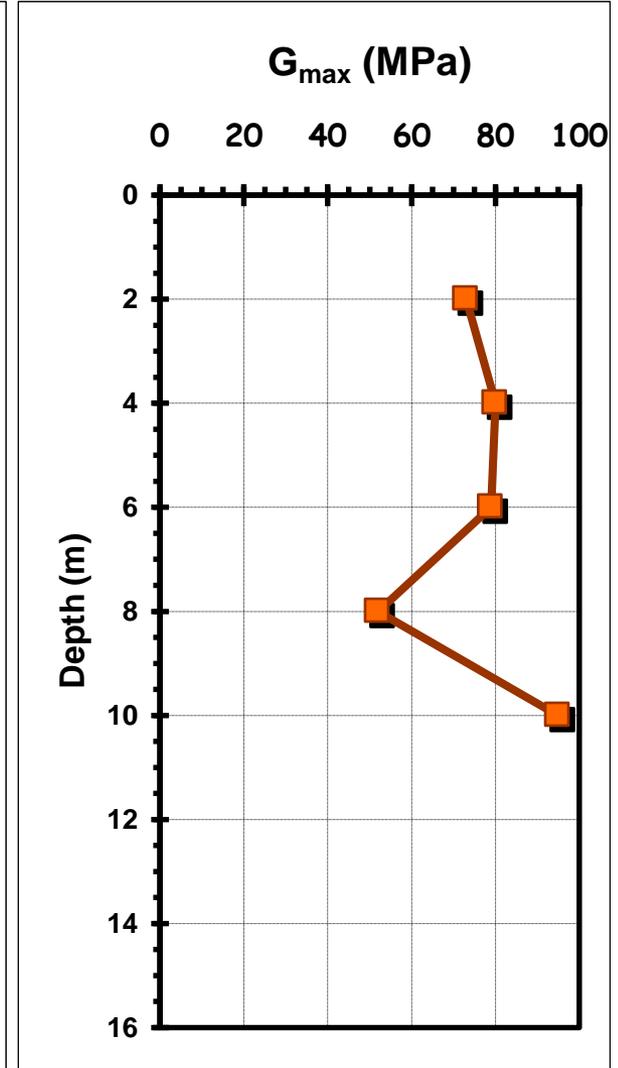
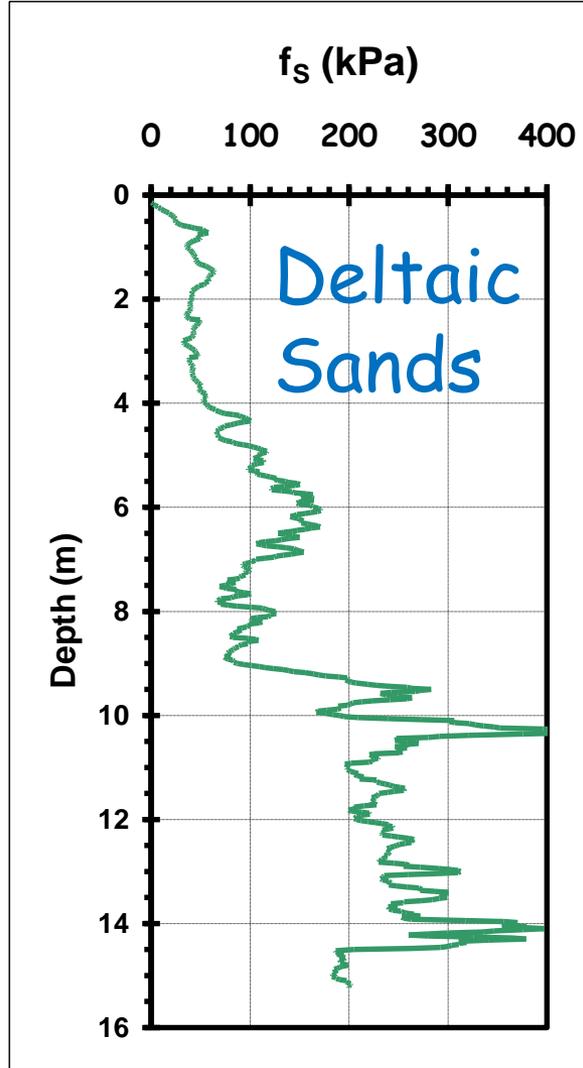
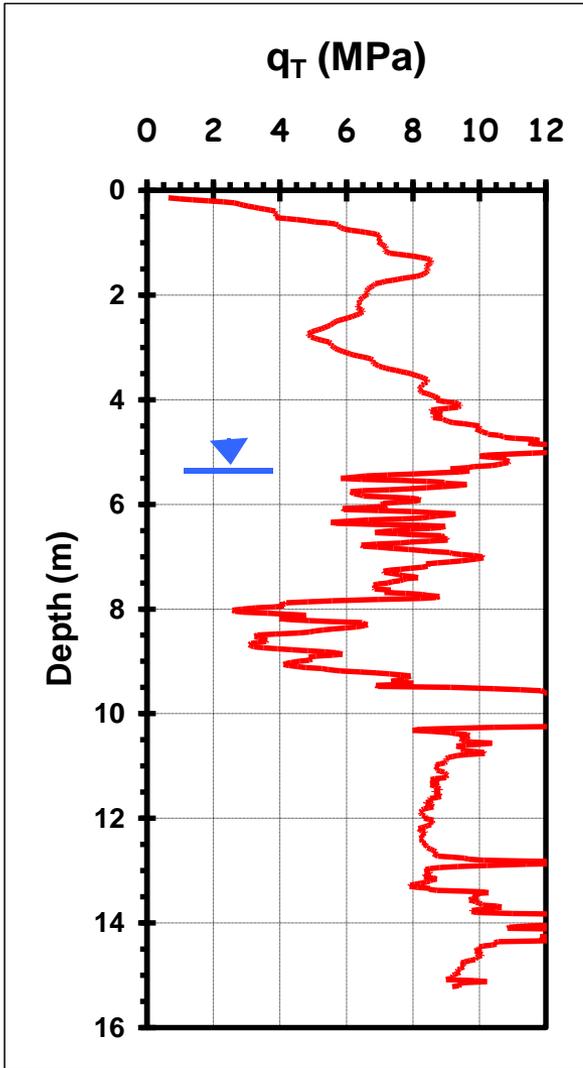
**Geotechnical
Special
Publication
GSP No. 41**

***Measured and
Predicted
Behavior of Five
Spread Footings
on Sand***



Class "A" Prediction – Texas A&M

ASCE and FHWA Symposium (1994)



ASCE - FHWA Symposium at Texas A&M

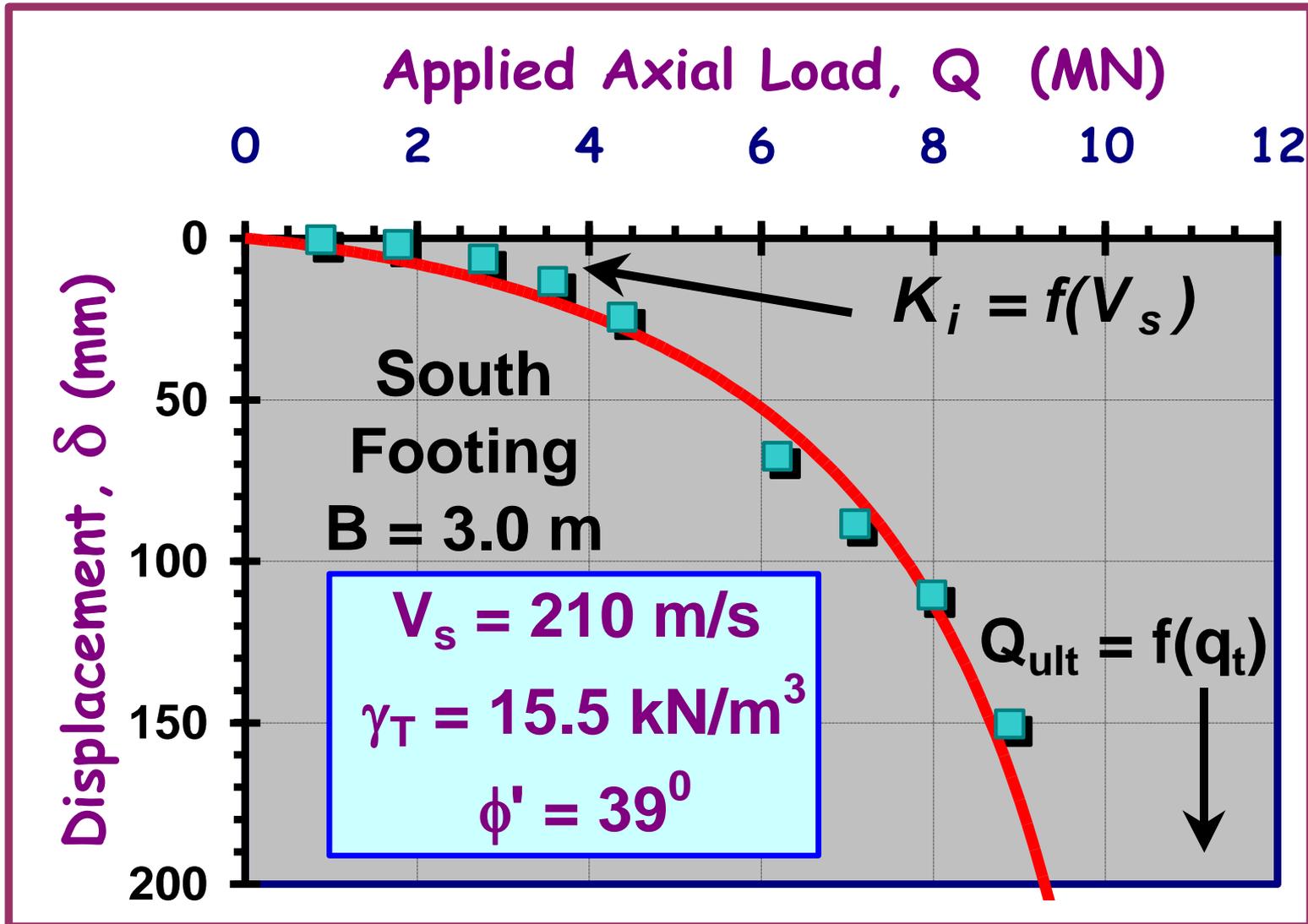
Five Footings on Sand:

B (meters) = 1.0, 1.5, 2.5, 3.0 – South, 3.0 - North



Class "A" Prediction – Texas A&M

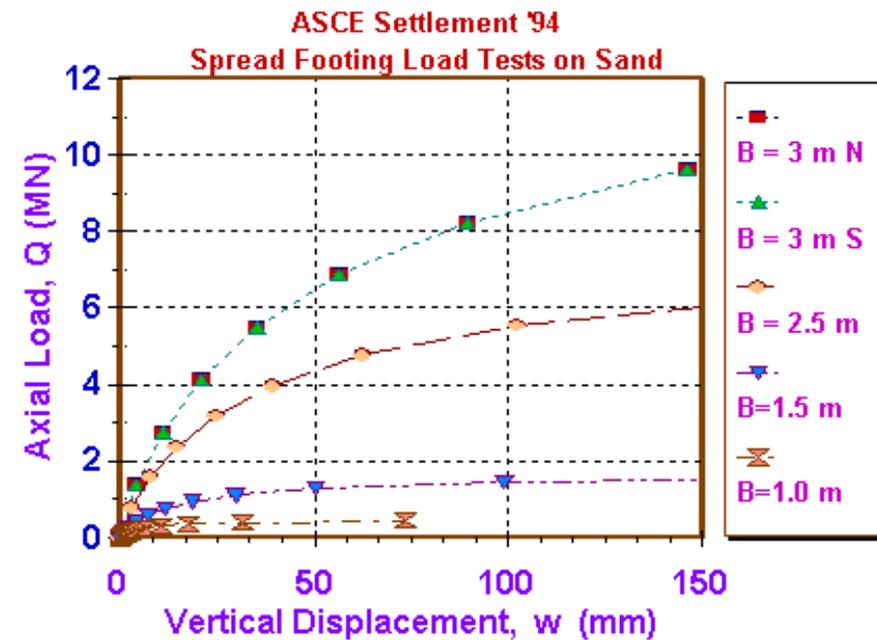
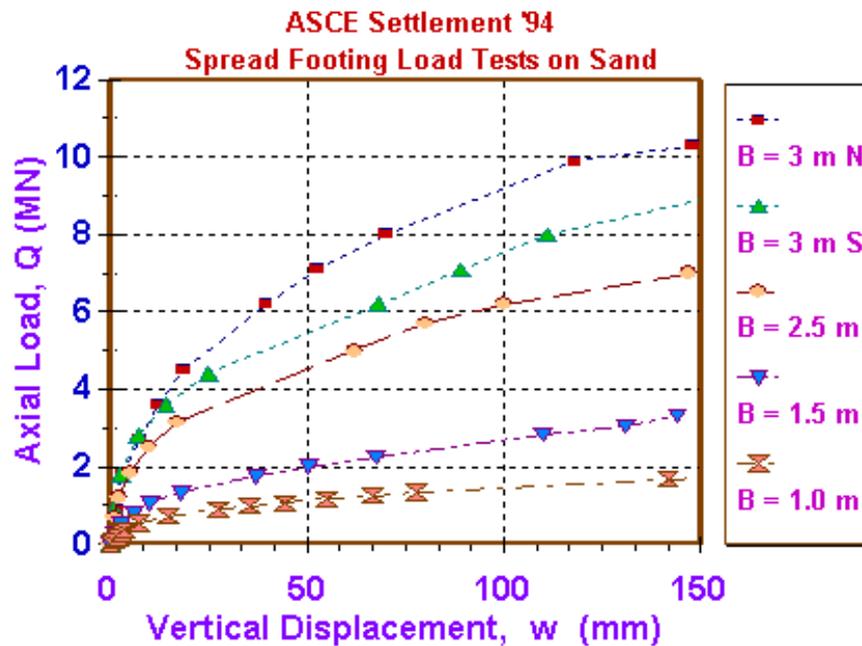
ASCE and FHWA Symposium (1994)



FHWA-ASCE Load Tests at Texas A&M

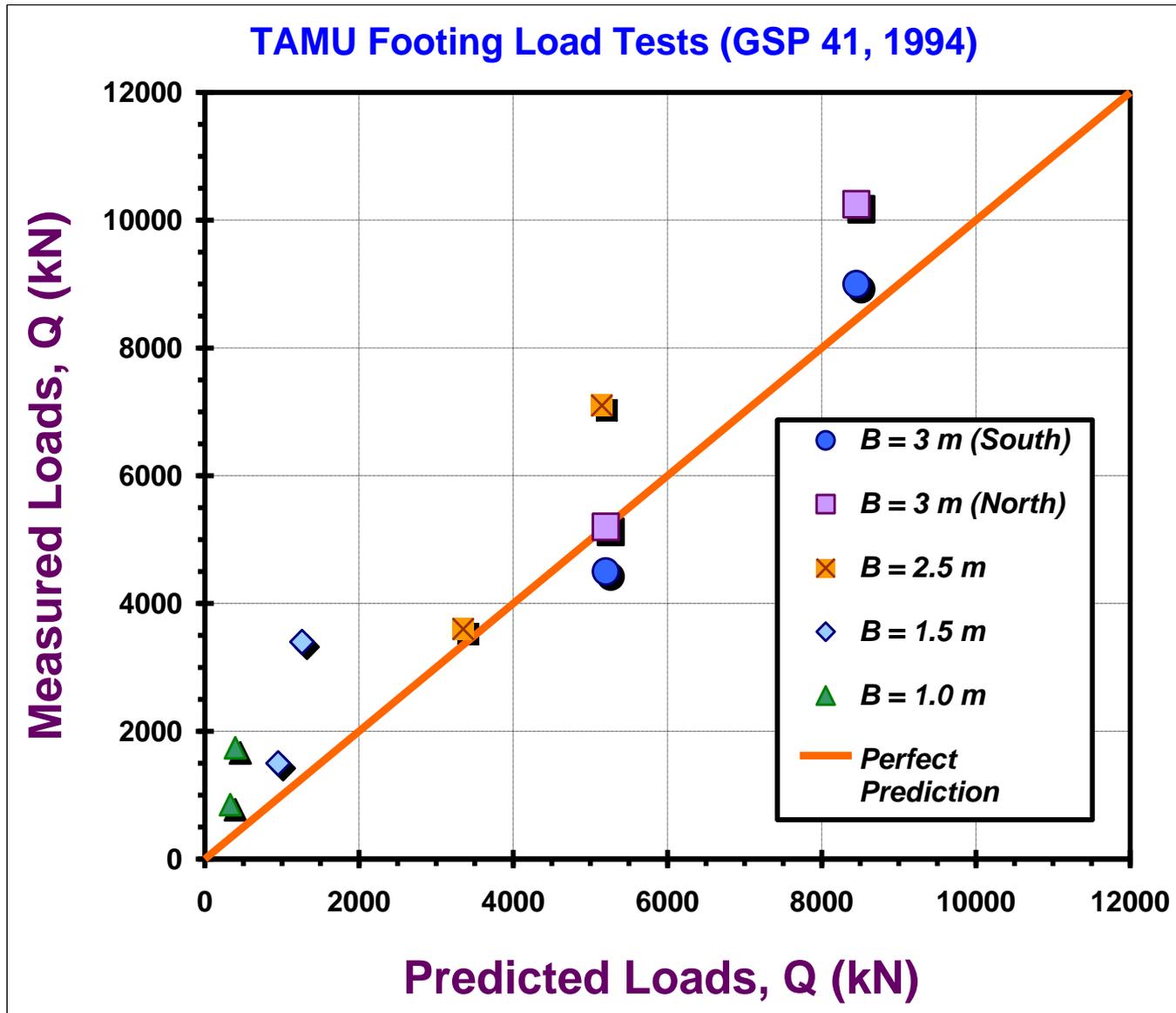
MEASURED FOOTING RESPONSES

PREDICTED LOAD-DISPLACEMENTS



Class "A" Prediction – Texas A&M

ASCE and FHWA Symposium (1994)



Class "A" Prediction

Belfast Footing Load Test (June 2001)

**Deformation
Characteristics of
Geomaterials**

**Comportement des Sols
et des Roches Tendres**

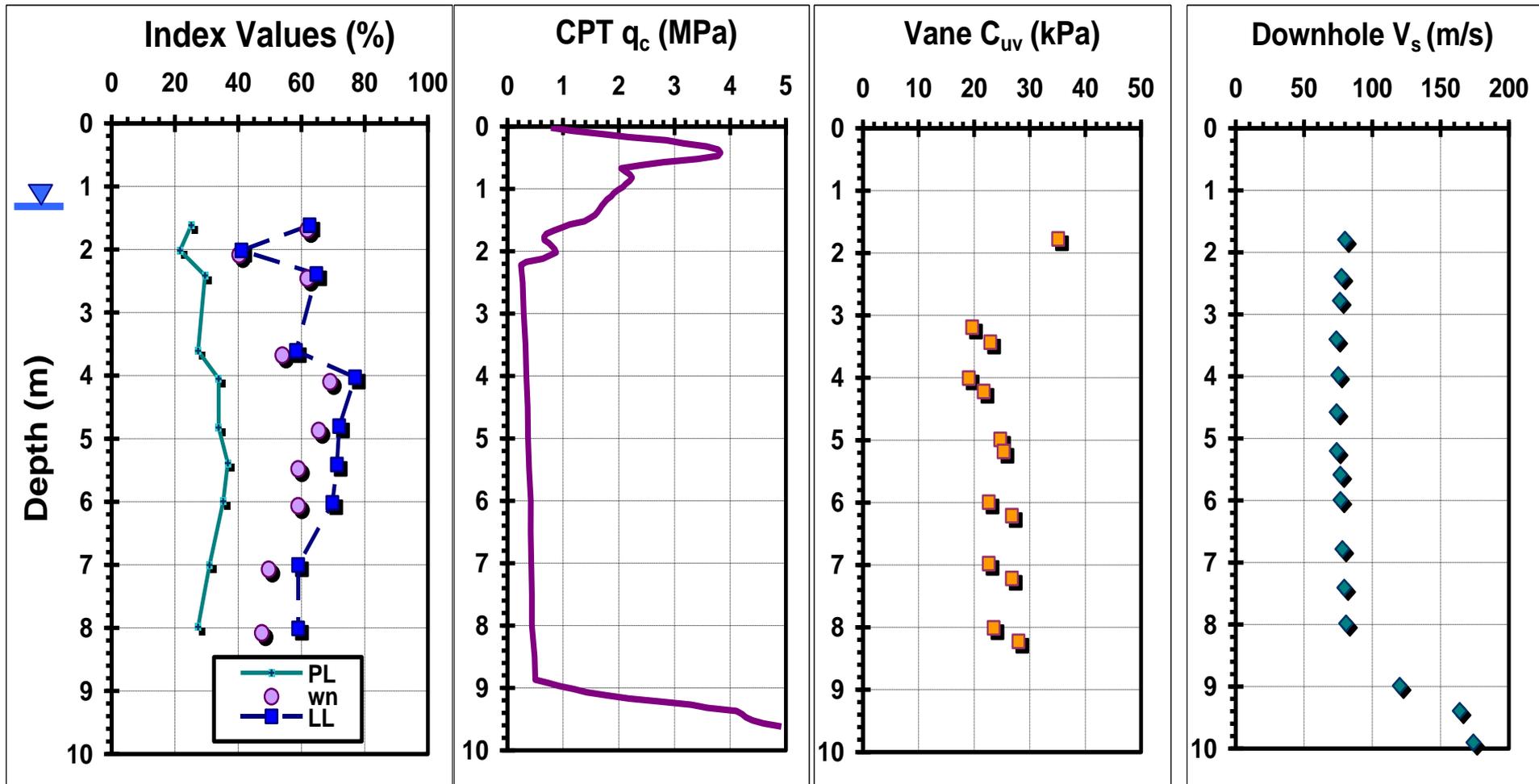


Edited by

H. Di Benedetto, T. Doanh
H. Geoffroy & C. Sauzéat

European Foundation Prediction Symposium

Belfast Test, Ireland (Data by Lehane, 2001)



Geotechnical News (December 2001) BiTech Publishers

Prediction Rating

- 1. Mayne - USA ←
- 2. Orr - Ireland
- 3. Murry - NZ
- 4 - 22 (anonymous)

Professor Mayne a Top Predictor of Ultimate Bearing Capacity



Professor Mayne

Many geotechnical experts recently participated by invitation in the prediction of the ultimate capacity of a pad footing in Belfast's soft clay.

The following three were the top three predictors:

Prof. Paul Mayne
(Georgia Institute of Technology)

Dr. Trevor Orr
(Trinity College Dublin)

Mr. Grant Murray
(Geotech. consultant in New Zealand)

Dr. Barry Lehane of Trinity College, Dublin coordinated the prediction exercise. Dr. Lehane plans to submit a brief note about the actual test and the predictive techniques employed to 'Ground Engineering'.

In the meantime, a summary of all the predictions is available at:

<http://www.jiscmail.ac.uk/files/engineering-geotech/>. The accuracy as well as the spread of predictions should be a cause of concern for the geotechnical community!

Burmister Lecture

Professor Osterberg of Northwestern University delivered the 2001 Burmister lecture at Columbia University on November 7, 2001. The title of the lecture was "What is New in Drilled Shaft Foundations?"

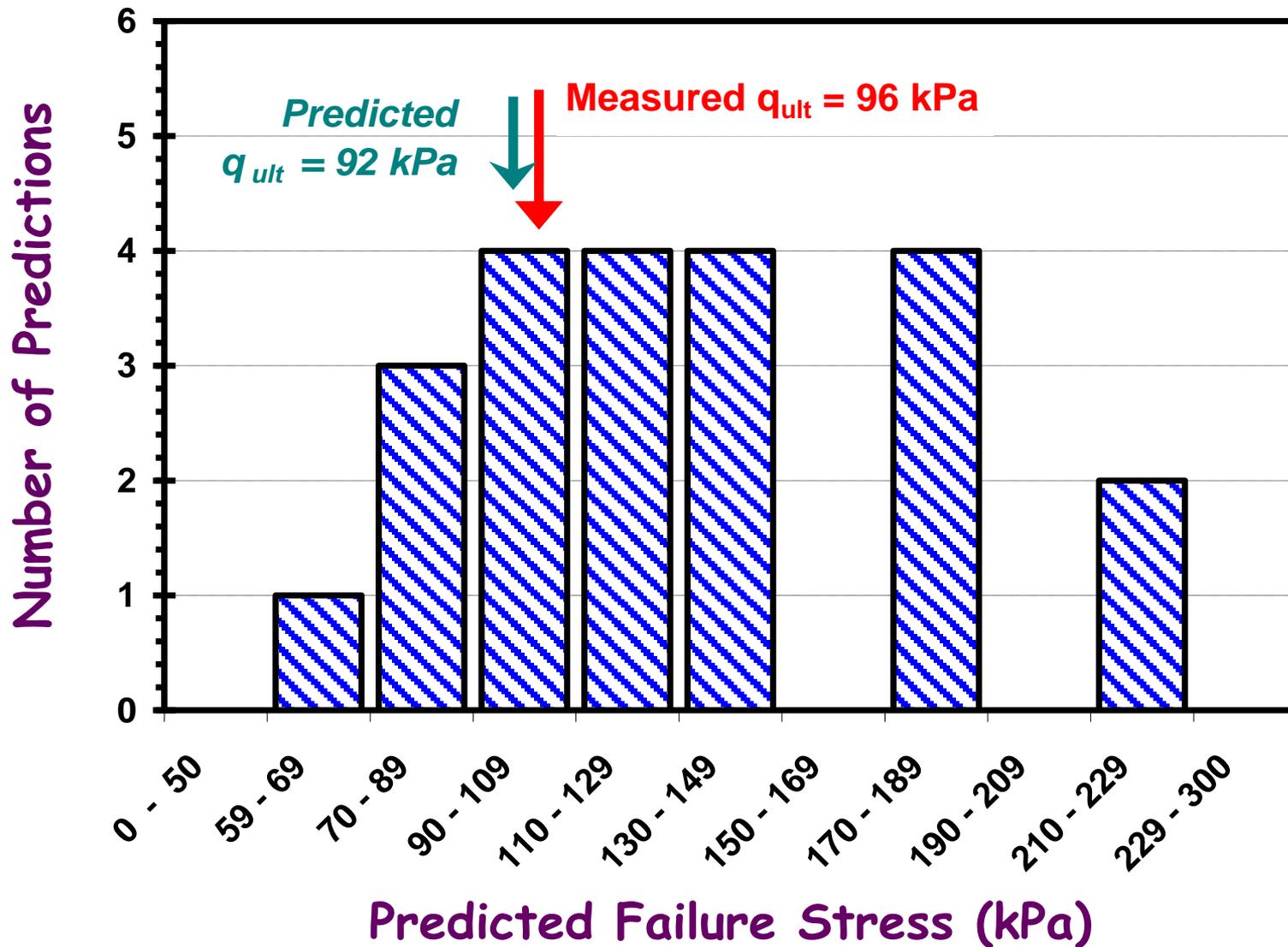
Jorj Osterberg has degrees from Columbia, Harvard and Cornell Universities. During his formal education he worked during summers for foundation contractors. His first full-time employment was a three year period with the Corps of Engineers at the Waterways Experiment Station in Vicksburg, Mississippi, after which he entered the academic world. While at Northwestern University, he rose through the ranks to Chair Professor.

He designed and built the soils laboratory, and developed the Osterberg Hydraulic Piston Sampler. Since his retirement he has been active in consulting and developing the Osterberg Load Cell method for load testing drilled shafts and driven piles. He holds 10 patents.

Osterberg is a former Chairman of the Soil Mechanics and Foundation Division of the ASCE. He is an Honorary Member of ASCE, and is a member of the National Academy of Engineering. He delivered the Terzaghi Lecture in 1985, and later received the Terzaghi

European Foundation Prediction Symposium

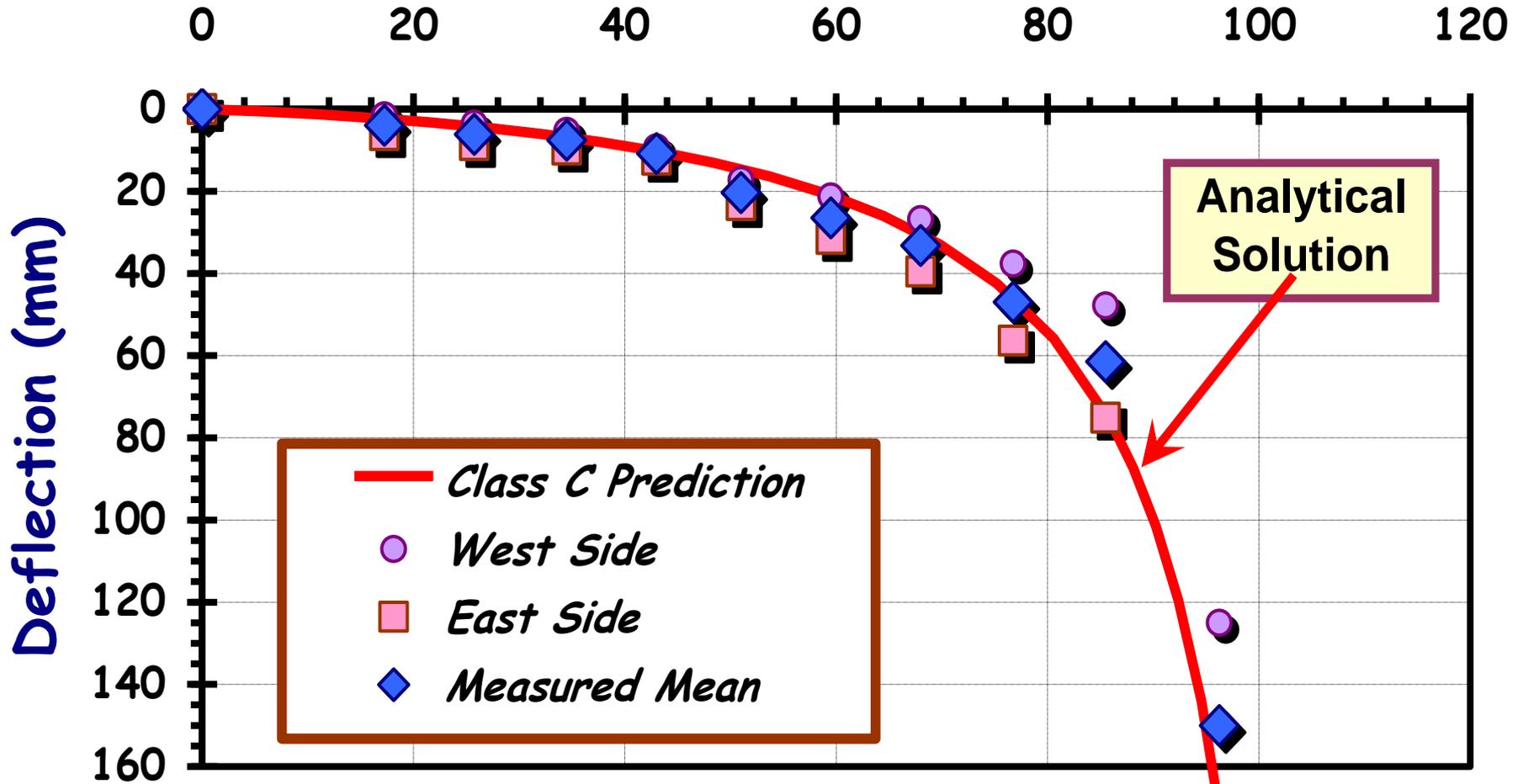
GT Class "A" Prediction (July, 2001)



Belfast Footing Load Test

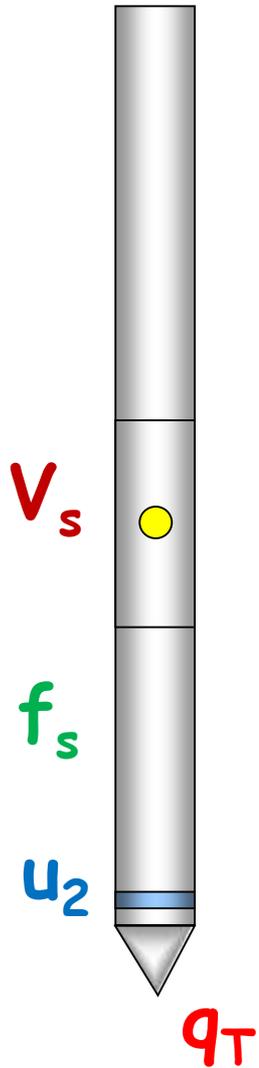
GT Class "C" Prediction

Applied Stress, q (kPa)

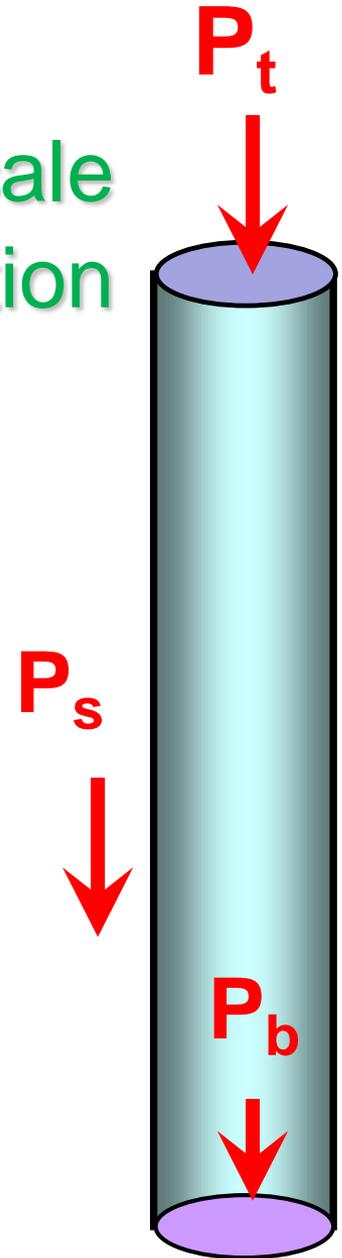


cone penetrometer
= mini-pile

Full-Scale
Deep Foundation



*Scaling relationships for force-
displacement-capacity
response of axial pile
foundation*



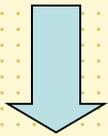
AXIAL PILE CAPACITY FROM CONE PENETROMETER

$$Q_{\text{Total}} = Q_s + Q_b - W_p$$

$$Q_{\text{side}} = \sum (f_p dA_s)$$

$$Q_{\text{base}} = q_b A_b$$

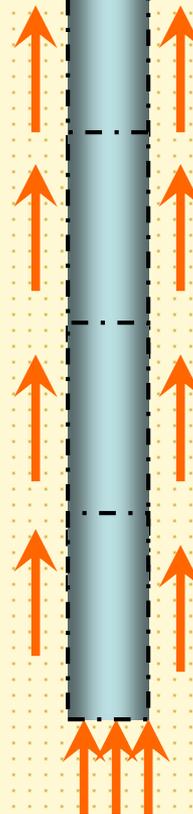
Method One
"Direct" CPT Method
(Scaled Pile)



unit side friction, f_p

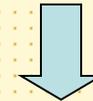
$f_p = fctn$ (soil type, pile type, q_t , or f_s and Δu)

$q_b = fctn$ (soil type, $q_t - u_b$, and degree of movement, s/B)

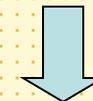


$q_b = \text{unit end bearing}$

Method Two: Rational
or "Indirect" Method



OCR, s_u , K_o , γ_t , D_R , ϕ'

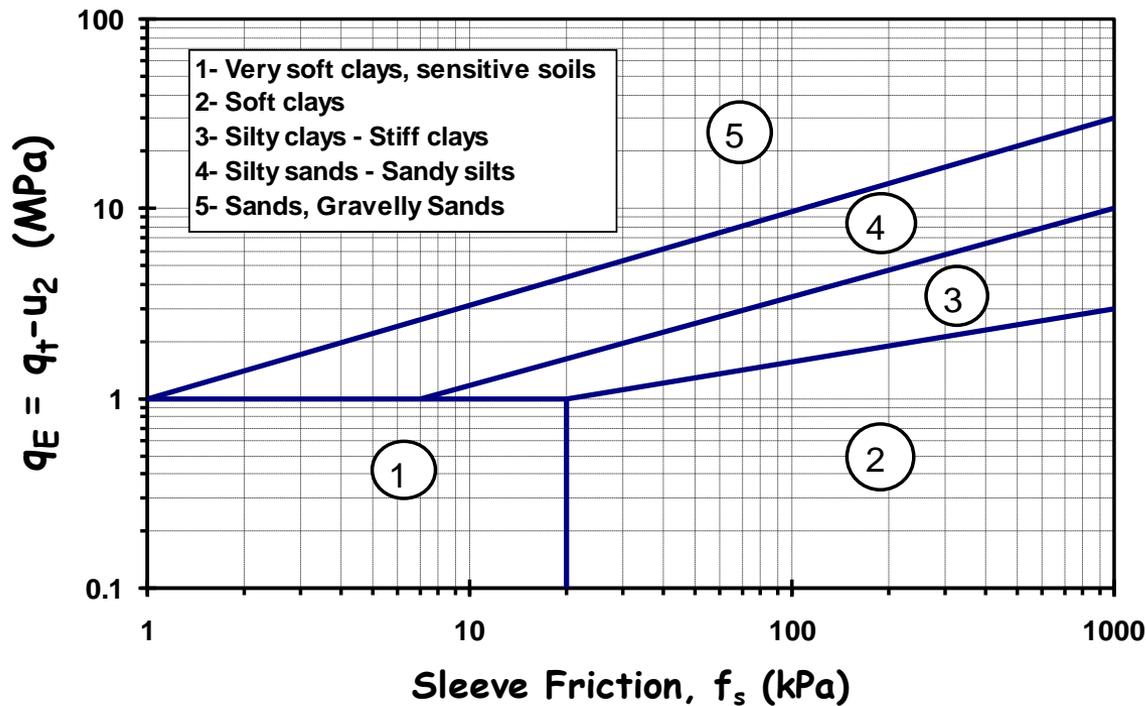


$f_p = c_m c_k K_o \sigma_{vo}' \tan \phi'$

Drained: $q_b = N_q \sigma_{vo}'$

Undrained: $q_b = N_c s_u$

Unicone CPTu Method



Eslami & Fellenius
 (1997 CGJ)

www.fellenius.net

A. At each elevation, determine effective cone resistance:

$$q_E = q_t - u_2$$

B. Plot q_E vs f_s for soil type (see chart).

C. Unit Side Resistance:

$$f_p = C_s \cdot q_E$$

D. Unit Tip Resistance:

$$B < 0.4\text{m}: q_b = q_E$$

$$B > 0.4\text{m}: q_b = q_E / (3B)$$

B = pile width (m)

Soil Type

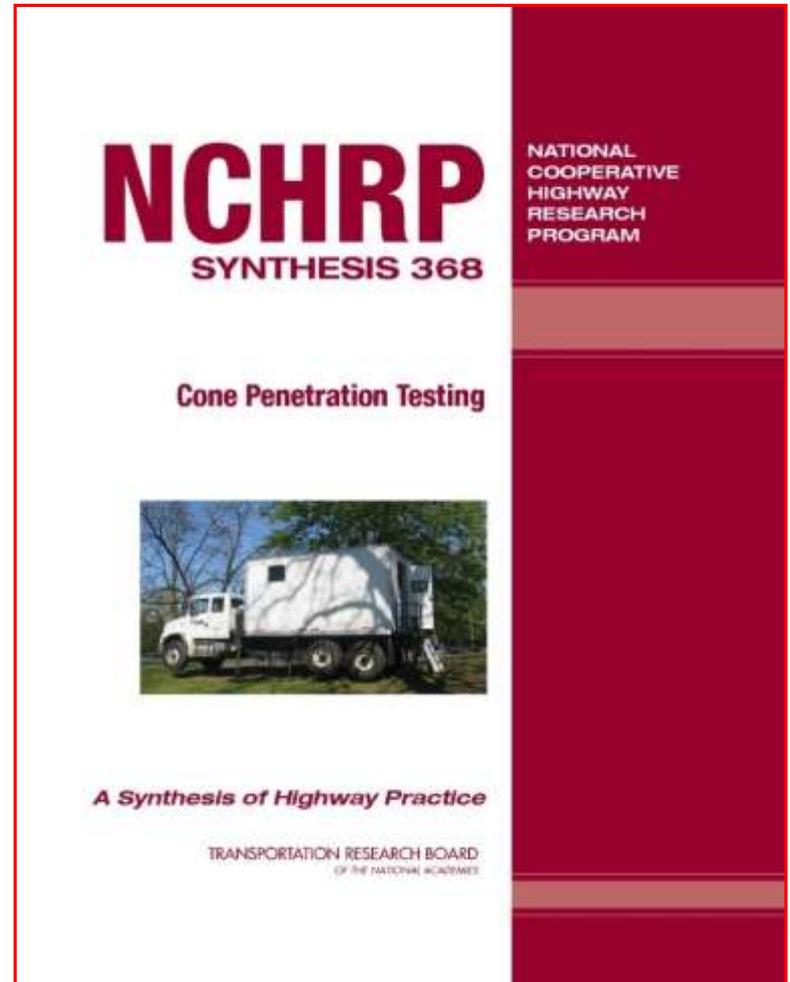
C_s Value

- 1. Very soft sensitive soils 0.080
- 2. Soft Clay 0.050
- 3. Stiff clay to silty clay 0.025
- 4. Silt-Sand Mix 0.010
- 5. Sands 0.004

NCHRP Synthesis 368: *Cone Penetration Test*

Chapter 8 on Pile Foundations

- www.trb.org
- webforum.com/tc16
- geosystems.ce.gatech.edu



RIGID PILE RESPONSE

Randolph Solution

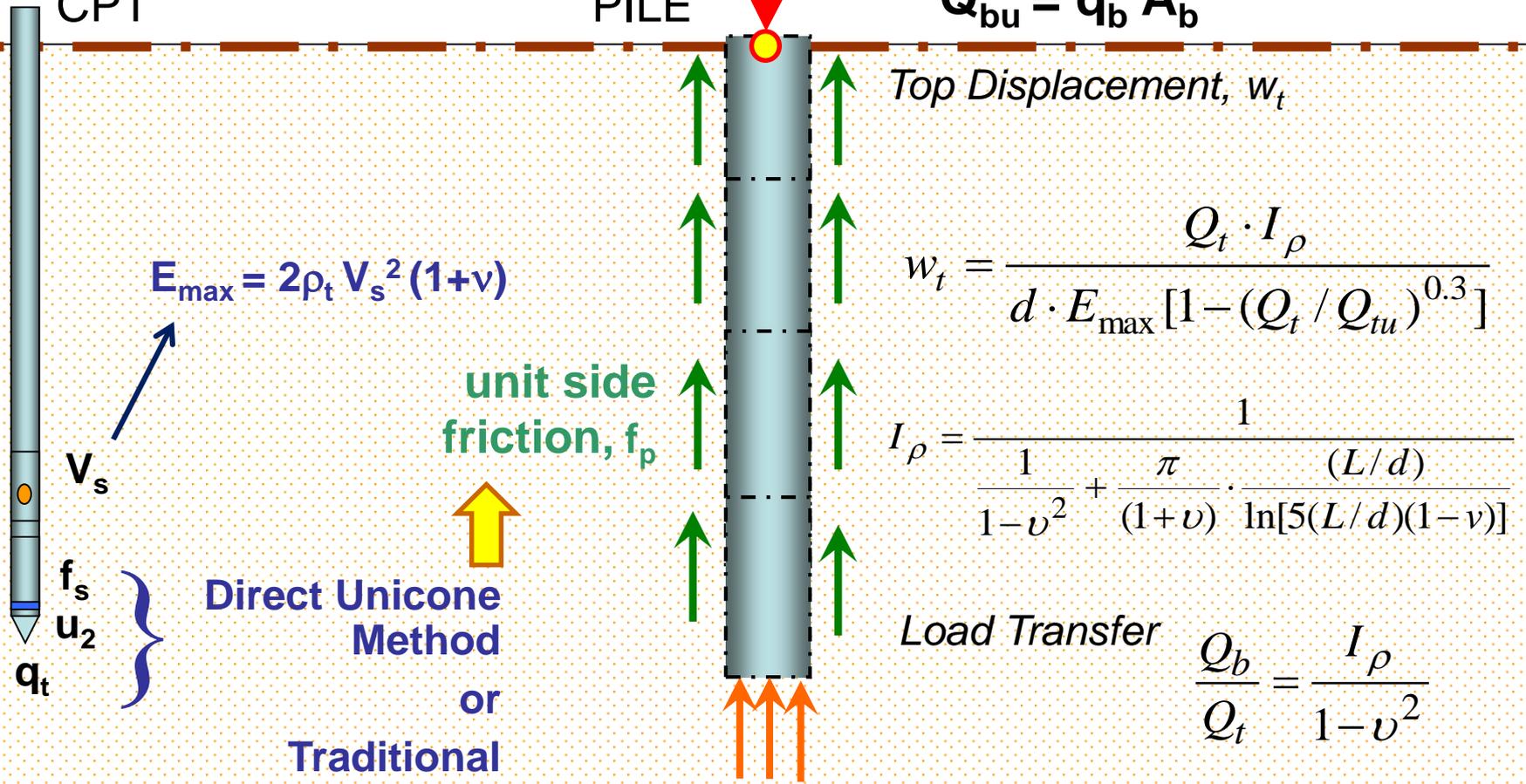
$$Q_{tu} = Q_s + Q_b$$

$$Q_{su} = \sum (f_p dA_s)$$

$$Q_{bu} = q_b A_b$$

CPT

PILE



Top Displacement, w_t

$$w_t = \frac{Q_t \cdot I_\rho}{d \cdot E_{\max} [1 - (Q_t / Q_{tu})^{0.3}]}$$

$$I_\rho = \frac{1}{\frac{1}{1-\nu^2} + \frac{\pi}{(1+\nu)} \cdot \frac{(L/d)}{\ln[5(L/d)(1-\nu)]}}$$

Load Transfer $\frac{Q_b}{Q_t} = \frac{I_\rho}{1-\nu^2}$

$$E_{\max} = 2\rho_t V_s^2 (1+\nu)$$

unit side friction, f_p

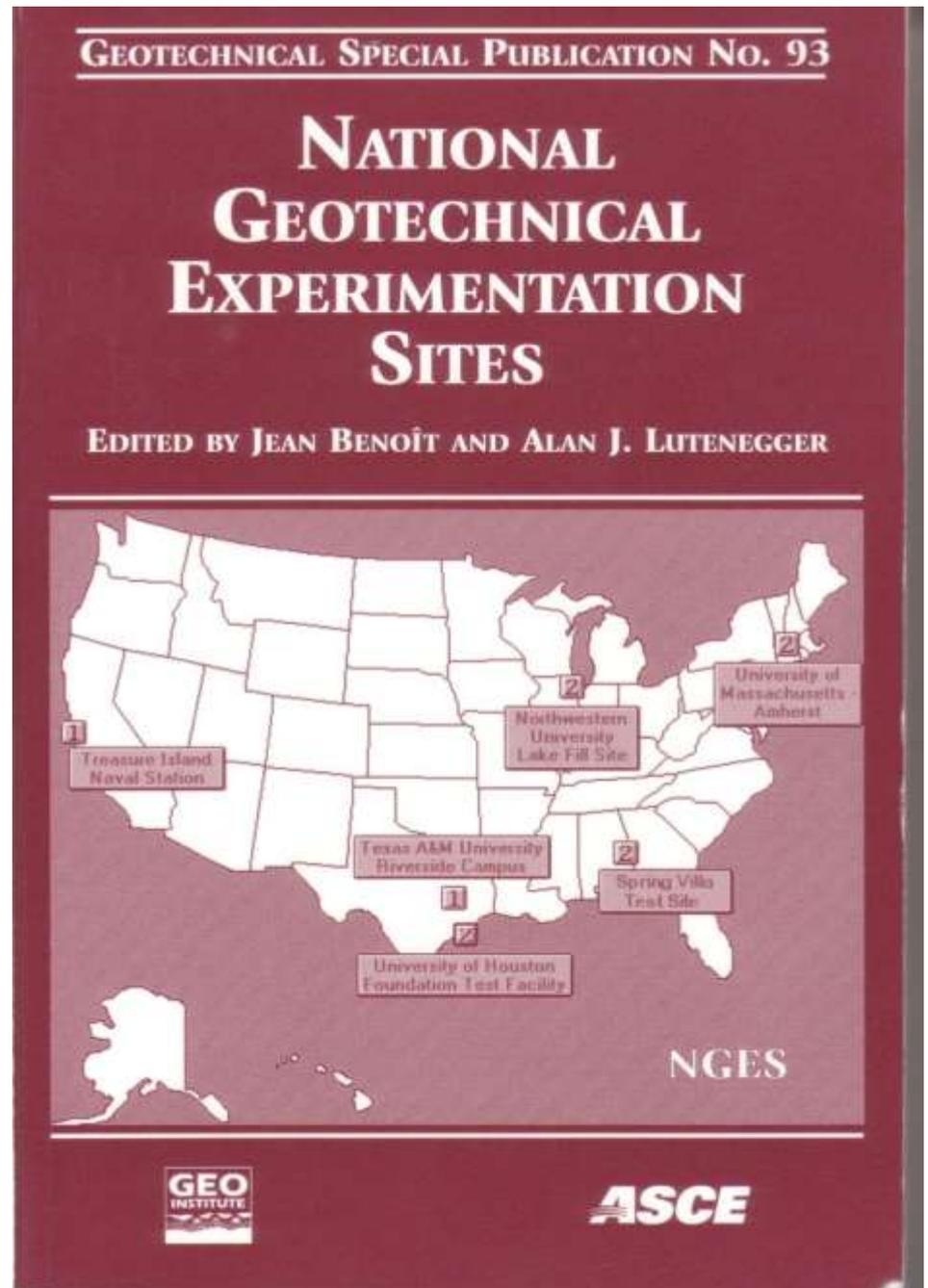
$q_b =$ unit end bearing

Direct Unicone Method
or
Traditional

Limit Plasticity +
Beta Side Resistance

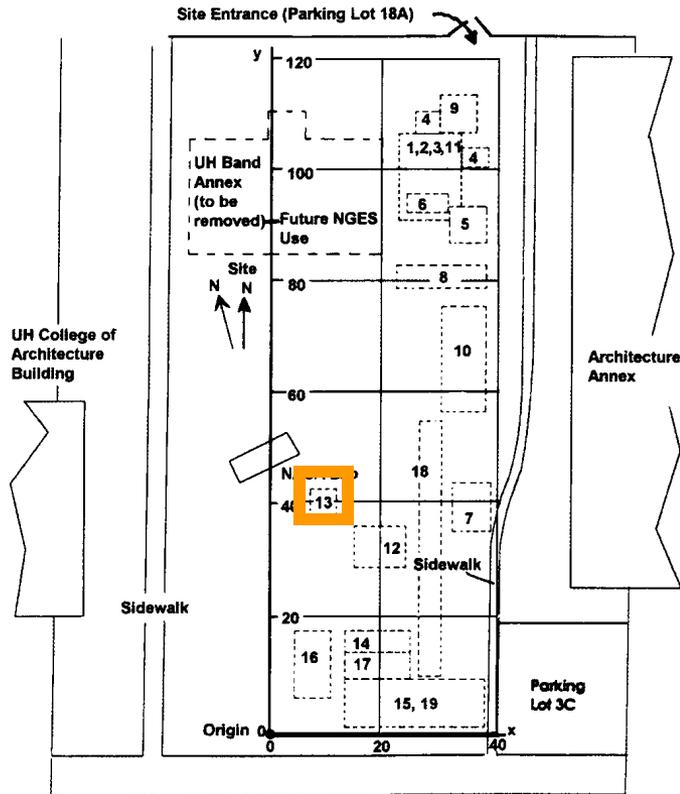
University of Houston NGES Texas

Situated in stiff overconsolidated Beaumont clay



Augered Cast-In-Place (ACIP) Piles at University of Houston

O'Neill, Ata, Vipulanandan, & Yin (2002)



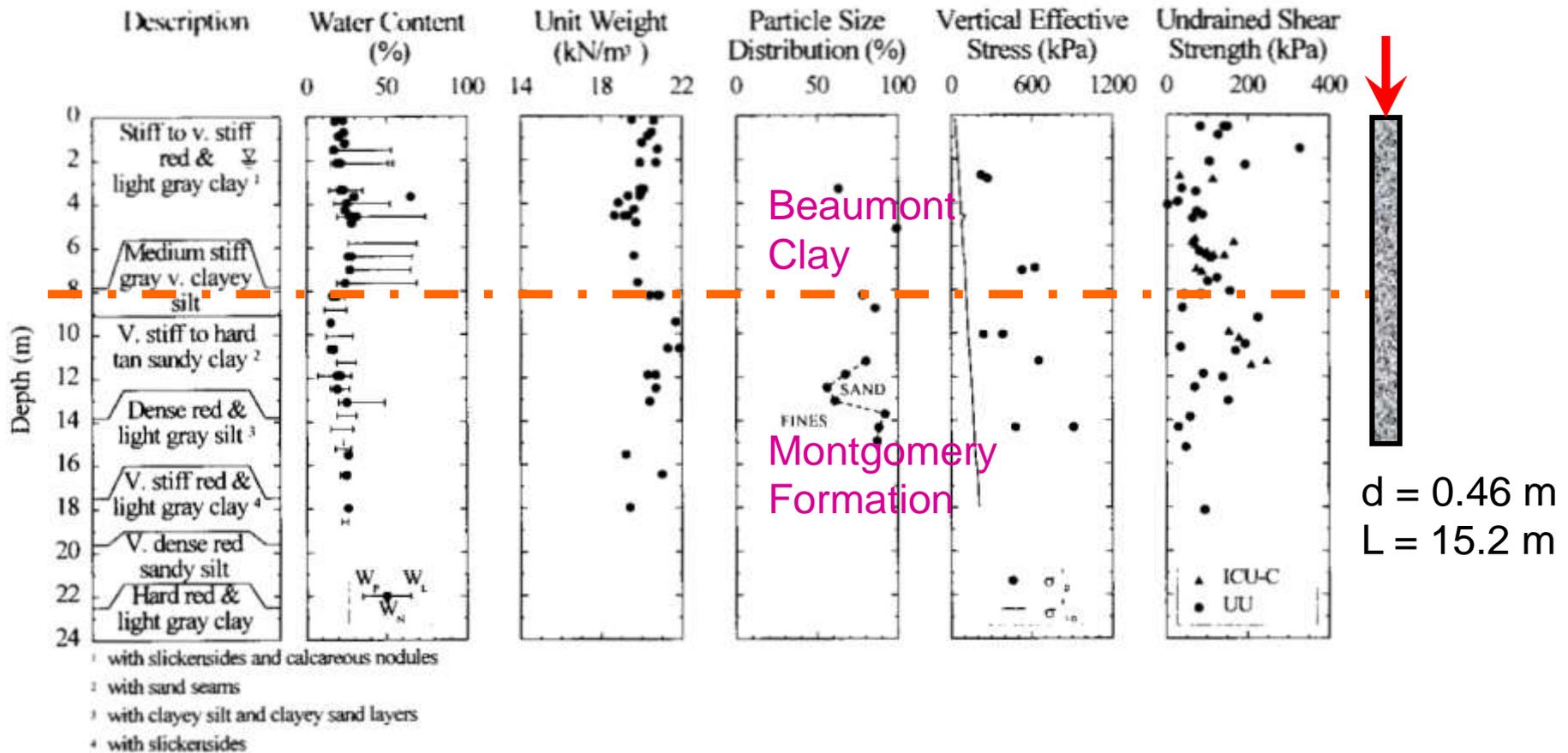
Latitude of Origin: 29.7236°
Longitude of Origin: 95.3405°
x and y Scales in m

Engineering Building D3 (Geotech Lab)



ACIP Concrete Piles at UH

(O'Neill et al. 2002)



Profile from J. Benoit (2000, GSP 93)

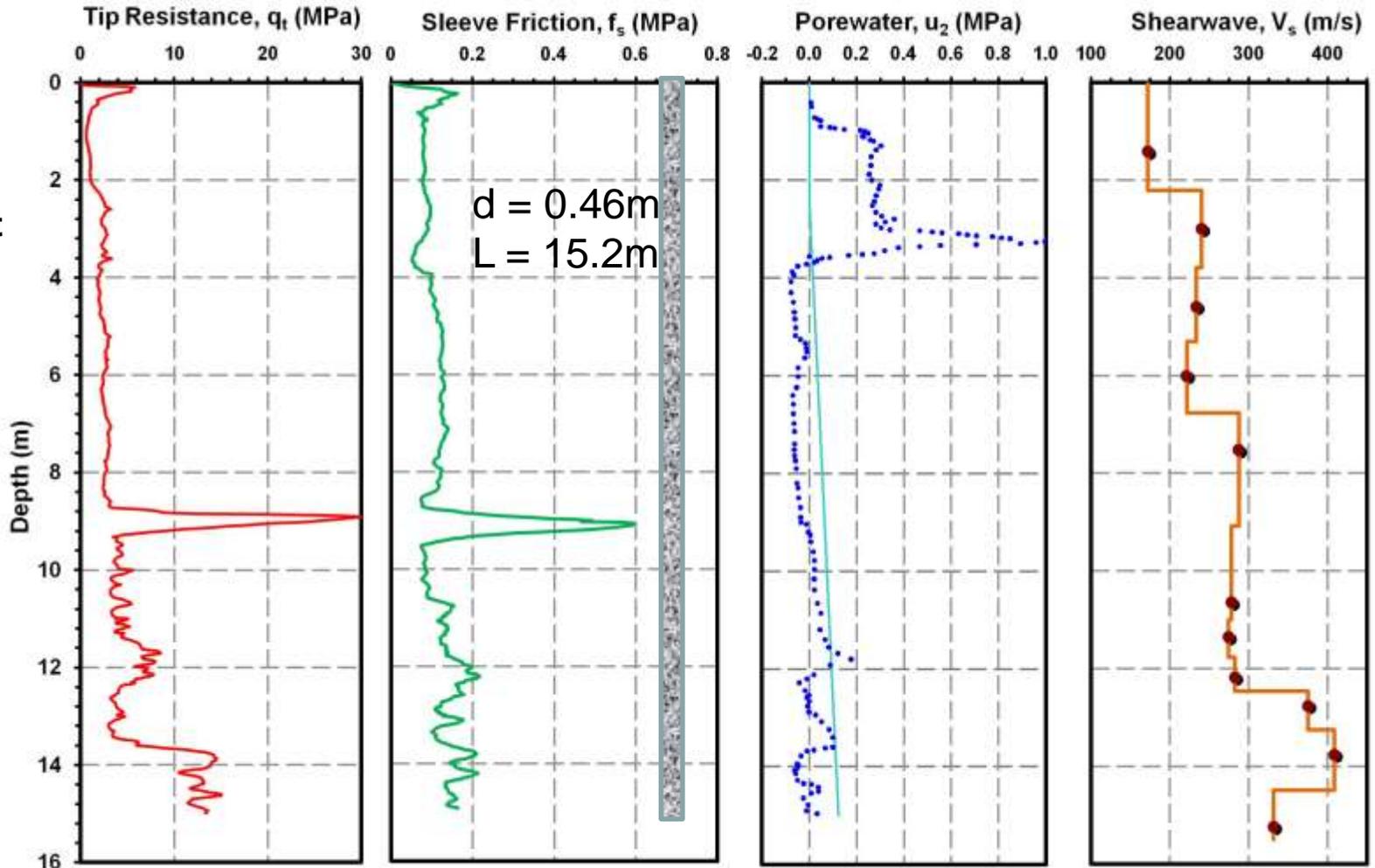
Load Test of Augercast Pile in Beaumont Clay

Seismic Piezocone Sounding, University Houston

Stiff
Beaumont
clay

Fissured
Clay

Very stiff
sandy
clay
(Montgomery
Formation)



Elastic Continuum Pile Solution

Auger Cast-in-place Piles at Univ. Houston

ACIP Pile, University of Houston

Input Parameters

Length L =	15.20	m	$\nu =$	0.50
Diam. d =	0.456	m	$I_\rho =$	0.058
$E_{max} =$	363,855	kPa	$Q_{cap.} =$	1800 kN

Elastic Influence Factor:

$$I_\rho = \frac{1}{\frac{1}{1-\nu^2} + \frac{\pi}{(1+\nu)} \cdot \frac{(L/d)}{\ln[5(L/d)(1-\nu)]}}$$

$Q/Q_{ult} = 1/FS$	E/E_{max}	Q_t (kN)	Q_b (kN)	Q_s (kN)	E (kPa)	s (m)	s (mm)
0.00	1.00	0	0	0	363,855	0.000	0.00
0.02	0.69	36	3	33	251,333	0.000	0.02
0.05	0.59	90	7	83	215,733	0.000	0.05
0.10	0.50	180	14	166	181,495	0.000	0.13
0.15	0.43	270	21	249	157,908	0.000	0.22
0.20	0.38	360	28	332	139,344	0.000	0.33
0.30	0.30	540	42	498	110,304	0.001	0.63
0.40	0.24	720	56	664	87,450	0.001	1.05
0.50	0.19	900	70	830	68,313	0.002	1.69
0.60	0.14	1,080	84	996	51,697	0.003	2.68
0.70	0.10	1,260	98	1,162	36,923	0.004	4.37
0.80	0.06	1,440	112	1,328	23,560	0.008	7.83
0.90	0.03	1,620	126	1,494	11,321	0.018	18.33
0.98	0.01	1,764	137	1,627	2,199	0.103	102.79

Pile Displacements:

$$s = \frac{Q_t \cdot I_\rho}{d \cdot E_s}$$

Load Transfer:

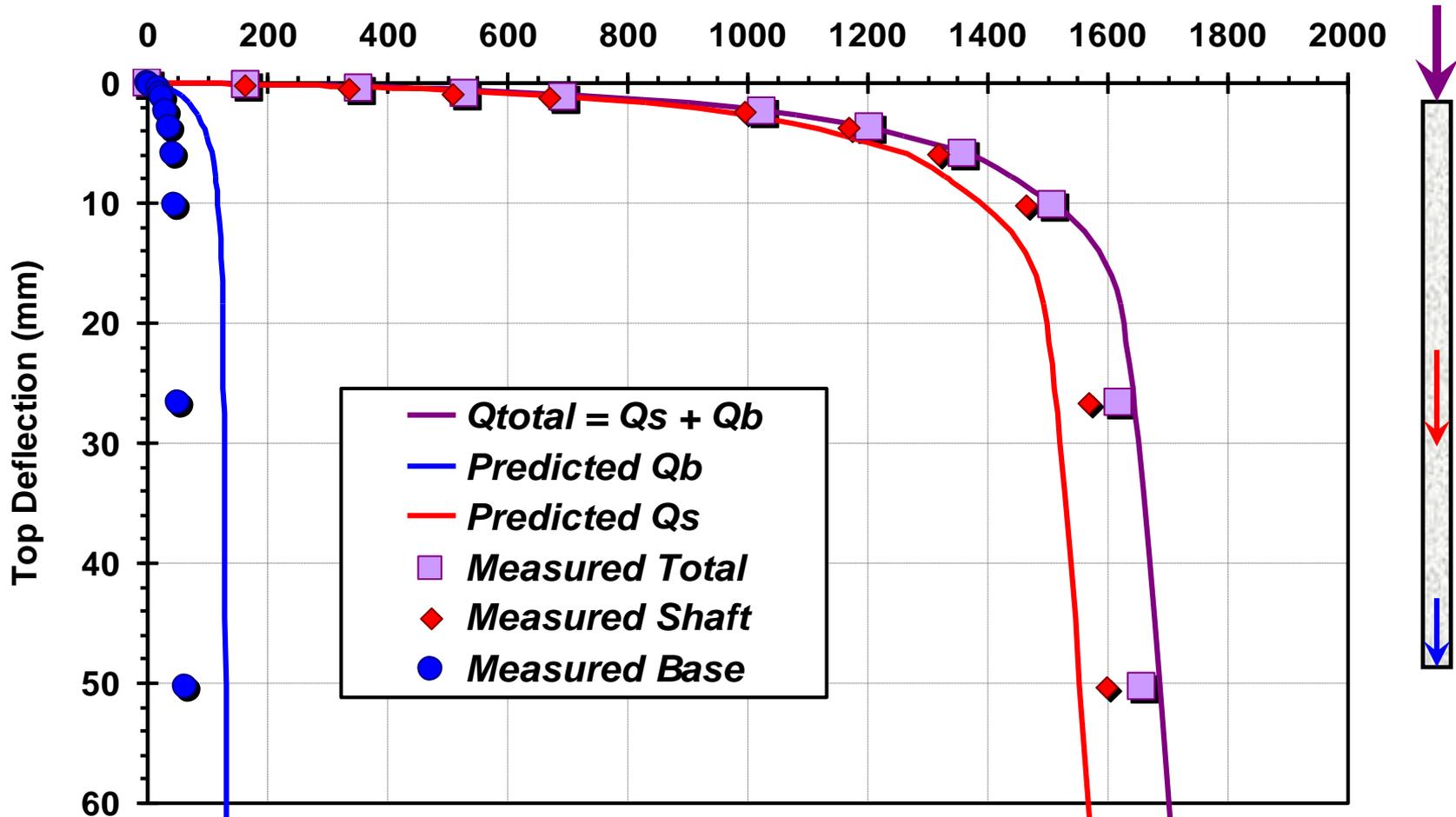
$$\frac{Q_b}{Q_t} = \frac{I_\rho}{1-\nu^2}$$

(O'Neill, 2000)

ACIP Concrete Piles at UH (O'Neill, 2000)

Rigid Elastic Pile Solution

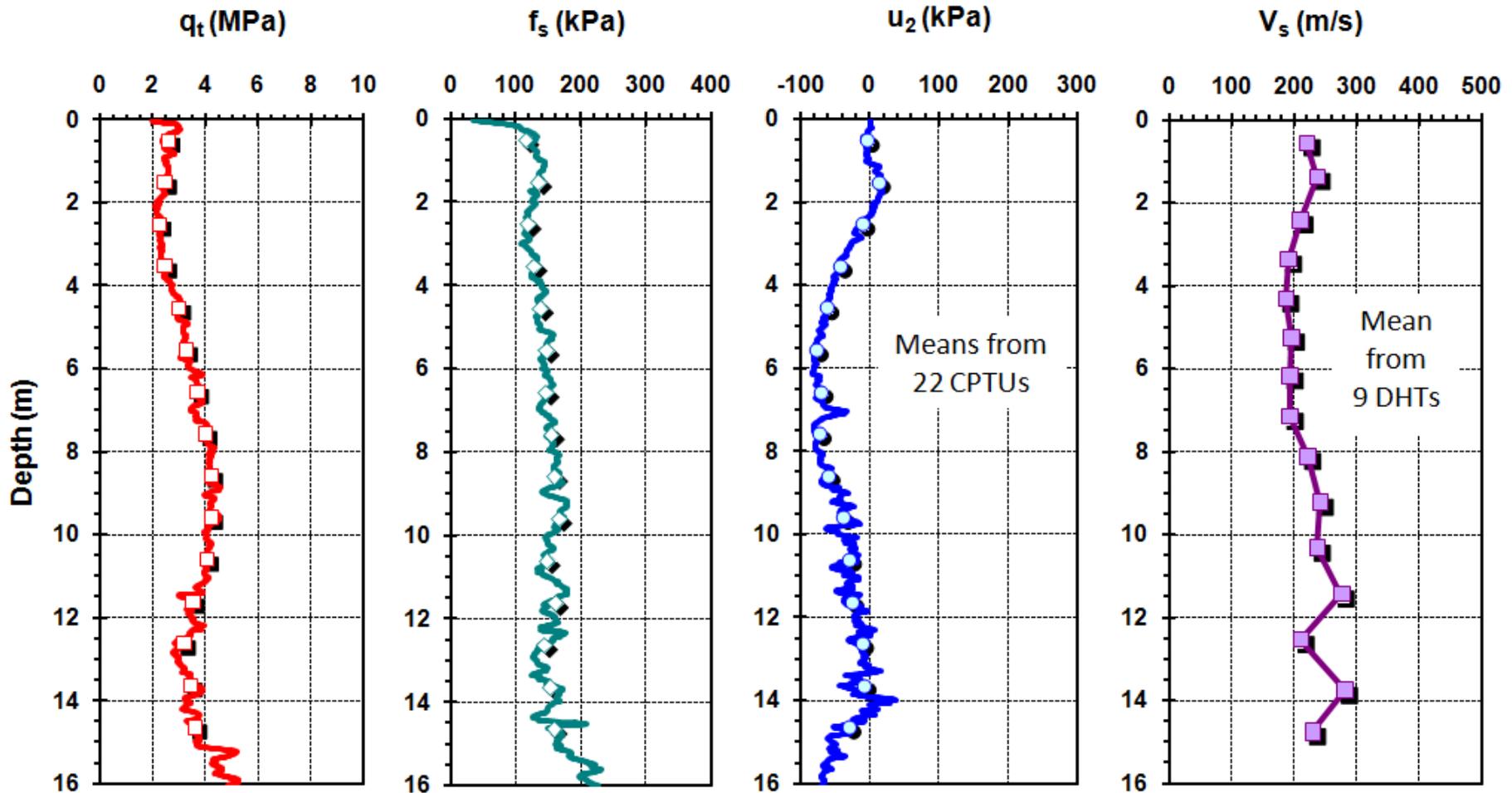
Axial Load, Q (kN)



Opelika National Geotechnical Experimentation Site, Alabama

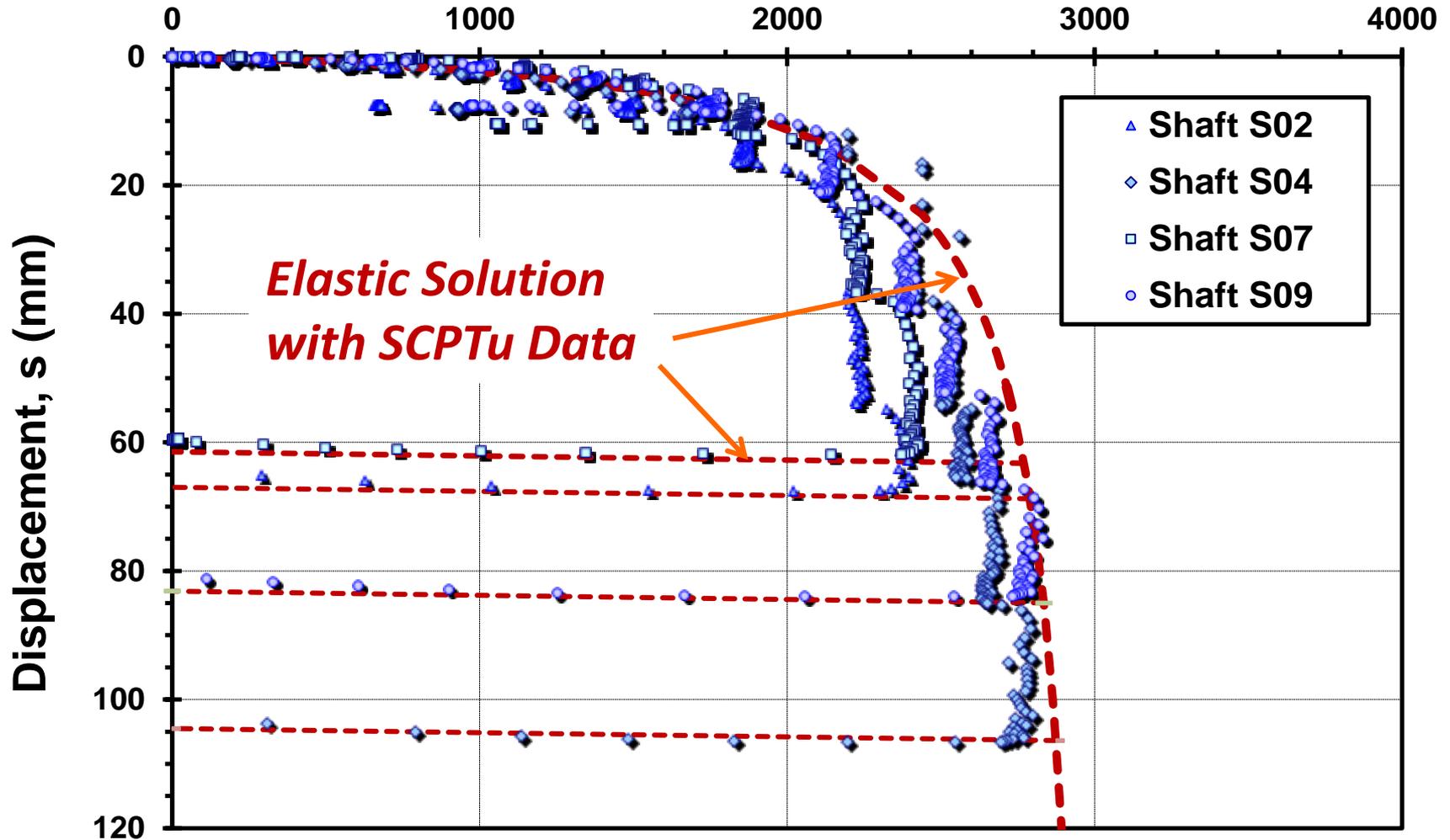


Mean SCPTu at Opelika NGES, Alabama



Axial Load Tests: Opelika NGES, Alabama (Brown ASCE JGGE 2002)

Applied Load, Q (kN)



Compressible Pile Solution

$$\text{Displacement : } w_t = \frac{P_t \cdot I_p}{d \cdot E_{sL}}$$

Influence factor: $I_p = x_1/x_3$

$$x_1 = 4 \cdot (1 + \nu) \cdot \left[1 + \frac{1}{\pi \lambda} \cdot \frac{8}{(1 - \nu)} \cdot \frac{\eta}{\xi} \cdot \frac{\tanh(\mu L)}{\mu L} \cdot \frac{L}{d} \right]$$

$$x_2 = \frac{4}{(1 - \nu)} \cdot \frac{\eta}{\xi} \cdot \frac{1}{\cosh(\mu L)}$$

$$x_3 = \frac{4}{(1 - \nu)} \cdot \frac{\eta}{\xi} + \frac{4 \pi \rho_E}{\zeta} \cdot \frac{\tanh(\mu L)}{\mu L} \cdot \frac{L}{d}$$

The proportion of load transferred from the top to base:

$$P_b/P_t = x_2/x_3$$

The proportion of load carried in side shear is:

$$P_s/P_t = 1 - P_b/P_t$$

The displacement at the pile toe/base is given by:

$$w_b = w_t / \cosh(\mu L)$$

NOTES: $\eta = d_b/d = \text{eta factor}$ (Note: $d_b = \text{base diameter}$, so that $\eta = 1$ for straight shaft piles)

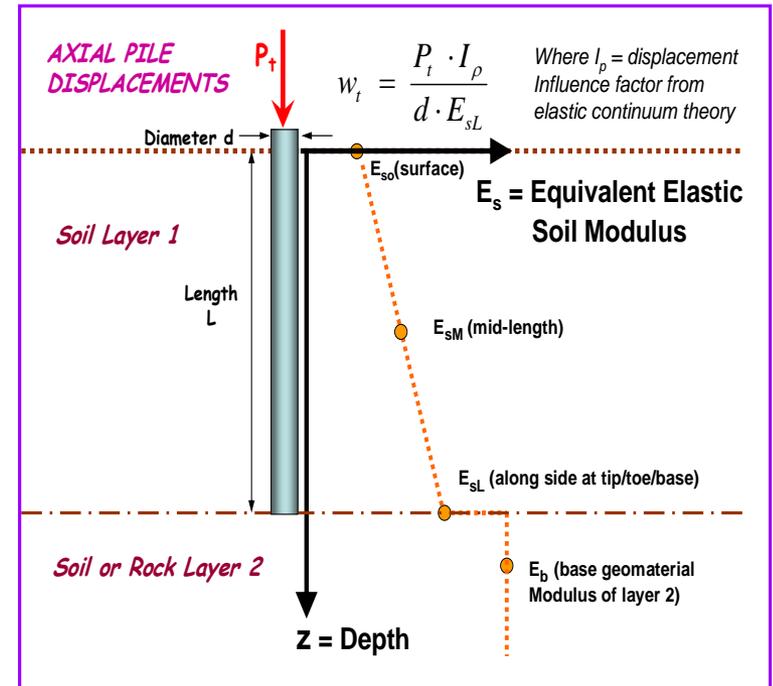
$\xi = E_{sL}/E_b = \text{xi factor}$ (Note: $\xi = 1$ for floating pile; $\xi < 1$ for end-bearing pile)

$\rho_E = E_{sm}/E_{sL} = \text{rho term}$. The Gibson parameter can be evaluated from: $\rho_E = 1/2(1 + E_{s0}/E_{sL})$.

$\lambda = 2 \cdot (1 + \nu) \cdot E_p/E_{sL} = \text{lambda factor}$

$\zeta = \ln\{[0.25 + (2.5 \cdot \rho_E \cdot (1 - \nu) - 0.25) \cdot \xi] \cdot (2 \cdot L/d)\} = \text{zeta factor}$

$\mu L = 2 \cdot (2/\zeta \cdot \lambda)^{0.5} \cdot (L/d) = \text{mu factor}$



Cone Rig at I-85 Bridge, Coweta Georgia



Load Test at I-85 Bridge, Coweta County, GA

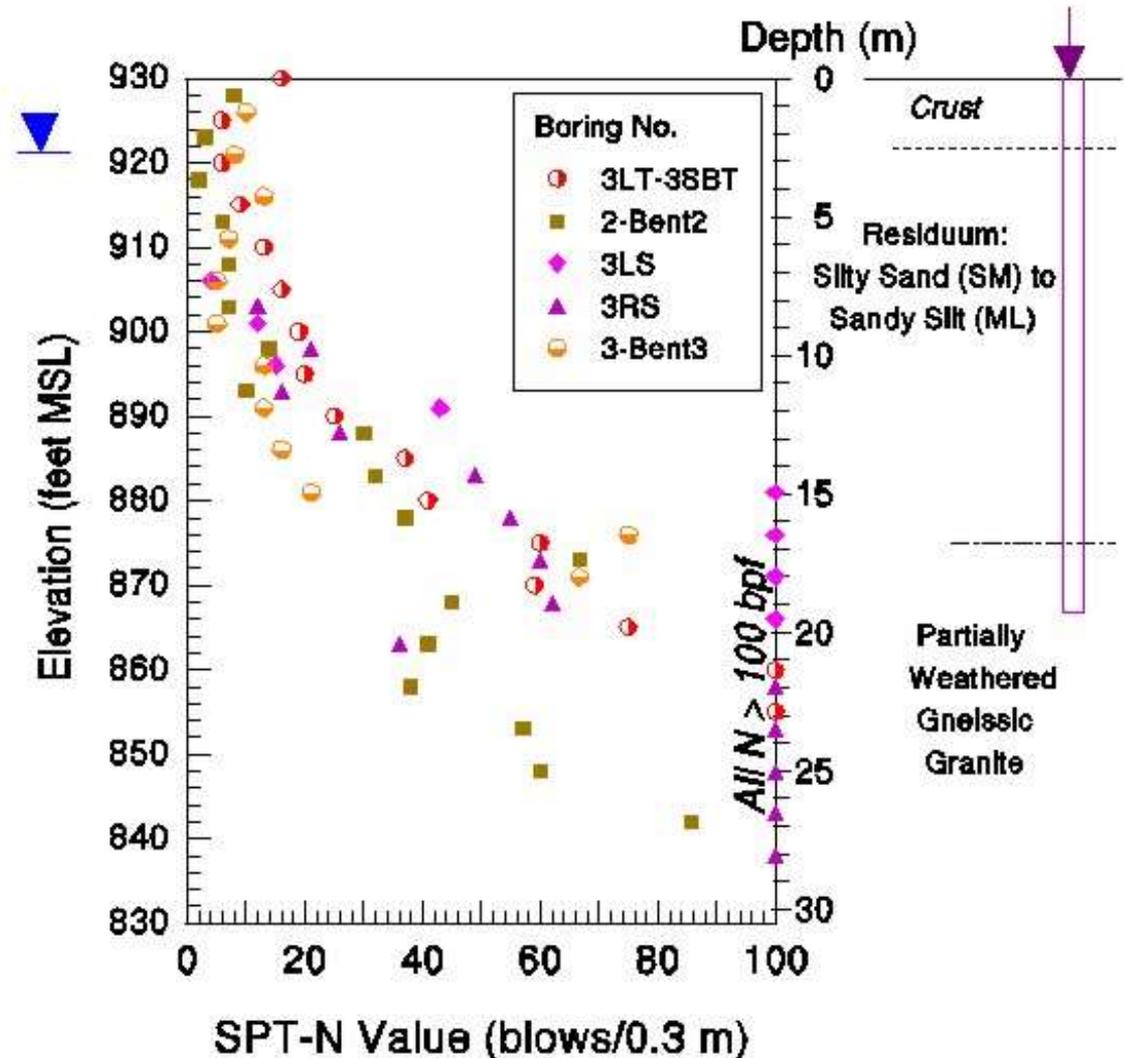


**GDOT Drilled
Shaft Load Test:**

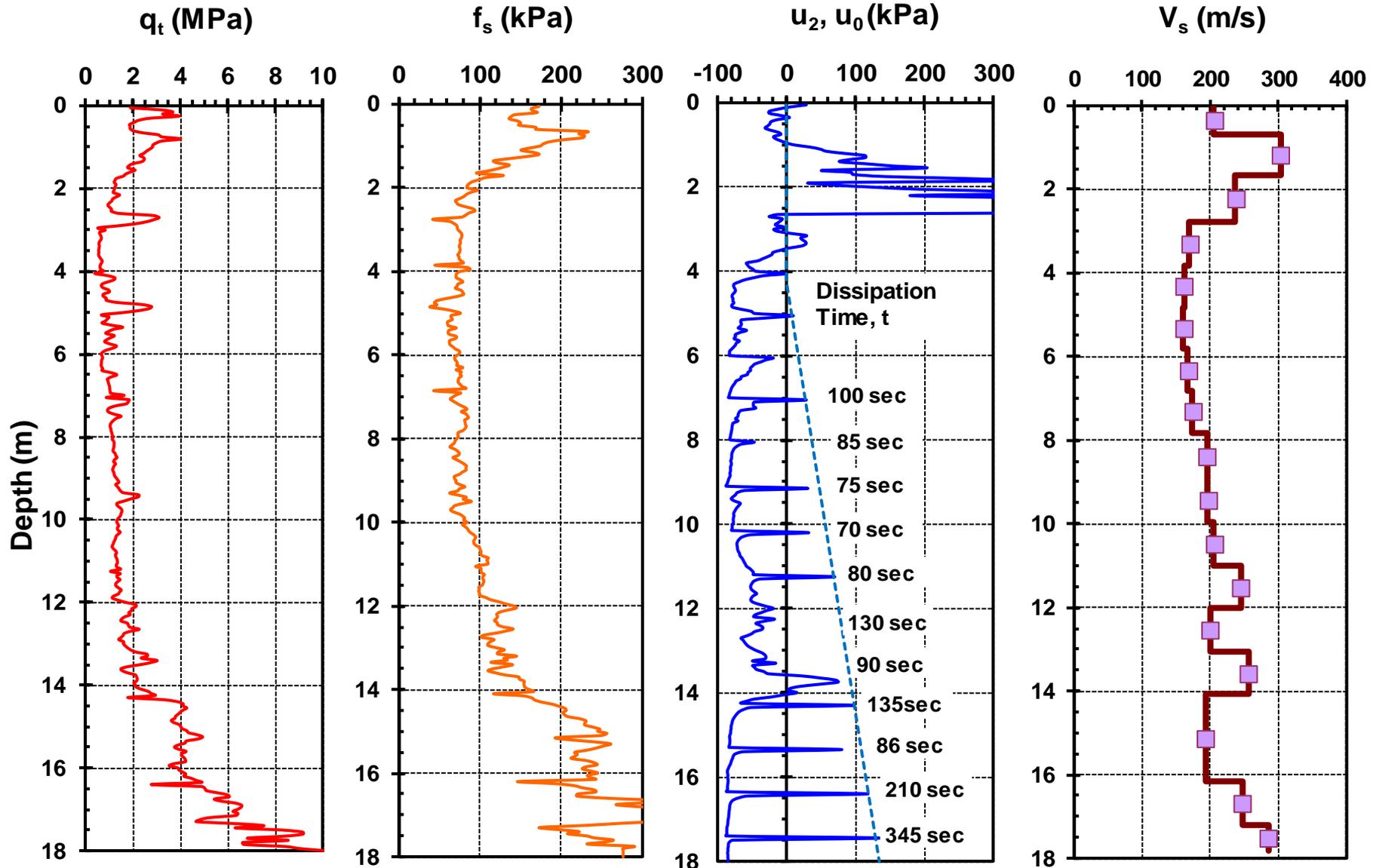
D = 0.91 m

L = 20.1 m

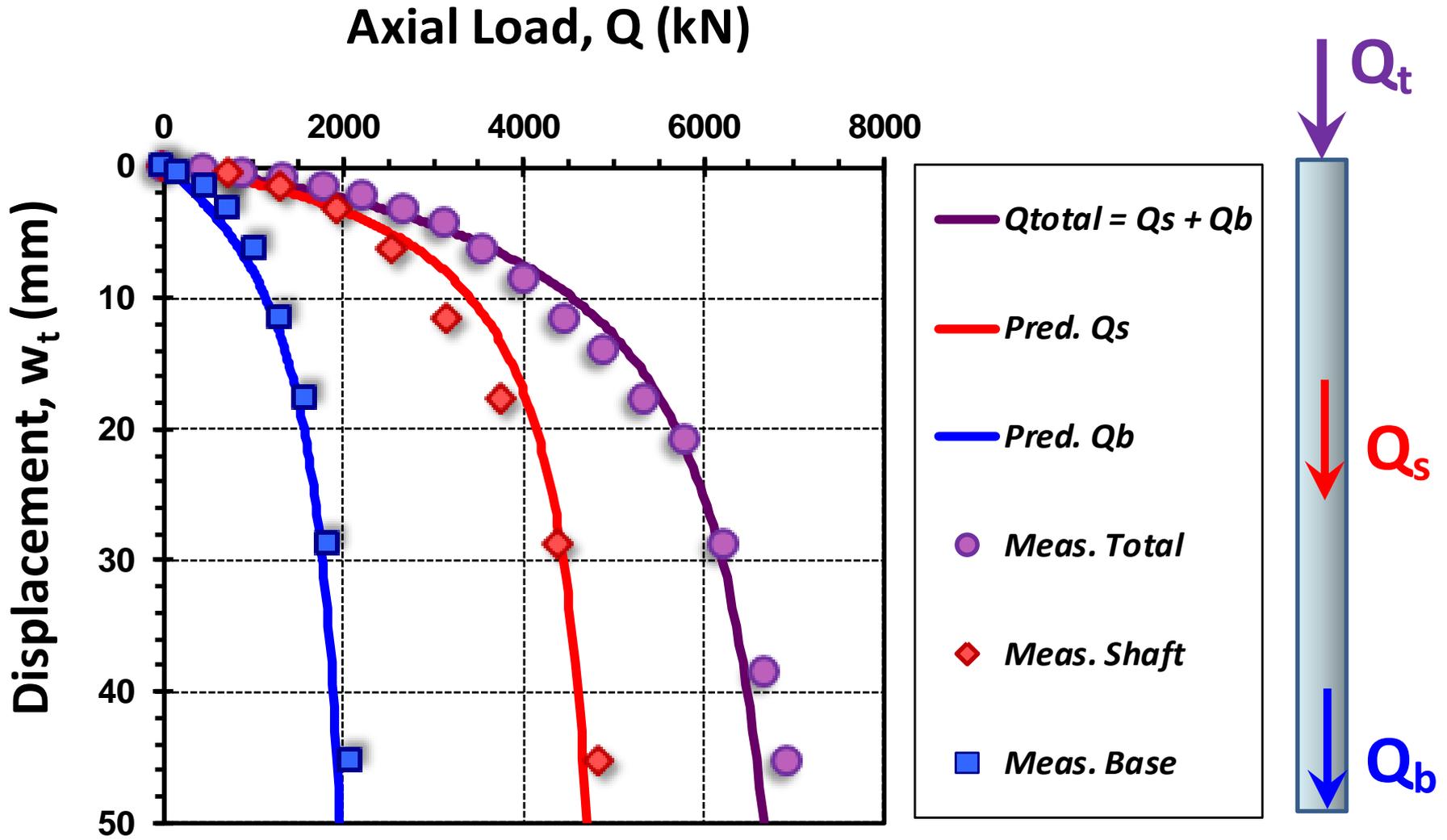
**Load Test
Directed by
Mike O'Neill**



SCPTu at I-85 Bridge - Newnan, Georgia



Axial Load Response of Coweta Shaft



Pile Load Tests



Dead Weight
www.hindu.com



Reaction Frame
www2.dot.ca.gov



Statnamic Load Test
www.statnamiceurope.com



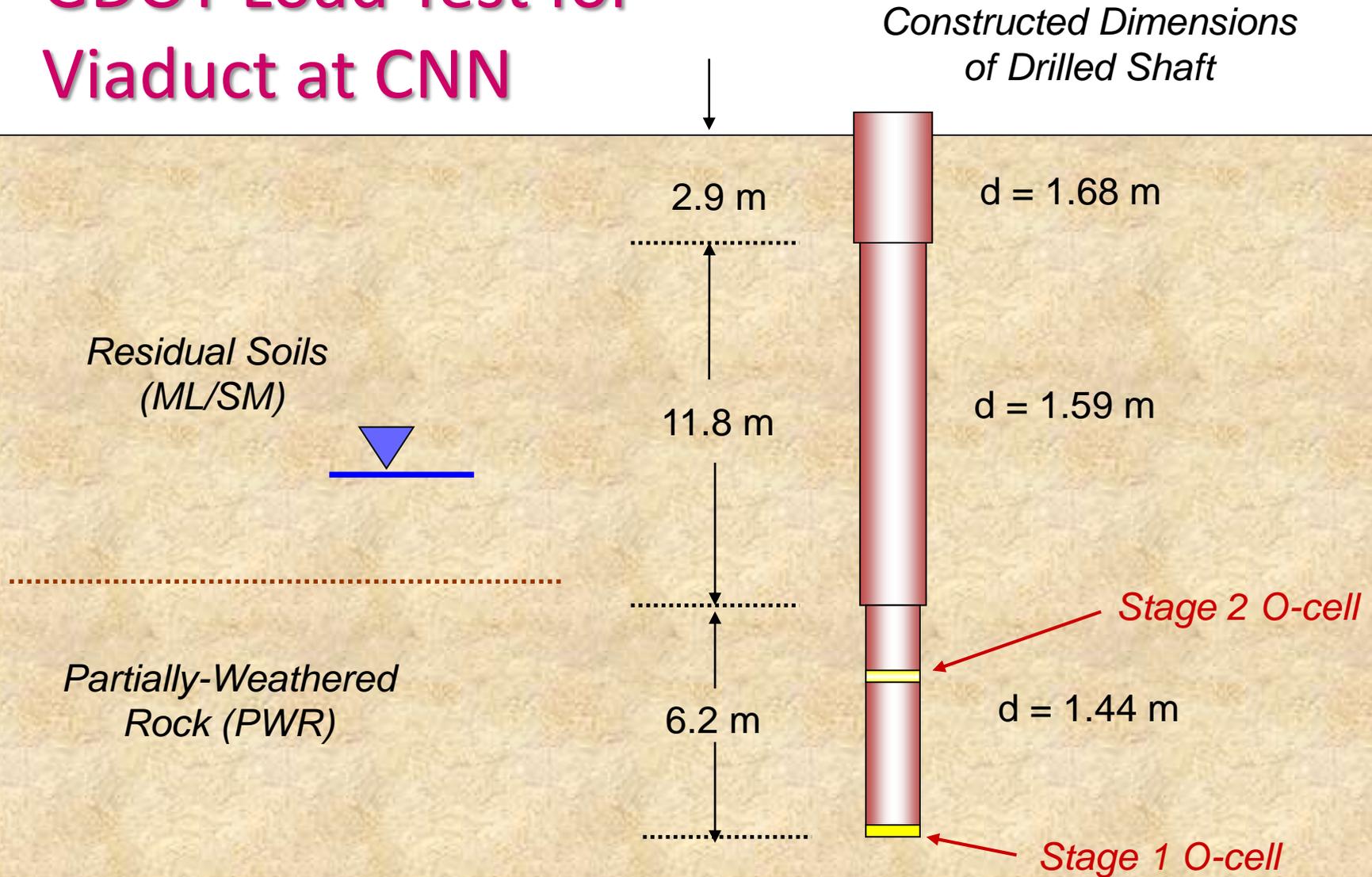
Osterberg Cell
www.fhwa.dot.gov

GDOT Viaduct at International Boulevard near CNN, Atlanta

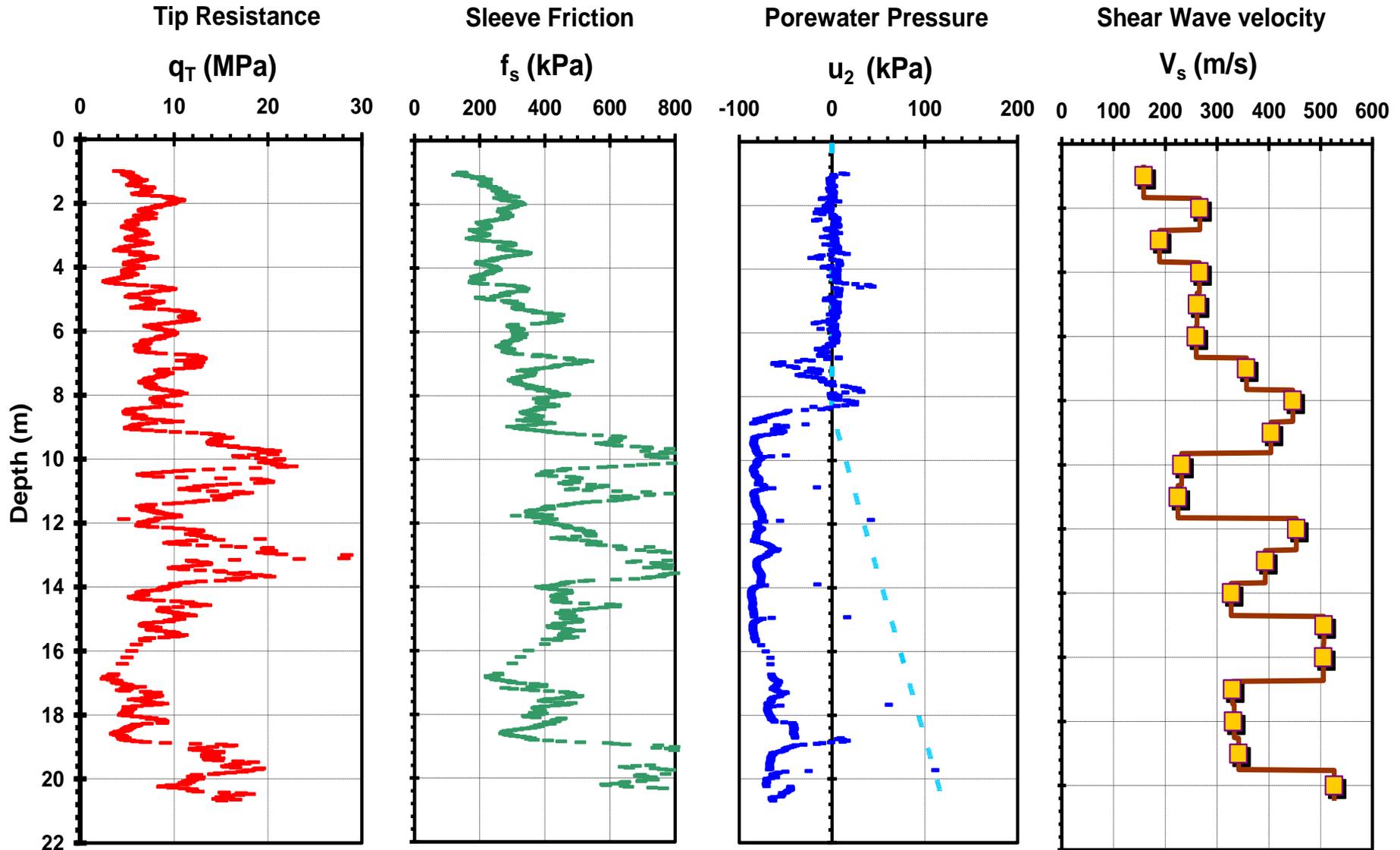
Drilled Shaft Load Test
by multi-stage O-Cells
GT Class "A" Prediction
March 2003



GDOT Load Test for Viaduct at CNN



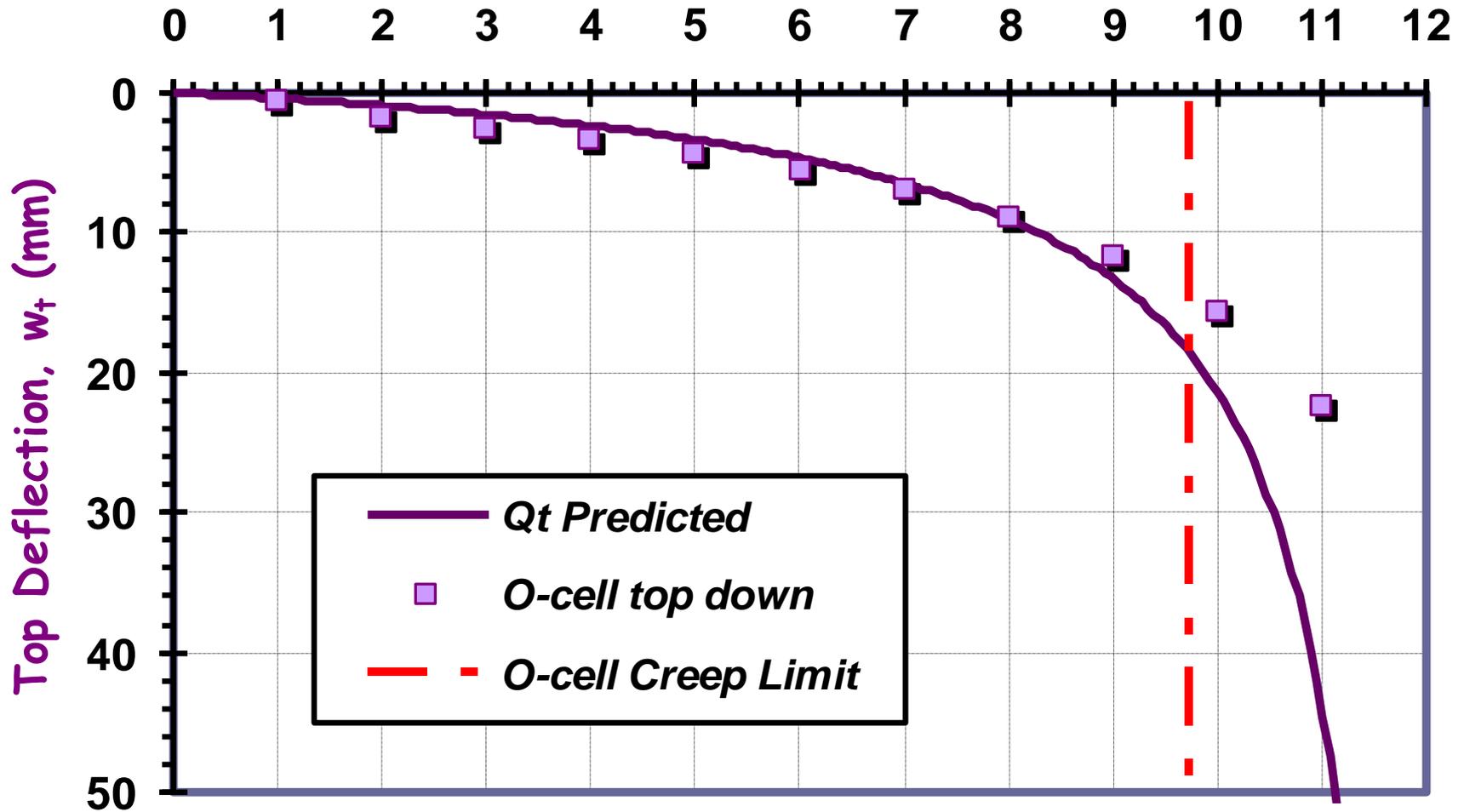
GT Seismic Piezocone Sounding (SCPTu) GDOT - International Blvd.



Class A Prediction - GDOT Bridge at CNN

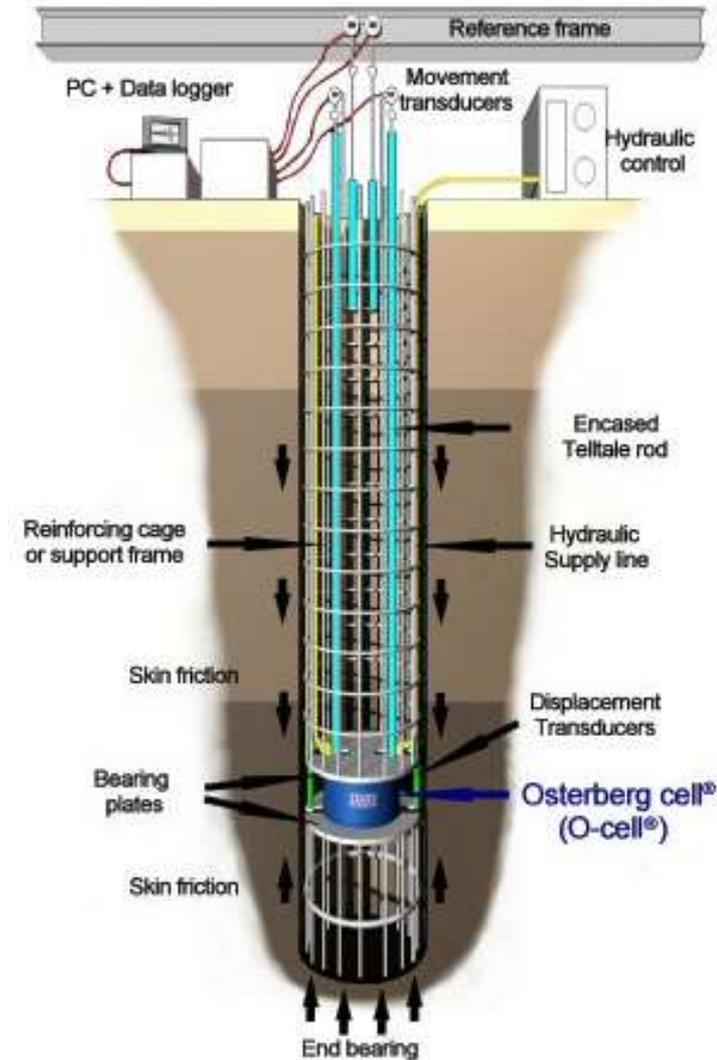
GDOT International Blvd. at CNN

Axial Load, Q (MN)



Osterberg Load Cell Test

- ❑ High capacity sacrificial hydraulic jack
- ❑ Originally installed at pile base
- ❑ Juxtaposes side resistance of upper pile segment vs. base resistance
- ❑ Continue until ultimate skin friction or end bearing are reached, else capacity of the O-cell
- ❑ Multiple O-cell can be used at several elevations within test shaft
- ❑ Staged O-cell tests have now reached up to 30+ tons on single drilled shaft



<http://www.loadtest.com/loadtest-uk/about/ocell/3%20O-cell.jpg>

O-Cell Elastic Solution

upper
segment



Diameter
 $d_1 = 2r_1$
Length
 L_1

Rigid pile shaft under upward loading

$$\frac{P_1}{G_{s1} r_{o1} w_1} = \frac{2\pi \cdot L_1}{\zeta_1 \cdot r_{o1}}$$

O-Cell



$P_1 = P_2$

Rigid pile under compression loading

lower
segment



Diameter
 $d_2 = 2r_2$
Length
 L_2

$$\frac{P_2}{G_{s2} r_{o2} w_2} = \frac{4}{(1-\nu)\xi} + \frac{2\pi \cdot L_2}{\zeta_2 \cdot r_{o2}}$$

P = applied force

L = pile length

r_o = pile radius

E_p = pile modulus

G_s = soil side shear modulus

ν = Poisson's ratio of soil

w = pile displacement

l = E_p/G_{sL} = soil-pile stiffness ratio

ξ = G_{s2}/G_{sb} (Note: floating pile: ξ = 1)

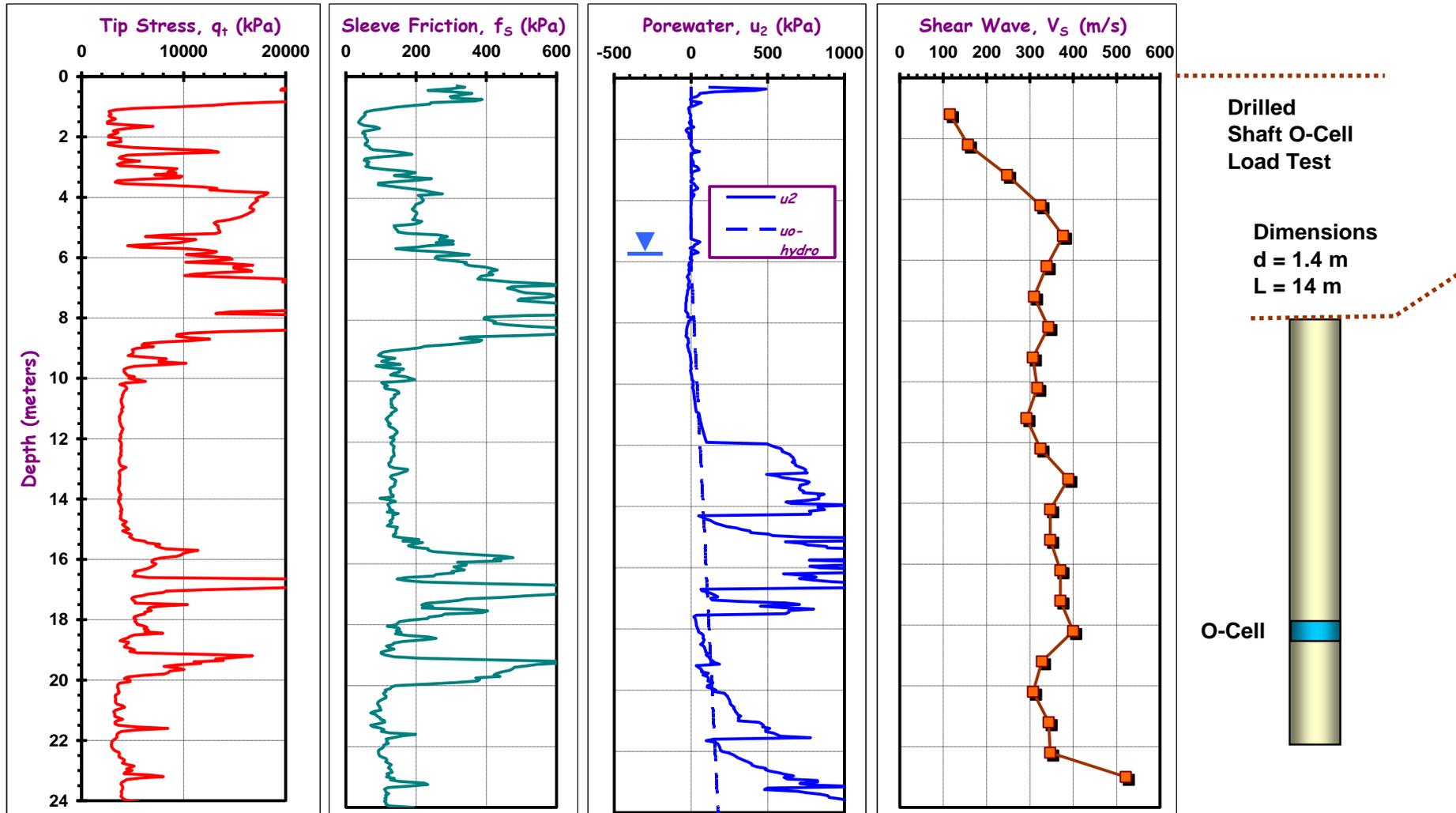
G_{sb} = soil modulus below pile base/toe

ζ = ln(r_m/r_o) = soil zone of influence

r_m = L{0.25 + ξ [2.5 (1-ν) - 0.25]}

Calgary Drilled Shaft O-Cell Load Test by Seismic Piezocone Tests

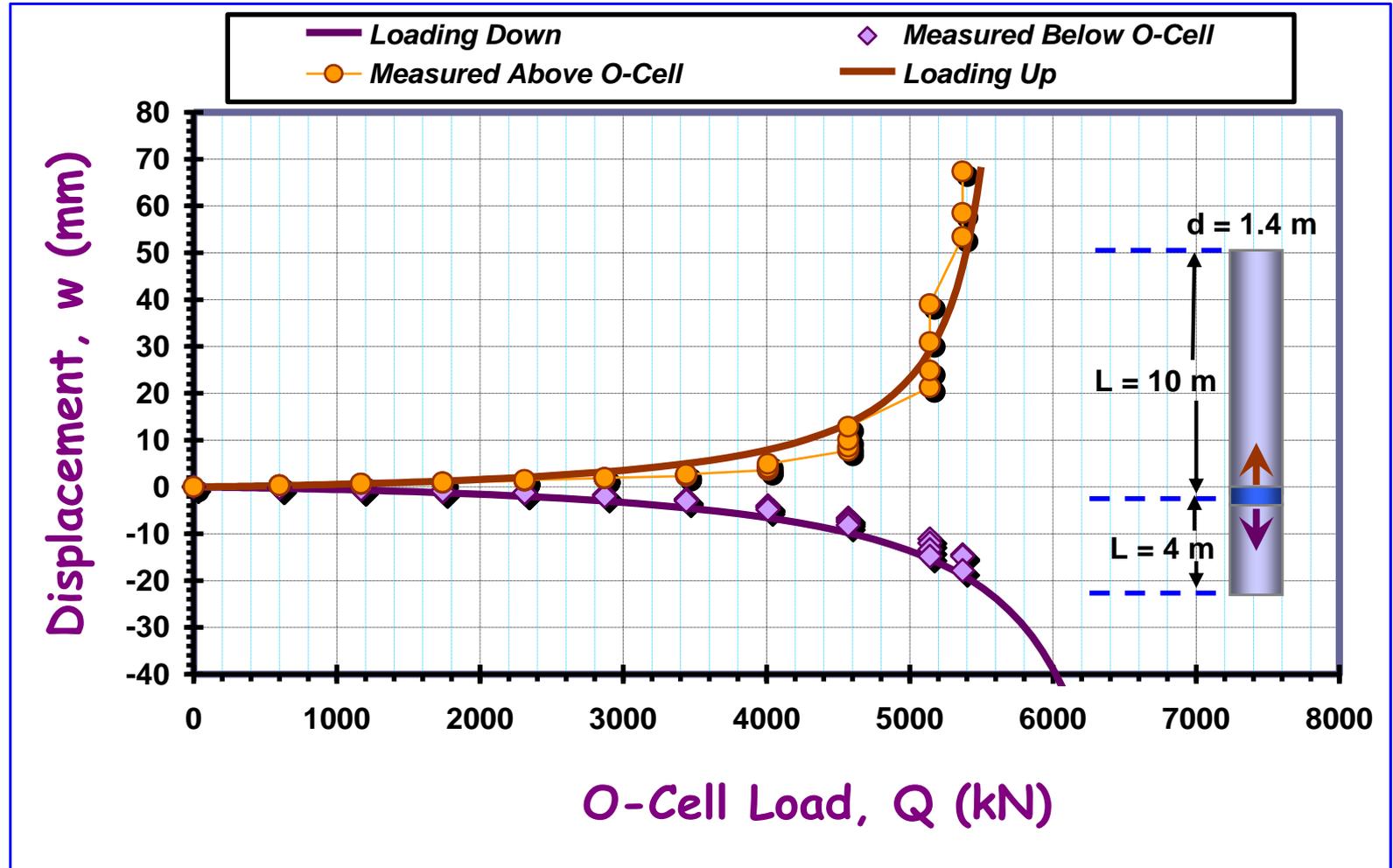
CPT05-13 Calgary



Evaluation of Calgary O-Cell Shaft Response by Seismic Piezocone Tests

Calgary Foothills Medical Center
O-Cell Load Test Results

O-cell load test data App. A, page 3 of 5
LOADTEST Project No. LOT-9121 (Figure 1)



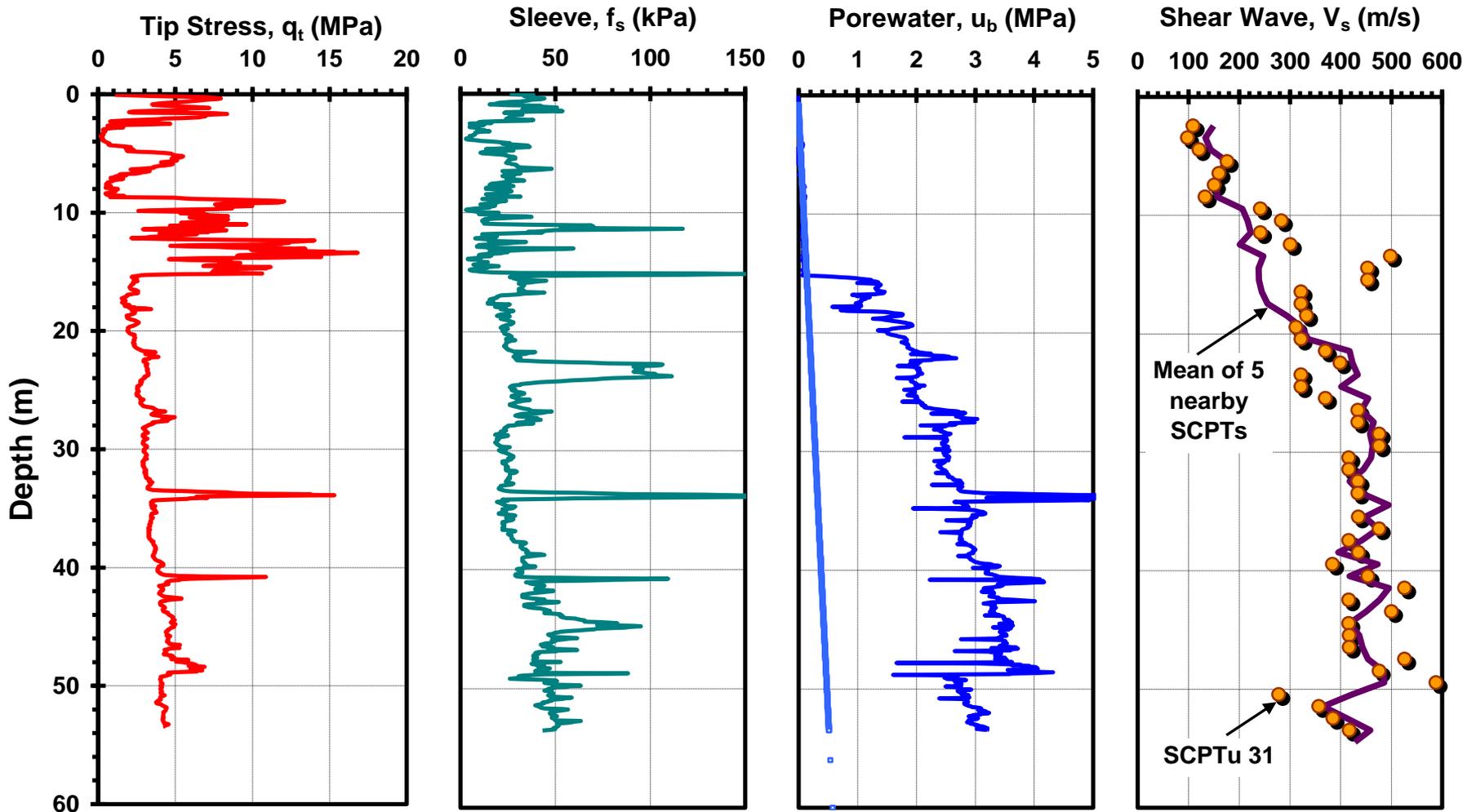
Cooper River Bridge, Charleston, SC



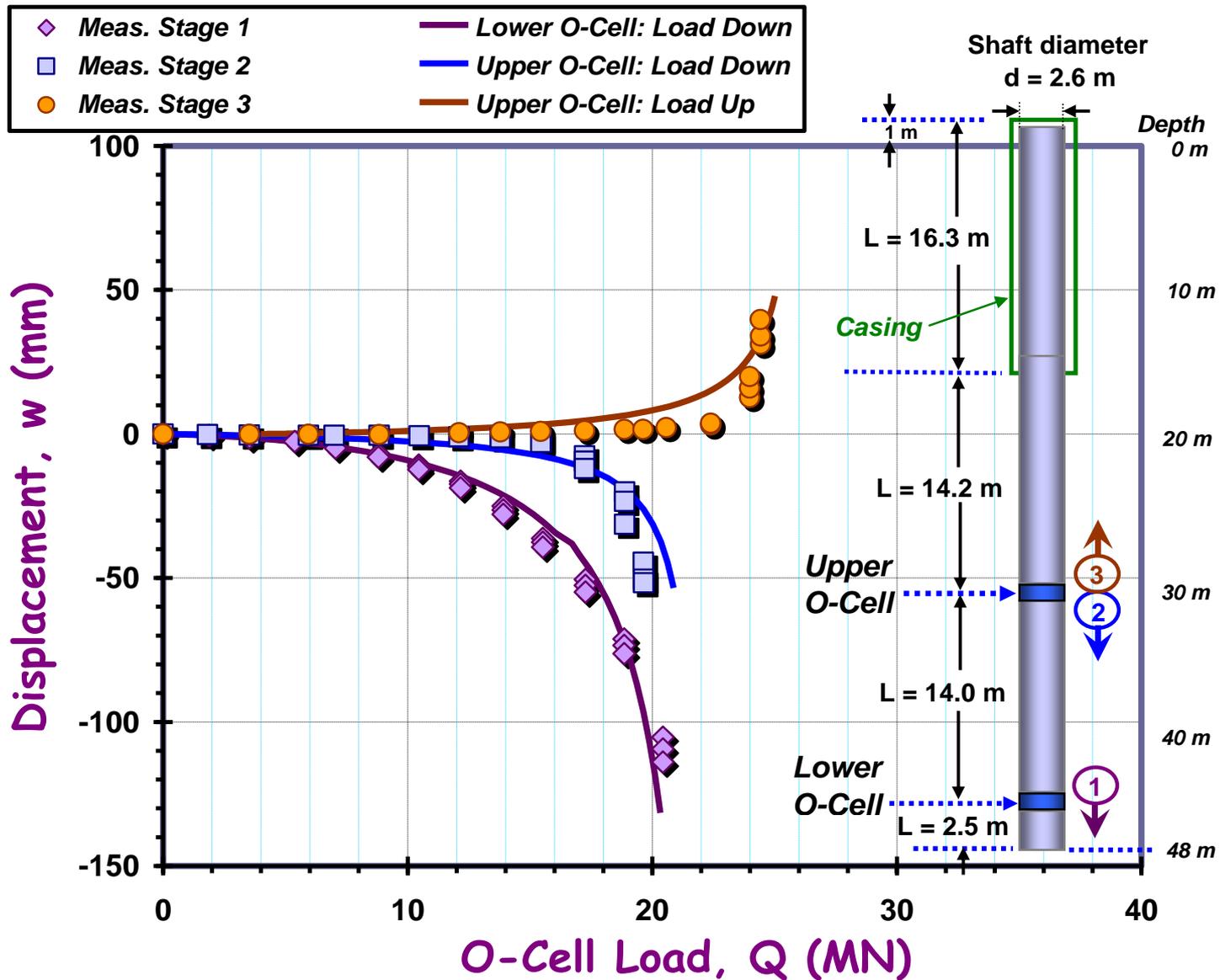
Deep Foundations: 2.5 m- and 3-m diameter drilled shafts with lengths of 45 to 60 m

Arthur Ravenel Bridge over Cooper River, SC

(Camp, ASCE GeoSupport GSP 2004)



Arthur Ravenel Bridge, Charleston, SC



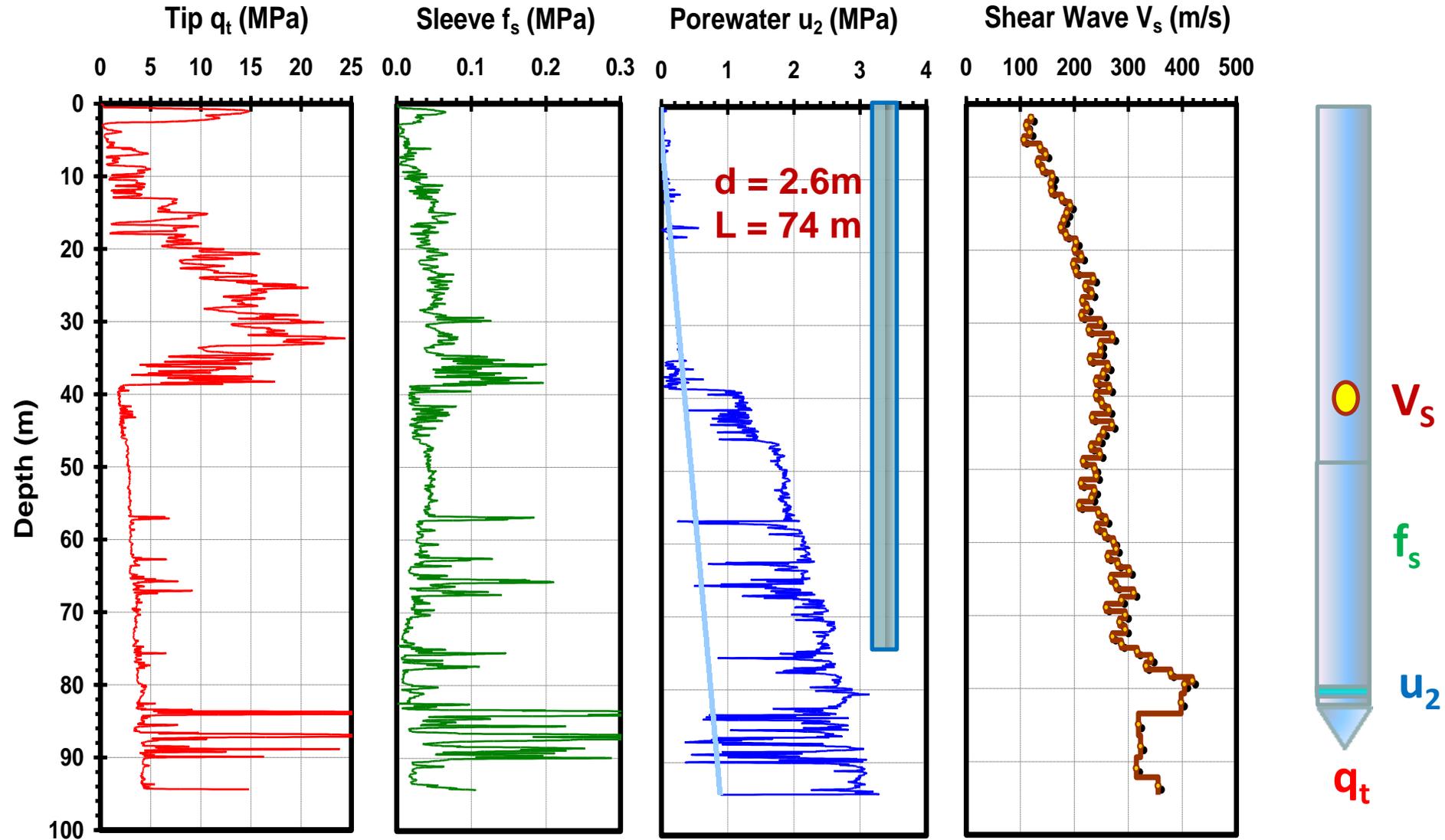
Arthur Ravenel Bridge over the Cooper River, Charleston, SC



Photo courtesy of Sparky Witte

Seismic Piezocone Sounding

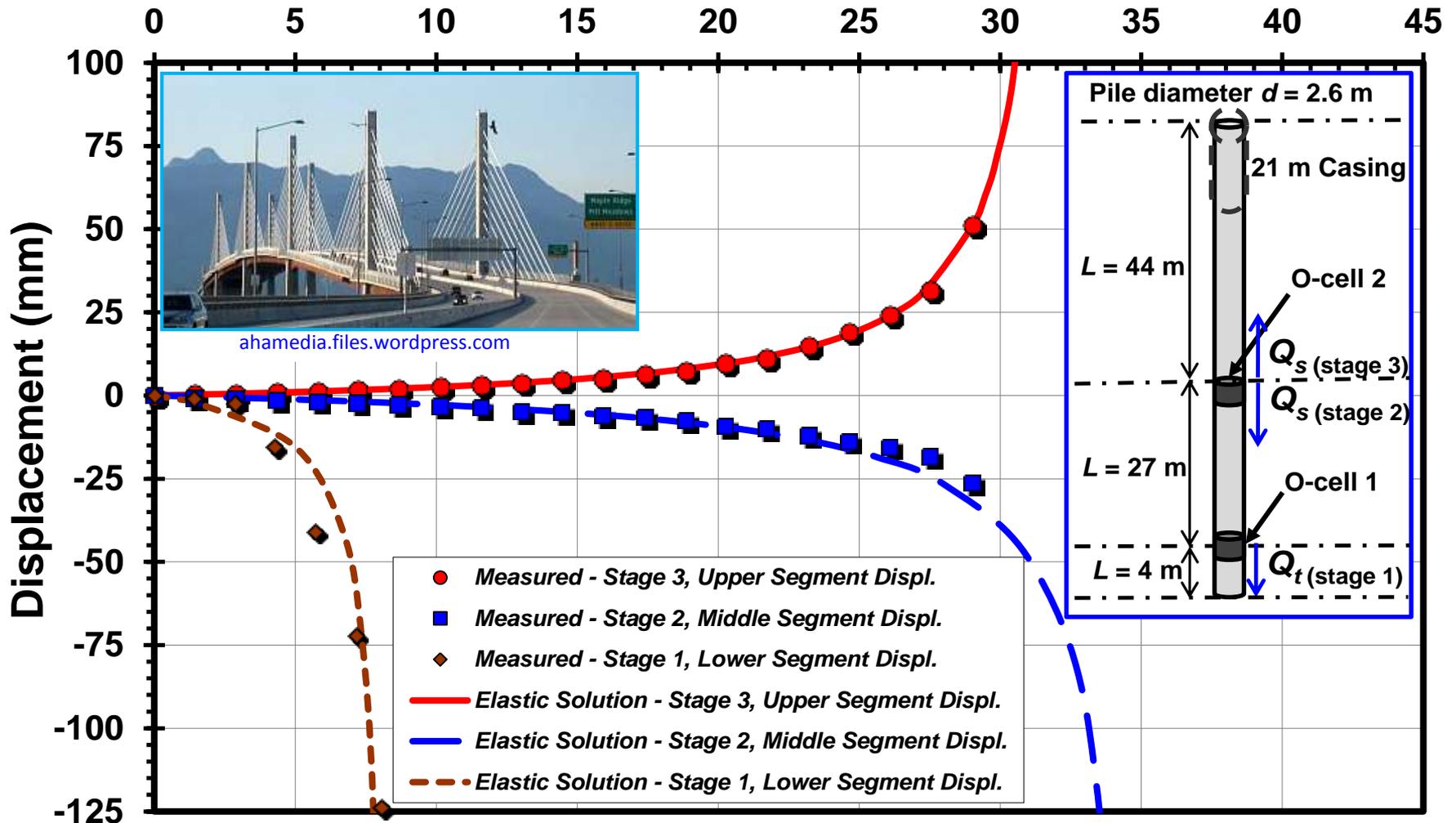
Golden Ears Bridge Site, Vancouver, BC



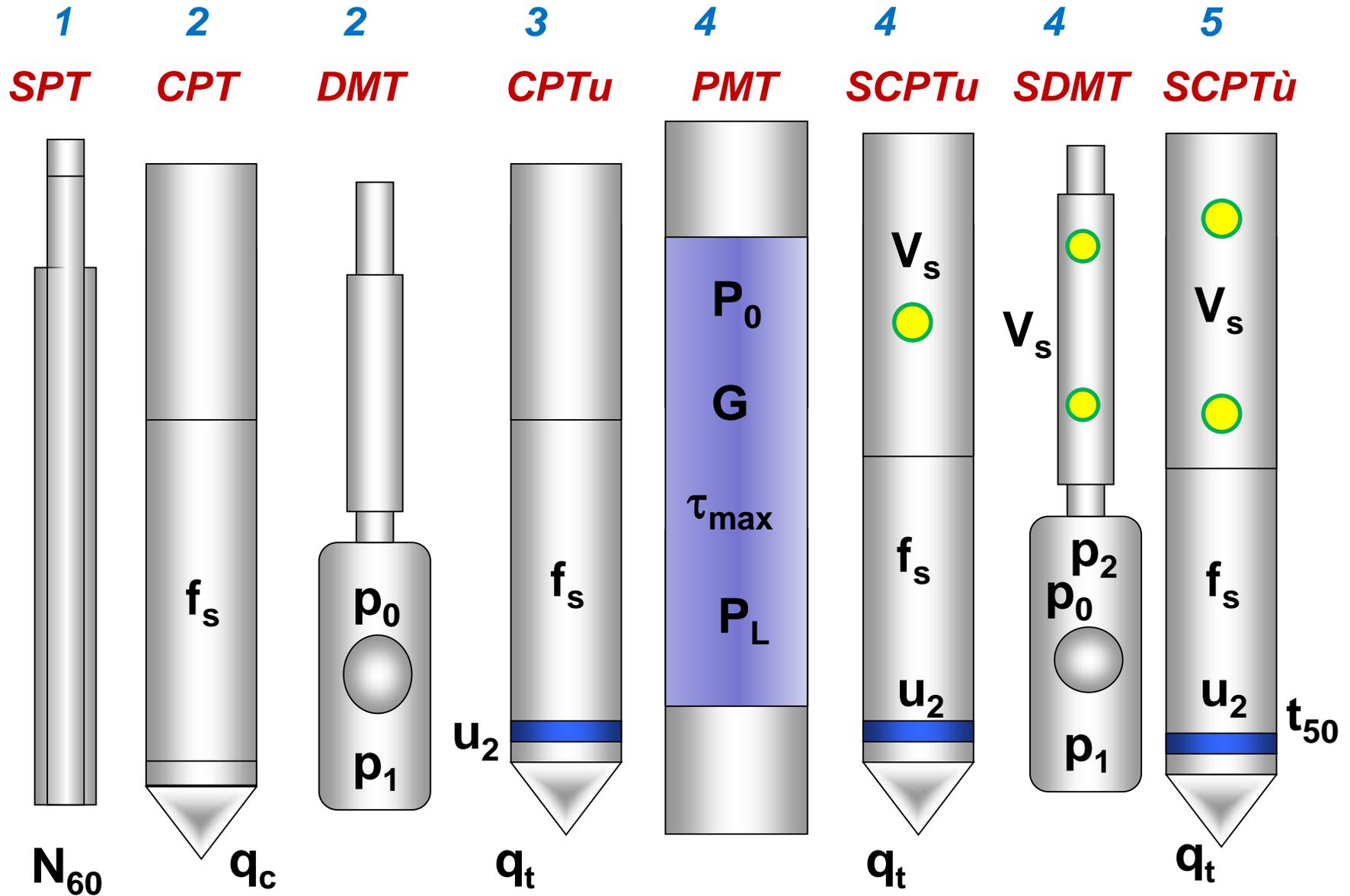
Application to Osterberg Load Testing

75-m long drilled shaft, Golden Ears Bridge, Vancouver, BC

O-Cell Load (MN)



Number of Measurements For Each Test Method



Geotechnical Site Characterization

More Measurements

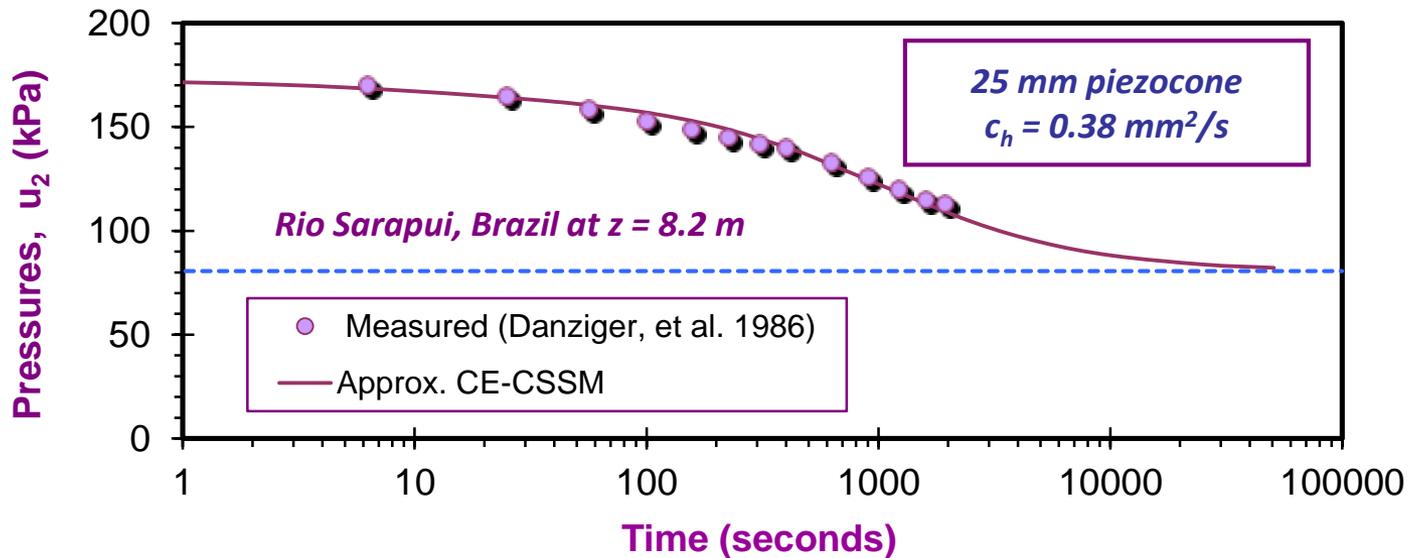
is

More Better

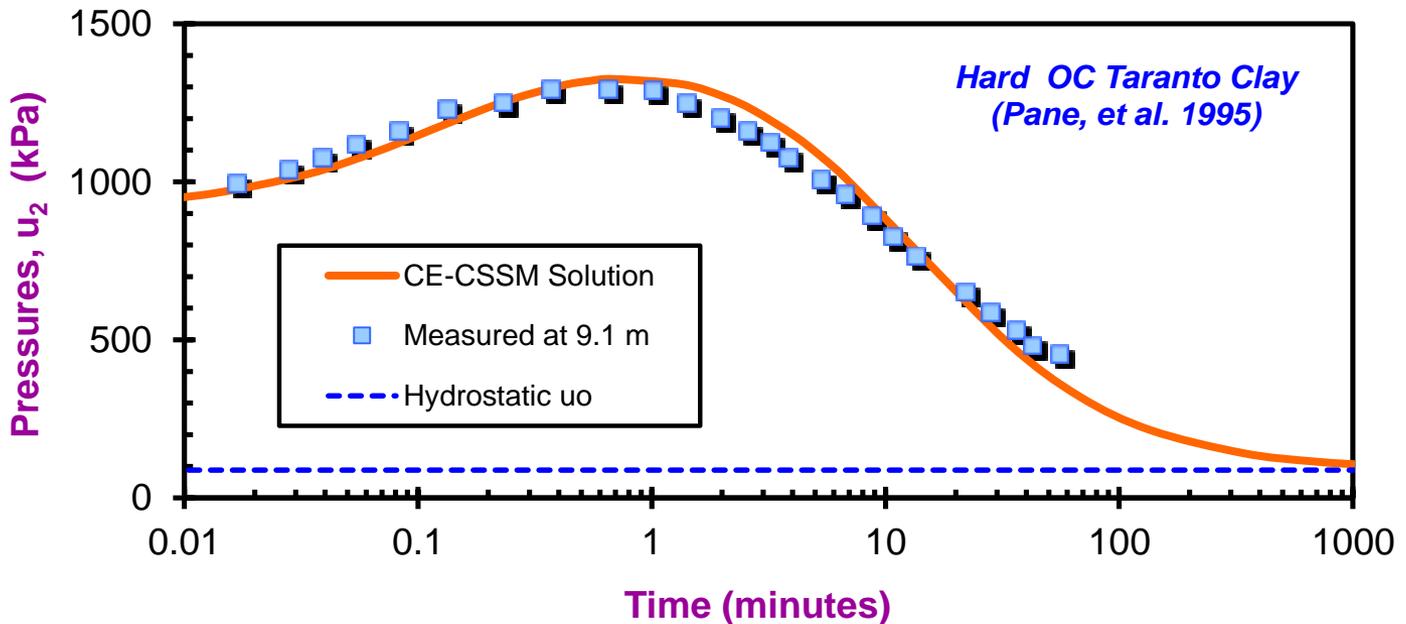


Evaluation of c_{vh} from Porewater Dissipations

Monotonic Response

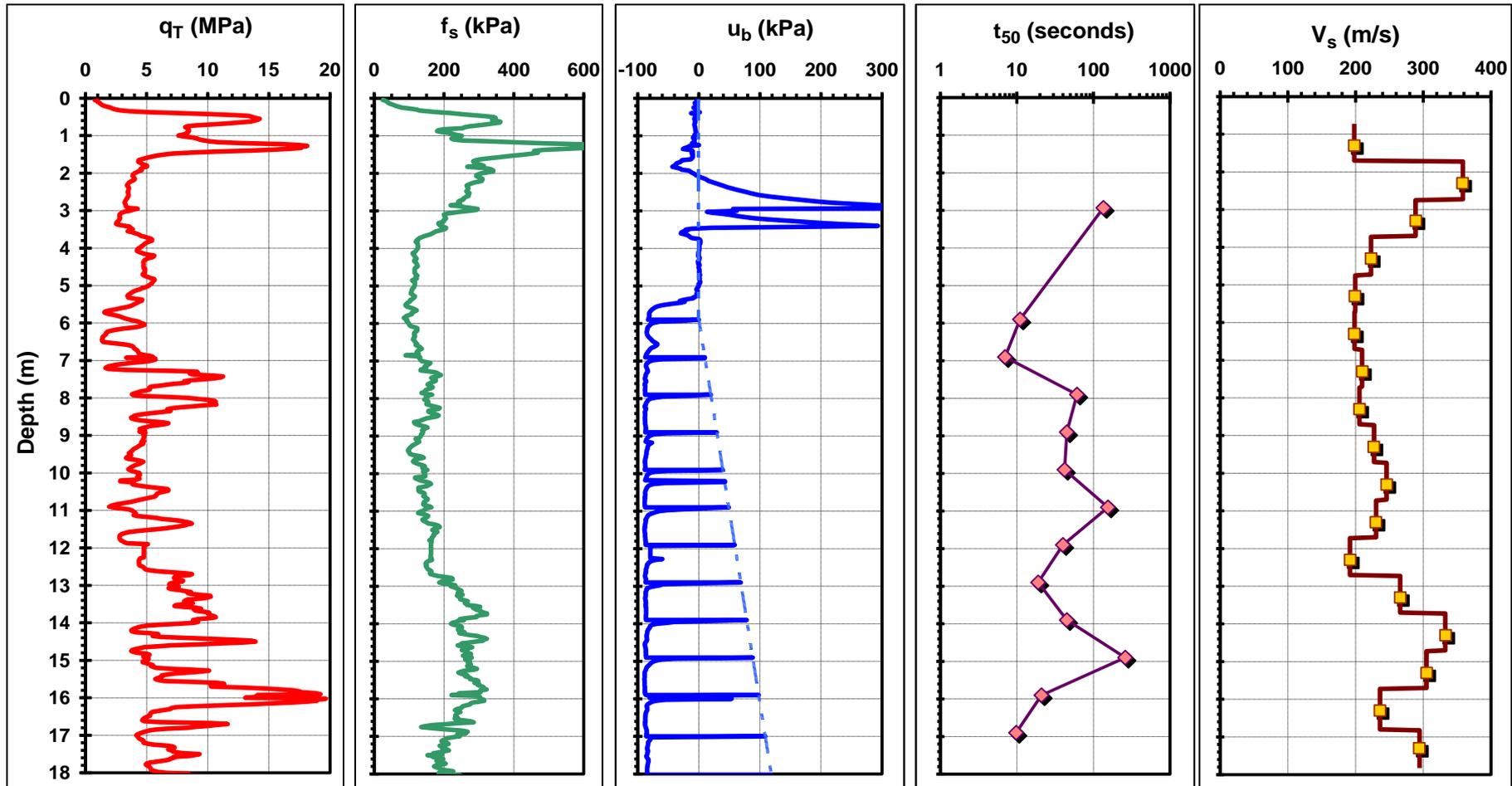


Dilatatory Response



SCPT_u at Atlanta Airport Runway 5

Five Independent Readings of Soil Behavior: q_t , f_s , u_b , t_{50} , and V_s .



Seismic Resistivity Dynamic Penetrometer Test (SRDPT) for hard ground



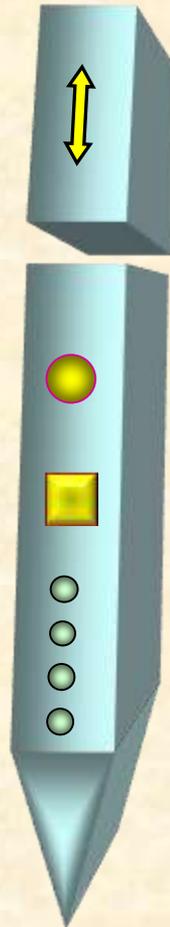
*Dynamic Driver Module
(Impact, Sonic)*

Shear Wave Velocity, V_s

Lateral Stress, σ_L

Resistivity, Ω

Tip Stress, q_d



Hydraulic Rig

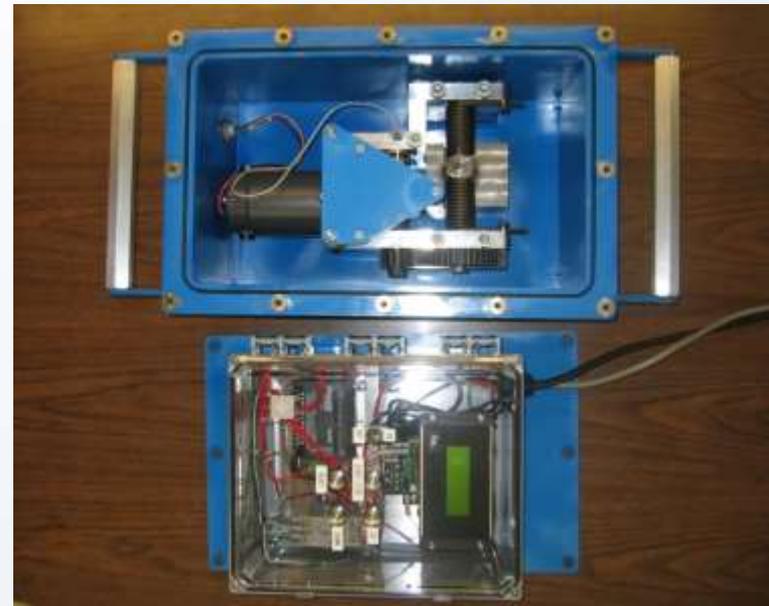
Square
Rods

Enlargement

**SRDPT provides
4 continuous
readings with depth**

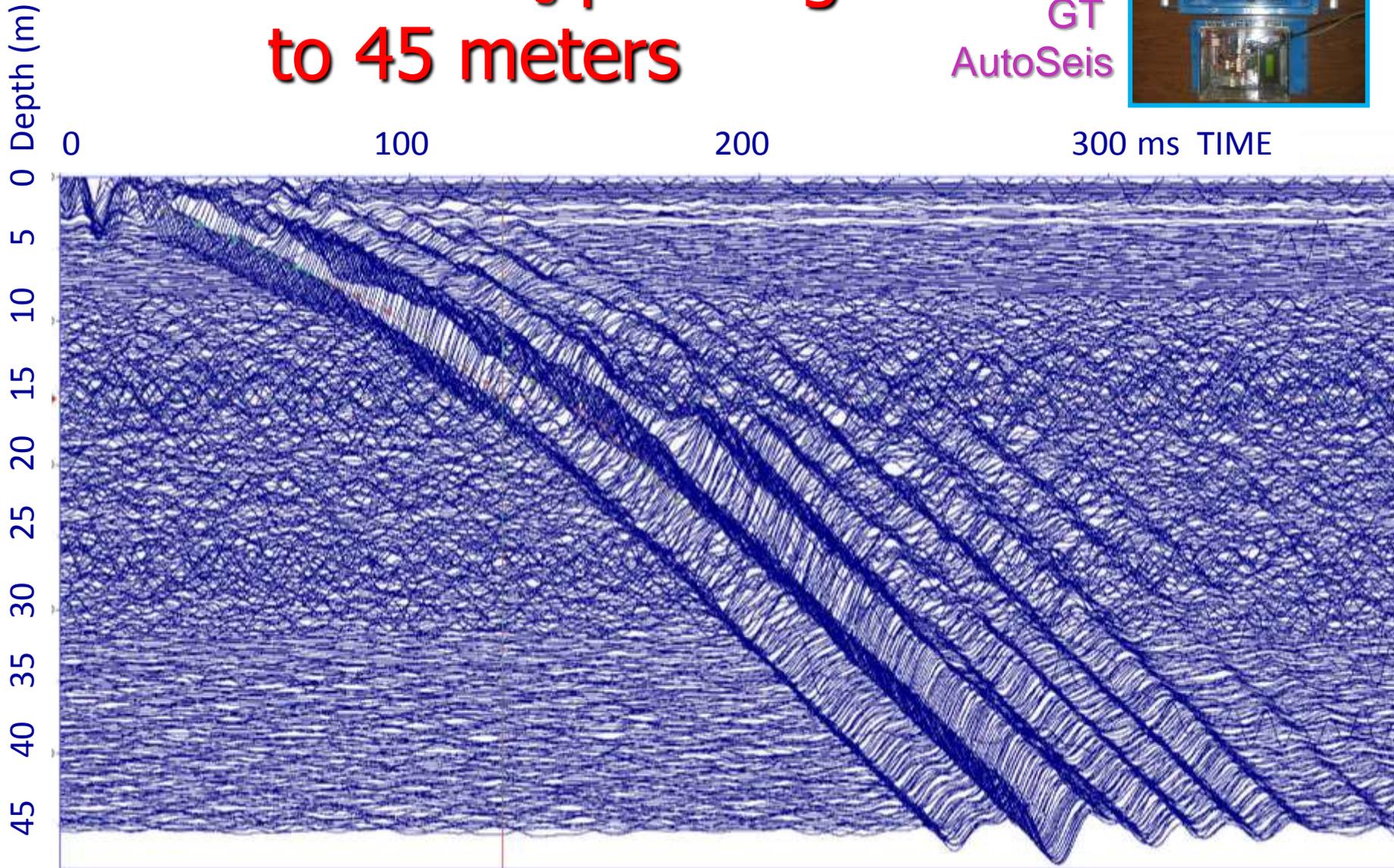
GT Roto AutoSeis

- Electro-Mechanical off 12-volt
- AC or DC power; variable speed
- Repeatable, Portable, reach 30-m depths
- Can generate shear wavelets every 1 second
- Patent received in February 2010



Continuous V_s profiling to 45 meters

GT
AutoSeis



courtesy Dave Woeller - ConeTec

Continuous-Interval Seismic Piezocone, BC

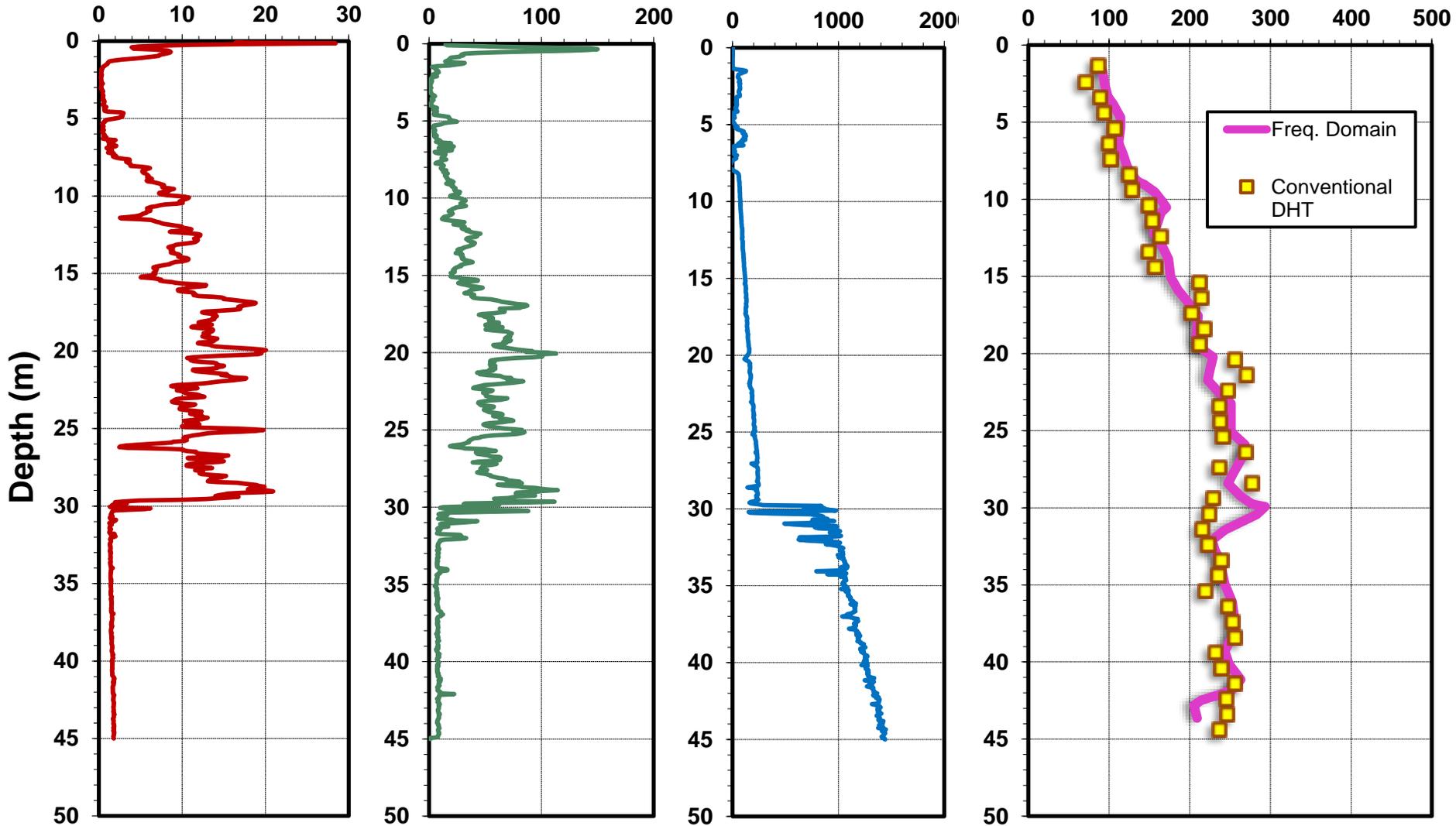


q_t (kPa)

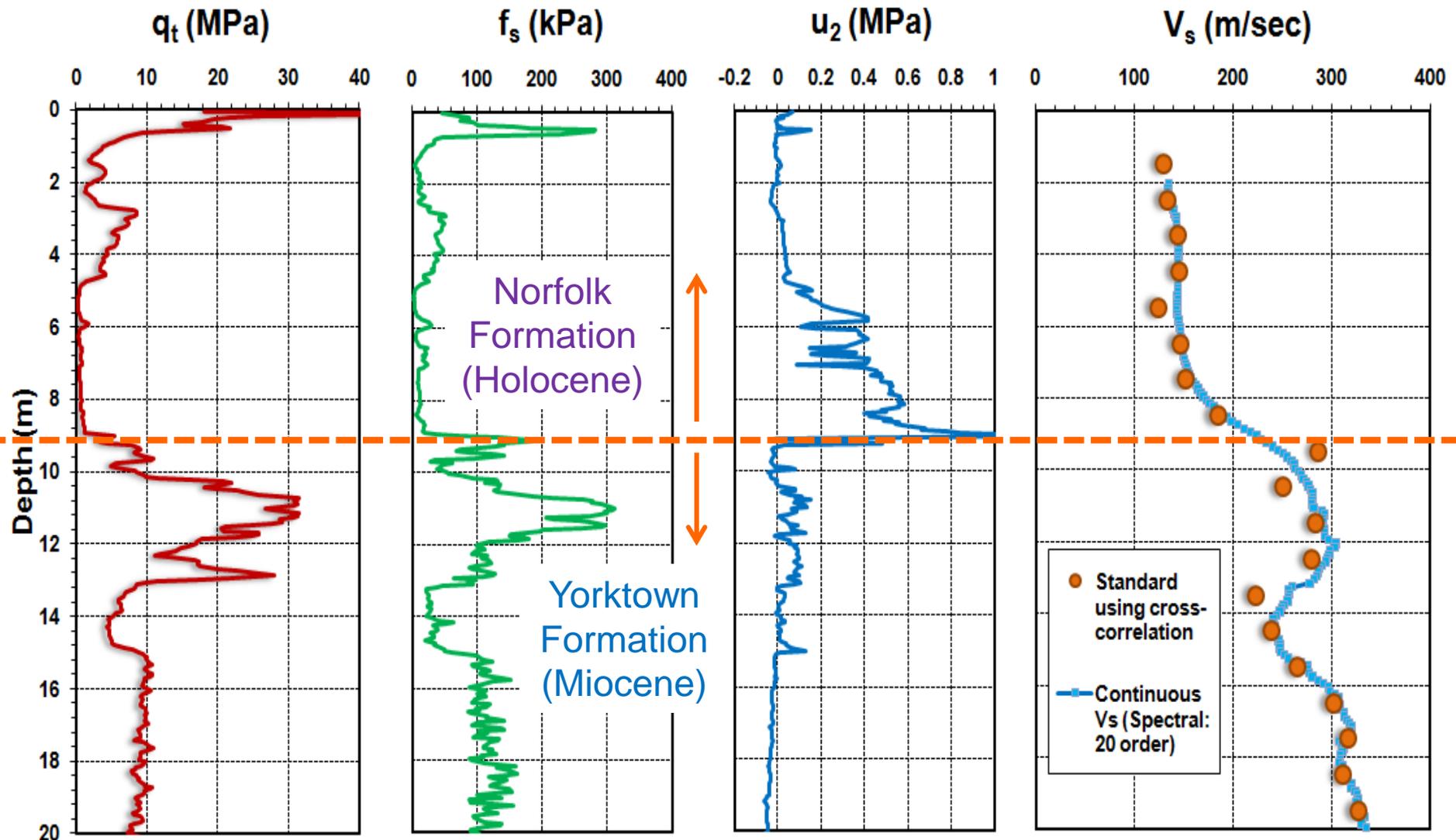
f_s (kPa)

u_2 (kPa)

V_s (m/sec)



Continuous-interval SCPTu at Norfolk, VA



International Travel: Common Link



In-Situ Common Link



Italy



Soil Test Rig
at Treporti Test
Embankment
Venice

In-Situ Common Link

Peru



CPT Rig at
ConeTec Yard
Lima

In-Situ Common Link

Ireland



InSitu CPT
rig for
University
Ireland
Galway

In-Situ Common Link

Australia



IGS Cone Rig
near
Coffs Harbour
Australia

In-Situ Common Link



South Africa



CPT Rig
built by
Eben Rust

In-Situ Common Link

Brazil



CPT Rig for
Univ.
Pernambuco
and
Federal Univ
Grand du Sol



thanks



U.S. DEPARTMENT OF
ENERGY

