UCI Samueli School of Engineering | Department of Civil and Environmental Engineering

CEE SEMINAR SERIES WINTER 2023

Databased Approach for Cone Penetration Test (CPT & CPTu) Applications in Foundation Engineering

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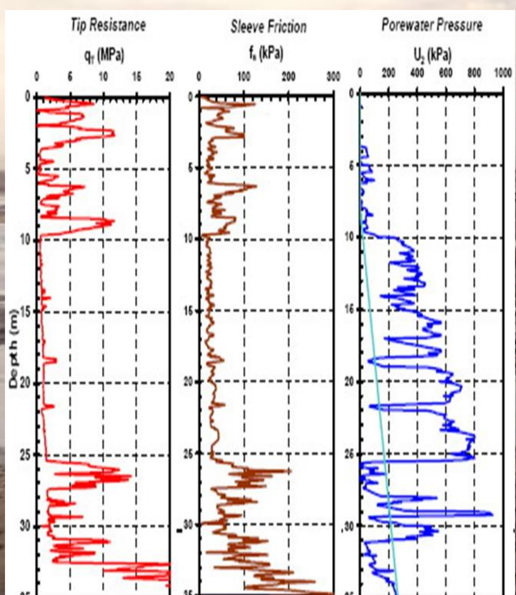
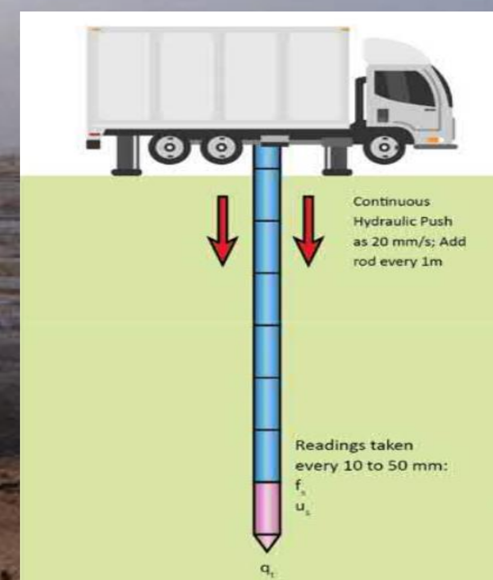
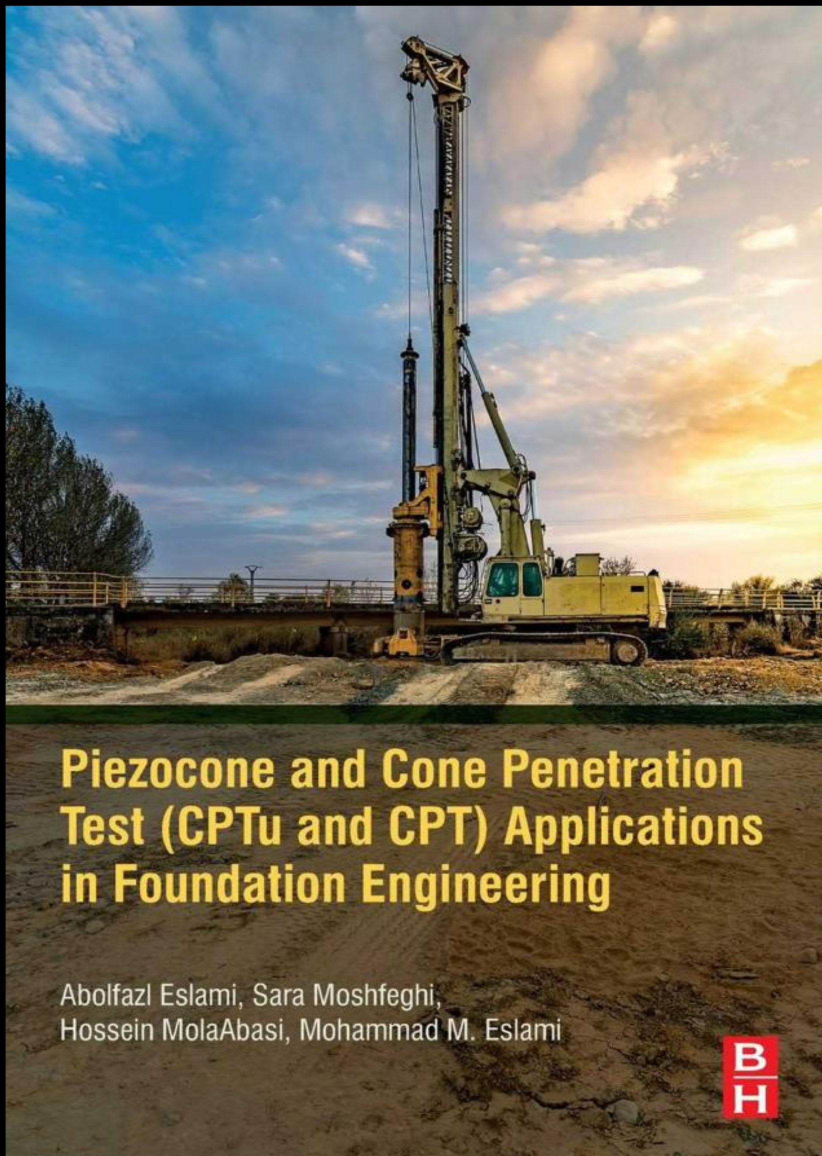


January 2023





Piezocone and Cone Penetration Test (CPTu and CPT) Applications in Foundation Engineering

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Outline

1. Geotechnical Engineering (GE) & Site Investigations
2. Cone & Piezocone Penetration Tests (CPT & CPTu)
3. Applications of CPT & CPTu in GE
4. Databased Approach in Foundation Engineering (FE)
5. CPT & Shallow Foundations
6. CPT & Deep Foundations
7. Case Studies
8. Summary and Conclusions

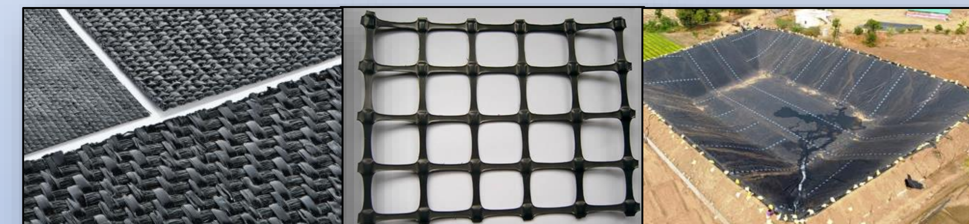
Geotechnical Engineering World

❖ **Geomaterials:**

Soil, Rock & Ground Water

❖ **Geosynthetics:**

Geotextile, Geogrid, Geomembrane, …



❖ **Geostructurs:**

Foundation, Earth Retention Systems, …

Major Topics in Geotechnical Engineering (GE)

(1) Sample recovery

(2) Subsurface profiling & Groundwater table

(3) Site response to geohazards

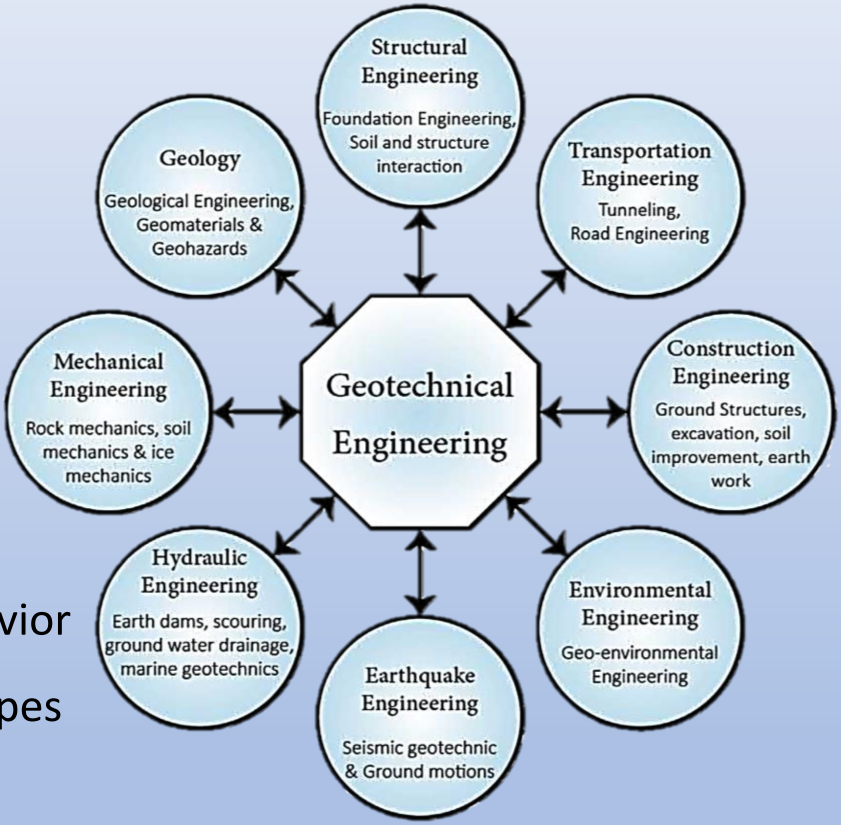
(4) Selecting and design of foundation systems

(5) Sufficiency of geomaterials for borrowing

(6) Health, safety and strategy management

(7) Recognition of underground structures behavior

(8) Support and stabilization of deposits and slopes



Overlap of Geotechnical Engineering with Other Disciplines

Data Sources

(1) Maps

(2) Aerial Photos

(3) Site Visit

(4) Non Destructive Tests

(5) Remote Sensing

(6) On-Situ Testing

(7) In-situ Penetration Testing

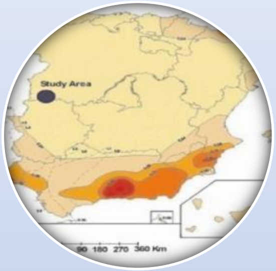
(8) Boring and Sampling

(9) Laboratory Testing

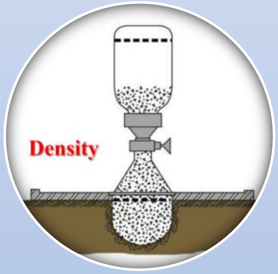
(10) Physical Modeling

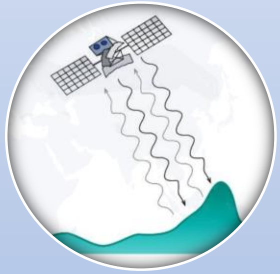
(11) Full-scale Tests

(12) Instrumentation & Monitoring





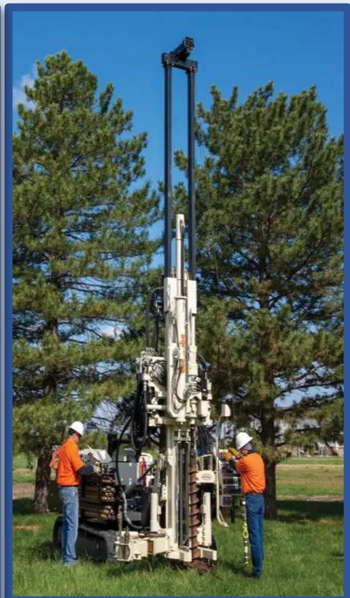



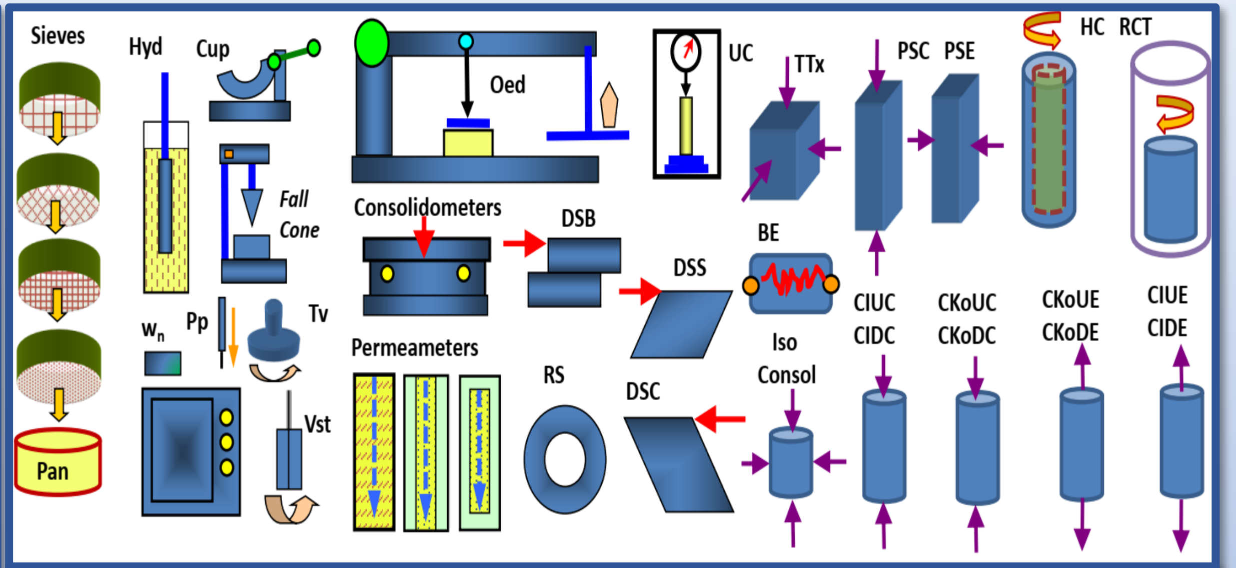






Major Approaches: Boring, Sampling & Laboratory Testing



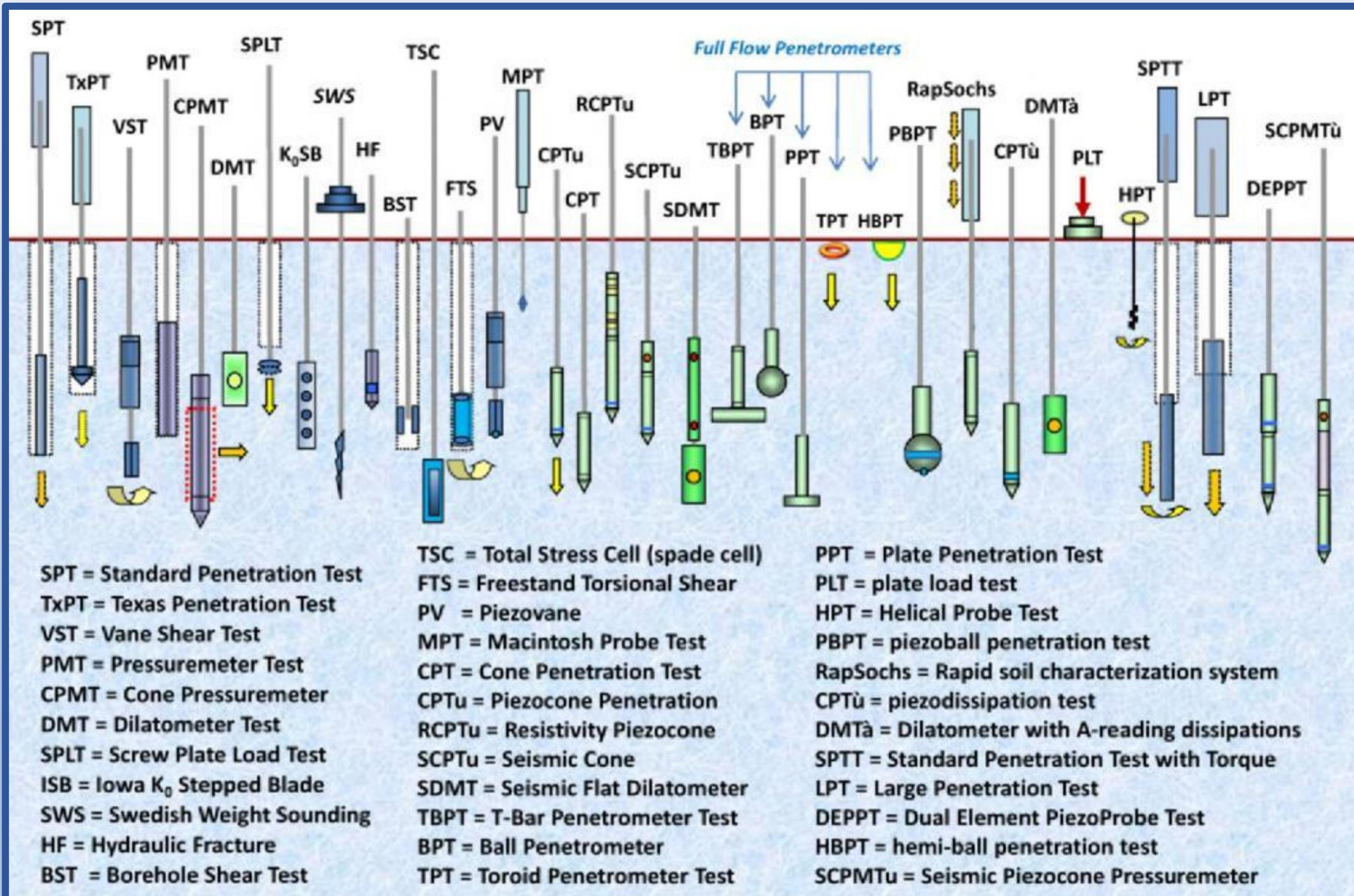


Grain size analyses
Hydrometer
Water content by oven
Liquid limit cup
Plastic limit thread
Fall cone device
Pocket penetrometer
Torvane
Unconfined compression
Miniature vane
Digital image analysis

Mechanical oedometer
Consolidometer
Constant rate of shear (CRS)
Falling-head permeameter
Constant-head permeameter
Flow permeameter
Direct shear box
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

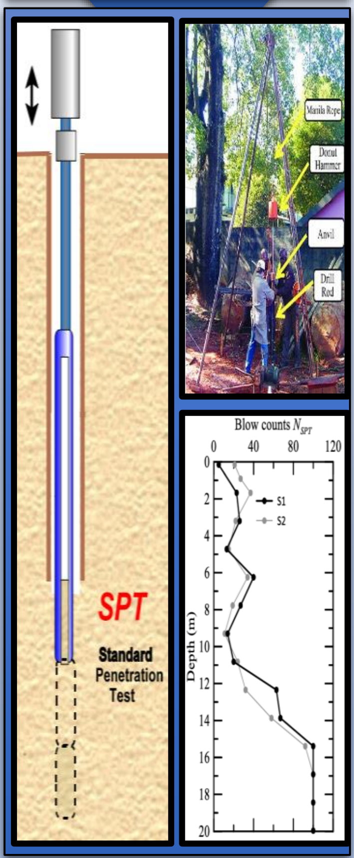
Major Approaches: Field Testing Devices and Probes



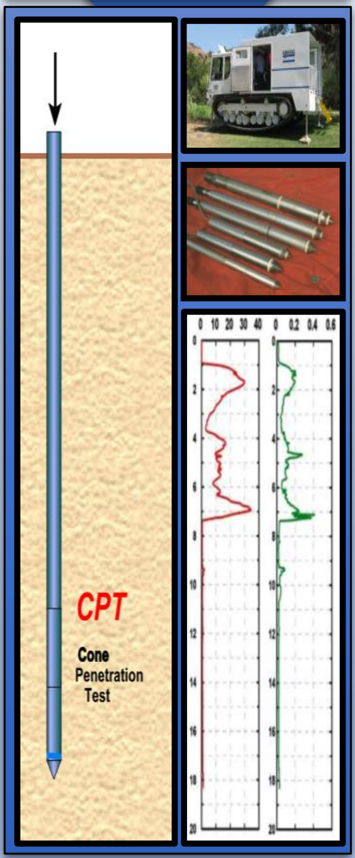
(Mayne, 2016)

Major Approaches: In Situ Penetration Tests

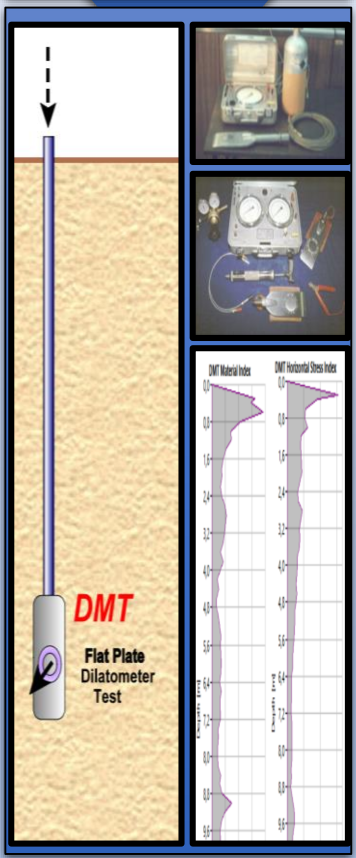
SPT



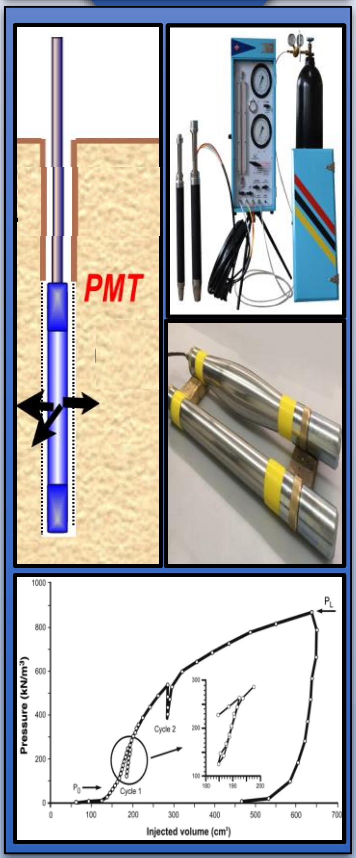
CPT



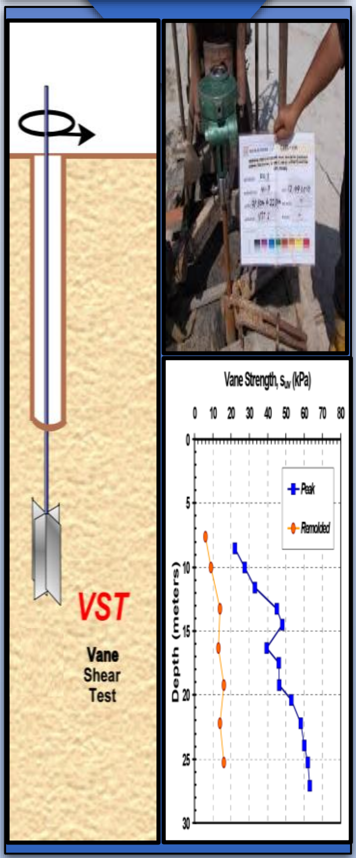
DMT



PMT



VST



NikoueiNahali, A. & Eslami, A. (2020 – 2022)

In Situ Tests and Their Applicability

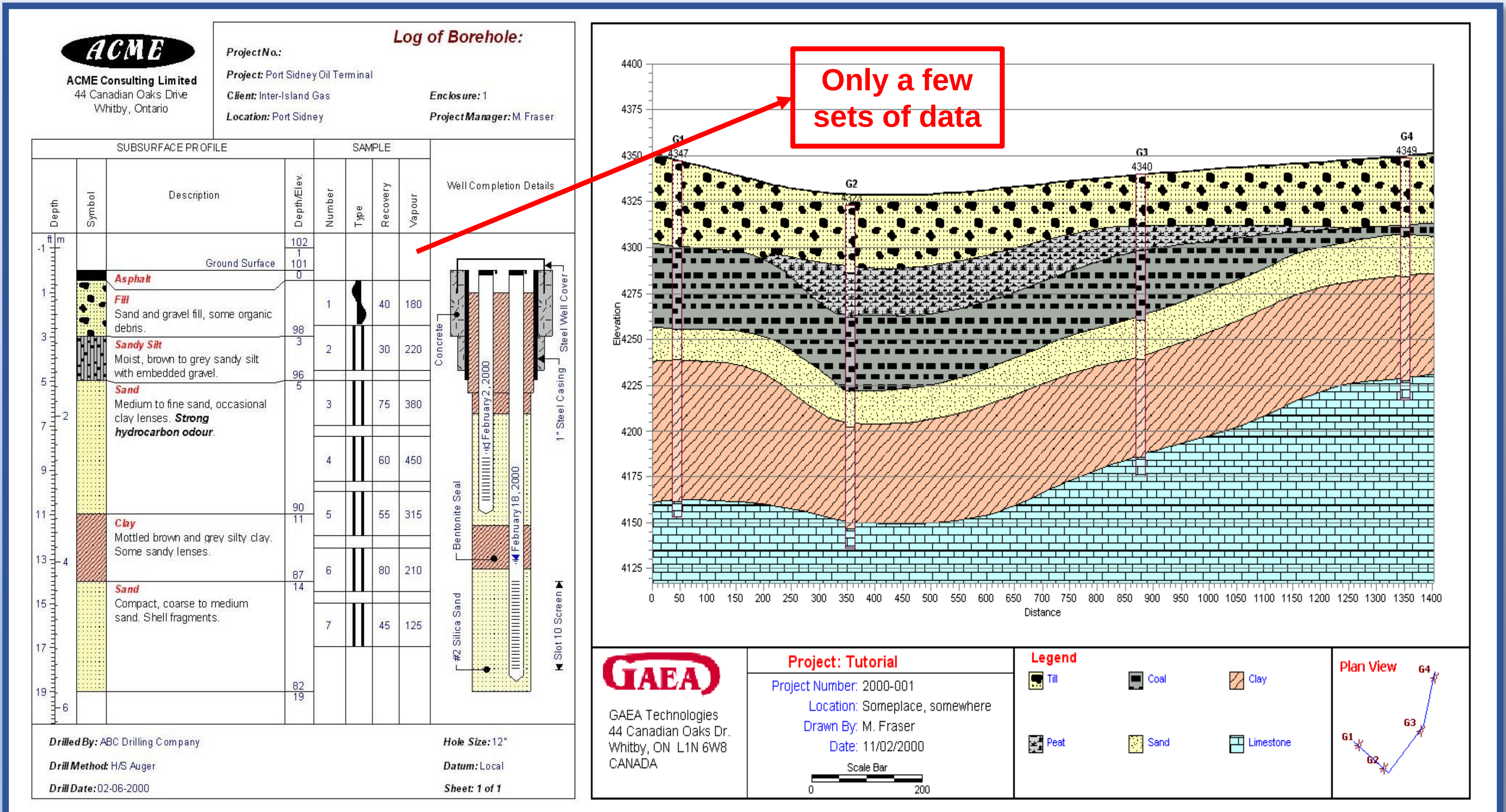
Group	Device	Soil Parameters													Ground Type						
		Soil type	Profile	u	*ϕ'	S_u	I_D	m_v	c_v	k	G_0	σ_h	OCR	σ-ε	Hard rock	Soft rock	Gravel	Sand	Silt	Clay	Peat
Penetrometers	Dynamic	C	B	-	C	C	C	-	-	-	C	-	C	-	-	C	B	A	B	B	B
	Mechanical	B	A/B	-	C	C	B	C	-	-	C	C	C	-	-	C	C	A	A	A	A
	Electric (CPT)	B	A	-	C	B	A/B	C	-	-	B	B/C	B	-	-	C	C	A	A	A	A
	Piezocone (CPTU)	A	A	A	B	B	A/B	B	A/B	B	B	B/C	B	C	-	C	-	A	A	A	A
	Seismic (SCPT/SCPTU)	A	A	A	B	A/B	A/B	B	A/B	B	A	B	B	B	-	C	-	A	A	A	A
	Flat dilatometer (DMT)	B	A	C	B	B	C	B	-	-	B	B	B	C	C	C	-	A	A	A	A
	Standard penetration test (SPT)	A	B	-	C	C	B	-	-	-	C	-	C	-	-	C	B	A	A	A	A
	Resistivity probe	B	B	-	B	C	A	C	-	-	-	-	-	-	-	C	-	A	A	A	A
Pressuremeters	Pre-bored (PBP)	B	B	-	C	B	C	B	C	-	B	C	C	C	A	A	B	B	B	A	B
	Self-boring (SBP)	B	B	A(1)	B	B	B	B	A(1)	B	A(2)	A/B	B	A/B(2)	-	B	-	B	B	A	B
	Full displacement (FDP)	B	B	-	C	B	C	C	C	-	A(2)	C	C	C	-	C	-	B	B	A	A
Others	Vane	B	C	-	-	A	-	-	-	-	-	-	B/C	B	-	-	-	-	-	A	B
	Plate load	C	-	-	C	B	B	B	C	C	A	C	B	B	B	A	B	B	B	A	A
	Screw plate	C	C	-	C	B	B	B	C	C	A	C	B	-	-	-	-	A	A	A	A
	Borehole permeability	C	-	A	-	-	-	-	B	A	-	-	-	-	A	A	A	A	A	A	B
	Hydraulic fracture	-	-	B	-	-	-	-	C	C	-	B	-	-	B	-	-	-	-	A	C
	Crosshole/downhole/surface seismic	C	C	-	-	-	-	-	-	-	A	-	B	-	A	A	A	A	A	A	A

Applicability: A = high, B = moderate, C =low, - = none

*ϕ' =Will depend on soil type, (1) = Only when pore pressure sensor fitted; (2) = Only when displacement sensor fitted

(Lunne et al., 1997)

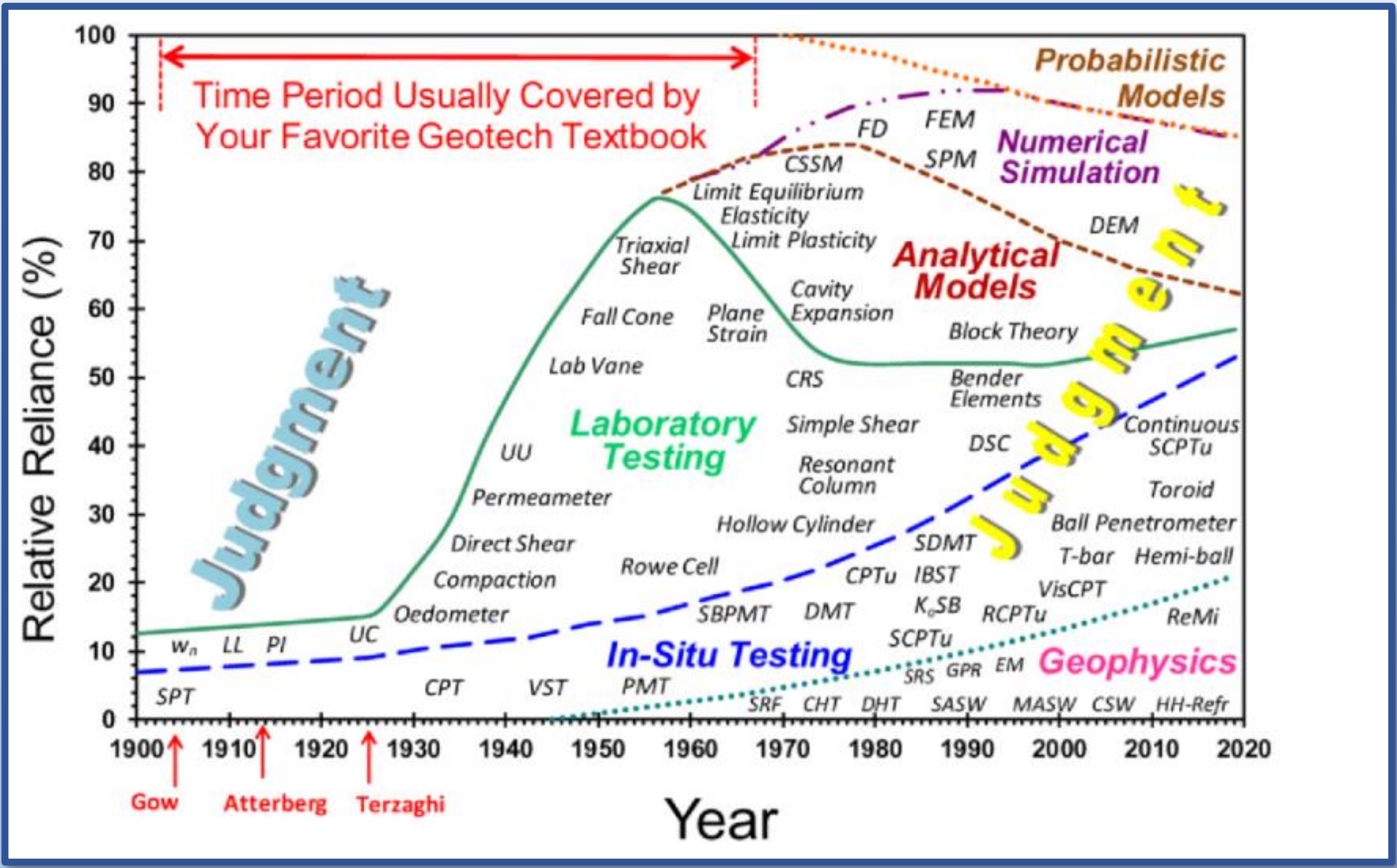
Typical Subsurface Log & Profile: Conventional Approach



Why In-Situ Testing?

Laboratory Tests Limitations	Field Tests Advantages
Difficulties for undisturbed sampling	Overcome sampling difficulties
Soil disturbance & maintenance	Minimum changes in stress state
Soil volume change	Simple and fast
Omitting confinement pressure	Economical
Size effect and boundaries	Dominant applications in FE

Evolution of Geotechnical Design Basis



(Mayne, 2016, adapted from Lacasse 1985)

1 Geotechnical Engineering (GE) & Site Investigations

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3 Applications of CPT & CPTu in GE

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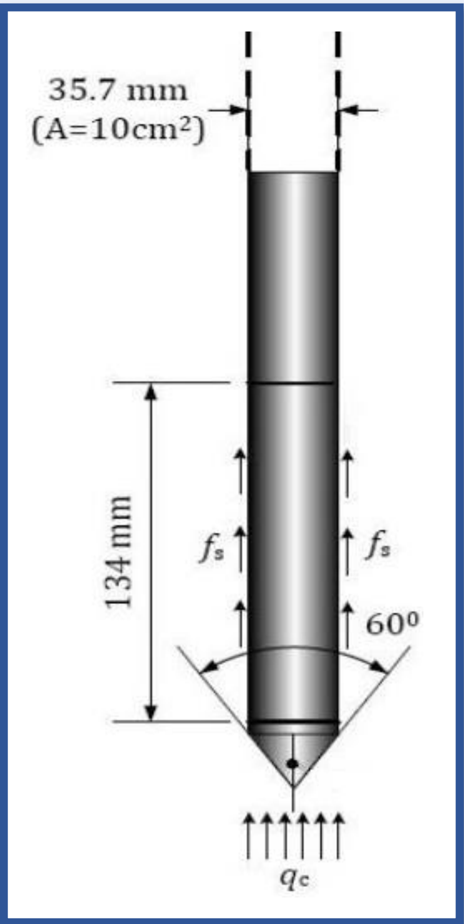
8 Summary and Conclusions

Background

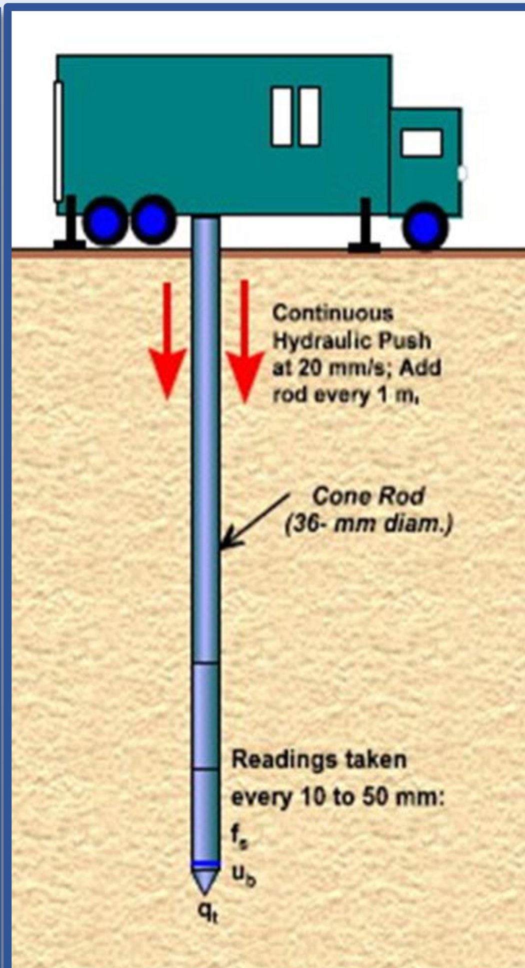
CPT involves driving a system of a steel cone and rods into the ground, and recording the mobilized resistance to penetration in the soil.

- Simple and relatively economical.
- Continuous records with depth.
- Interpretable on both empirical and analytical bases.
- Sensors can be incorporated with penetrometer.
- A large experience-based knowledge is now available

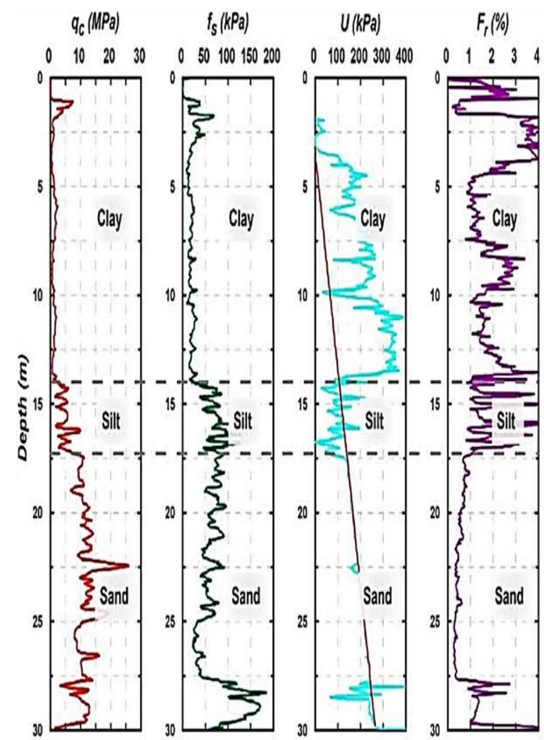


CPT; mostly applicable in soft to medium, compressible & problematic deposits

Equipment & Procedure



Penetration rate: 20 mm/s
Set of data: per 25 mm or 1 inch



Data & Graphical Presentation

1. Measured Parameters

q_c, f_s, u

2. Corrected Parameters

- Corrected tip resistance:

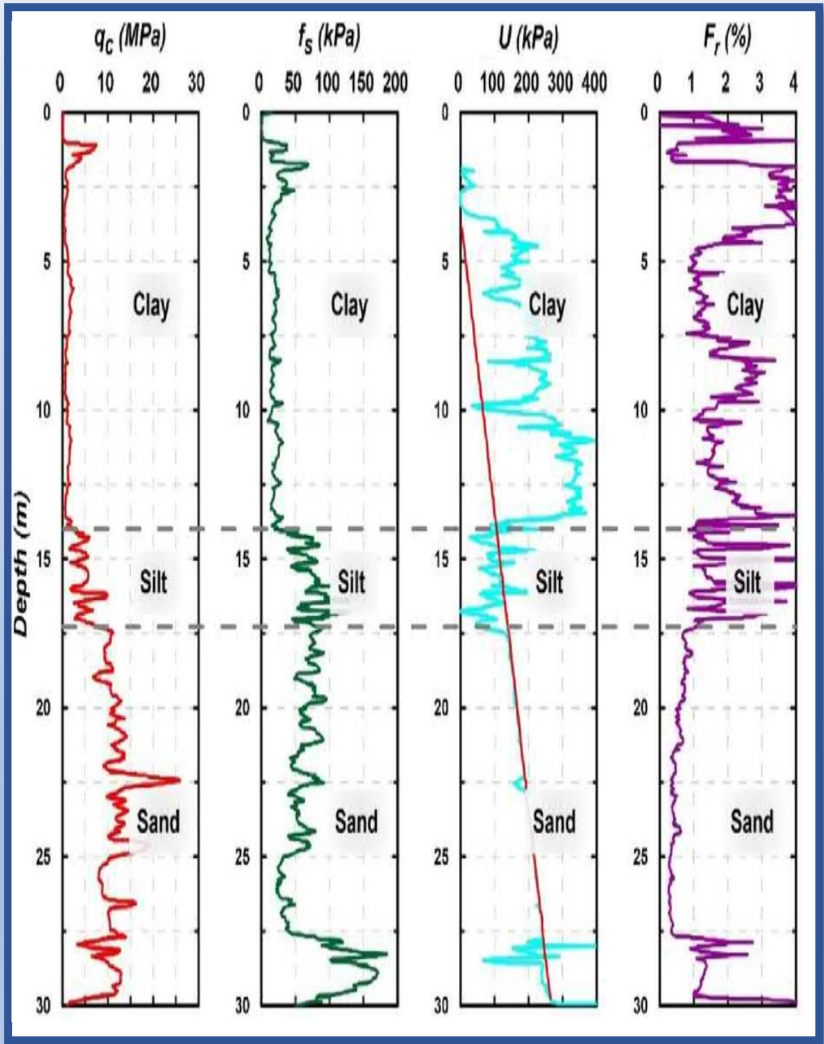
$$q_t = q_c + u_2(1-a)$$

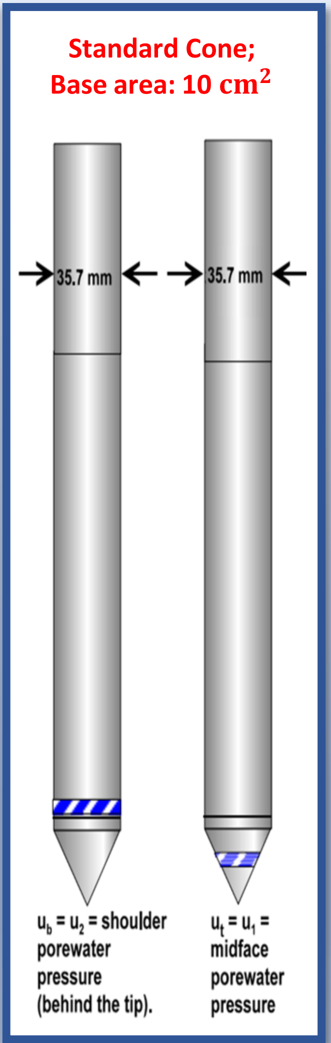
- Friction ratio:

$$R_f = {f_s}/{q_c}$$

- Pore pressure coefficient:

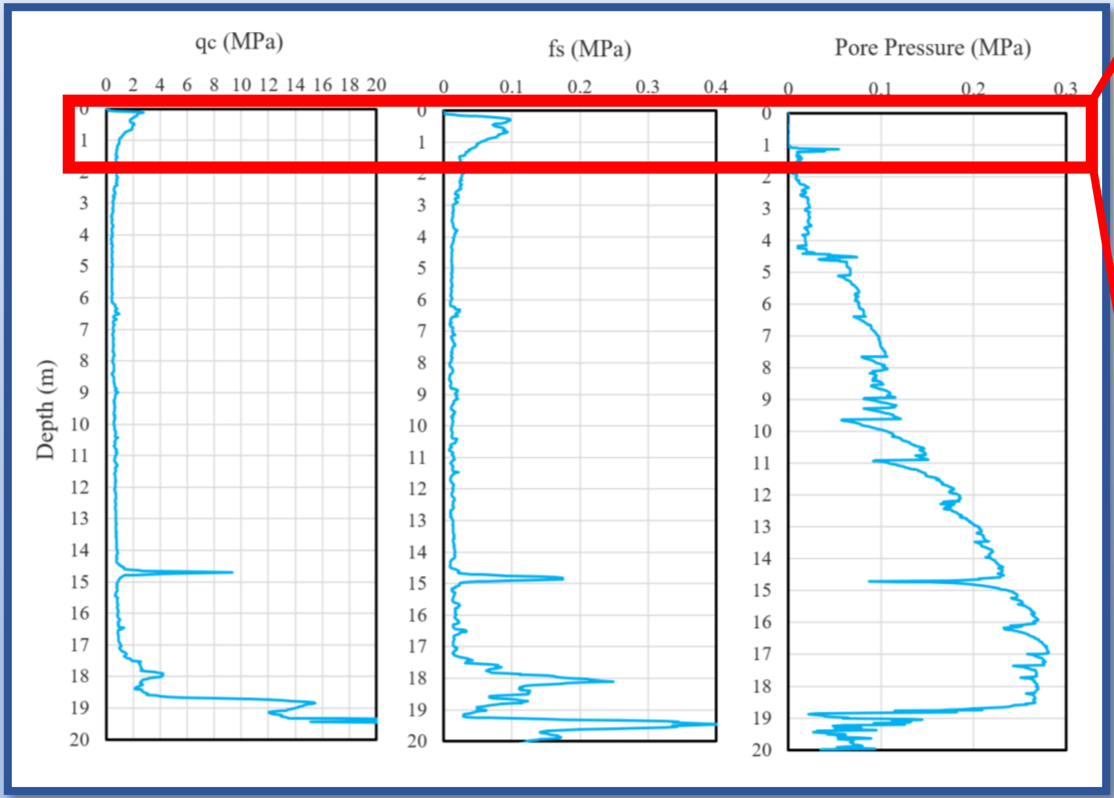
$$B_q = {\Delta u}/{(q_t - \sigma_{vo})}$$





Data & Graphical Presentation

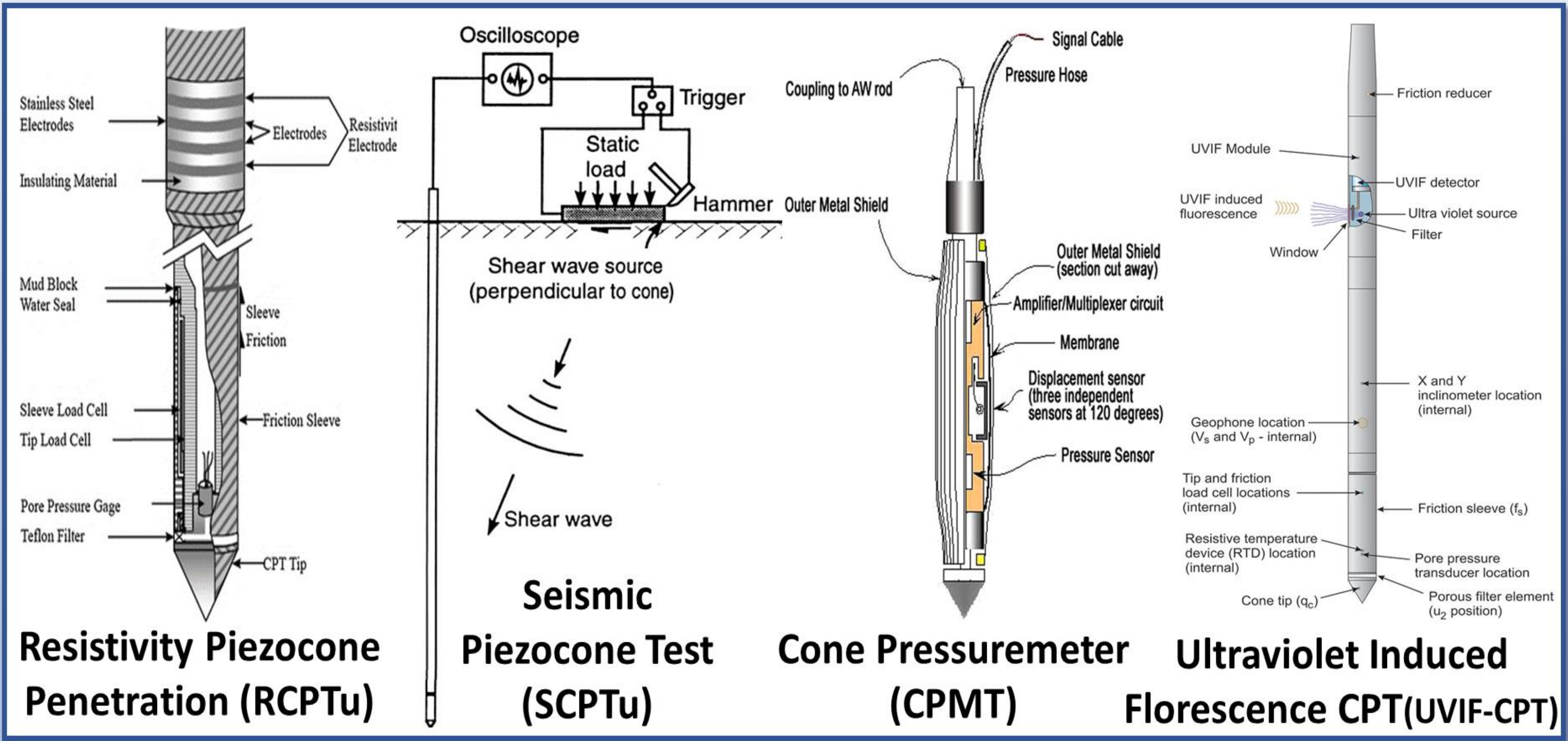
Tons of Data in 1 Meter !!!



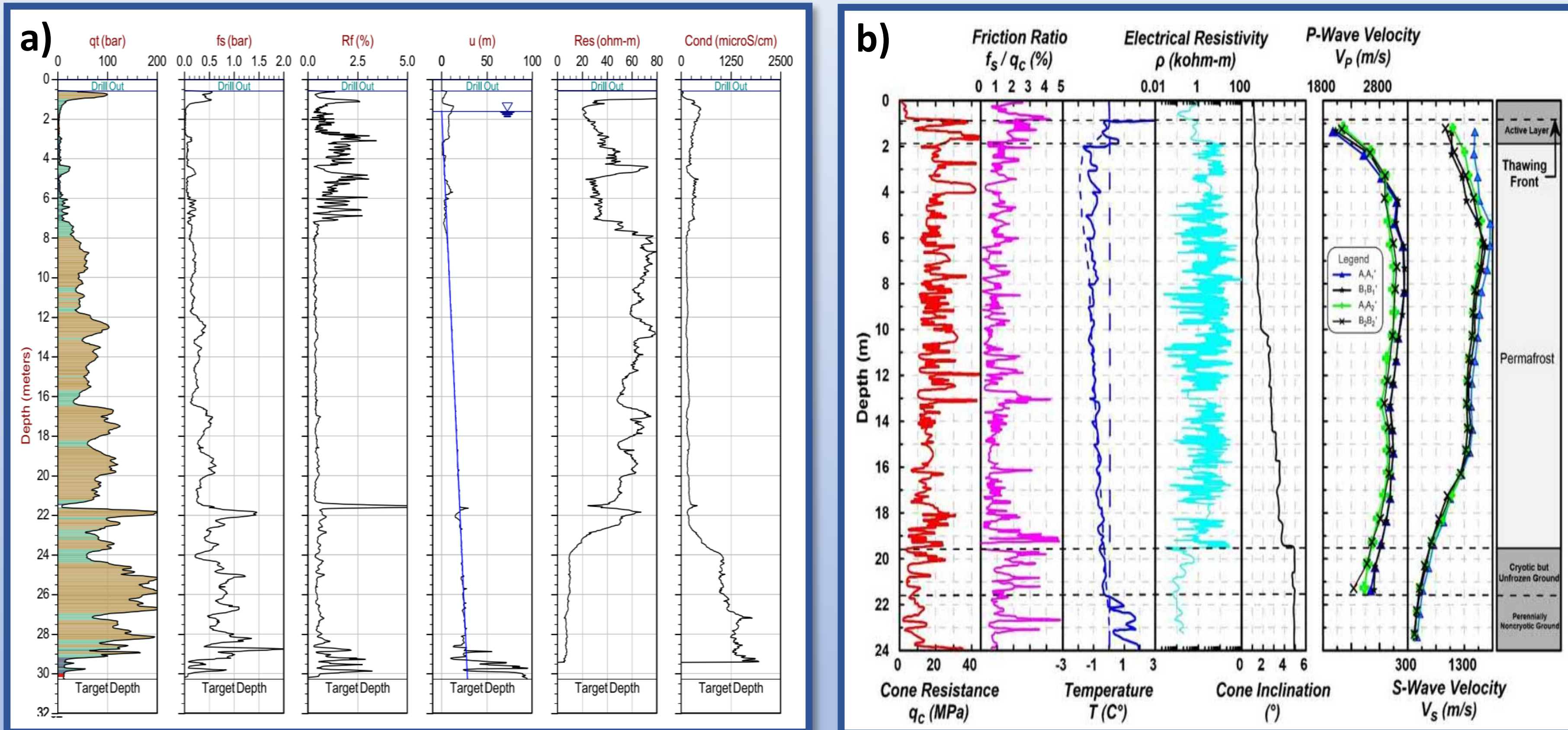
(Fakharian et al., 2021)

z	qc	fs	u2
m	MPa	MPa	MPa
0	0	0	0
0.02	0.06	-0.0003	0
0.04	0.24	-0.0003	0
0.06	0.16	0.001	-0.0005
0.08	0.71	0	-0.0005
0.1	2.47	0.0004	-0.001
0.12	2.79	0.0147	-0.001
0.14	2.48	0.0215	-0.001
0.16	2.31	0.0386	-0.001
0.18	2.32	0.0479	-0.001
0.2	2.27	0.0639	-0.001
0.22	2.27	0.0759	-0.0005
0.24	2.22	0.0878	-0.0005
0.26	2.1	0.0957	-0.001
0.28	2.07	0.0976	-0.001
0.3	1.99	0.0981	-0.0005
0.32	1.88	0.096	-0.0005
0.34	1.81	0.0926	-0.0005
0.36	1.79	0.092	-0.0005
0.38	1.75	0.0873	0
0.4	1.75	0.083	0
0.42	1.83	0.0764	0
0.44	1.92	0.0728	0
0.46	1.96	0.072	0
0.48	2.06	0.0743	0
0.5	2.08	0.0762	0
0.52	2.05	0.0812	-0.0005
0.54	1.99	0.0863	-0.0005
0.56	1.97	0.0879	-0.001
0.58	1.91	0.0897	-0.001
0.6	1.92	0.0888	-0.0005
0.62	1.91	0.0865	-0.0005
0.64	1.9	0.0885	-0.0005
0.66	1.83	0.0903	-0.0005
0.68	1.73	0.0935	0
0.7	1.68	0.0918	-0.0005
0.72	1.5833	0.0877	0
0.74	1.4867	0.0836	0
0.76	1.39	0.0795	0
0.78	1.36	0.0806	0
0.8	1.33	0.0792	0
0.82	1.28	0.0775	0
0.84	1.2	0.0772	0
0.86	1.18	0.0739	-0.0005
0.88	1.16	0.0704	-0.0005
0.9	1.14	0.0648	0
0.92	1.09	0.0634	-0.0005
0.94	1.04	0.0619	0
0.96	1.02	0.0586	-0.0005
0.98	0.98	0.0558	0
1	0.99	0.0536	0

Special Cones



Special Cones



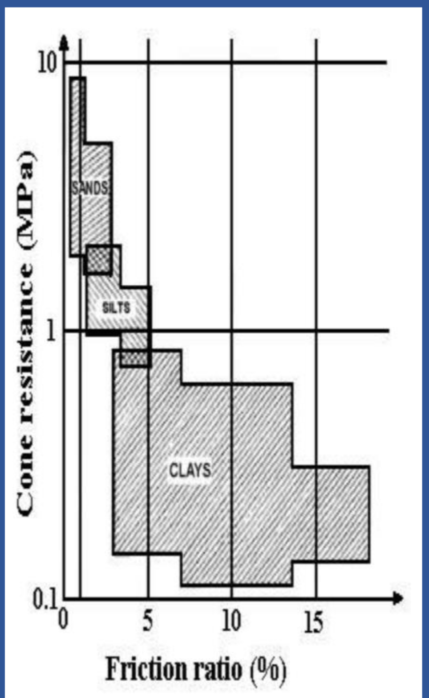
a) Example of resistivity piezocone profiles (ConeTec, 2019) & b) Example of seismic cone records and soil profiling

Essential Applications of CPT in GE

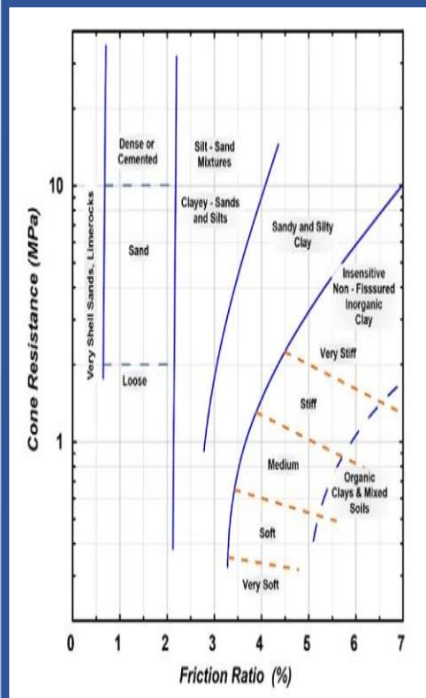
- Soil Characterization and Profiling
- Soil Behavior Classification (SBC)
- Estimating Soil Engineering Parameters
- Identifying Problematic Deposits

Soil Behavior Classification and Profiling

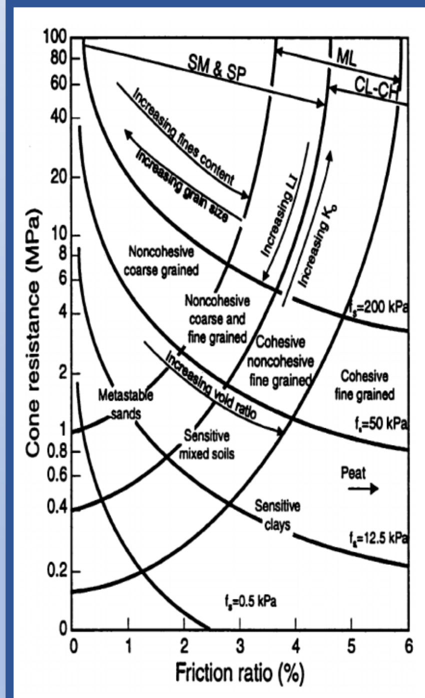
Begemann (1965)



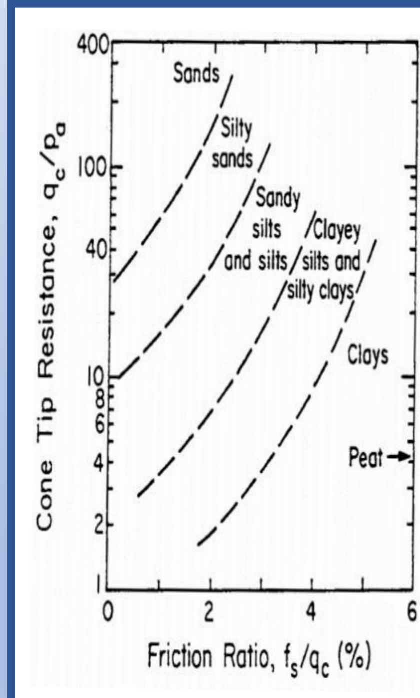
Schmertmann (1978)



Douglas and Olsen(1981)

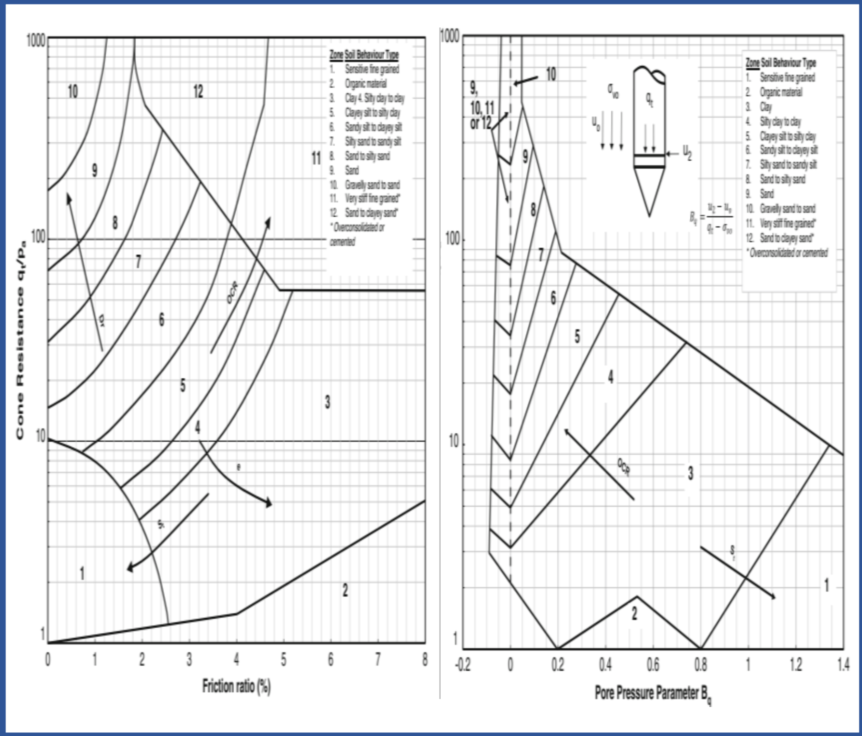


Campanella et al. (1983)

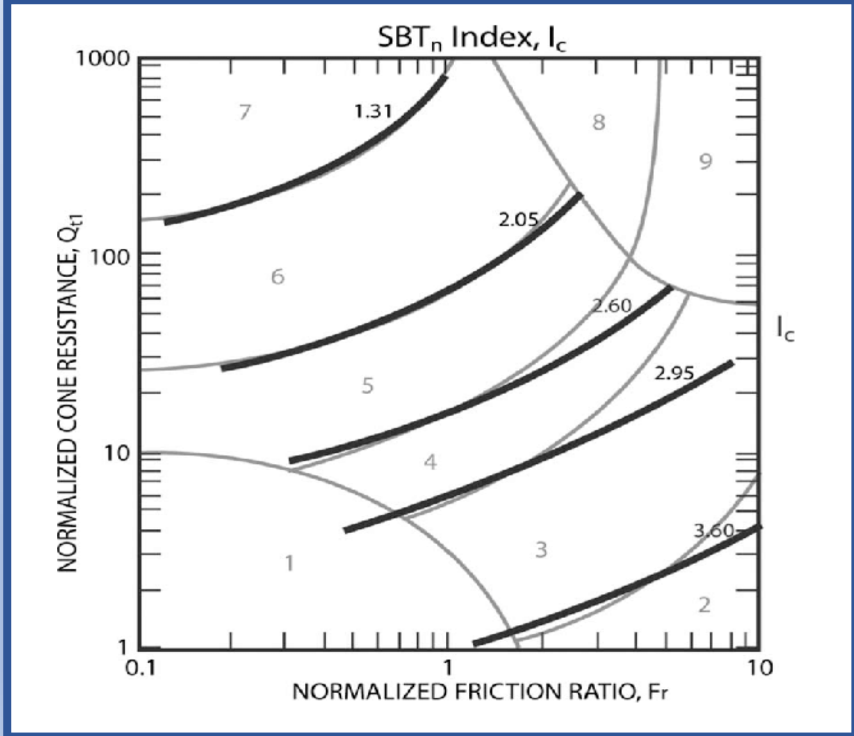


Soil Behavior Classification and Profiling

Robertson et al. (1986)

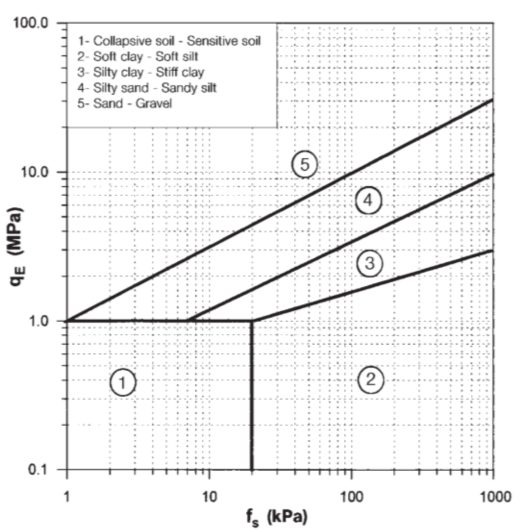


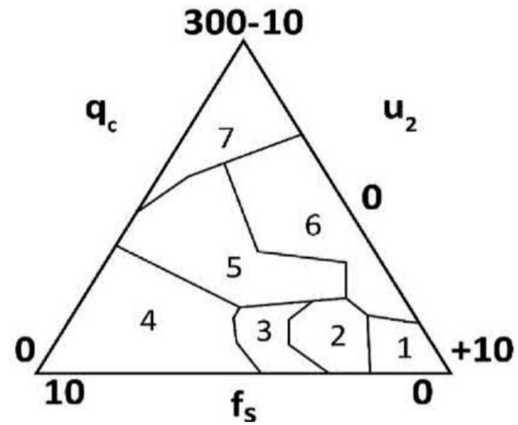
Robertson (2010)



Soil Behavior Classification and Profiling

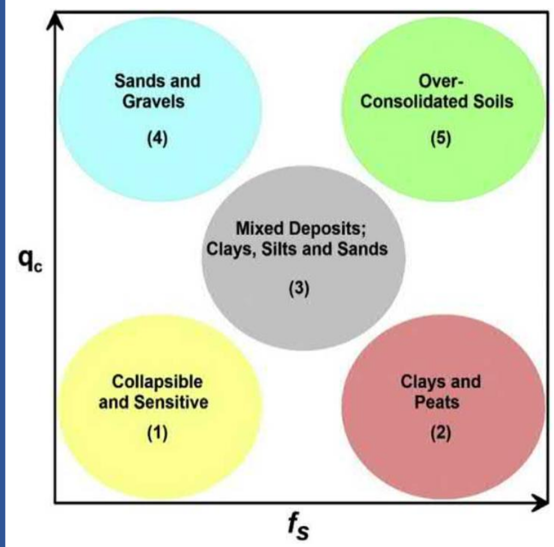
Eslami and Fellenius (1997)	Eslami et al. (2016 & 2022)	Eslami et al. (2018)





1	2	3
Sensitive Soil	Clays	Silts

4	5	6	7
Over Consolidated Clay	Mixed Soil (Clayey silt to sandy silt)	Sands	Very Dense Sand



Estimating Soil Engineering Parameters

- ❖ Case – based empirical methods
- ❖ Simplified analytical methods
- ❖ Numerical analyses
- ❖ Soft computing in data handing

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_y' (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_ψ, k_θ

STRENGTH

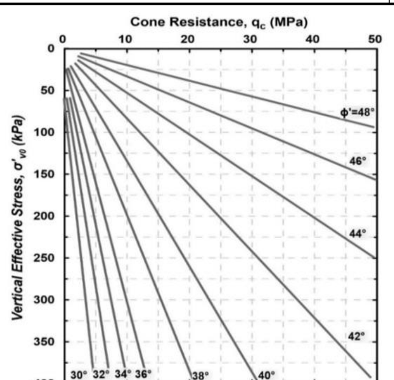
- Drained and Undrained, τ_{max}
- Peak (s_u, c', ϕ')
- Post-peak, τ'
- Remolded strength
- Softened or critical state, $s_{u\ (rem)}$
- Residual (c_r', ϕ_r')
- Cyclic Behavior (τ_{cyc}/σ_{vo}')

Estimating Soil Engineering Parameters

Relative Density (D_r)

Proposed correlations for friction angle based on CPT result

Reference	Correlations	Soil type and Remarks
Meyerhof (1974)	$\varphi = tan^{-1}(q_c/0.5N_q)$	Sand q_c (MPa)
Robertson et al. (1986)	$\varphi = tan^{-1}[0.1 + 0.38log(q_c/\sigma'_v)]$	Sand
Kulhawy and Mayne (1990)	$\varphi = 17.6 + 11\text{Log}\left(q_c/\sqrt{100\sigma'_v}\right)$	Sand σ_v' and q_c are in kPa unit
Uzielli et al. (2013)	$\varphi = 25\left(q_c/\sqrt{100\sigma'_v}\right)^{0.1}$	Sand σ_v' and q_c are in kPa unit
Mayne (2007)	$\varphi' = 17.6 + 11\log(q_{t1})$	Sand $q_{t1} = (q_{ct}/Pa)\Big/\sqrt{(\sigma'_v/Pa)}$
Robertson and Cabal (2012)	$\tan\varphi' = \frac{1}{2.68}(\log(q_c/\sigma'_v) + 0.29)$	Uncemented, unaged, moderately compressible quartz sands
Mayne (2014)	$\varphi = 29.5B_q^{0.121}[0.256 + 0.33B_q + \log Q_t]$	Cohesive Soils $Q_t = \frac{q_t-\sigma_v}{\sigma'_v}$ $B_q = \frac{u_2-u_0}{q_t-\sigma_v}$

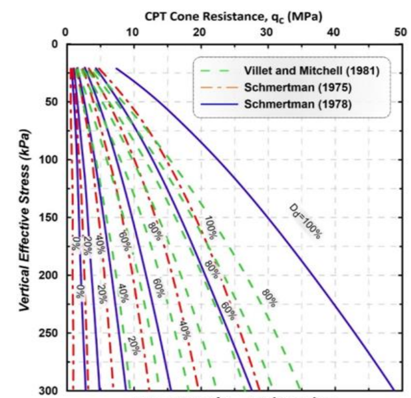


Correlation of q_c and σ'_v with internal friction angle (Robertson and Campanella, 1983)

Friction Angle (φ)

Correlations predicting D_r from CPT records

Reference	Proposed correlation	Remarks
Baldi et al. (1986)	$D_r = \frac{1}{C_2}ln(\frac{q_c}{C_0(\sigma_v')^{0.55}})$	C_0 and C_2: soil constants, C_0=157 and C_2=2.41 normally consolidated sand). q_c and σ_v' are in kPa unit
Jamiolkowski et al. (2001)	$D_r = 26.8\,ln\frac{q_c/p_a}{(\sigma_v'/p_a)^{0.5}} - b_x$	$b_x = 52.5$ for *high* compressibility sands $b_x = 67.5$ for *medium* compressibility sands $b_x = 82.5$ for*low* compressibility sands
Kulhawy and Mayne (1990)	$D_r = \frac{Q_{cn}}{305Q_cQ_{OCR}}$	$Q_{cn} = q_t/p_a/(\sigma_v'/p_a)^{0.5}$ Q_c =Compressibility factor (0.91 for high, 1.0 for medium, and 1.09 for low). Q_{OCR} = Over consolidation factor, $OCR^{0.18}$
Mayne (2007)	$D_r = 100(0.268\,ln(\frac{q_t/p_a}{\sqrt{\sigma_v'/p_a}}) - 0.675)$	q_c and σ_v' are in kPa unit

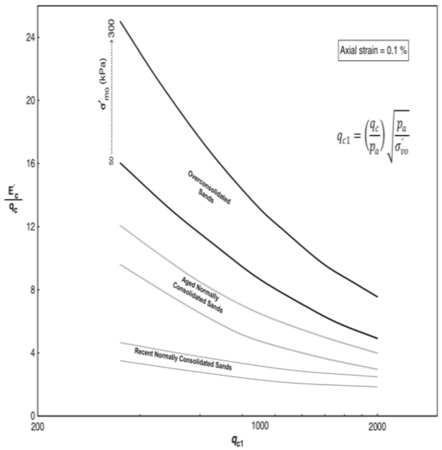


Comparison of D_r - q_c relationships

Estimating Soil Engineering Parameters

Stiffness (E_s)

Soil Type	CPT
Sand	$E_s = (2-4)q_u$ $= 8000q_u$ - - - - - - - - - - - - - - - $E_s = 1.2(3D_r^2+2).q_c$ $E_s = (1+D_r^2).q_c$
Saturated Sand	$E_s = F.q_c$ $e = 1.0 \quad F = 3.5$ $e = 0.6 \quad F = 7.0$
OCR Sand	$E_s = (6-30)q_c$
Clay Sand	$E_s = (3-6)q_c$
Silty Sand	$E_s = (1-2)q_c$ $q_c < 2500kPa \quad E_s^{'} = 2.5q_c$ $2500 < q_c < 5000kPa \quad E_s^{'} = 4q_c + 5000$
Soft Clay	$E_s = (3-8)q_c$

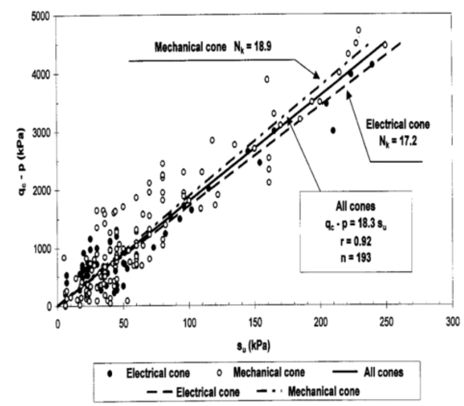


Drained Young's modulus from CPT for silica sands (Bellotti et al., 1989)

Undrained Shear Strength (S_u)

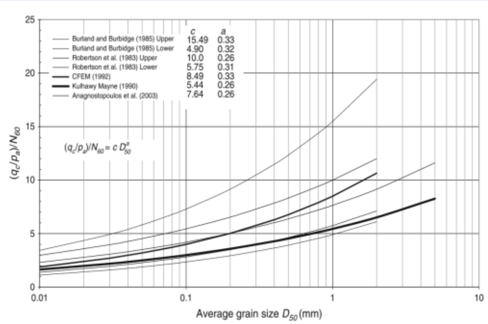
Correlations for undrained shear strength of the cohesion of soils

Reference	Correlations	Remarks
Lunne et al. (1997)	$S_u = {(q_c - \sigma_v)}/{N_c}$	N_c: cone factor
Risery (1974)	$S_u = {q_c}/{23}$	-
Kulhawy and Mayne (1990)	$S_u = \frac{\Delta u}{N_{\Delta u}}$	Δu = excess pore pressure measured at u_2 position = $u_2 - u_0$ $N_{\Delta u}$ = Pore pressure cone factor $N_{\Delta u} = N_{kt}$ Bq $N_{\Delta u}$ varies between 4 and 10
Naeini and Moayed (2007)	${S_u}/{\sigma'_v} = 0.107 + 0.111q_{cn1}$	q_{cn1}: normalized cone tip resistance; FC<30%
Rémai (2013)	The same as Kulhawy and Mayne (1990) method	$N_{\Delta u}$=24.3 Bq



Relationship between cone resistance and undrained shear strength for cohesive soils
(Anagnostopolous et al, 2003)

CPT (q_c) correlations with SPT (N)



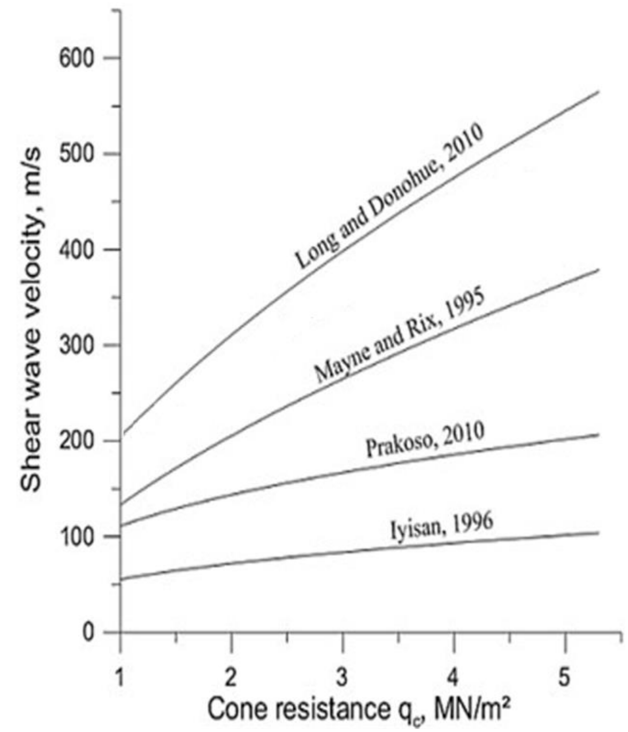
(Adopted from Robertson & Campanella, 1983)

Estimating Soil Engineering Parameters

Shear Wave Velocity (V_s)

Empirical correlations between V_s and CPT data (Ameratunga et al., 2016)

Reference	Proposed correlation (m/s)	Soil Type	Units of Parameters	
			q_c	f_s
Hegazy and Mayne (1995)	$V_s = 12.02(q_c)^{0.319}(f_s)^{-0.0466}$	Sand	kPa	kPa
	$V_s = 3.18(q_c)^{0.549}(f_s)^{0.025}$	Clay	kPa	kPa
Mayne and Rix (1995)	$V_s = 1.75(q_c)0.627$	Clay	kPa	kPa
Madiai and Simoni (2004)	(1) $V_s = 211(q_c)^{0.23}$ (2) $V_s = 155(q_c)^{0.29}(f_s)^{-0.10}$	All	MPa	MPa
Mayne (2006)	$V_s = 18.5+118.8\log(f_s)$	All	-	kPa
MolaAbasi et al. (2015)	$V_s=100[1.36-0.35f_s+0.15q_c-0.05f_s^2-0.018q_c^2+0.39f_s\,q_c]$	Clay	MPa	MPa
	$V_s=100[1.73+2.74f_s+0.03q_c-4.015f_s^2-0.00026q_c^2+0.007f_sq_c]$	Sand	MPa	MPa
	$V_s=100[1.47+2.07f_s+0.10q_c+9.50f_s^2-0.0023q_c^2-0.034f_s\,q_c]$	Mixed	MPa	MPa
	$V_s=100[1.40+1.59f_s+0.09q_c-1.33f_s^2-0.002q_c^2+0.05f_s\,q_c]$	All	MPa	MPa



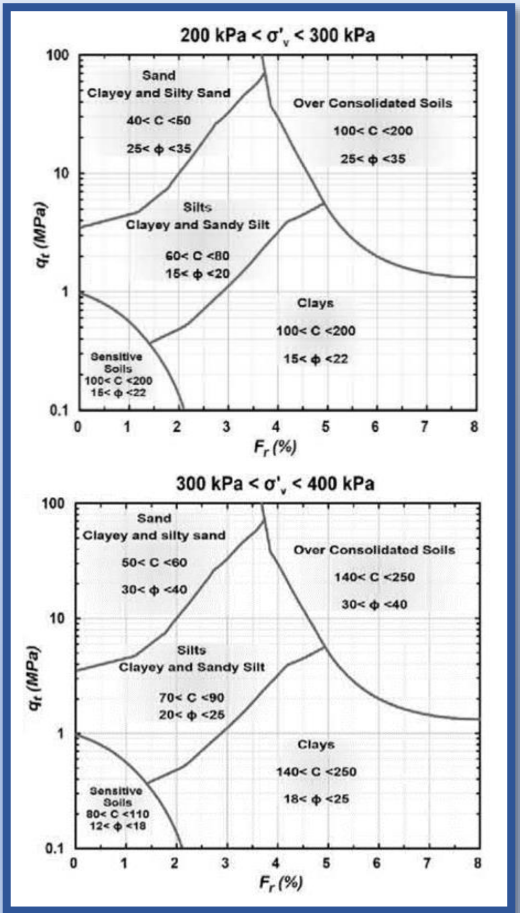
Estimating Soil Engineering Parameters

- **Eslami & Mohammadi (2016)**

q_c, f_s, u_2 → **C′ , ϕ′**

$$
\begin{cases}
C + 0.000789(1 - \sin\phi)\sigma'_{v_0}\tan\left(\frac{2}{3}\phi\right)\left[\dfrac{q_c - \left(\dfrac{\sigma_{v_0} - 2\sigma_{h_0}}{3}\right)}{\left(\dfrac{\sigma'_{v_0} - 2\sigma'_{h_0}}{3}\right)}\right]^{1.44} = f_s \\
\left(\tan^2\left(\frac{\pi}{4} + \frac{\phi}{2}\right)e^{\pi\tan\phi} - 1\right)C\cot\phi + \bar{q}.\tan^2\left(\frac{\pi}{4} + \frac{\phi}{2}\right)e^{\pi\tan\phi} + \\
\gamma B\left[\tan^2\left(\frac{\pi}{4} + \frac{\phi}{2}\right)e^{\pi\tan\phi} + 1\right]\tan\phi = q_E + N_u\Delta U
\end{cases}
$$

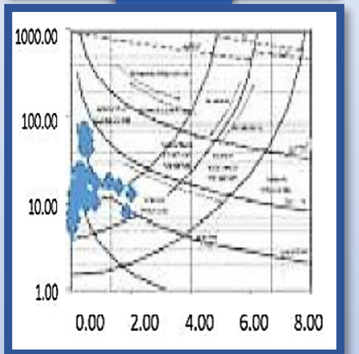
Variation range for C (kPa) and ϕ (Degree)



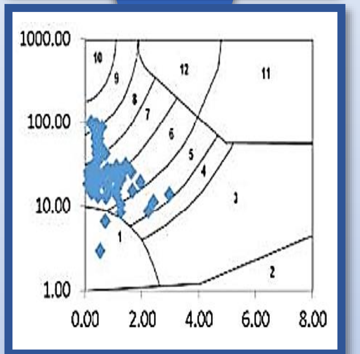
Identifying Problematic Deposits

- ***Collapsible Soils*** **Boundaries in Different Charts**

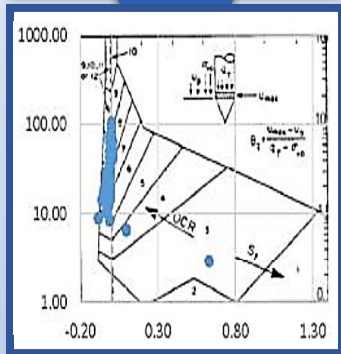
Douglas & Olsen (1981)



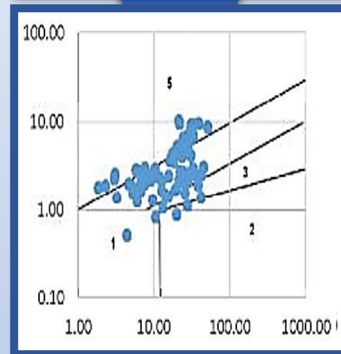
Robertson et al. (1986)



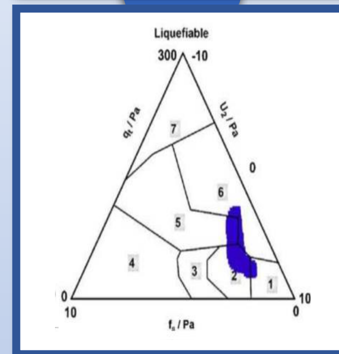
Robertson et al. (1986)



Eslami & Fellenius (1997)

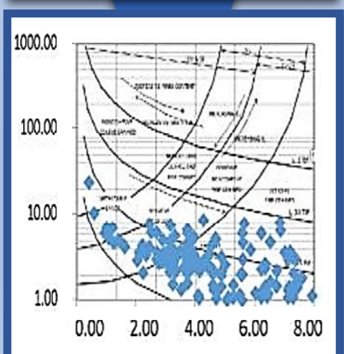


Eslami et al. (2016)

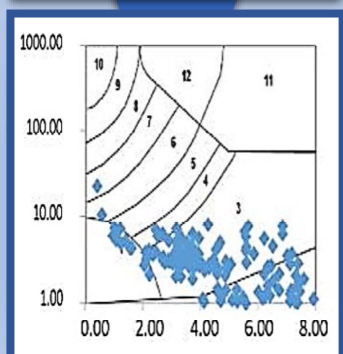


- ***Peaty Soils*** **Boundaries in Different Charts**

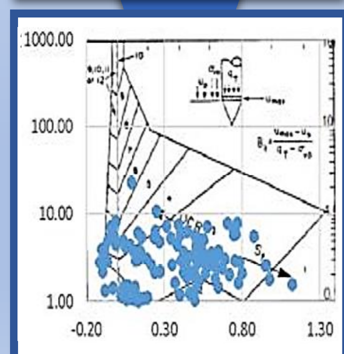
Douglas & Olsen (1981)



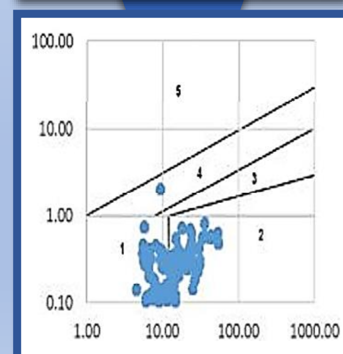
Robertson et al. (1986)



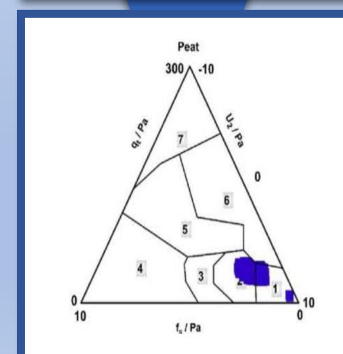
Robertson et al. (1986)



Eslami & Fellenius (1997)



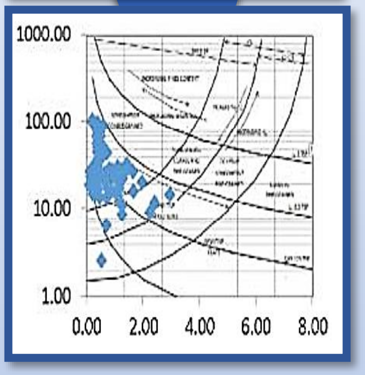
Eslami et al. (2016)



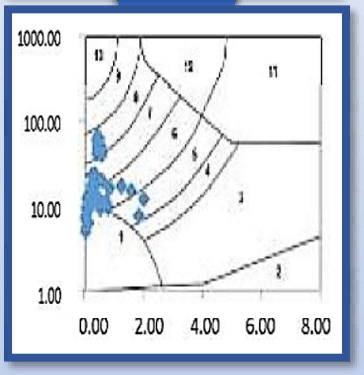
Identifying Problematic Deposits

- ***Liquefiable Soils*** **Boundaries in Different Charts**

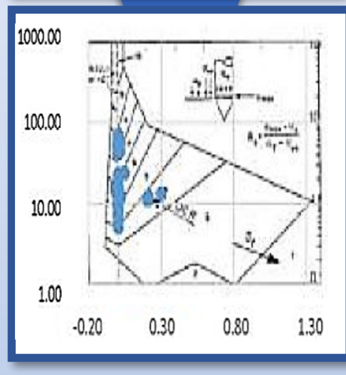
Douglas & Olsen (1981)



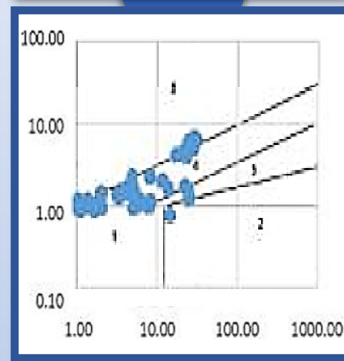
Robertson et al. (1986)



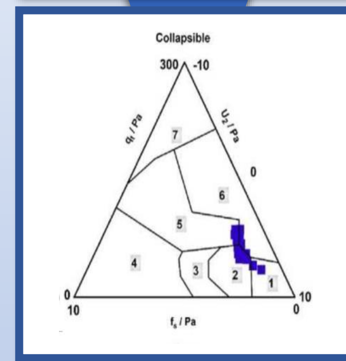
Robertson et al. (1986)



Eslami & Fellenius (1997)

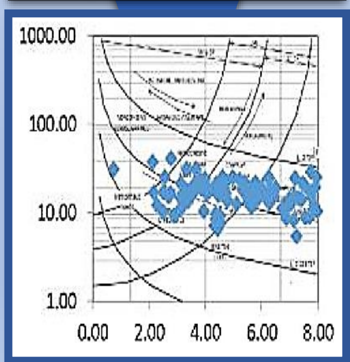


Eslami et al. (2016)

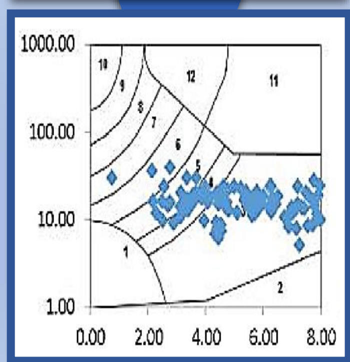


- ***Expansive Soils*** **Boundaries in Different Charts**

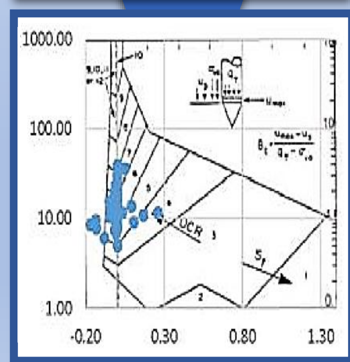
Douglas & Olsen (1981)



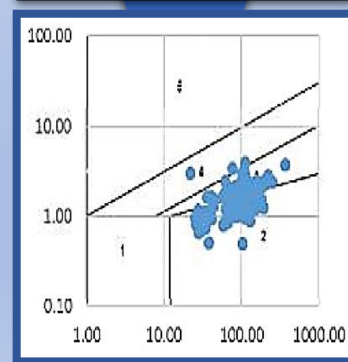
Robertson et al. (1986)



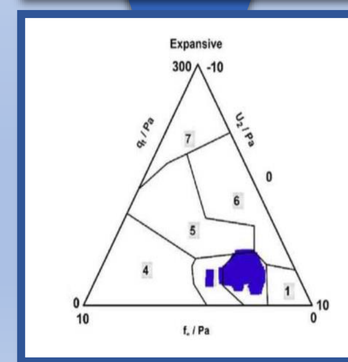
Robertson et al. (1986)



Eslami & Fellenius (1997)

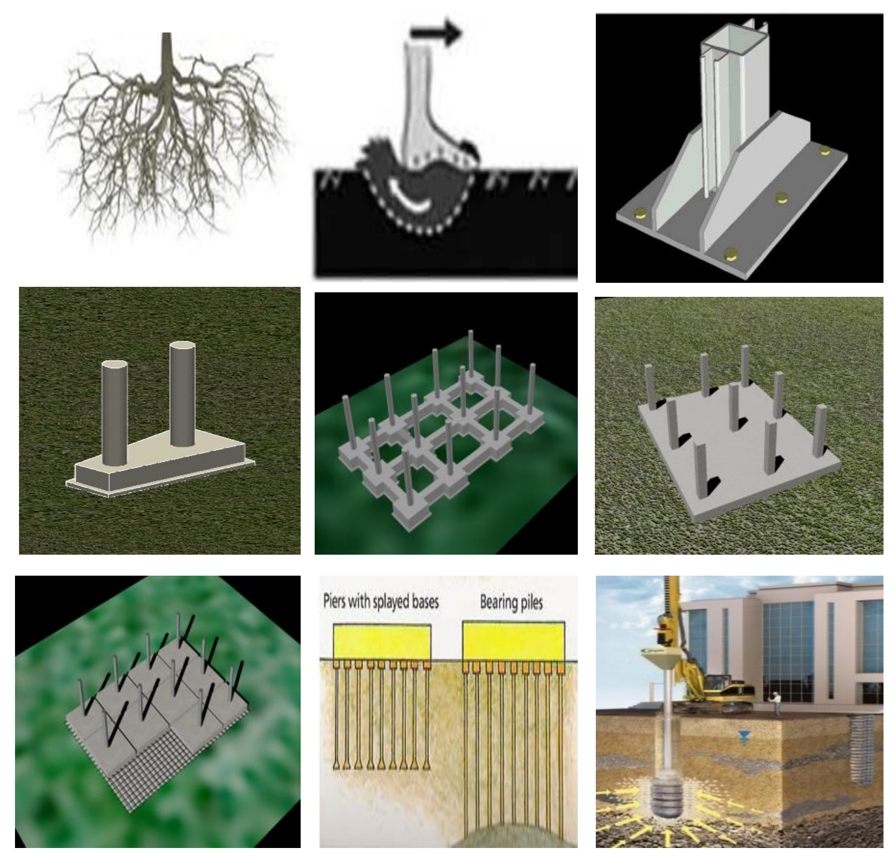


Eslami et al. (2016)



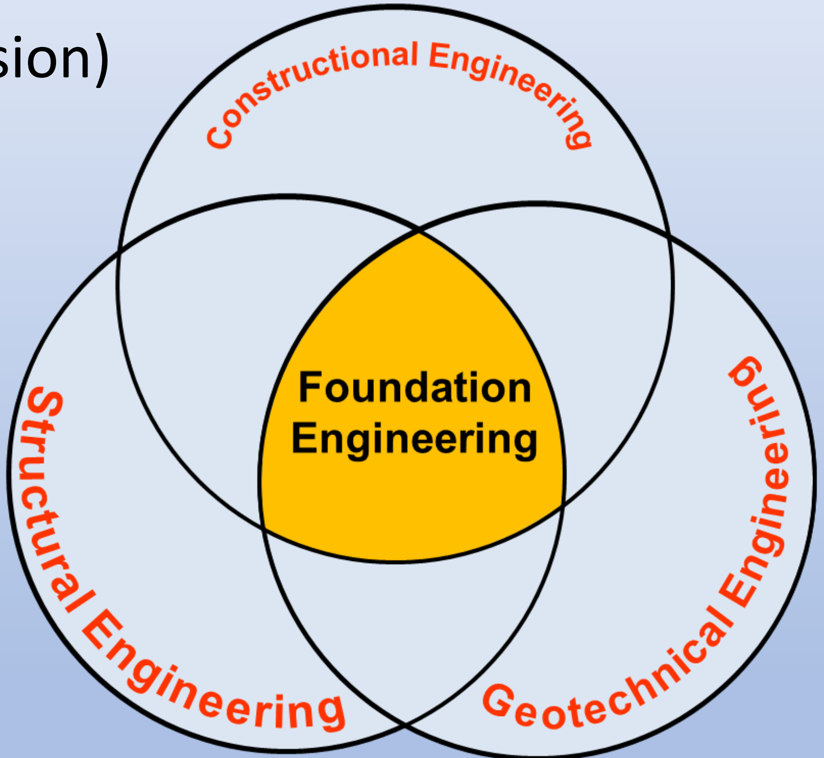
Typical Structures

Typical Foundations



Major Analysis & Design Requirements

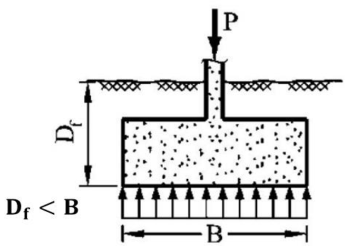
1. Bearing Capacity
2. Serviceability (Settlement and Torsion)
3. Structural Design
4. Stability Control
5. Full or Model Scale Testing
6. Constructional Aspects
7. Durability
8. Economic Requirements



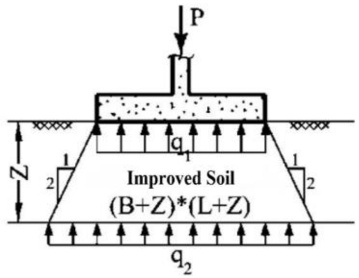
Multidisciplinary: Structural, Geotechnical and Constructional

Foundations Classification

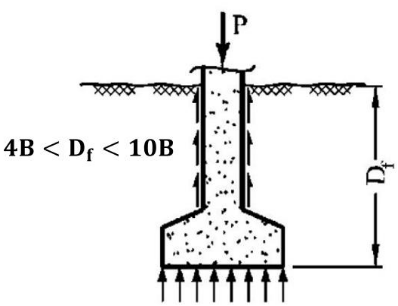
• Embedment



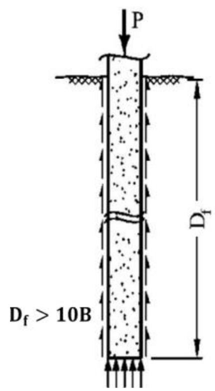
Shallow Foundations



Shallow Foundations
+ Soil Improvement

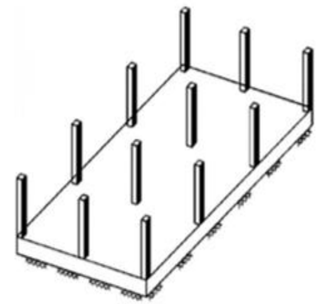


Semi-deep
Foundations

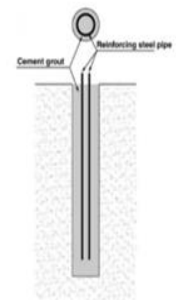


Deep Foundations

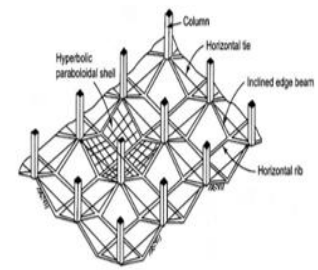
• Load Transfer System



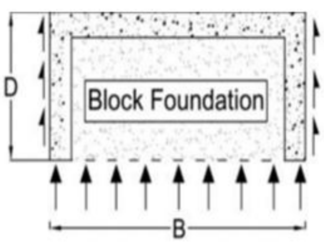
Section-act
Foundation



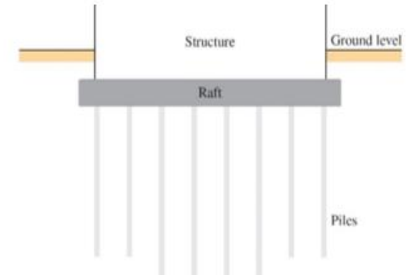
Vector-act
Foundation



Surface-act
Foundation



Block-act
Foundation



Hybrid
Foundation

(Eslami & Ebrahimipour, 2023)

Databases

Databases are collections of data which are organized in order to facilitate access and retrieving data when they are needed.

Databases in Geotechnical Engineering

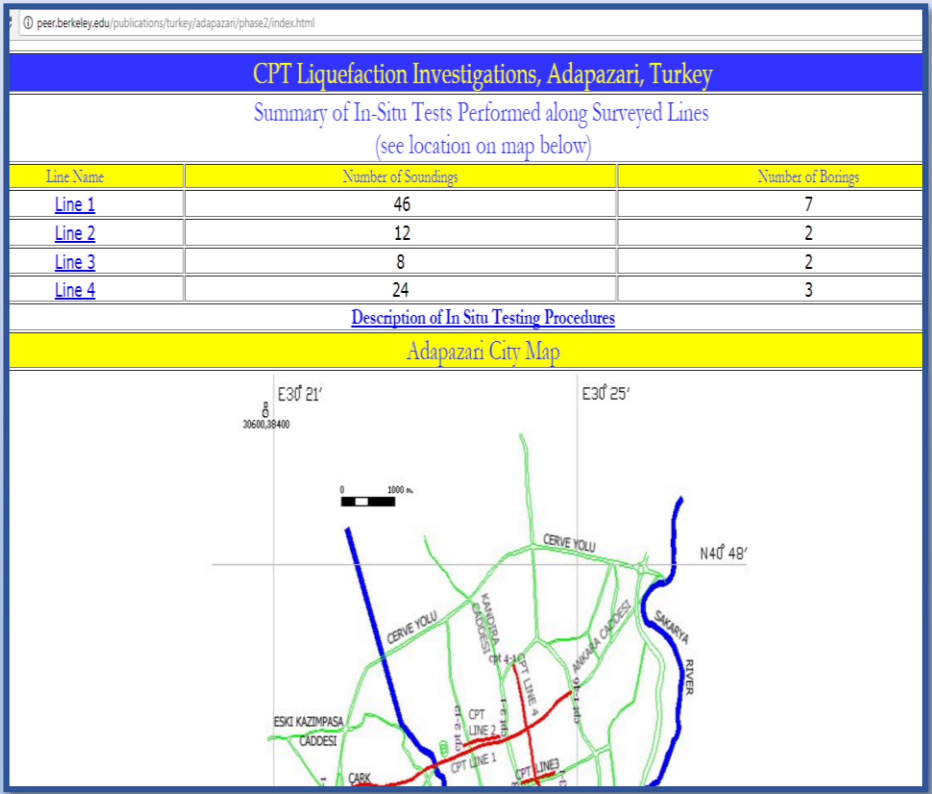
1. Pile loading test (vertical & lateral)
2. Retaining walls and displacement
3. In-situ tests
4. Specifications of geotechnical boreholes
5. Settlement of shallow foundations

Advantages & Applications

1. Cost saving and project execution time
2. Optimization of design methods
3. Evaluation of design methods
4. Development of new methods
5. Improvement of geotechnical studies

Overview of Some Databases in Geotechnical Engineering

Berkeley Liquefaction Investigation


peer.berkeley.edu/publications/turkey/adapazari/phase2/index.html

CPT Liquefaction Investigations, Adapazari, Turkey

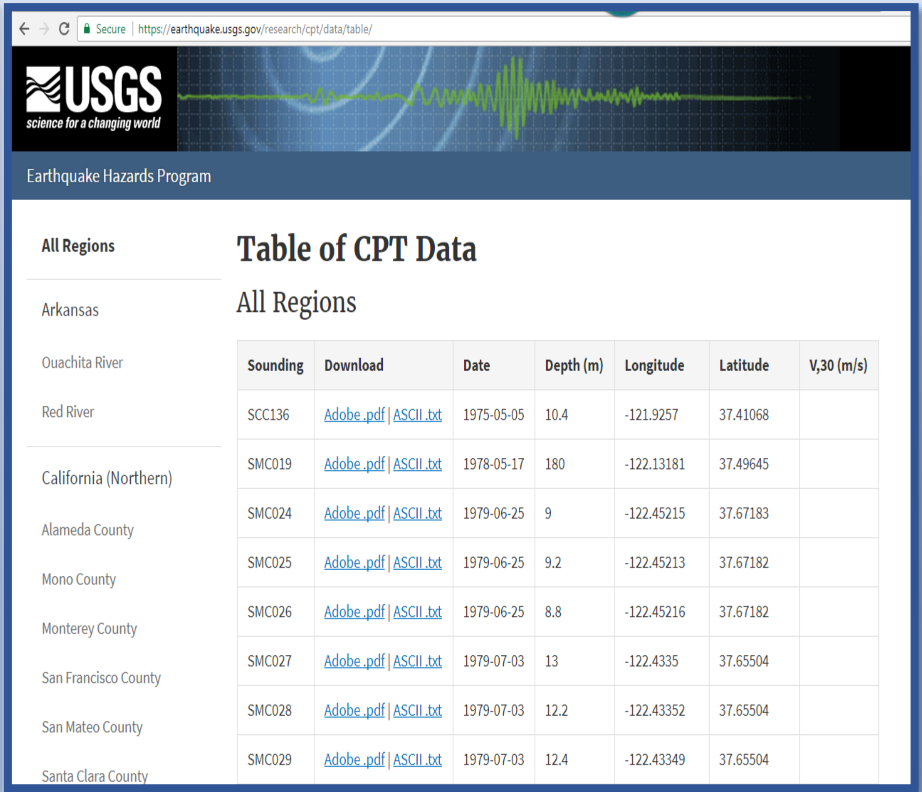
Summary of In-Situ Tests Performed along Surveyed Lines
(see location on map below)

Line Name	Number of Soundings	Number of Borings
Line 1	46	7
Line 2	12	2
Line 3	8	2
Line 4	24	3

Description of In Situ Testing Procedures

Adapazari City Map

USGS Earthquake Hazards Program


Secure | https://earthquake.usgs.gov/research/cpt/data/table/

USGS
science for a changing world

Earthquake Hazards Program

All Regions
Arkansas
Ouachita River
Red River
California (Northern)
Alameda County
Mono County
Monterey County
San Francisco County
San Mateo County
Santa Clara County

Table of CPT Data

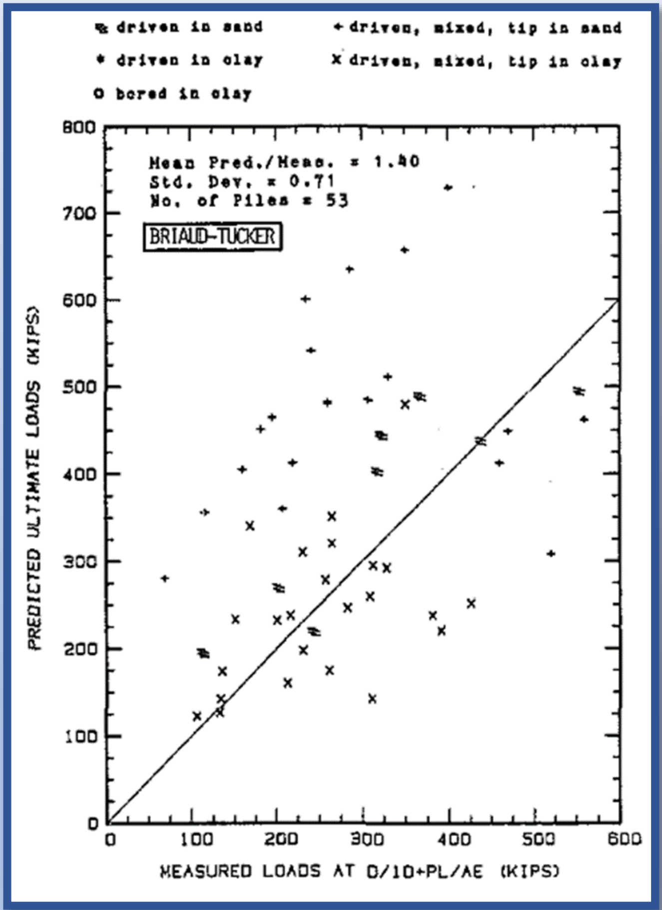
All Regions

Sounding	Download	Date	Depth (m)	Longitude	Latitude	V,30 (m/s)
SCC136	Adobe .pdf | ASCII .txt	1975-05-05	10.4	-121.9257	37.41068	
SMC019	Adobe .pdf | ASCII .txt	1978-05-17	180	-122.13181	37.49645	
SMC024	Adobe .pdf | ASCII .txt	1979-06-25	9	-122.45215	37.67183	
SMC025	Adobe .pdf | ASCII .txt	1979-06-25	9.2	-122.45213	37.67182	
SMC026	Adobe .pdf | ASCII .txt	1979-06-25	8.8	-122.45216	37.67182	
SMC027	Adobe .pdf | ASCII .txt	1979-07-03	13	-122.4335	37.65504	
SMC028	Adobe .pdf | ASCII .txt	1979-07-03	12.2	-122.43352	37.65504	
SMC029	Adobe .pdf | ASCII .txt	1979-07-03	12.4	-122.43349	37.65504	

Overview of Some Databases in CPT & Pile

Briaud & Tucker (1988) Database

- **Assessment of 13 methods for determining the bearing capacity and settlement based on SPT, CPT, PMT and dynamic formulas**
- **98 case studies of steel and concrete piles with square, H, circular cross sections**
- **Pile lengths between 3 and 25 m**
- **The ultimate loads range from 307 to 2536 kN**



Overview of Some Databases in CPT & Pile

Eslami & Fellenius (1997) Database

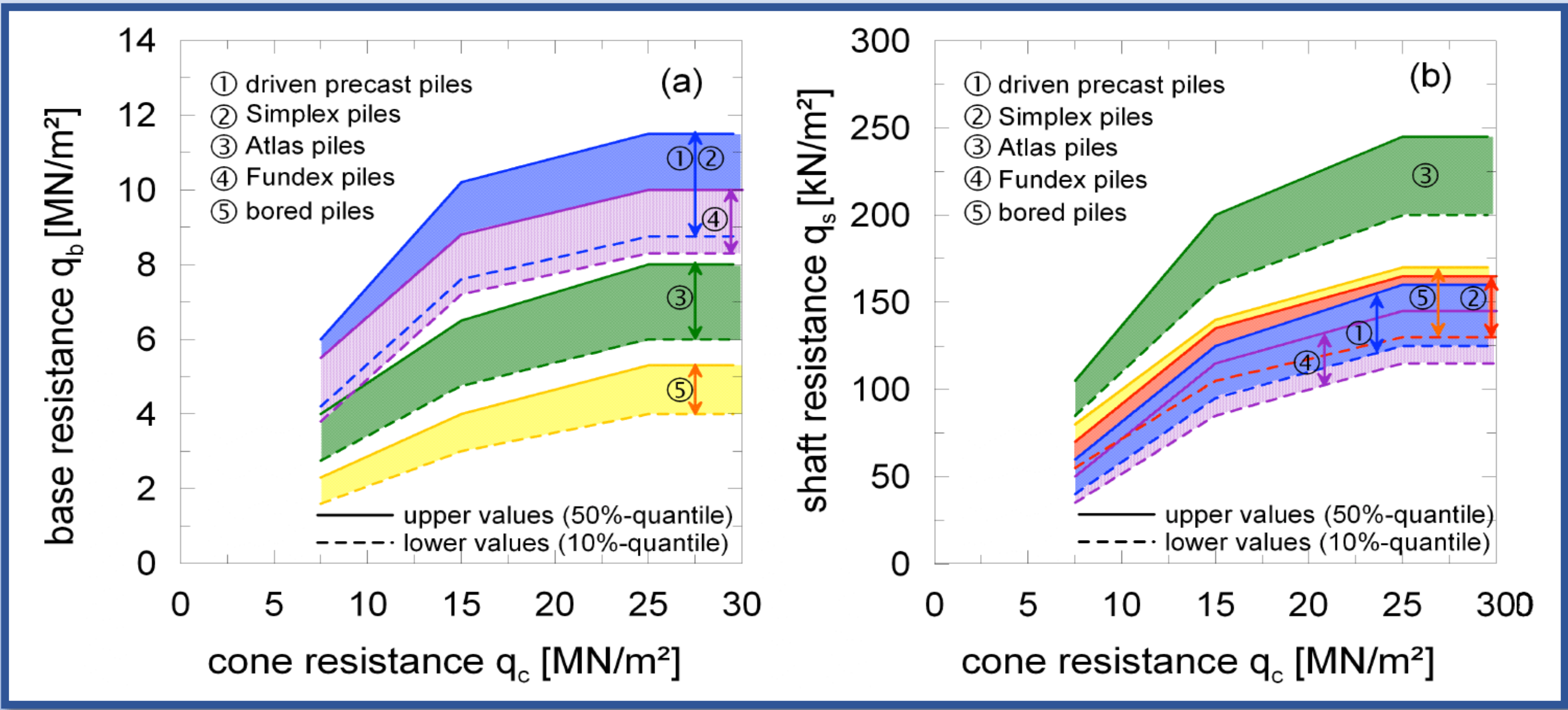
- **102 case studies from 40 sites and 13 countries**
- **Clay, silt and sand deposits**
- **Mainly square or circular in sections**
- **Steel and concrete materials**
- **Piles bearing capacity: 80 to 8000 kN**

No.	Case	Reference	Site location	Pile shape and material[a]	Pile diameter, b (mm)	Embedment length, D (m)	Total capacity, R_{ult} (kN)	Soil profile
Group I								
1	UBC3	Campanella et al. 1989	B.C., Canada	P, S	324	16.8	630	Soft clay, sand
2	UBC5	Campanella et al. 1989	B.C., Canada	P, S	324	31.1	1100	Soft clay, sand, silt
3	NWUP	Finno 1989	Ill., U.S.A.	P, S	450	15.2	1020	Sand, clay
4	FHWASF	O'Neil 1988	Calif., U.S.A.	P, S	273	9.1	490	Sand
5	BGHD1	Altaee et al. 1992*a*, 1992*b*	Iraq	Sq, C	285	11.0	1000	Uniform sand
6	BGHD2	Altaee et al. 1992*a*, 1992*b*	Iraq	Sq, C	285	15.0	1600	Uniform sand
7	POLA1	CH2M Hill 1987	Calif., U.S.A.	Oct, C	610	25.8	5455	Silt, sand
8	POLA2TOE	Urkkada 1995	Calif., U.S.A.	Oct, C	610	32.5	3650	Silt, sand
9	TWNTP4	Yen et al. 1989	Taiwan	P, S	609	34.3	4330	Sand, clay, sand
10	TWNTP5	Yen et al. 1989	Taiwan	P, S	609	34.3	2500	Sand, clay, sand
11	TWNTP6	Yen et al. 1989	Taiwan	P, S	609	34.3	4460	Sand, clay, sand
12	L&D314	Briaud et al. 1989	Ill., U.S.A.	HP, S	360	12.0	1170	Sand
13	L&D35	Briaud et al. 1989	Ill., U.S.A.	P, S	350	12.2	630	Sand
14	L&D316	Briaud et al. 1989	Ill., U.S.A.	HP, S	360	11.2	870	Sand
15	L&D32	Briaud et al. 1989	Ill., U.S.A.	P, S	300	11.0	500	Sand
16	L&D38	Briaud et al. 1989	Ill., U.S.A.	P, S	400	11.1	945	Sand
17	L&D315	Briaud et al. 1989	Ill., U.S.A.	HP, S	360	11.3	817	Sand
18	A&N2	Haustorfer and Plesiotis 1988	Australia	Sq, C	450	13.7	4250	Sand
19	N&SB144	Nottingham 1975	Fla., U.S.A.	P, S	270	22.5	765	Sand
20	QBSA	Konrad and Roy 1987	Que., Canada	P, S	220	7.5	83	Sensitive clay
21	UHUC1	O'Neil 1981	Tex., U.S.A.	P, S	273	13.2	780	Clay, sandy clay
22	UHUT1	O'Neil 1981	Tex., U.S.A.	P, S	273	13.2	485	Clay, sandy clay
23	UHUC11	O'Neil 1981	Tex., U.S.A.	P, S	273	13.2	800	Clay, sandy clay
24	UHUT11	O'Neil 1981	Tex., U.S.A.	P, S	273	13.2	520	Clay, sandy clay

Overview of Some Databases in CPT & Pile

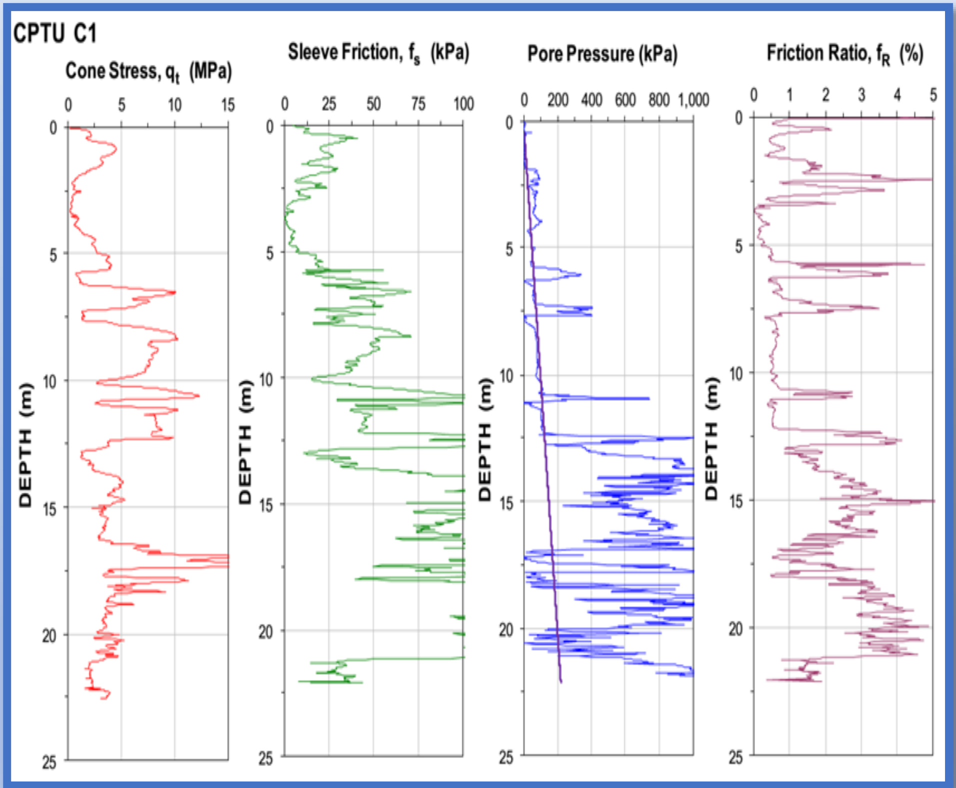
Kempfert & Becker (2010)

- **German method**
- **1000 case records**

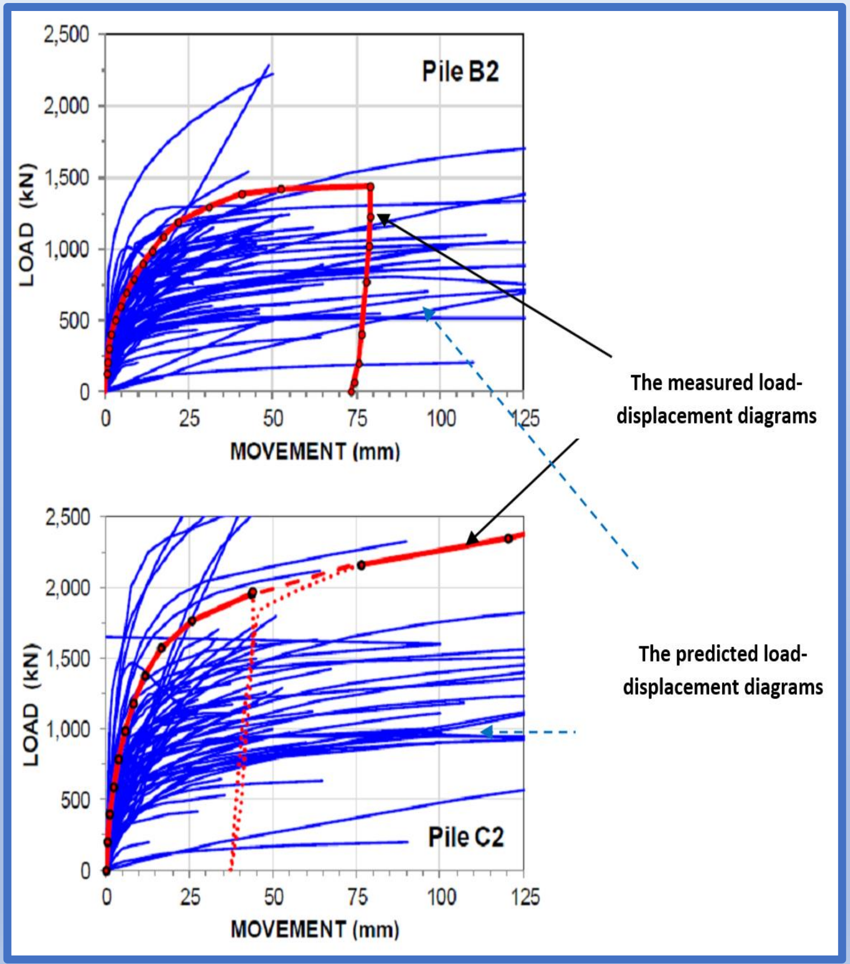


Overview of Some Databases in CPT & Pile

Bolivian Pile Prediction Event (Fellenius et al., 2017)



Typical CPTu log in the site



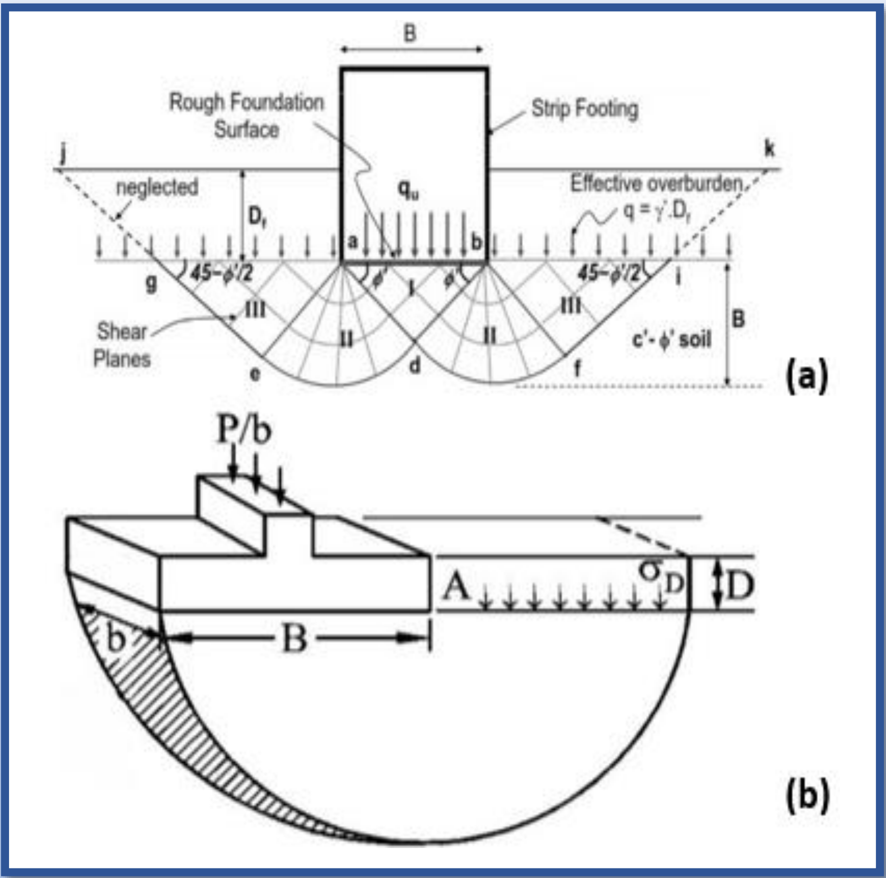
Typical predicted and measured load-movement

Several Comprehensive CPT & Pile Databases

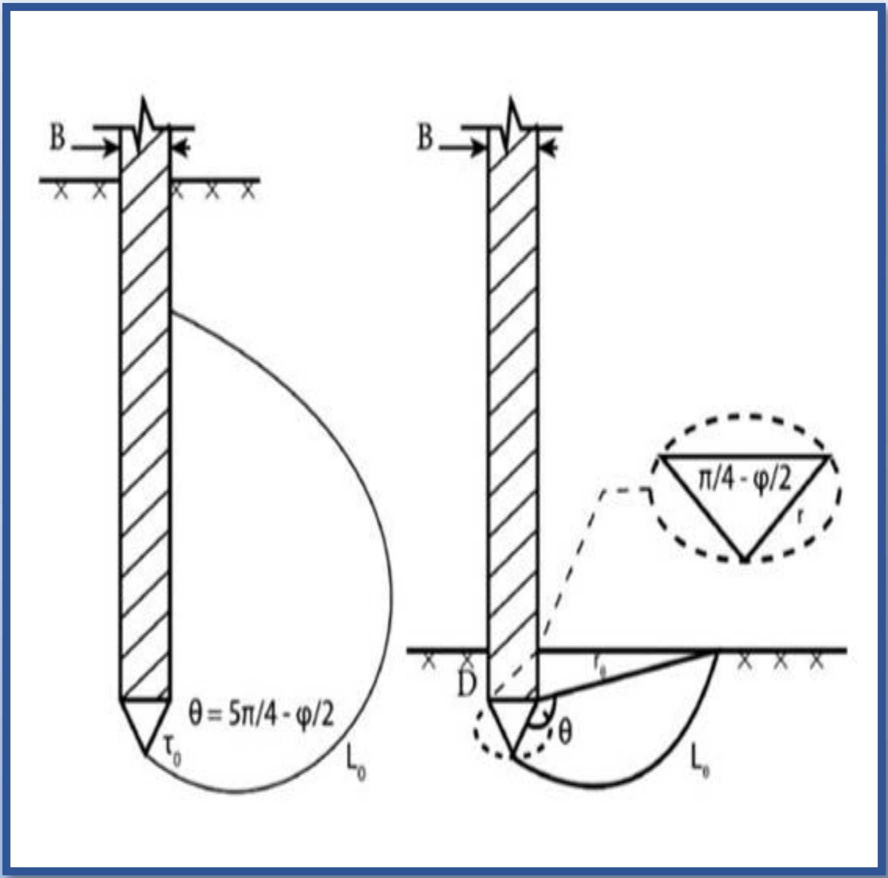
Nottingham (1975)	Briaud & Tucker (1988)
Meyerhof (1976, 1983)	Alsamman (1995)
Schmertmann (1978)	Eslami & Fellenius (1997)
de Ruiter & Beringen (1979)	Abu-Farsakh & Titi (2004)
Bustamante & Gianesselli (1982)	Lehane et al., (2005)
Tummay & Fakhroo (1982)	Kempfert & Becker (2010)

1. Geotechnical Engineering (GE) & Site Investigations
2. Cone & Piezocone Penetration Tests (CPT & CPTu)
3. Applications of CPT & CPTu in GE
4. Databased Approach in Foundation Engineering (FE)
5. **CPT & Shallow Foundations**
6. CPT & Deep Foundations
7. Case Studies
8. Summary and Conclusions

Direct Application for Settlement & Load-Displacement



Shear failure zone, a) drained condition, b) undrained (Terzaghi, 1943)



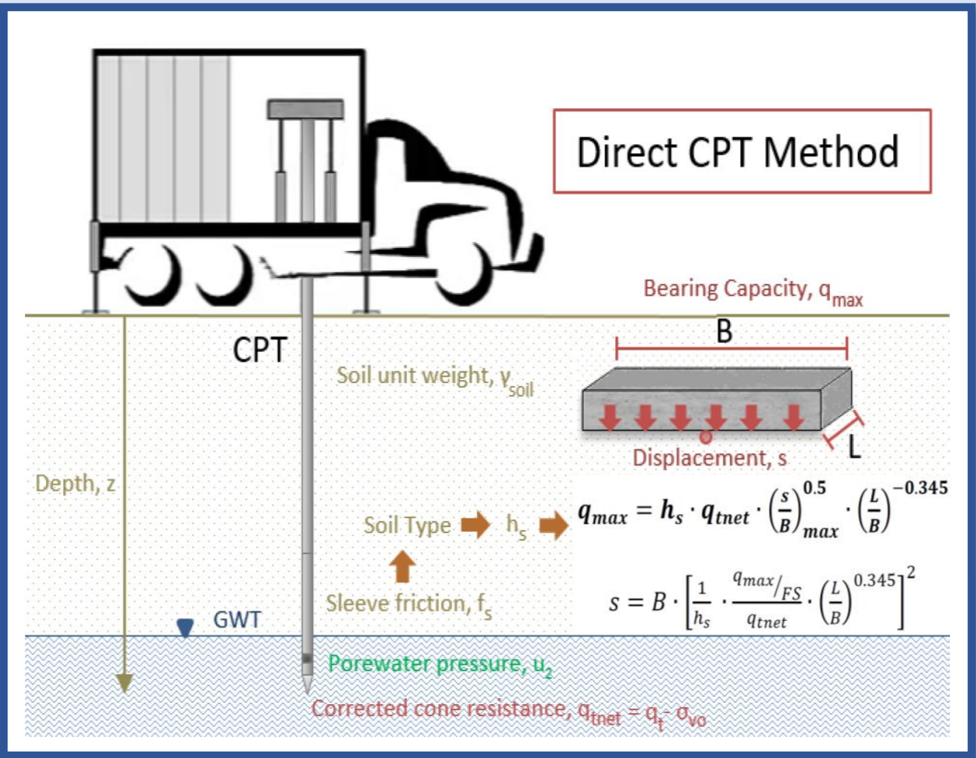
Comparison of rupture surface length for shallow and deep conditions

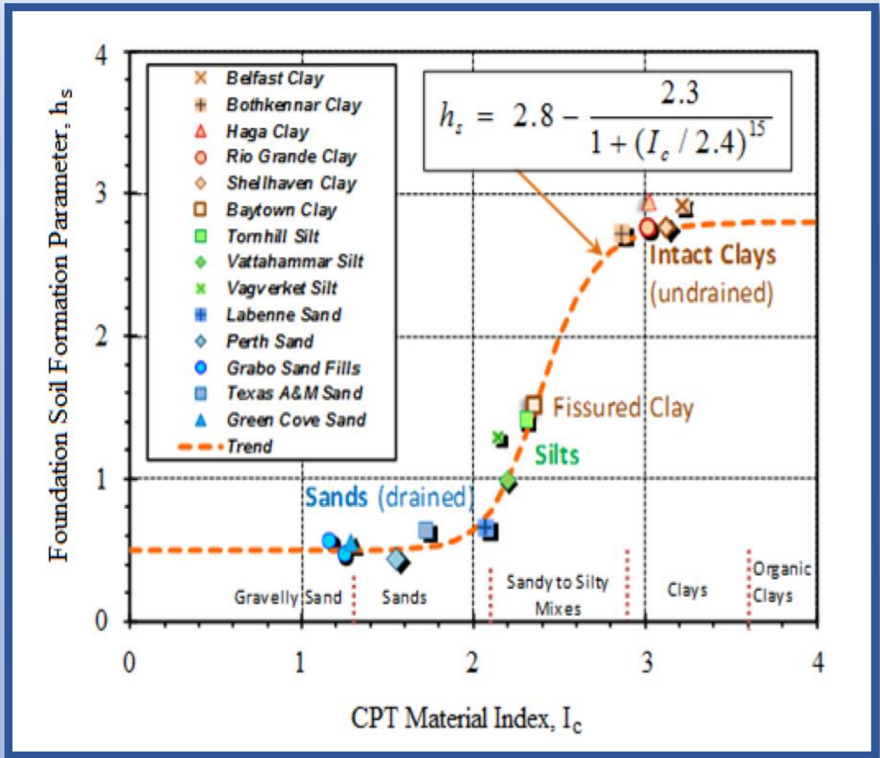
Direct Application for Settlement & Load-Displacement

Reference	Equations	Remarks
Schmertmann (1978)	$q_{ult} = \bar{q} N_q + 0.5\gamma B N_\gamma$ $N_q = N_\gamma = 1.25\sqrt{q_{c1} \times q_{c2}}$	q_{c1} = arithmetic average of q_c values in an interval between footing base and 0.5B beneath footing base. q_{c2} = arithmetic average of q_c values in an interval between 0.5B to 1.5B beneath footing base.
Meyerhof (1976)	$q_{ult} = \bar{q}_c \left(\frac{B}{12.2}\right)\left(1 + \frac{D_f}{B}\right)$	$\bar{q}_c$ = arithmetic average of q_c values in a zone including footing base and 1.5B beneath the footing. F.S. at least 3 is recommended
Bowles (1996)	$q_{ult} = 28 - 0.0052(300 - \bar{q}_c)^{1.5}$, for strip footings $q_{ult} = 48 - 0.0052(300 - \bar{q}_c)^{1.5}$, for square footings	$\bar{q}_c$ = the arithmetic average of q_c values in an interval between footing base and 1.5B beneath, in terms of kg/cm^2.
CFEM (2006)	$q_{ult} = 0.30\ \bar{q}_c$ $q_{all} = 0.10\ \bar{q}_c$	a safety factor of 3 has been suggested
Tand et al. (1994)	$q_{ult} = R_k q_c + \sigma_{v0}$	R_k values range from 0.14 to 0.2, depending on the footing shape and depth, and σ_{v0} is the initial vertical stress at the footing base.
Eslami and Gholami (2006)	$q_{ult} = \bar{\alpha} \times \bar{q}_{cg}$ $\varphi = \dfrac{\log\left(\frac{\bar{q}_c}{\gamma\ z}\right) + 0.5095}{0.0915}$	$\bar{q}_{c,g}$ = geometric average of q_c values from footing base to 2B beneath footing depth.

Direct Application for Settlement & Load-Displacement

- **Minnesota CPT Design Guide (2018)**





Foundation soil formation parameter h_s versus CPT material index, I_c (Mayne, 2017)

Direct Application for Settlement & Load-Displacement

- **Valikhah & Eslami (2019)**

$$\Delta H = \left(\frac{1}{mj}\left[\left(\frac{\sigma_0'+\Delta\sigma'}{\sigma_r'}\right)^j - \left(\frac{\sigma_0'}{\sigma_r'}\right)^j\right]\right)\times H$$

$$m = 0.25b \times \left(\frac{2B+1}{3B}\right)^3 \times q_c$$

b: penetration cone diameter

B: foundation width

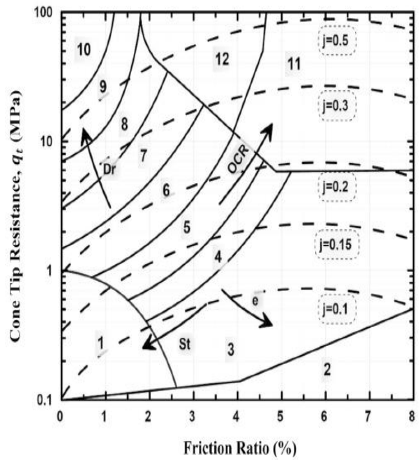
(b and B are in m and q_c is in kPa)

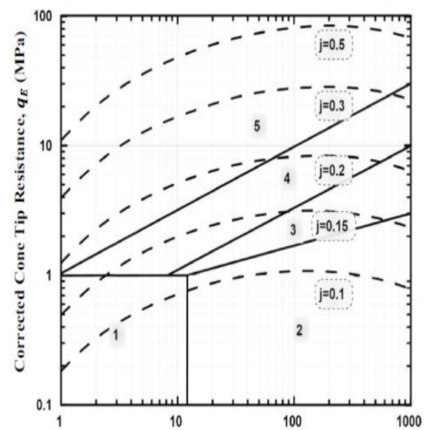
$$j = \frac{q_c}{x+yq_c}$$

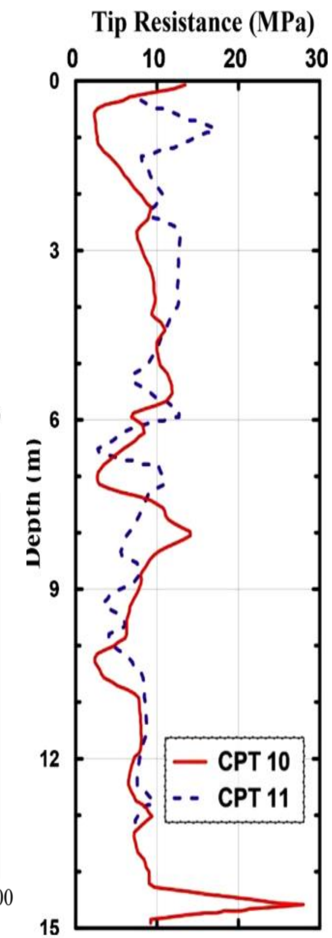
$$x = 0.02R_f + 0.5$$

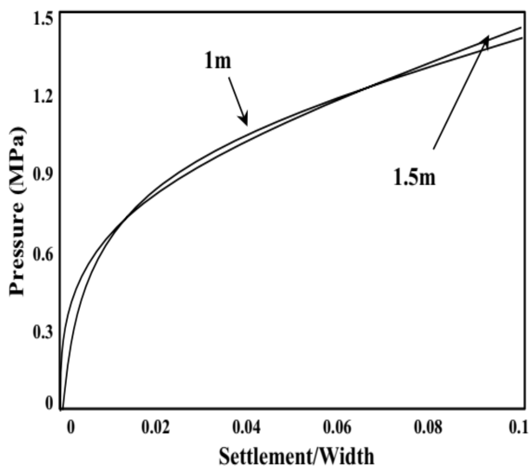
$$y = 7.53(\sigma_0')^{-0.25}$$

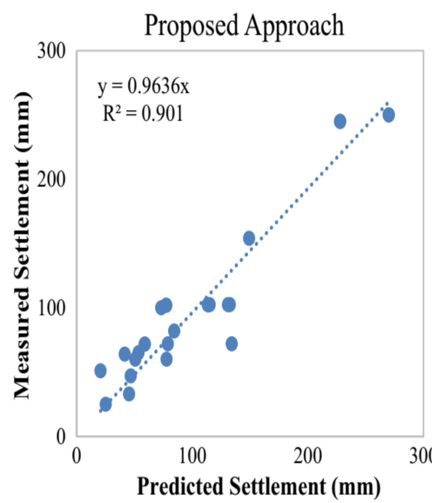
(q_c and σ_0' are in kPa)



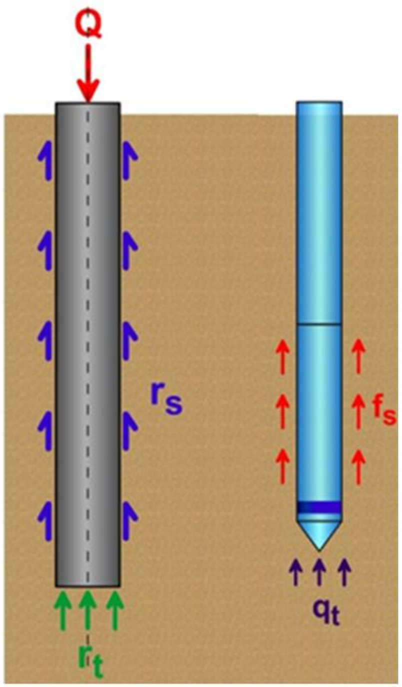








Background



Indirect Approach: q_c & f_s → C,Ø → r_t, r_s

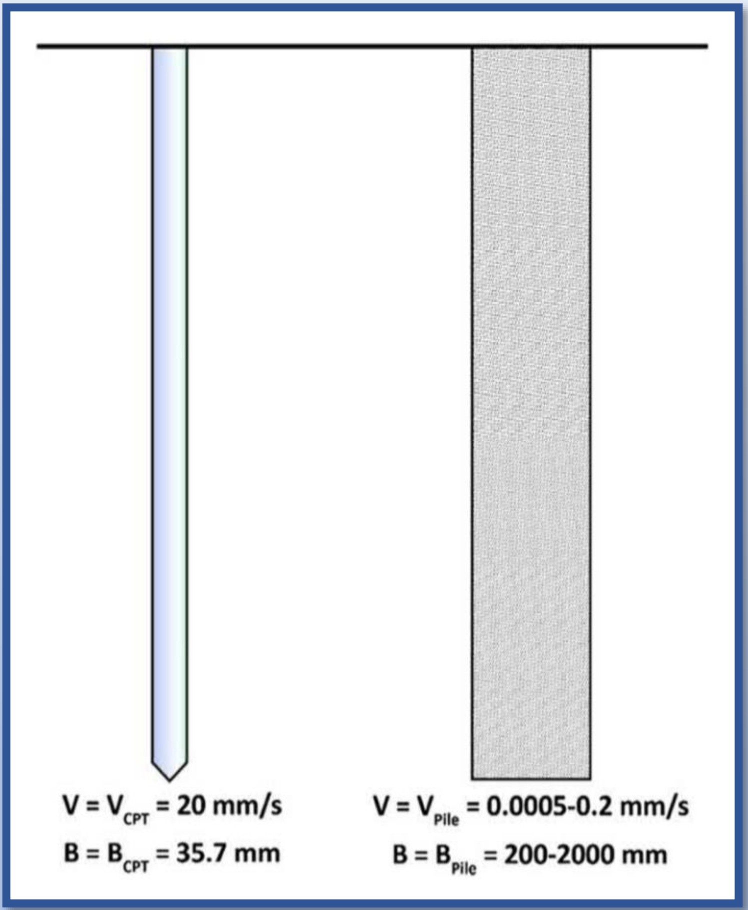
Direct Approach:
- q_c → r_t
- f_s → r_s

Penetrometers can be realized as a *model pile*

Scale Effect Correlations

- **Determinant Factors for Toe Capacity**

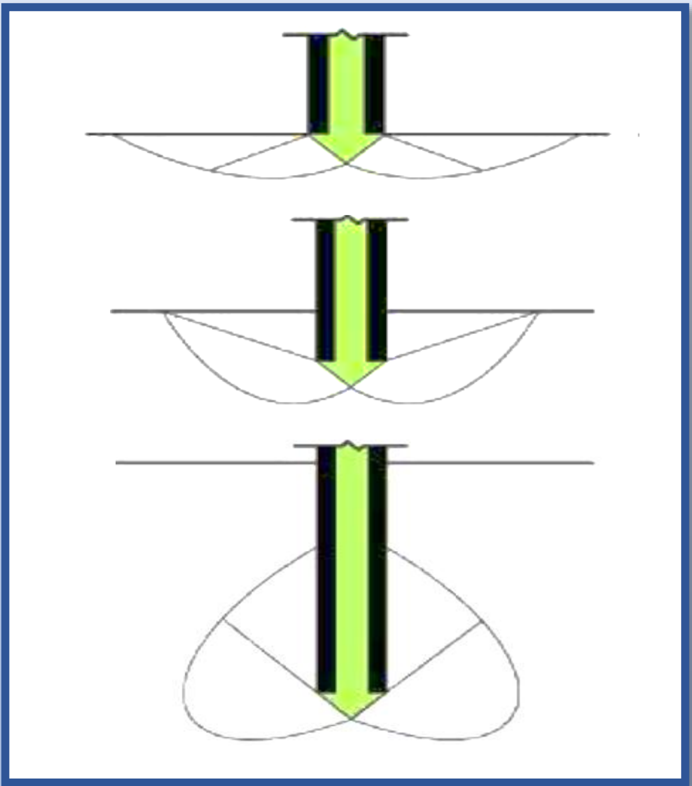
1. Embedment depth
2. Influence zone
3. Data production processing and averaging
4. Diameter
5. Nonhomogeneous condition
6. Penetration rate and failure mechanism
7. Ultimate capacity interpretation



Pile and CPT differences

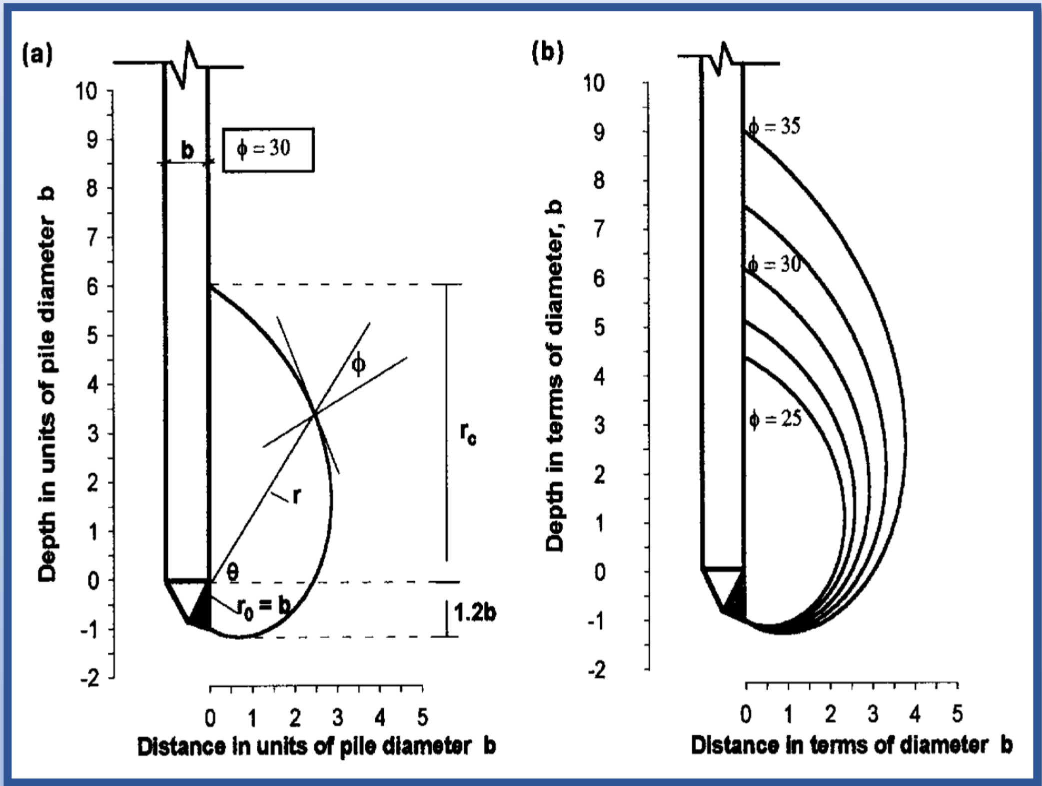
Scale Effect Correlations

Embedment Depth



Schematic view of transformation of shear failure from shallow to deep (Nottingham, 1975)

Influence Zone



a) Principle of a logarithmic spiral rupture, b) rupture surfaces around pile toe for different soils (Eslami & Fellenius, 1997)

Direct Application for Deep Foundations Bearing Capacity

List of common CPT- and CPTu-based methods for pile bearing capacity

No.	Method/ Reference	No.	Method/ Reference
1	Begemann (1963, 1965, 1969)	15	Fugro-05 (Kolk et al. 2005)
2	Meyerhof (1956, 1976, 1983)	16	UCD-05 (Gavin and Lehane 2005)
3	Aoki and Velloso (1975)	17	ICP-05 (Jardine et al. 2005)
4	Nottingham (1975), Schmertmann (1978)	18	UWA-05 (Lehane et al. 2005)
5	Penpile (Clisby et al.1978)	19	NGI-05 (Clausen et al. 2005)
6	Dutch (de Ruiter & Beringen 1979)	20	Cambridge-05 (White & Bolton 2005)
7	Philipponnat (1980)	21	Togiliani (2008)
8	LCPC (Bustamante & Gianeselli 1982)	22	German (Kempfert and Becker 2010)
9	Cone-m (Tumay & Fakhroo 1982)	23	UCD-11 (Igoe et al. 2010, 2011)
10	Price and Wardle (1982)	24	V–K (Van Dijk and Kolk 2011)
11	Gwizdala (1984)	25	SEU (Cai et al. 2011, 2012)
12	UniCone (Eslami & Fellenius 1997)	26	HKU (Yu and Yang 2012)
13	KTRI (Takesue et al. 1998)	27	UWA-13 (Lehane et al. 2013)
14	TCD-03 (Gavin and Lehane 2003)	28	Modified UniCone (Niazi and Mayne 2016)

Direct Application for Deep Foundations Bearing Capacity

Meyerhof (1956, 1976, 1983)

Toe resistance: $r_t = q_{c.a} c_1 c_2$

$q_{c.a}$ = arithmetic average of q_c values in a zone ranging from "1b" below through "4b" above pile toe

$c_1 = \left(\frac{B+0.5}{2B}\right)^n$; modification factor for scale effect when $b > 0.5$, otherwise $C_1=1$

$c_2 = \frac{D_b}{10B}$; modification factor for penetration into dense strata when $D_b < 10b$, otherwise $C_2=1$

B = pile diameter (m)

n = an index; 1 for loose sand, 2 for medium dense sand, and 3 for dense sand

D_b = embedment of pile (m) in dense sand strata

Shaft resistance: $r_s = Kf_s$, $(K = 1)$; $r_s = cq_c$, $(c = 0.5\%)$

Direct Application for Deep Foundations Bearing Capacity

Eslami & Fellenius (1997)

- Toe Capacity

$$r_t = c_t \times q_{Eg}$$

$$q_E = q_t - u$$

$$q_t = q_c + (1 - a)u_2$$

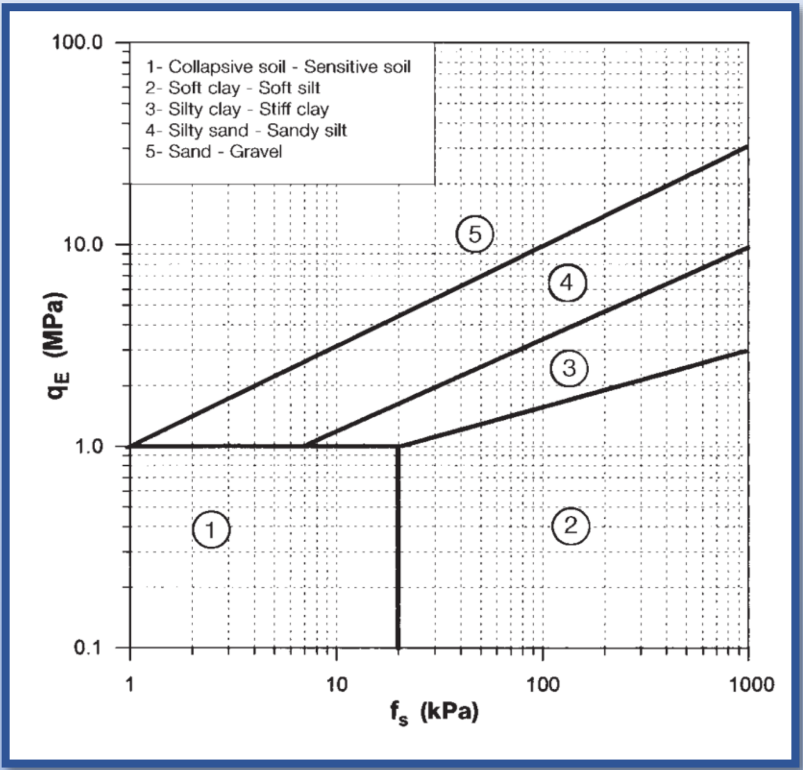


Chart for soil classification

Shaft coefficient correlation

Soil type	Cs
Soft sensitive soils	8.0%
Clay	5.0%
Stiff clay and mixture of clay and silt	2.5%
Mixture of silt and sand	1.0%
Sand	0.4%

- Shaft Capacity

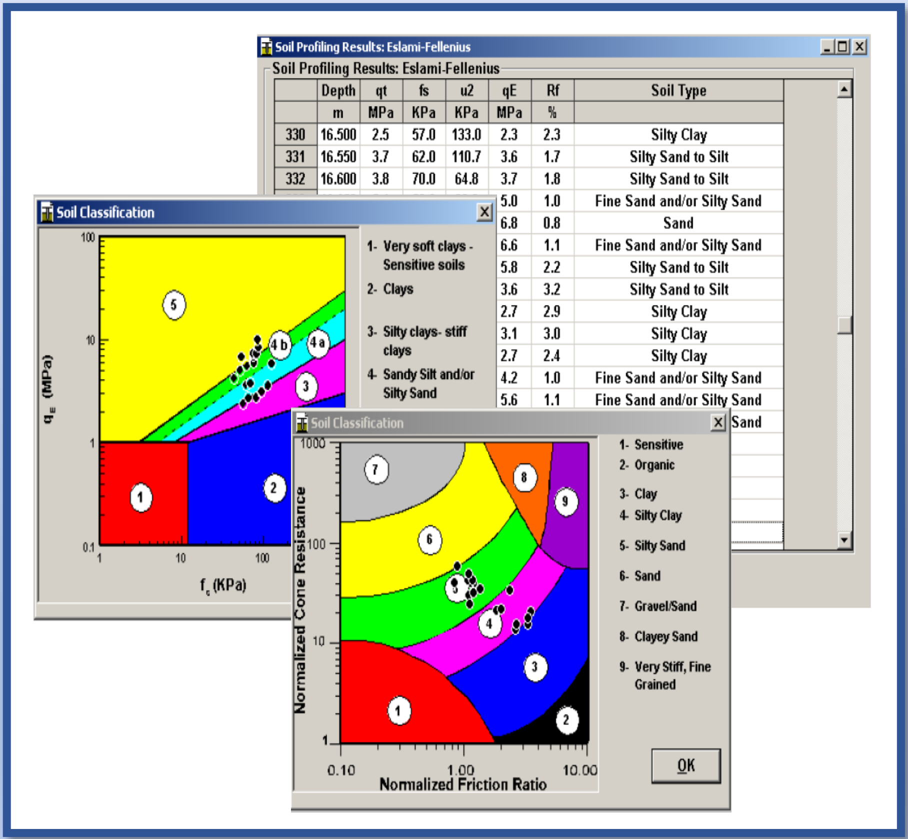
$$r_s = c_s \times q_{Eg}$$

$$q_{Eg} = \sqrt[n]{q_{E1} \times q_{E2} \times \cdots \times q_{En}}$$

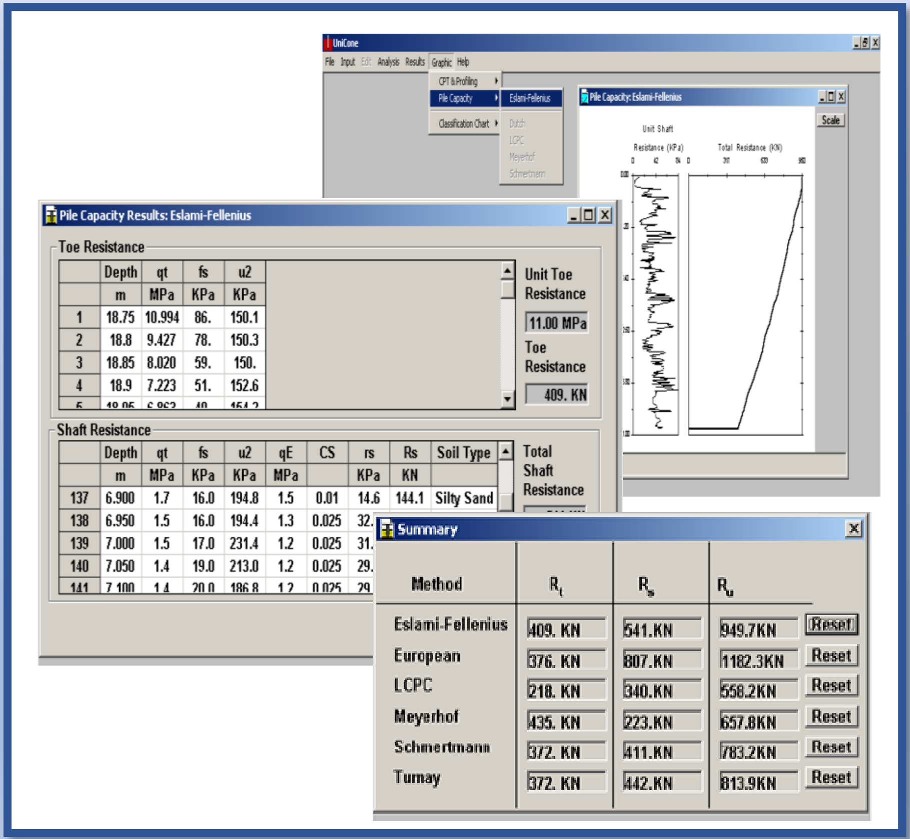
Direct Application for Deep Foundations Bearing Capacity

Unicone: Fellenius, Eslami & Infante (2002)

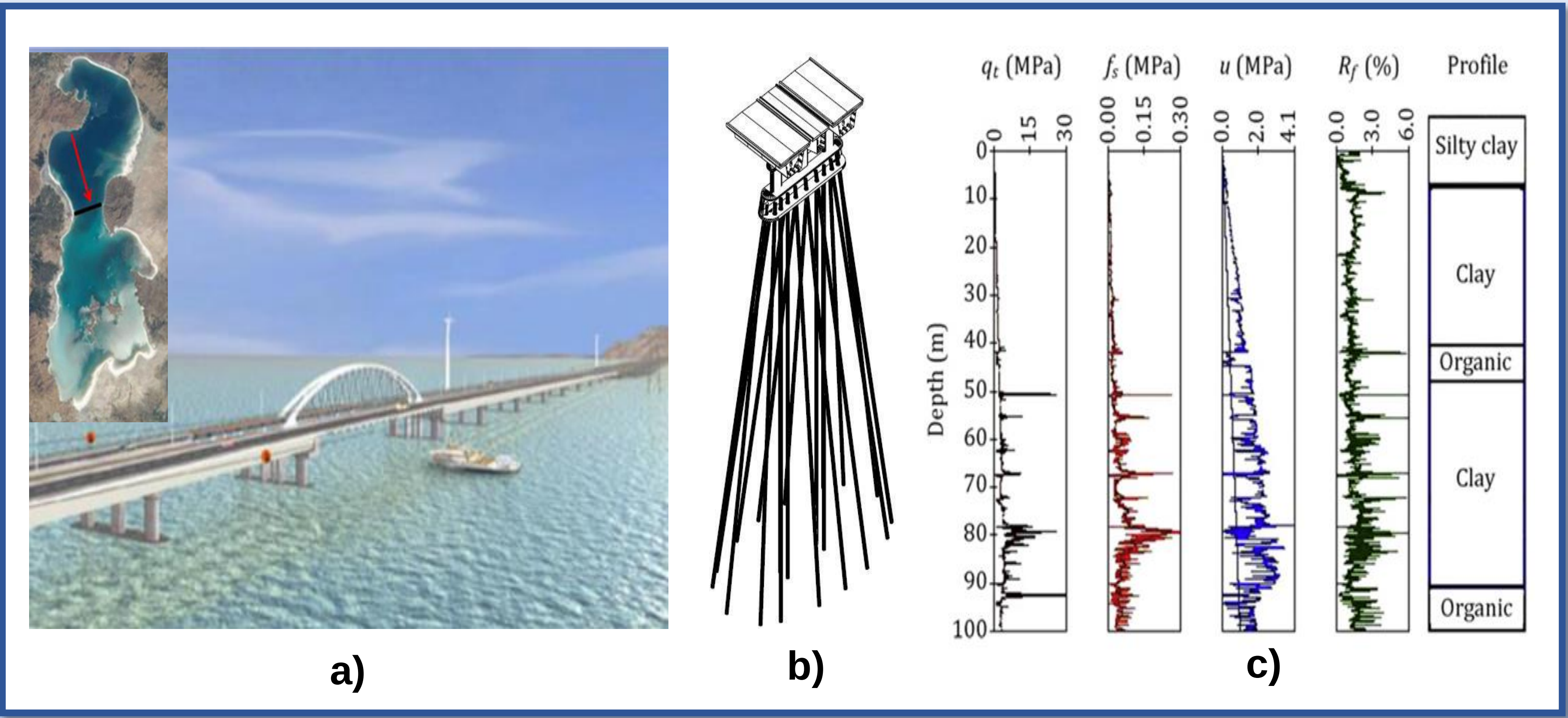
Pile Capacity Calculation



Soil Profiling

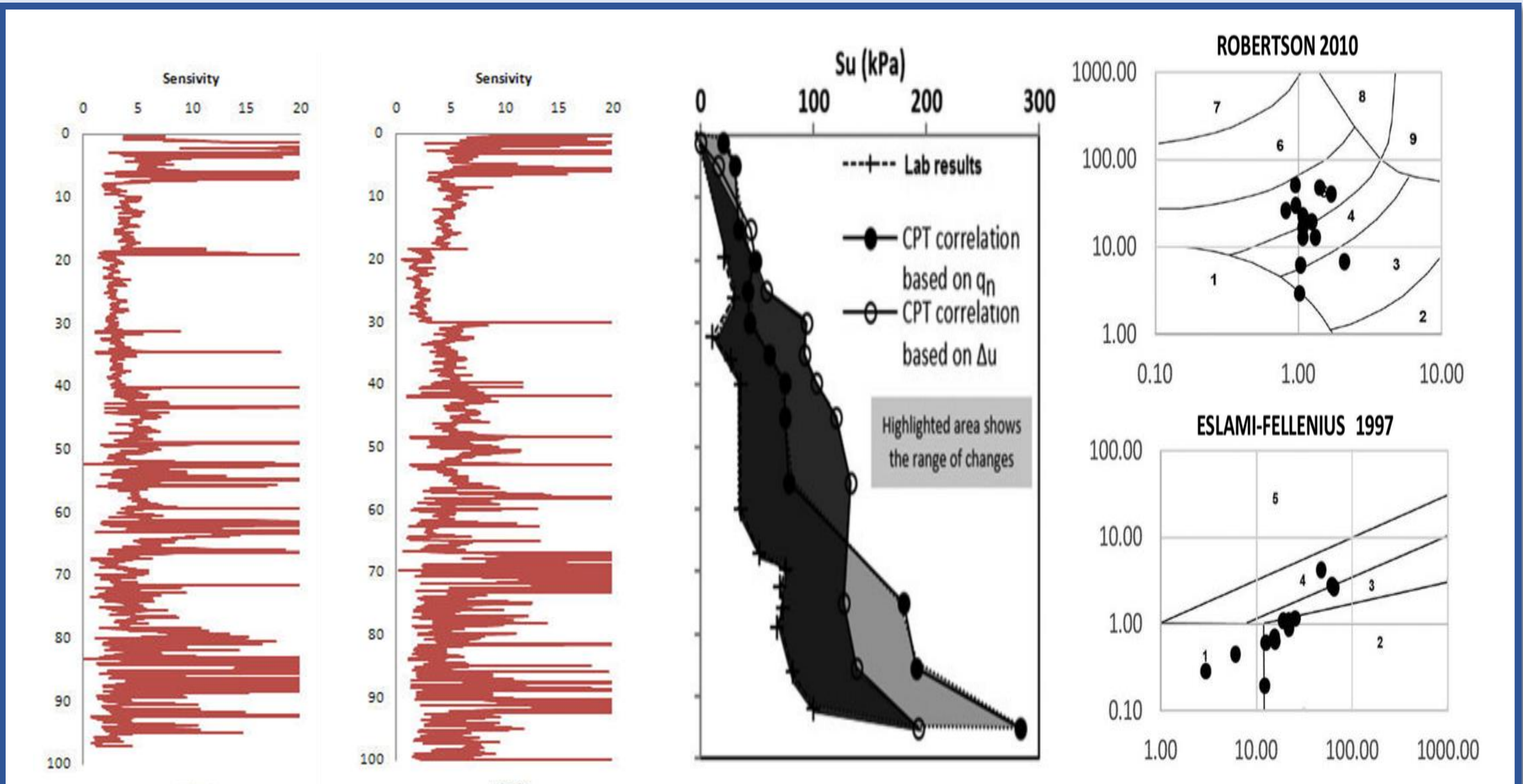


Case No.1: Urmia Lake Causeway (Eslami et al., 2011)



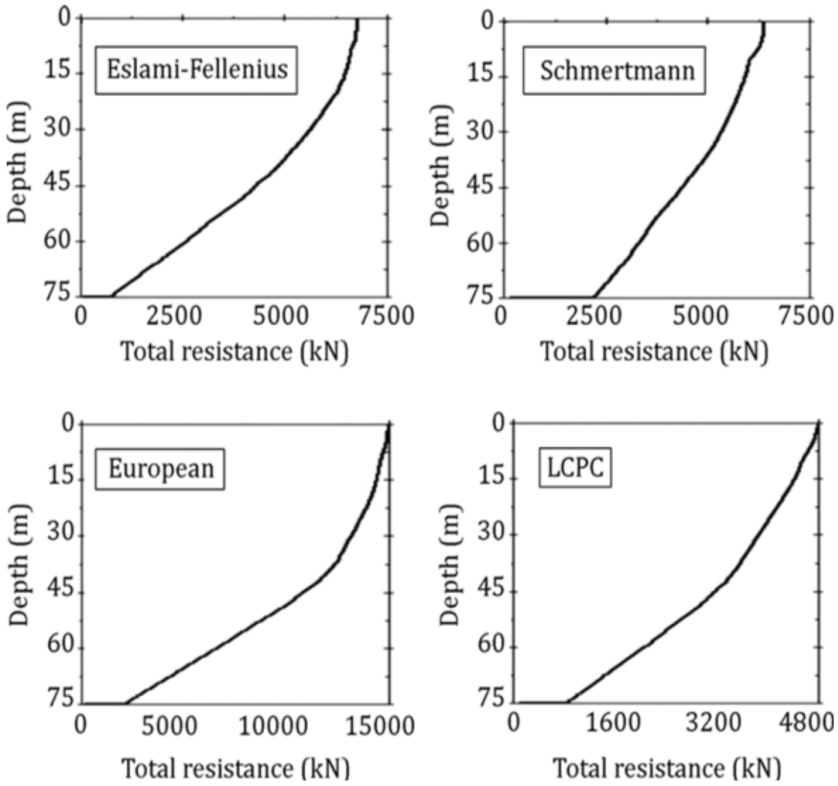
a) Longitudinal view of the bridge, b) pile groups under each pillar , c) typical CPT logs

Case No.1: Urmia Lake Causeway (Eslami et al., 2011)

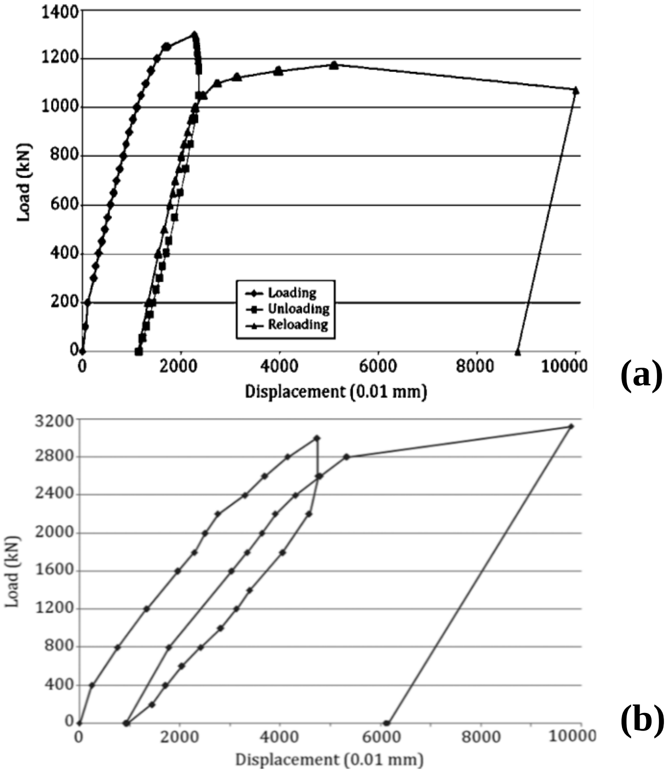


CPT test soil profiling

Case No.1: Urmia Lake Causeway (Eslami et al., 2011)



Pile total capacity distribution (length of 75 m, diameter of 813 mm & wall thickness of 38.1 mm). (Eslami et al., 2011)



Static load test result; a) compressive (length of 30 m, diameter of 356 mm & wall thickness of 12 mm), b) tension (length of 70 m, diameter of 305 mm & wall thickness of 16 mm) (Eslami et al., 2011)

Case No.2: Torre Latino Americana, Mexico City, Mexico (Coduto et al., 2016)

- **43-story Building**
- **Milestone in floating foundations technology**

The soil profile:

- **0–5.5 m depth: Old fill (GWT at 2 m)**
- **5.5–9.1 m depth: Becarra sediments**
- **9.1–33.5 m depth: Tacubaya clays;**

moisture content = 100 – 400%, C_c = 8; S_u = 35–70 kPa.

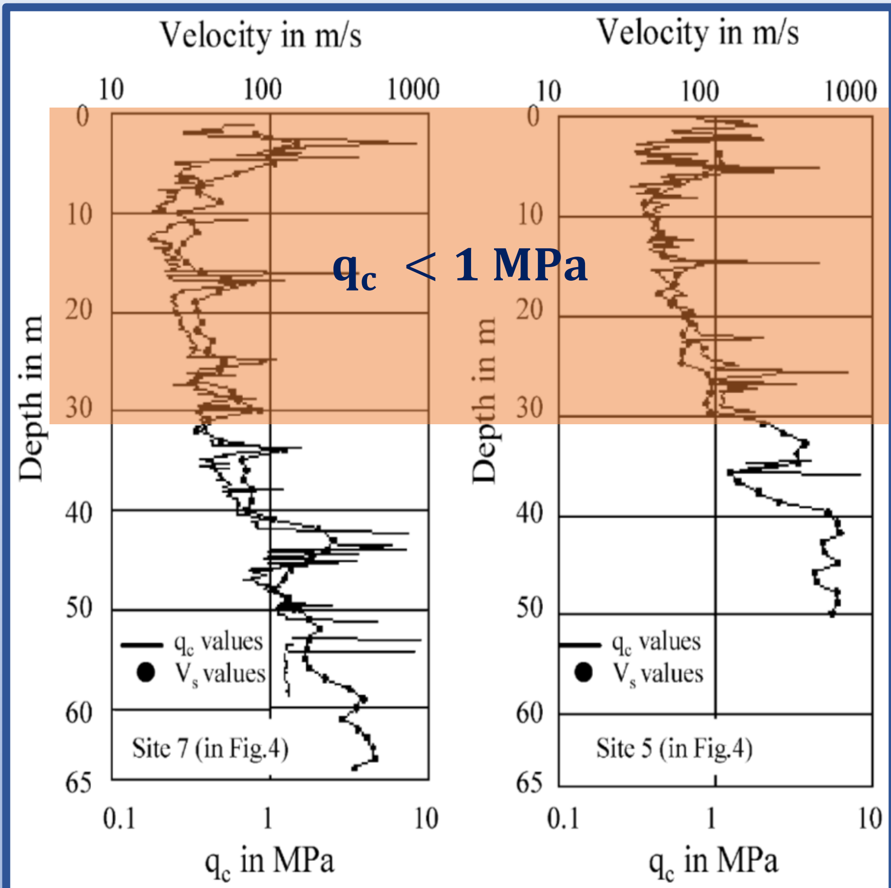
- **33.5–70.0 m depth: Tarango sands**

The Palace of Fine Arts, located across the street from the Tower, settled over 3 m (10 ft) from 1904 to 1962 (Zeevaert, 1957).

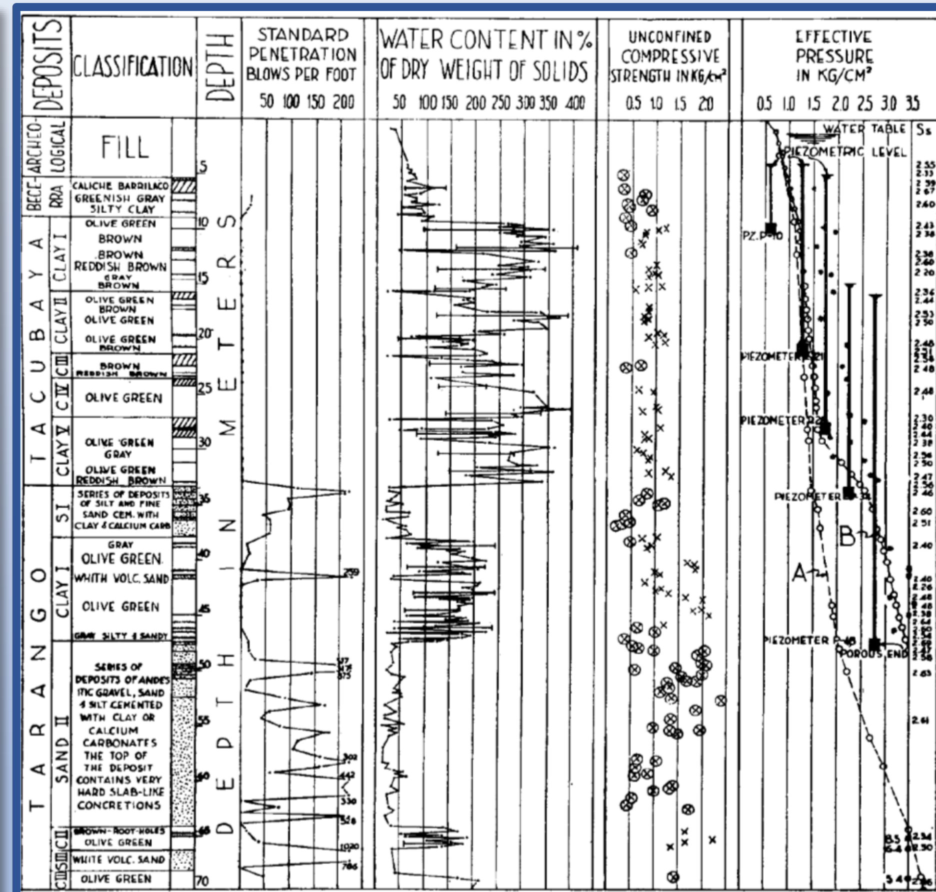
Typical compression Index C_c values (Holtz et al., 2011)

Soil	C_c
Normally consolidated medium sensitive clays	0.2 to 0.5
Chicago silty clay (CL)	0.15 to 0.3
Boston blue clay (CL)	0.3 to 0.5
Vicksburg buckshot clay (CH)	0.5 to 0.6
Swedish medium sensitive clays (CL-CH)	1 to 3
Canadian Leda clays (CL-CH)	1 to 4
Mexico City clay (MH)	7 to 10
Organic clays (OH)	10 to 15
Peats (Pt)	Long, short
Organic silt and clayey silts (ML-MH)	1.5 to 4
San Francisco Bay mud (CL)	0.4 to 1.2
San Francisco Old Bay clays (CH)	0.7 to 0.9
Bangkok clay	0.4

Case No.2: Torre Latino Americana, Mexico City, Mexico (Coduto et al., 2016)



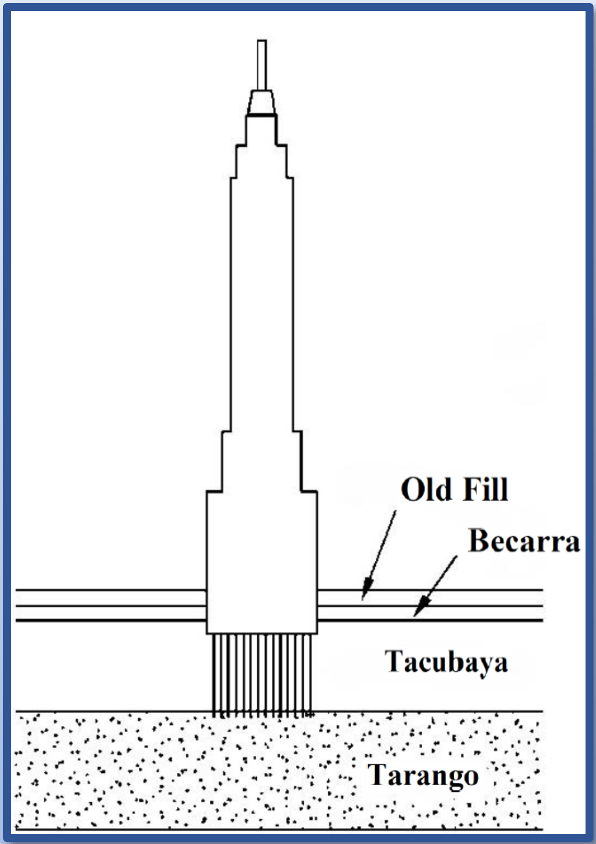
Stratigraphic characteristics of Mexico City soil deposits (Romo & Garcia, 2003)



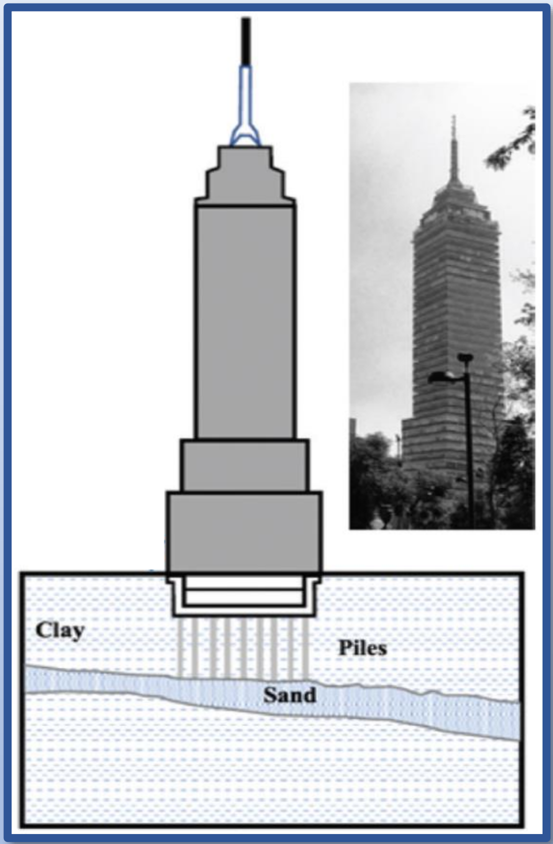
Classic log & SPT result (Zeevaert, 1957)

Case No.2: Torre Latino Americana, Mexico City, Mexico (Coduto et al., 2016)

(a)



(b)



(c)

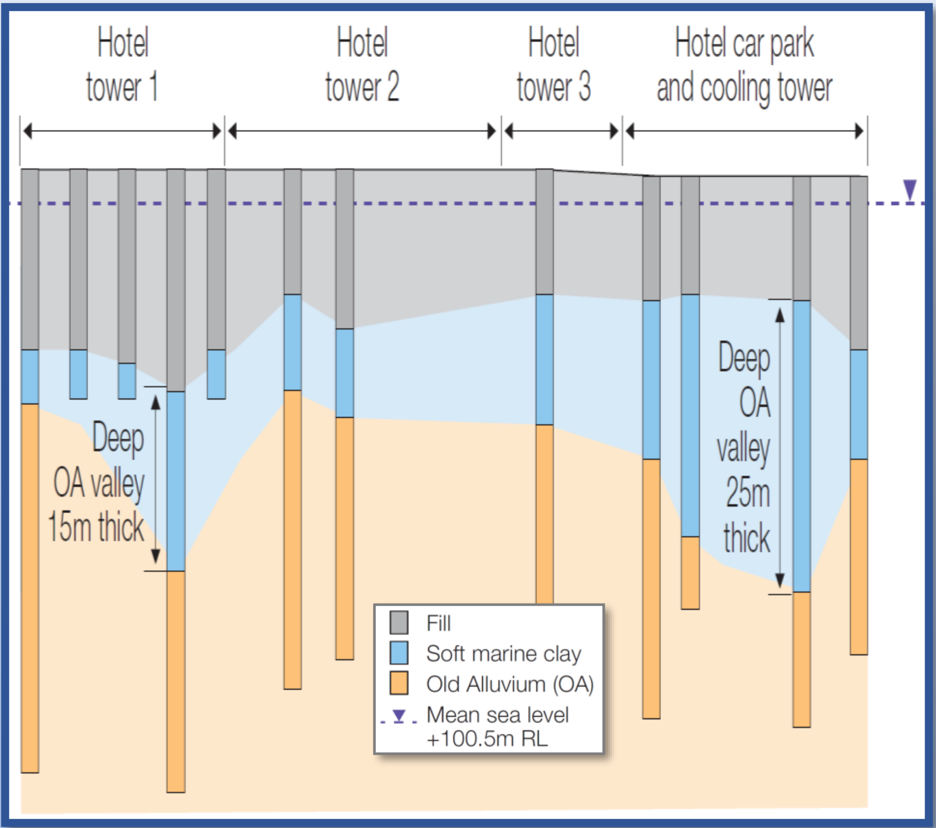
Torre Latino Americana Tower: a) general view of, b) the foundation and the sublayer profile (Coduto et al., 2016), c) schematic of the tower

Case No.3: Marina Bay Sands, Singapore (Arup Group, 2018)

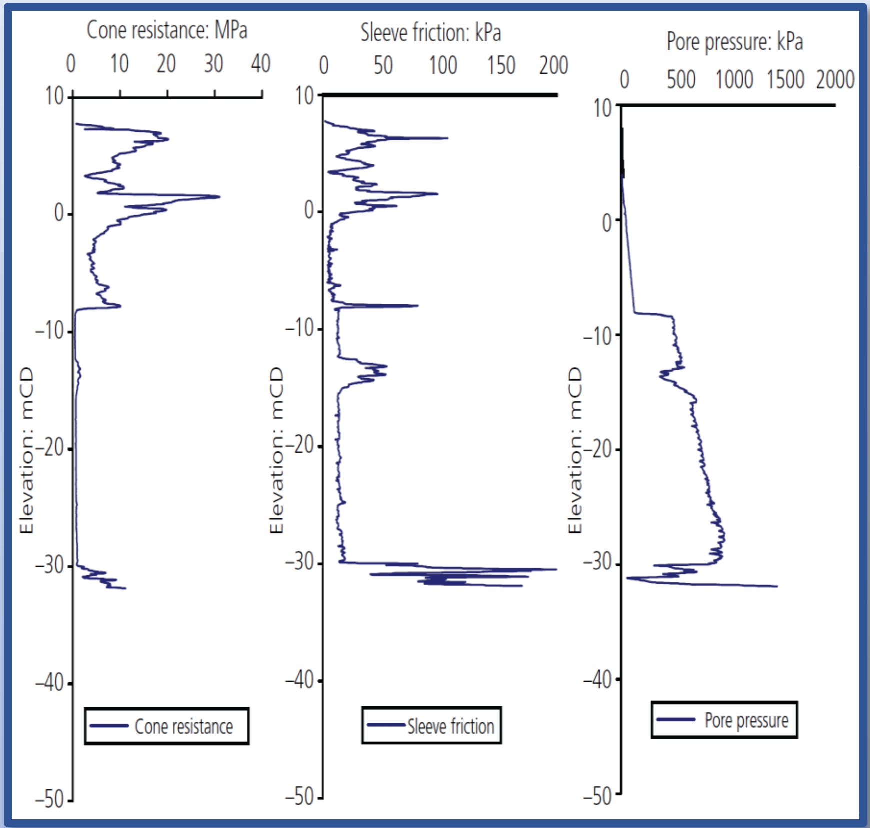
- **Year of Completion: 2010**
- **Height: 207 m**
- **Number of Storeys: 57**
- **Gross floor area: 581,400 m^2**
- **Primary use: Hotel, Conference, Retail, Leisure**

General View of the complex

Case No.3: Marina Bay Sands, Singapore (Arup Group, 2018)



Typical Soil Profile of the site

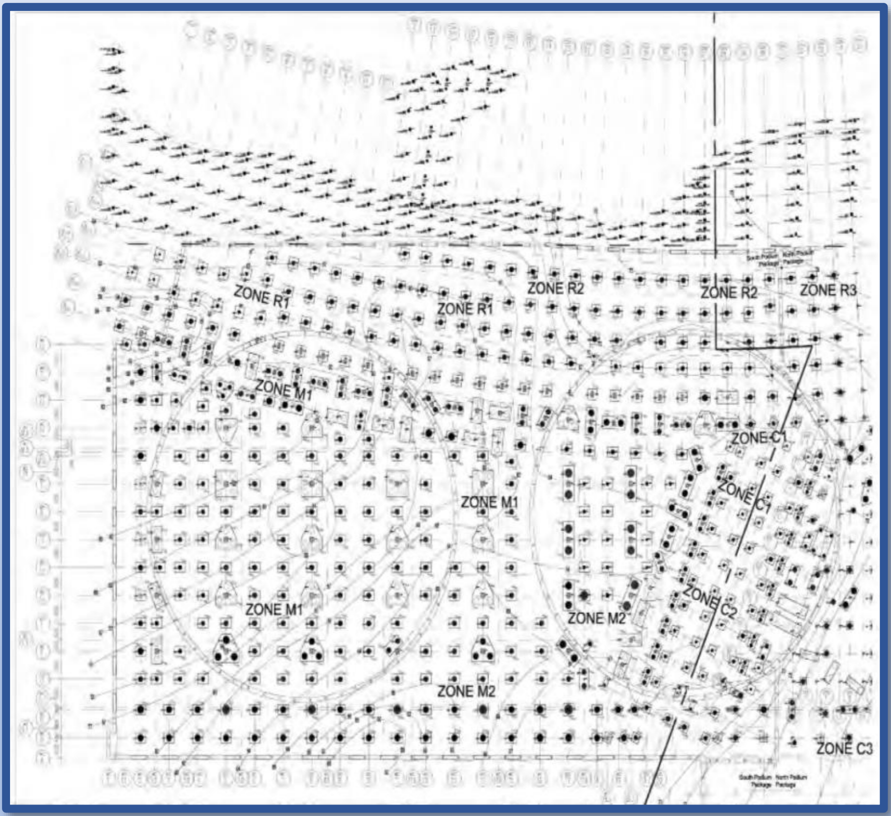


Typical CPTu result of marine clay in Singapore (Bo et al., 2019)

Case No.3: Marina Bay Sands, Singapore (Arup Group, 2018)

Test Piles:

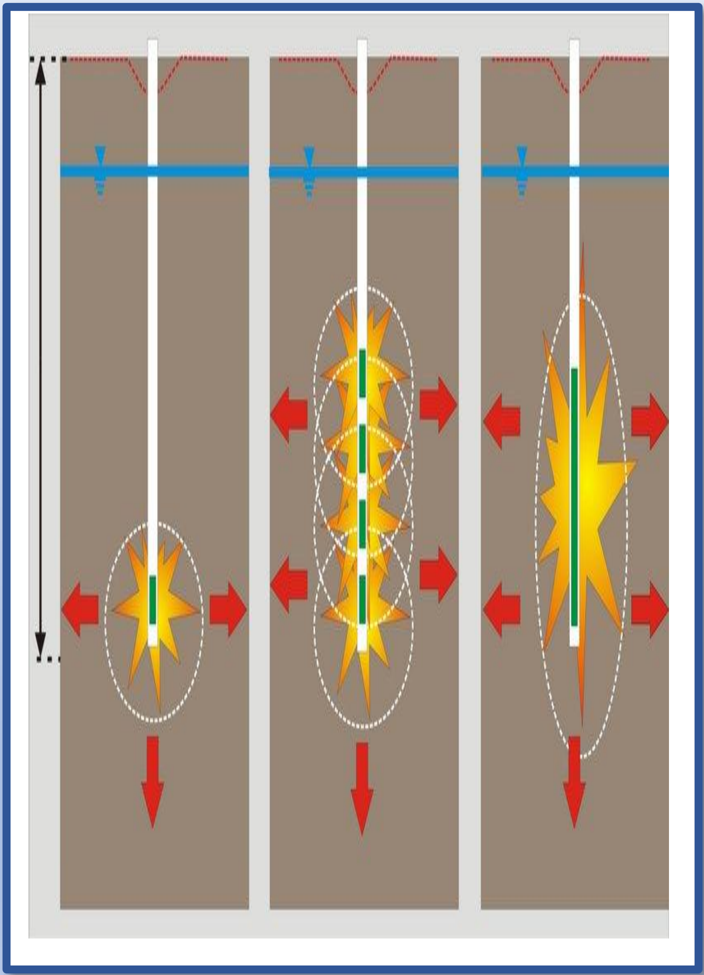
Diameter: 1.8 - 3 m, Length: 70 - 80 m, Treshold of Loading : 2200 – 5500 ton

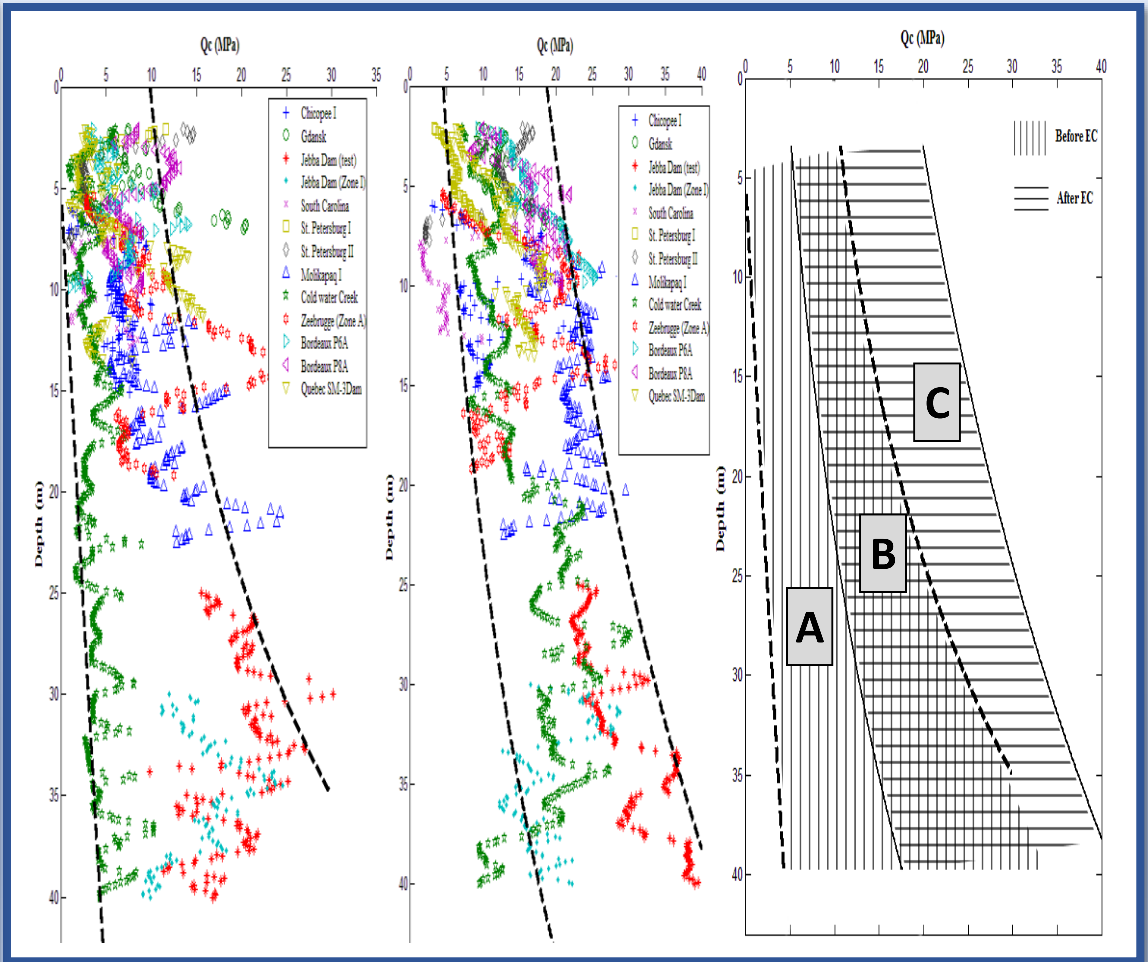


A forest of drilled shafts (Foundation Drilling, 2012)

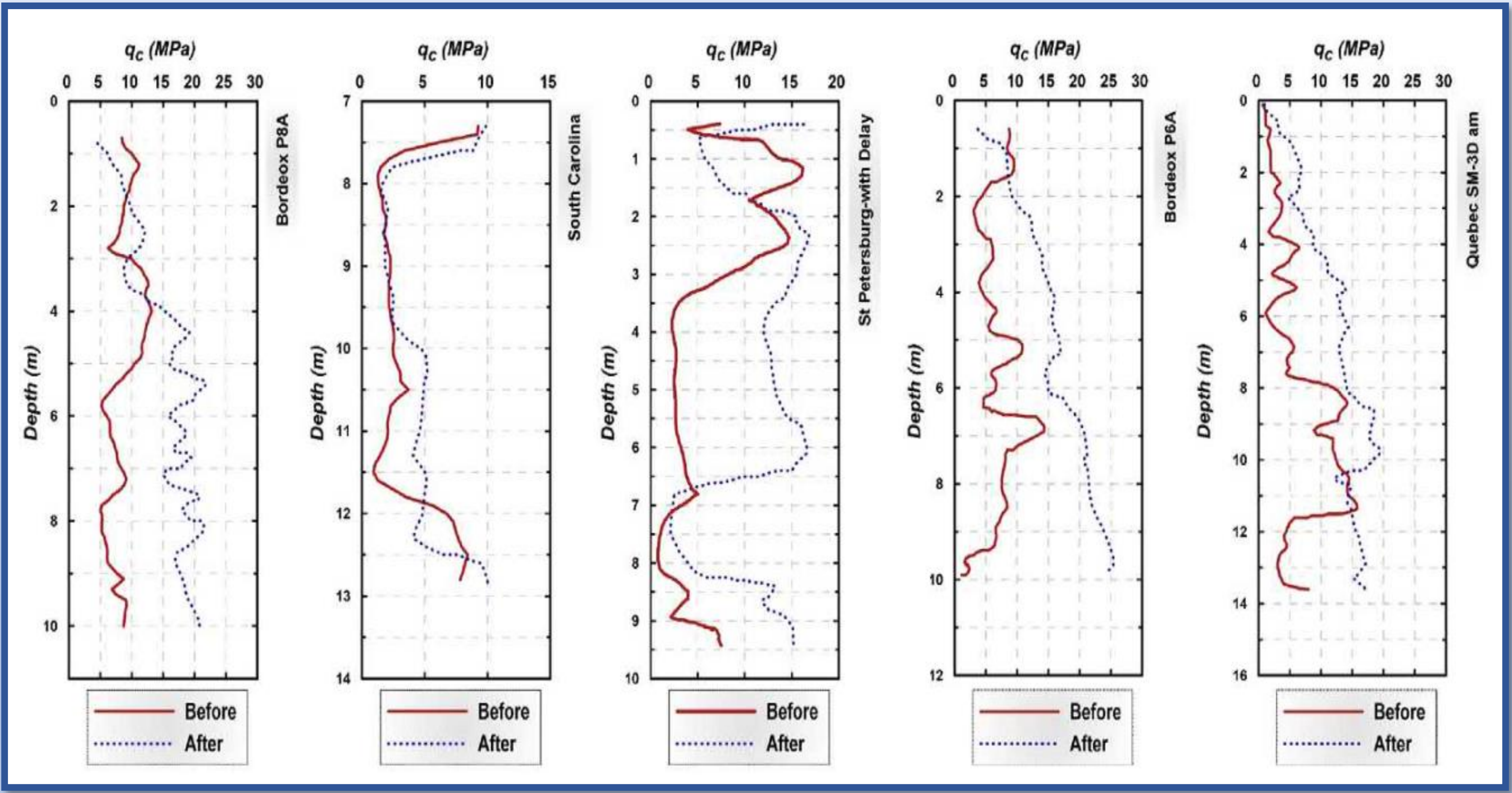
O-Cell implementation in Marine Bay Sands project (Foundation Drilling, 2012)

Case No.4: Explosive Compaction Ground Modification
(Eslami & Shakeran, 2016)

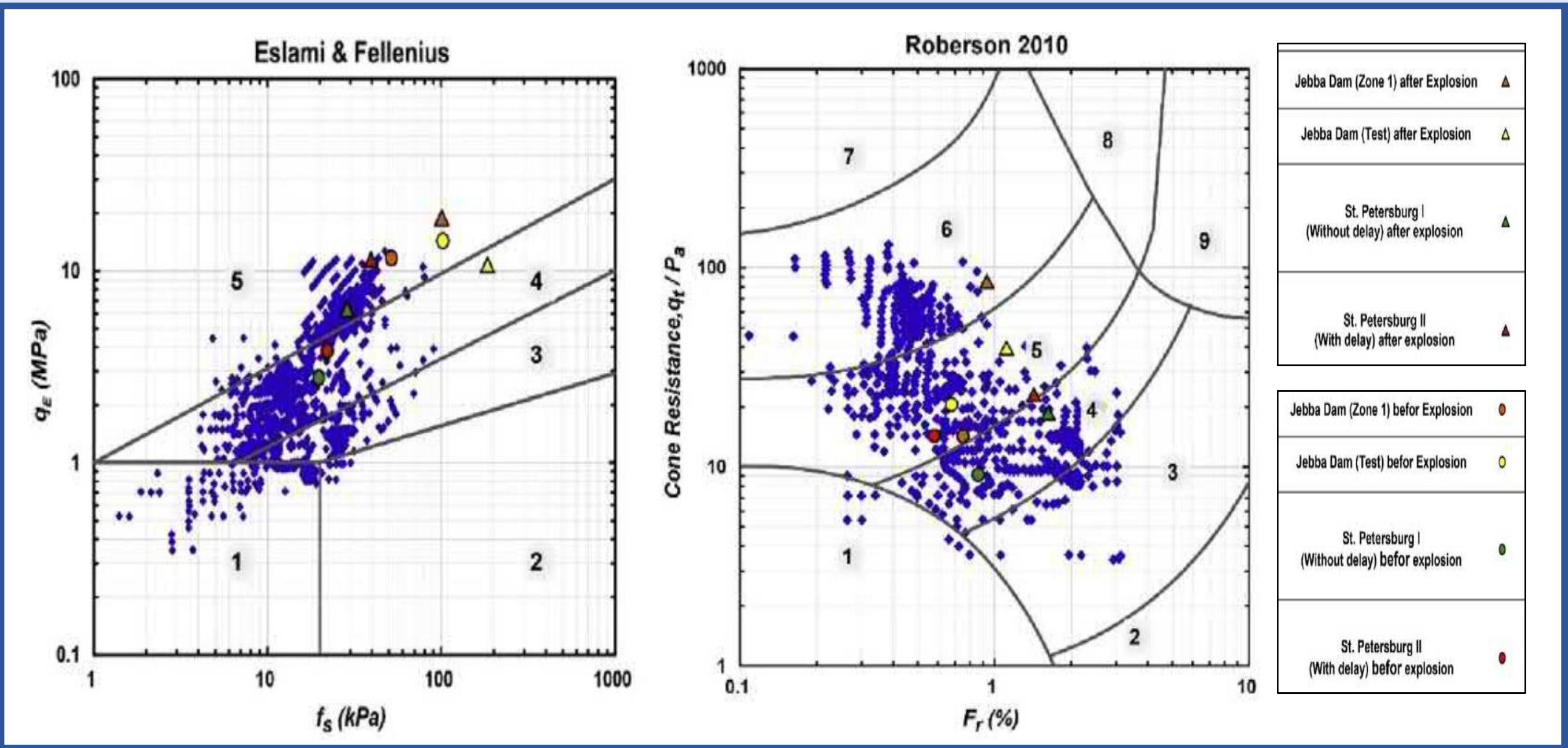




Case No.4: Explosive Compaction Ground Modification
(Eslami & Shakeran, 2016)



Case No.4: Explosive Compaction Ground Modification
(Eslami & Shakeran, 2016)



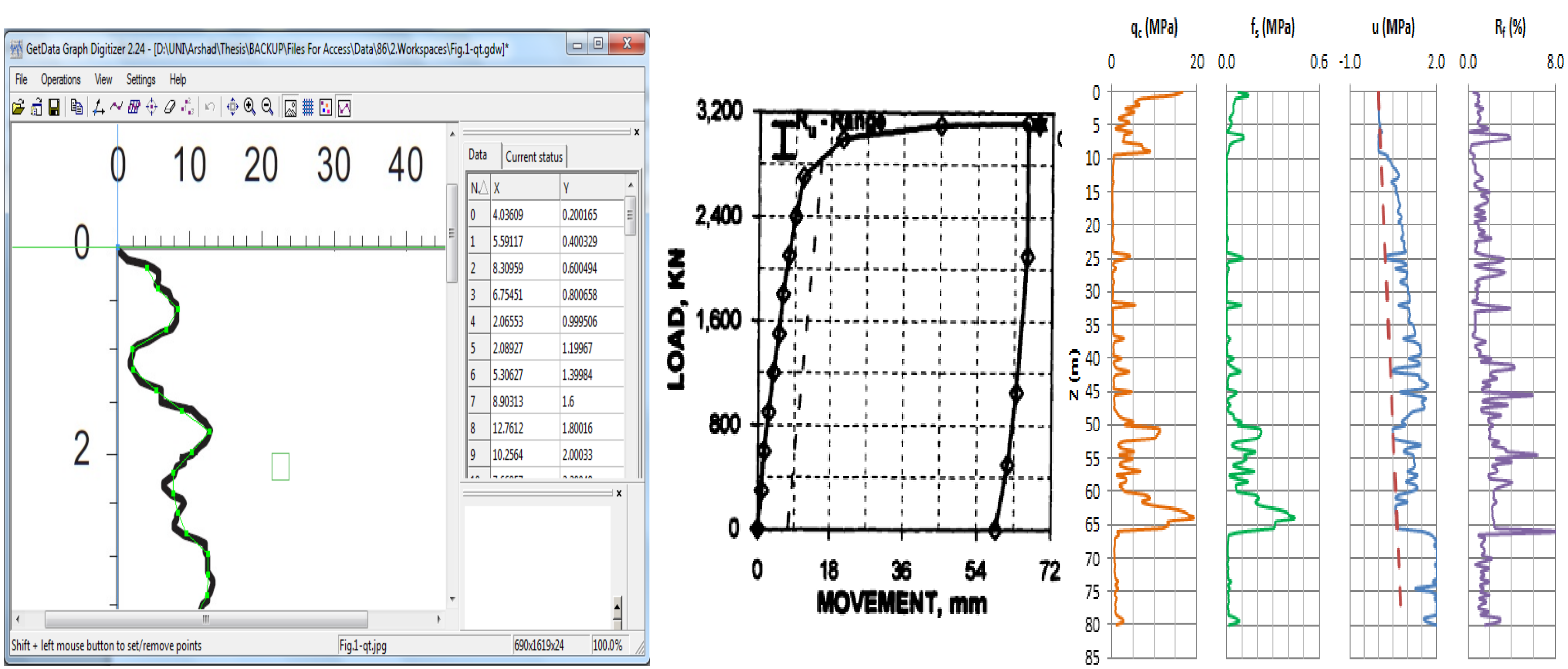
SBC charts for soil behavior assessment before and after explosion

Case No.5: AUT:Geo-CPT&Pile Database (Eslami et al., 2015 - 2019)

- **600 Records of pile axial loading tests along with adjacent CPT or CPTu profiles.**
- **Digitizing load-displacement diagrams derived from loading tests and CPT profiles**
- **Soil Properties**
    - **Clayey, silty and sandy soils.**
    - **Classified within three categories: Sandy, Clayey and Mixed soils**

Case No.5: AUT:Geo-CPT&Pile Database (Eslami et al., 2015 - 2019)

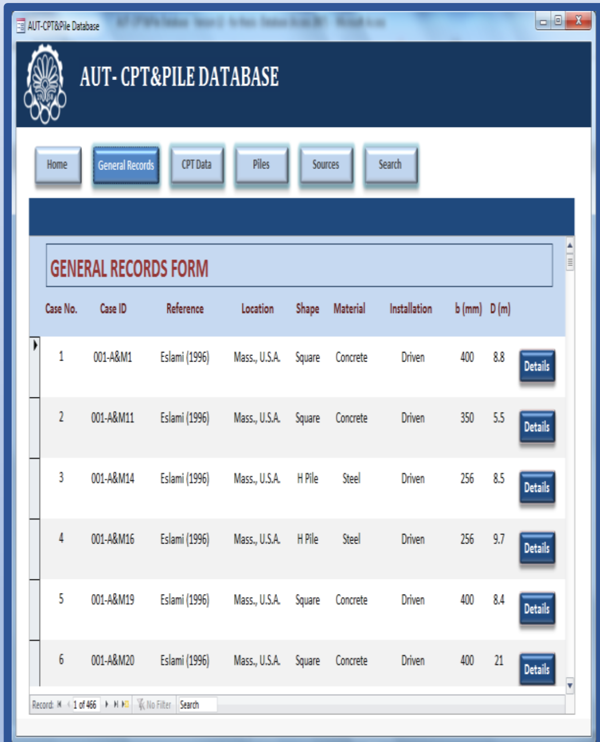
Digitizing load-displacement diagrams derived from loading tests and CPT profiles



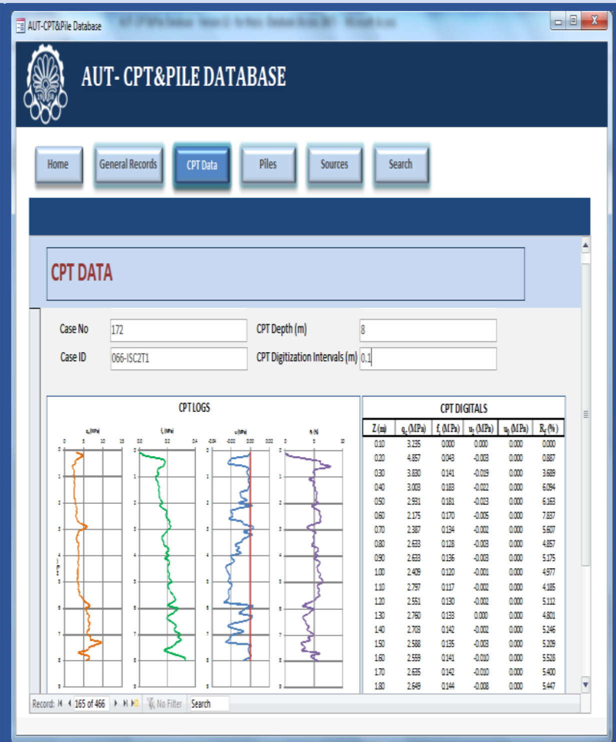
Case No.5: AUT:Geo-CPT&Pile Database (Eslami et al., 2015 - 2019)

Database structure

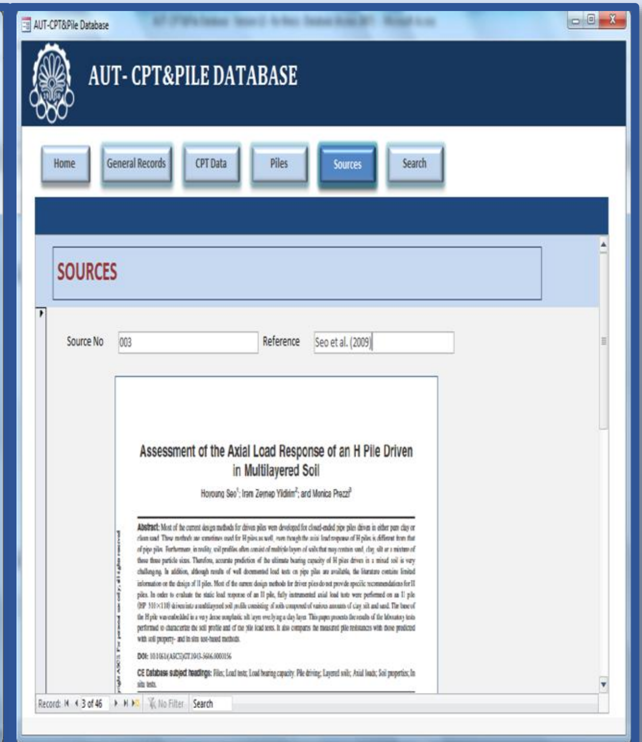
General Records Form



CPT Data Form



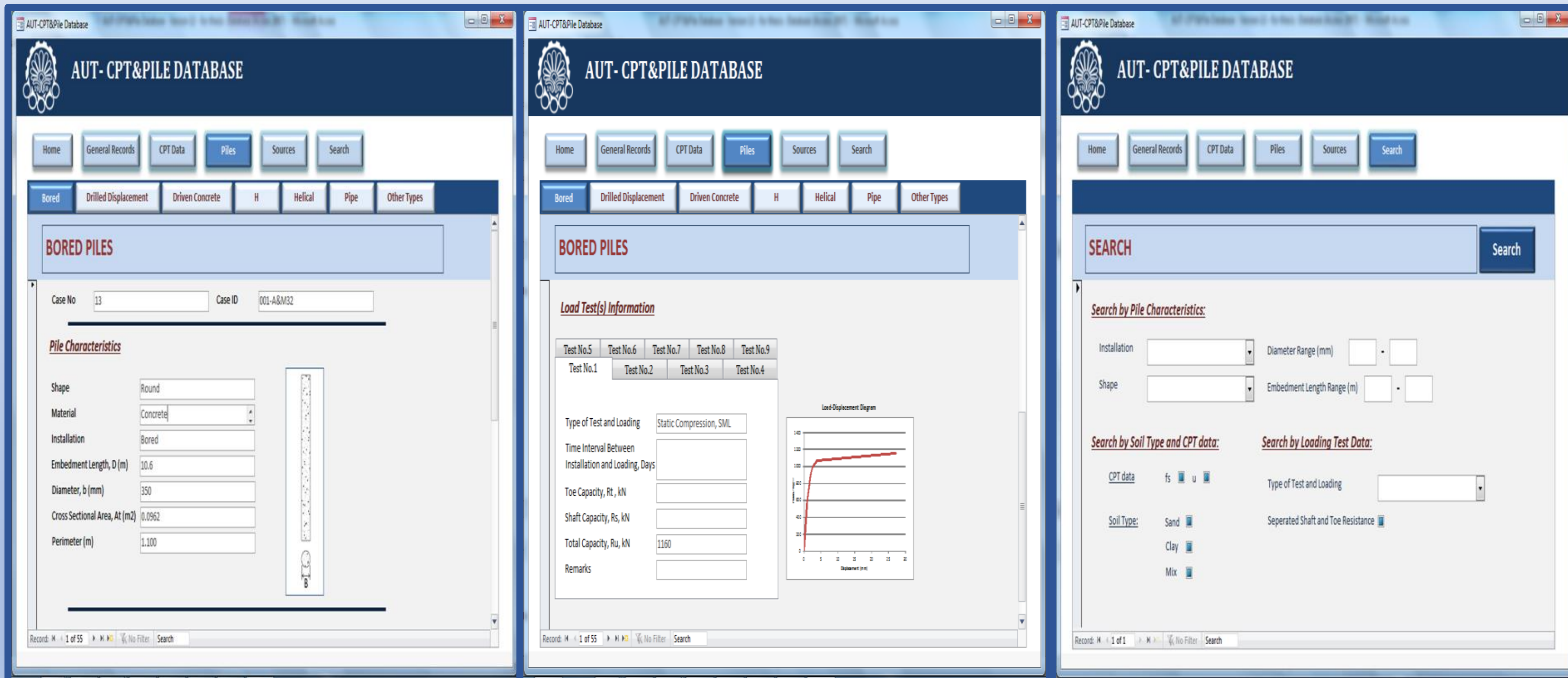
Sources



Case No.5: AUT:Geo-CPT&Pile Database (Eslami et al., 2015 - 2019)

Database structure

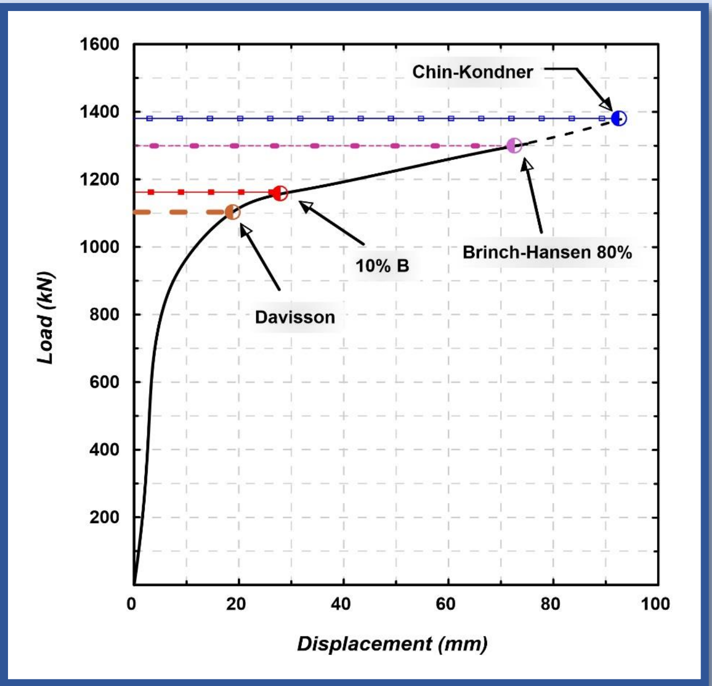
Piles Information **Search**



Case No.5: AUT:Geo-CPT&Pile Database (Eslami et al., 2015 - 2019)

Relevant Publications

Moshfeghi & Eslami (2016)



Interpretation of load displacement diagram for Case 001-L&D31 (Moshfeghi & Eslami, 2016)

International Journal of Geotechnical Engineering

Taylor & Francis

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Study on pile ultimate capacity criteria and CPT-based direct methods

Sara Moshfeghi and Abolfazl Eslami*

Due to the variety of current Cone Penetration Test (CPT)-based methods of estimating the pile bearing capacity, for optimum design, it is necessary to evaluate the performance of such methods in various geotechnical conditions. Geotechnical databases including piling and *in situ* testing records have been recognised as useful tools for analysis, design and economical construction. In order to evaluate current CPT-based pile bearing capacity methods, AUT-CPT and Pile database has been compiled including 450 full scale pile load tests and CPT sounding records. This database consists of different pile types with a relatively wide range of geometries and various soil conditions. Forty-three records of piles driven in sand deposits were then employed to evaluate effects of ultimate capacity interpretation criteria from load displacement diagrams. The Brinch Hansen 80% criterion and the load at the displacement of 10% of the pile diameter were compared to estimated capacities from 10 CPT-based design methods currently used in practice. The Brinch Hansen 80% criterion and the load at the displacement of 10% of the pile diameter lead to reasonable results, the Brinch Hansen 80% criterion showed less scatter. For evaluating the accuracy and the precision of CPT-based methods, the results were compared to estimated capacities. Methods with the best performance are introduced. Generally, comparisons indicate that the CPT-based methods mainly predict the pile capacity with reasonable accuracy.

Keywords: Ultimate pile bearing capacity, Direct CPT method, Load test, Failure criterion, Database

Case No.5: AUT:Geo-CPT&Pile Database (Eslami et al., 2015 - 2019)

Relevant Publications

Moshfeghi & Eslami (2018)

MARINE GEORESOURCES & GEOTECHNOLOGY
https://doi.org/10.1080/1064119X.2018.1448493

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Reliability-based assessment of drilled displacement piles bearing capacity using CPT records

S. Moshfeghi and A. Eslami

Department of Civil and Environmental Engineering, Amirkabir University of Technology, AUT, (Tehran Polytechnic), Tehran, Iran

ABSTRACT
Drilled displacement piles (DDPs) are known as an alternative to conventional foundations in coastal areas, given the elimination of environmental impacts and difficulties caused by installation process of driven piles and more consistency with environment. Despite increasing employment of these piles, the extent of research works does not yet suffice the requisites to reach a routine design. This paper aims to analyze six cone penetration test (CPT)-based methods of determining the bearing capacity of DDP. The statistical and reliability-based approaches were used in two parts of assessing performance of the methods with respect to soil-pile characteristics followed by evaluating reliability of the prediction outcome. A database is compiled including 65 DDP load tests with adjacent CPT profiles. Performance of the methods are analyzed. Finally, a reliability parameter, i.e., confidence interval, is introduced to demonstrate a more realistic insight into the evaluations by expressing performance of the methods in terms of a range for possible average values of the predictions ratios, rather than simply an arithmetic mean. The study reveals that the commonly used CPT-based methods which have not been specifically developed for DDP show great potential for design. The results indicate that the investigated methods can have promising performance if some modifications are applied.

ARTICLE HISTORY
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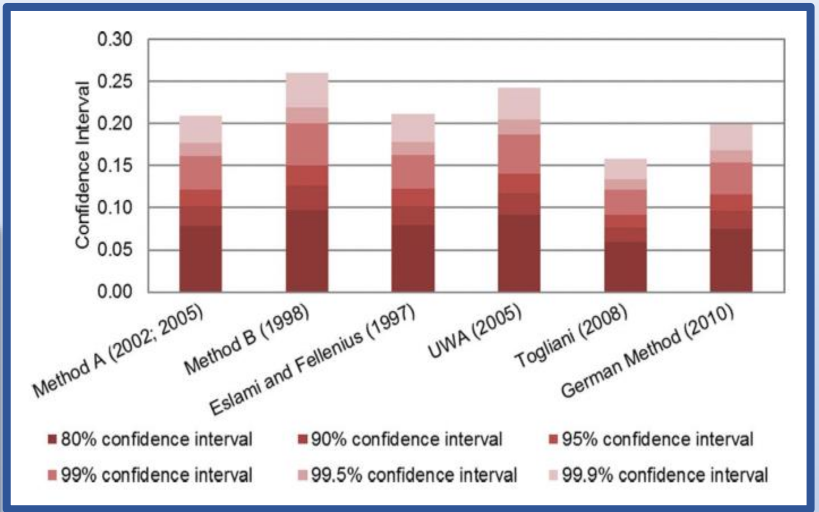
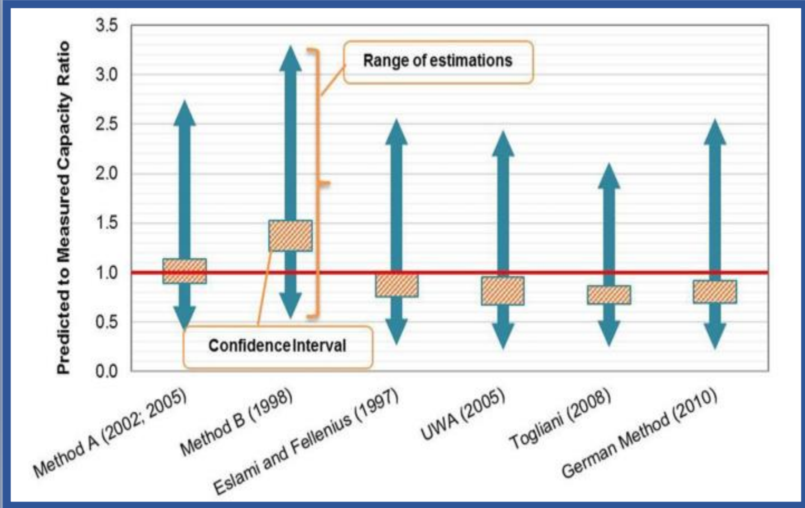
KEYWORDS
Bearing capacity; confidence interval; CPT methods; drilled displacement pile (DDP); reliability-based evaluation



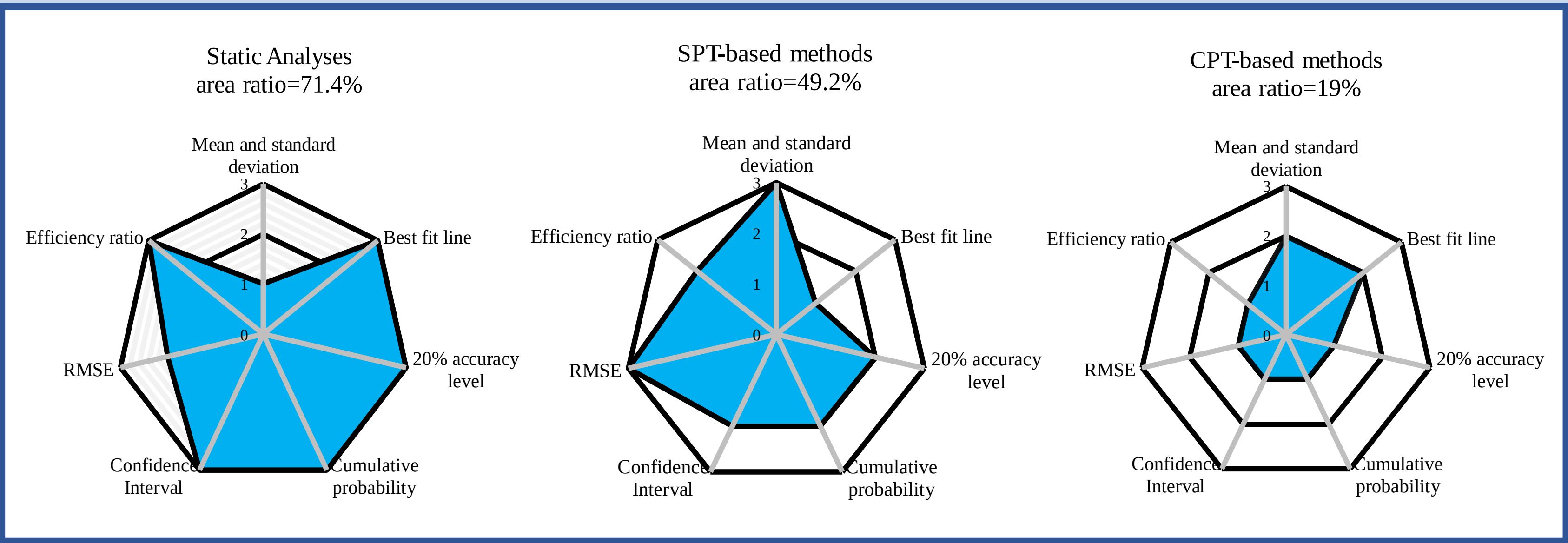


Case No.5: AUT:Geo-CPT&Pile Database (Eslami et al., 2015 - 2019)

Relevant Publications

Heidarie, Jamshidi & Eslami (2019)

Reliability based assessment of axial pile bearing capacity; static analysis, SPT & CPT-based methods



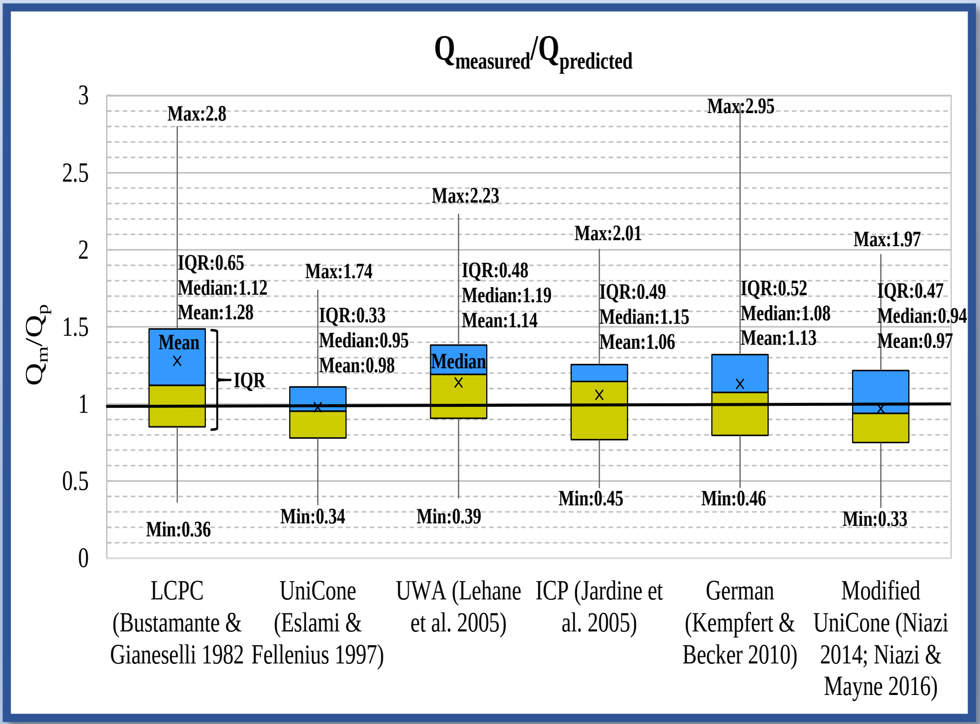
Associated error for approaches

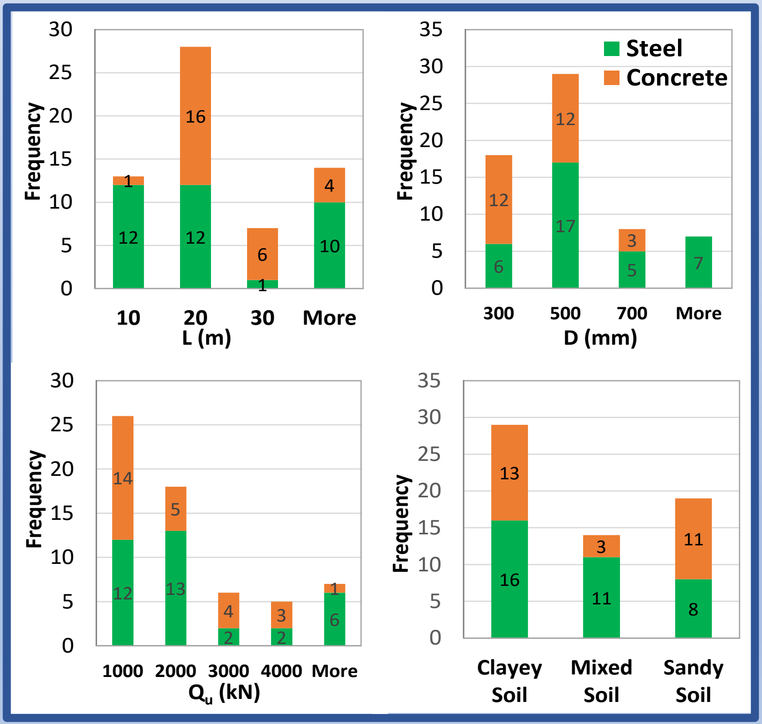
Case No.5: AUT:Geo-CPT&Pile Database (Eslami et al., 2015 - 2019)

Relevant Publications

Eslami & Heidari (2020)

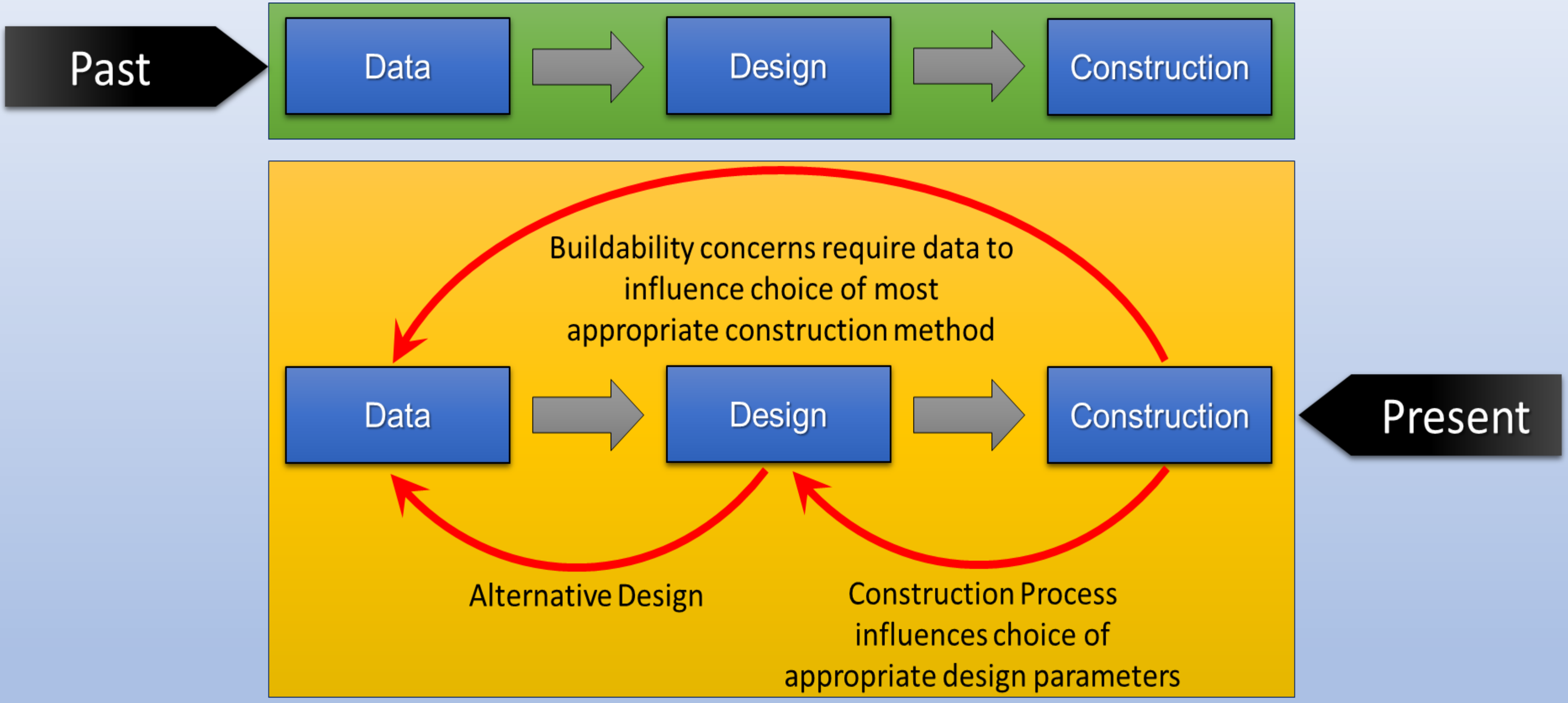
Uncertainty and Reliability Appraisal of CPT-Based Methods for Axial Pile Bearing Capacity





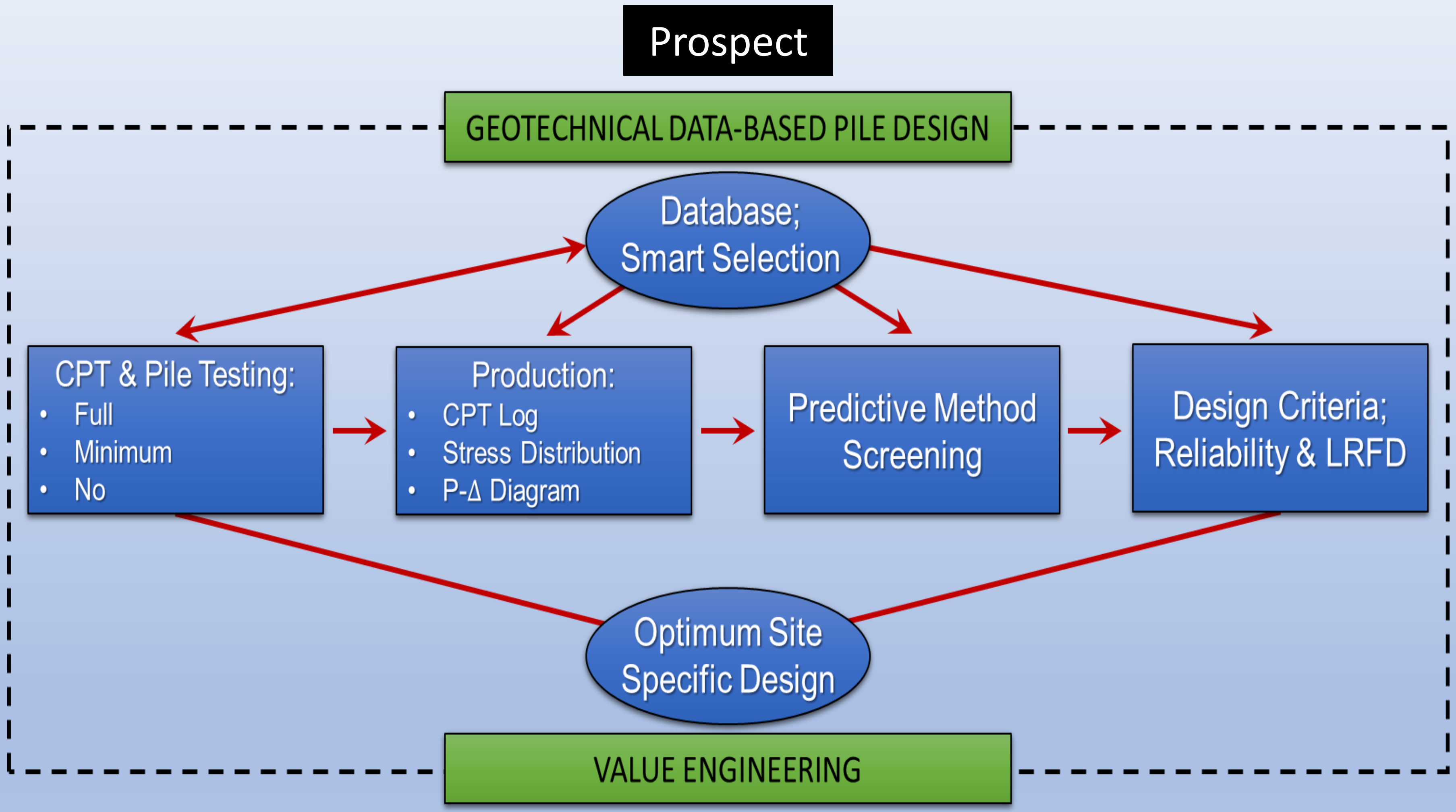
- **Geotechnical Engineering (GE):**
  - In-situ tests:
    - ✓ Uncertainty reduction
    - ✓ Efficient approach
- **Cone & Piezocone Penetration Tests (CPT & CPTu):**
  - Major records: q_t, f_s, u_2; fast & continuous
  - Providing tons of data
- **Major Applications of CPT in GE:**
  - Versatile tool for soft to medium deposits
  - Identification & remediation of surprising soils
- **CPT and Foundation Engineering (FE)**
  - In-situ tests more pronounced than laboratory tests
  - Towards reliable design
- **Databases**
  - Soft Computing as a tool
  - Value Engineering as an aim

Past & Present Trends in Design & Construction

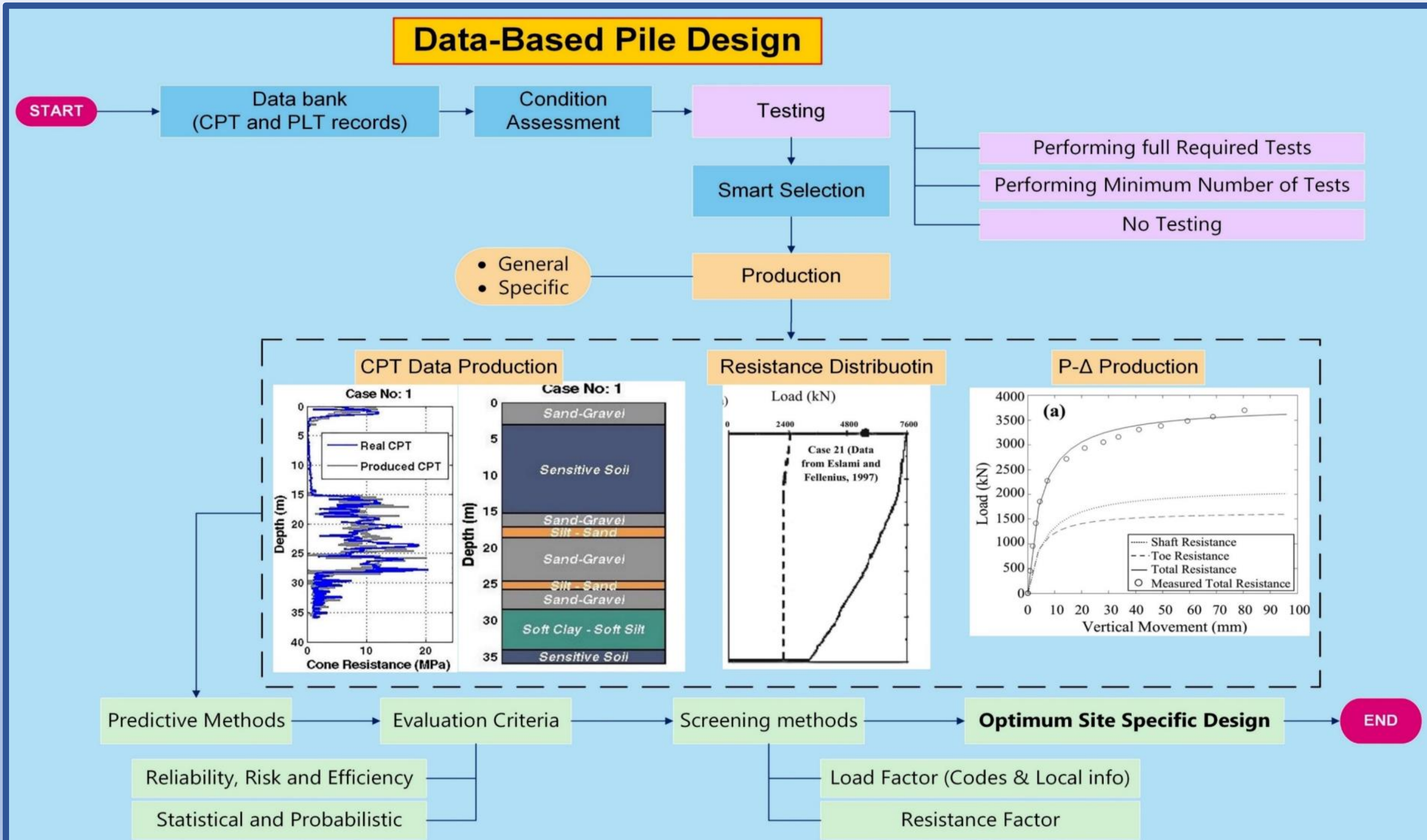


(ICE, Manual Geotechnics, 2012)

Future Trend in Design & Construction



8. Summary and Conclusions



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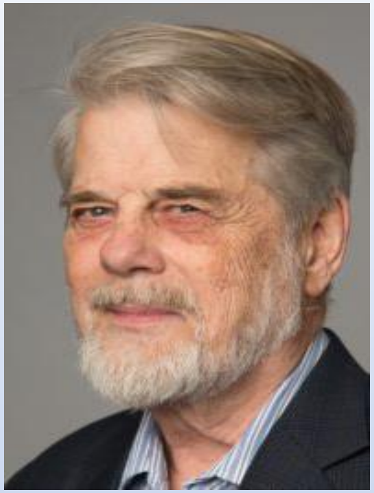
The Mentors



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Thanks For Your Attention