INTERPRETING GROUND CONDITIONS AND LIQUEFACTION POTENTIAL USING CONE PENETRATION TESTING (CPT)

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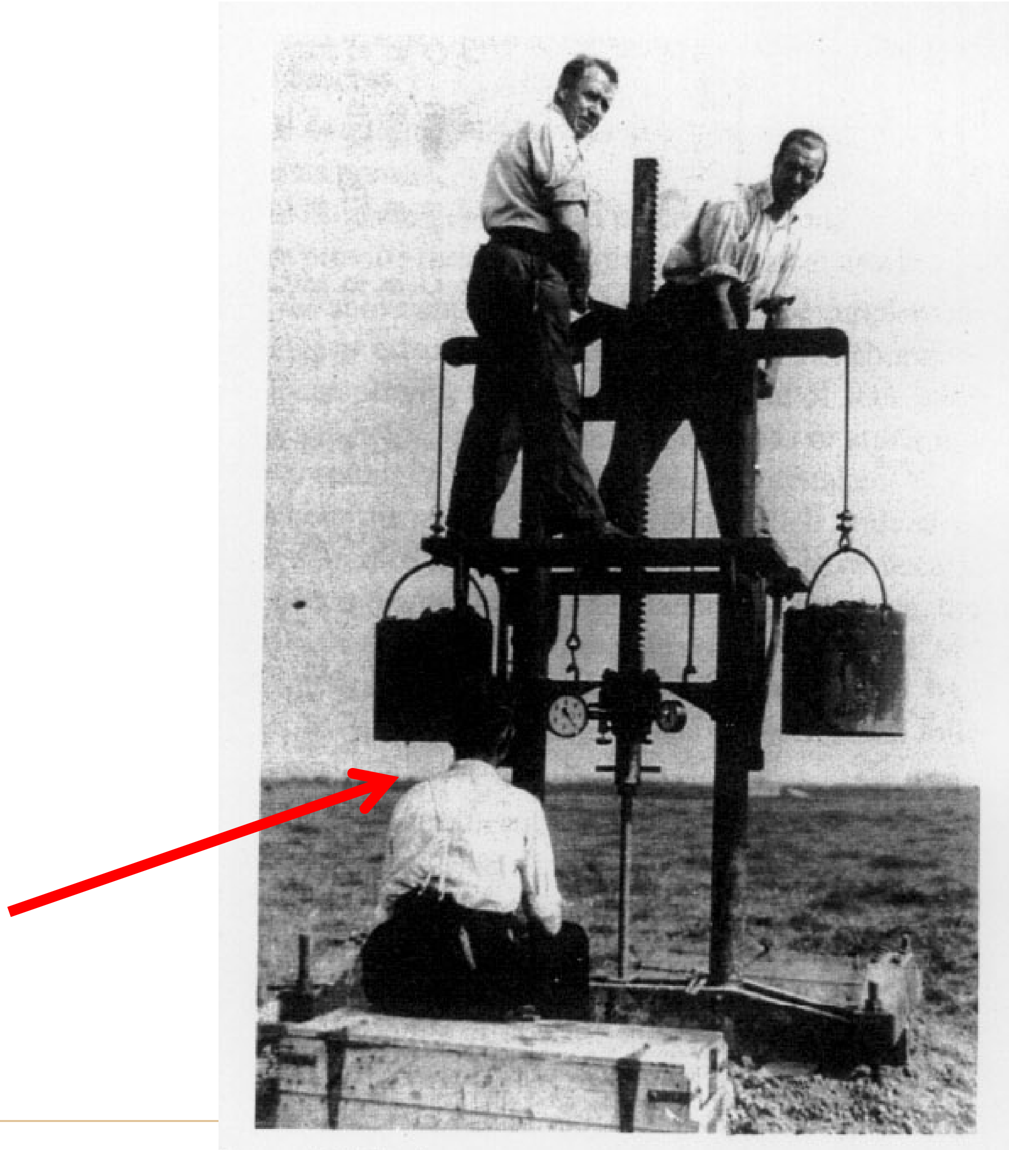
30 Jan 2013

A Brief History of the CPTs - starting in the 1940s

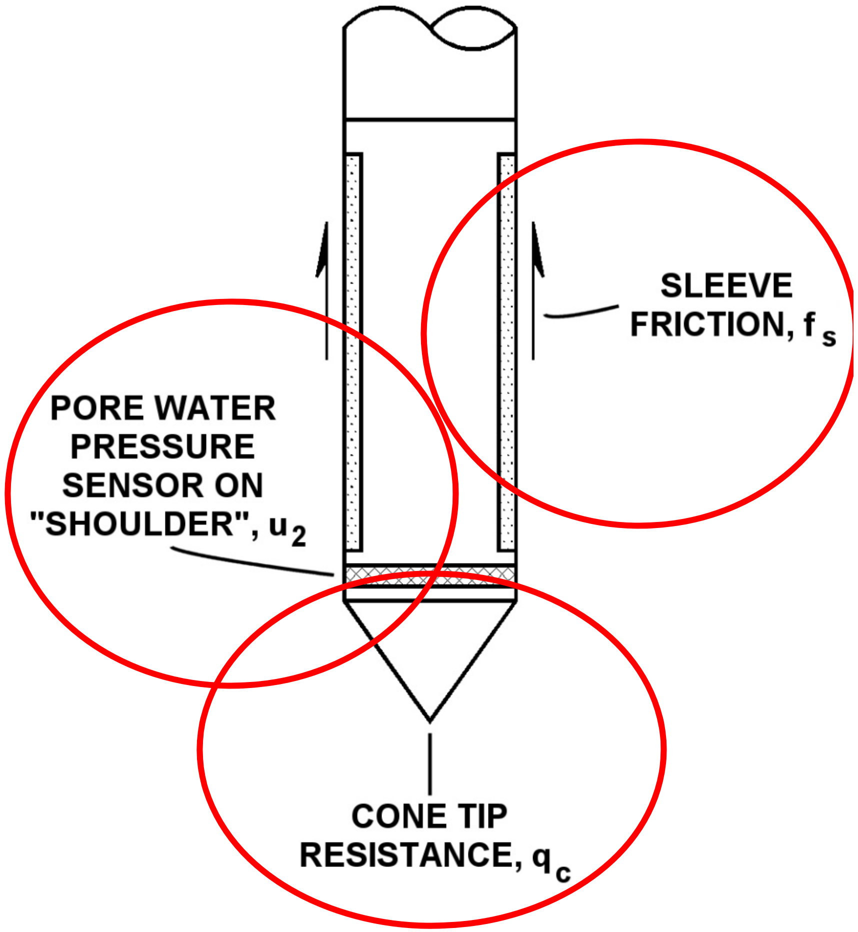


CPT Developments

1935: First cone in a form recognisable today - measured cone resistance only

1970: First commercial electrical friction cone leading to improved soil type interpretation

1984: First commercial piezocone leading to further improvements in soil type interpretation



CPT Equipment

Piezocone – Component Parts

Soil seal

Water seal

Cone + friction sleeve sensor

Amplifier unit

Friction sleeve connection

Cone Load sensor

Inclinometer

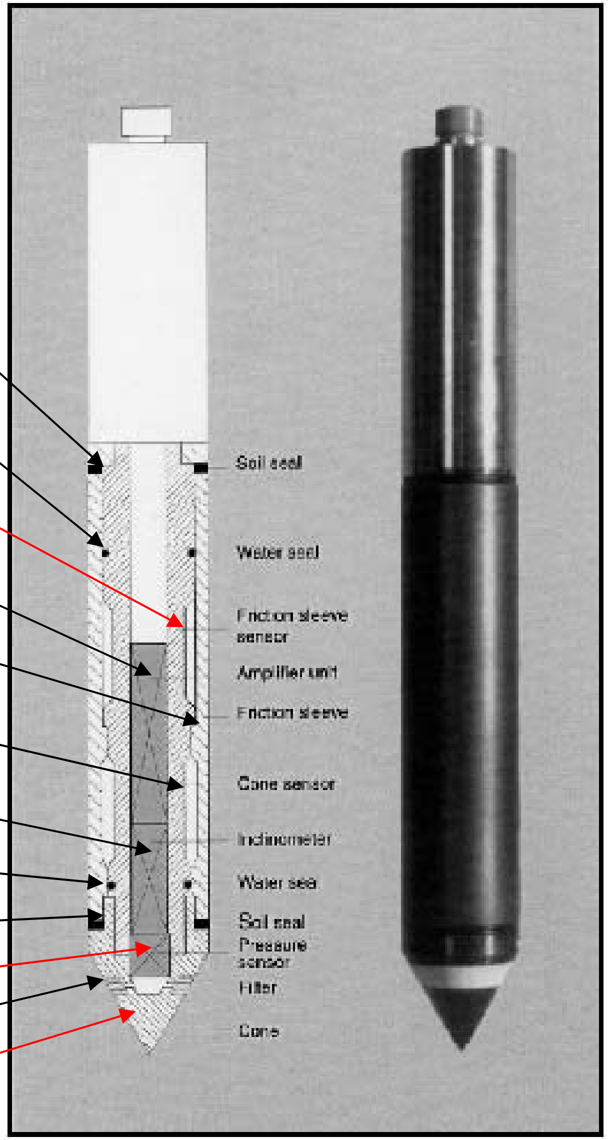
Water seal

Soil seal

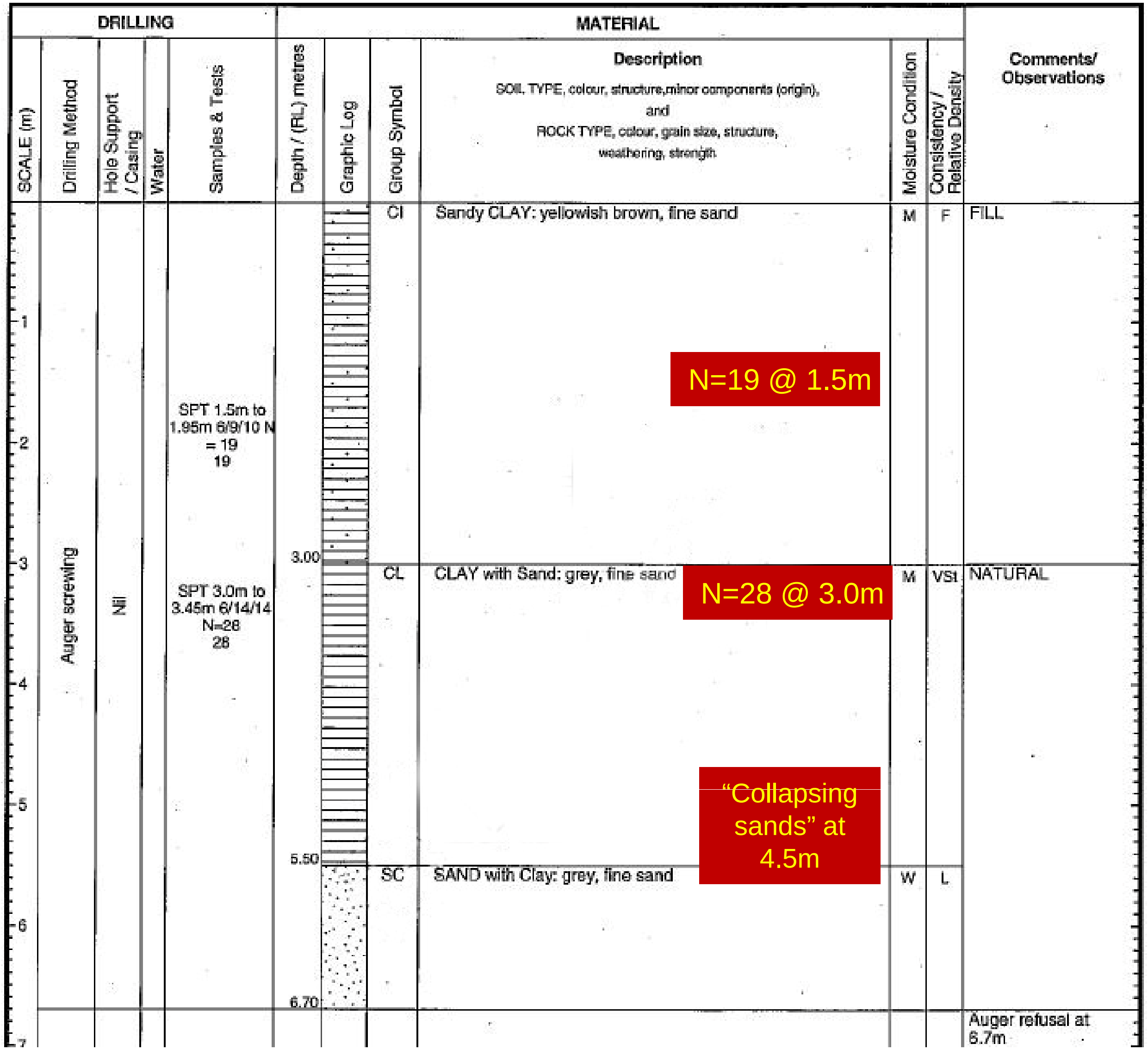
Water Pressure sensor

Filter on cone face

Cone



Why Use CPT?



DRILLING | MATERIAL | Comments/ Observations

SCALE (m) | Drilling Method | Hole Support / Casing | Water | Samples & Tests | Depth / (RL) metres | Graphic Log | Group Symbol | Description: SOIL TYPE, colour, structure, minor components (origin), and ROCK TYPE, colour, grain size, structure, weathering, strength | Moisture Condition | Consistency / Relative Density

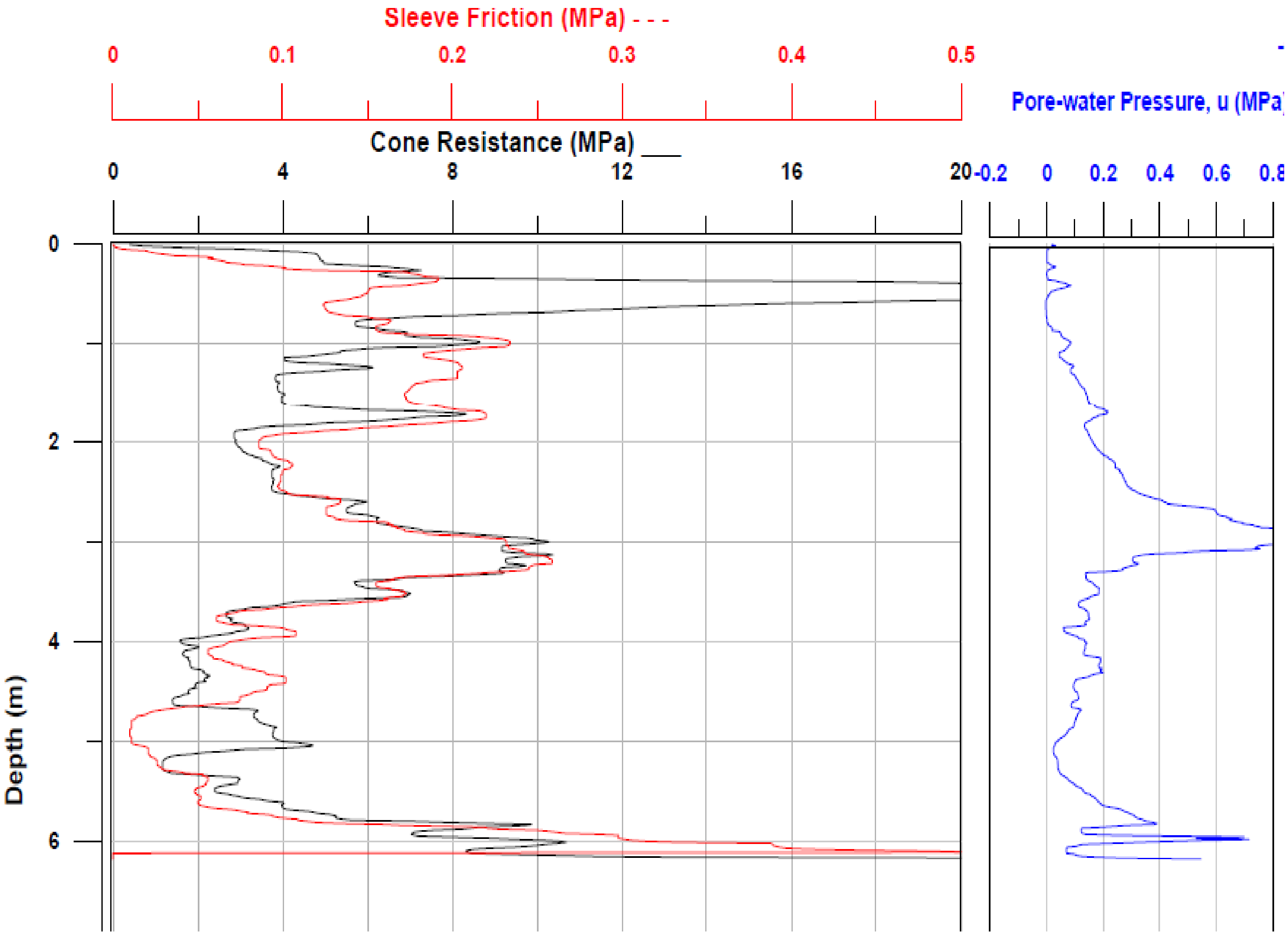
Depth (m)	Drilling Method	Hole Support / Casing	Samples & Tests	Group Symbol	Description	Moisture	Consistency	Comments/ Observations
0	Auger screwing	Nil	SPT 1.5m to 1.95m 6/9/10 N = 19 19	CI	Sandy CLAY: yellowish brown, fine sand	M	F	FILL
3.00			SPT 3.0m to 3.45m 6/14/14 N=28 28	CL	CLAY with Sand: grey, fine sand	M	VSt	NATURAL
5.50				SC	SAND with Clay: grey, fine sand	W	L	
6.70								Auger refusal at 6.7m

N=19 @ 1.5m

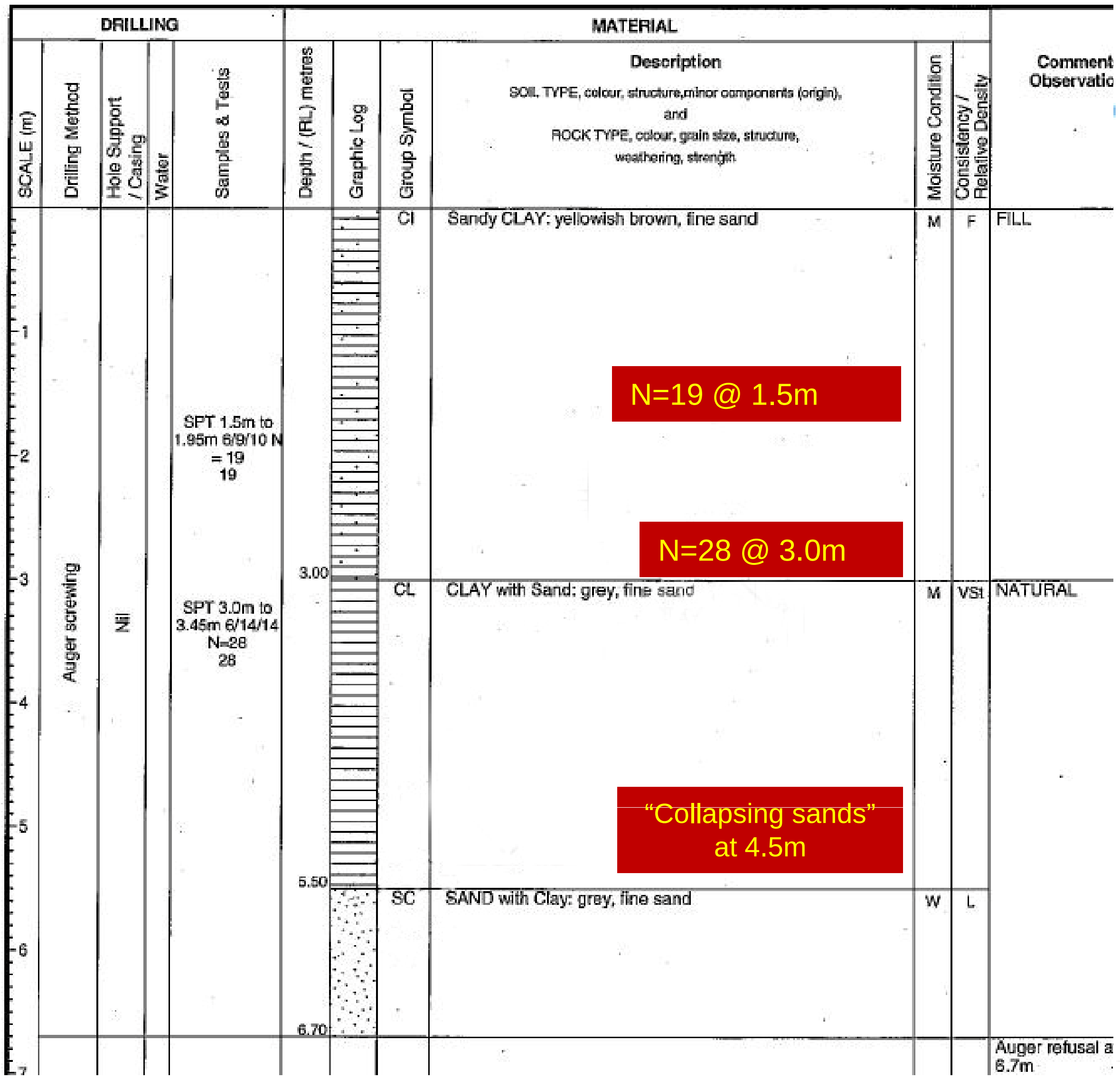
N=28 @ 3.0m

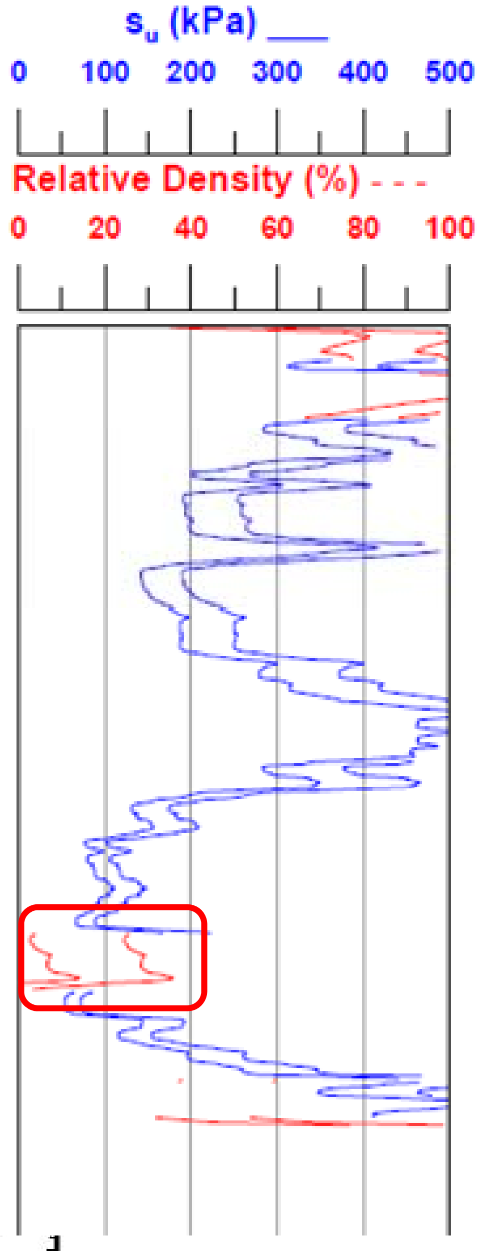
"Collapsing sands" at 4.5m

CPT Immediately Adjacent to Previous Borehole

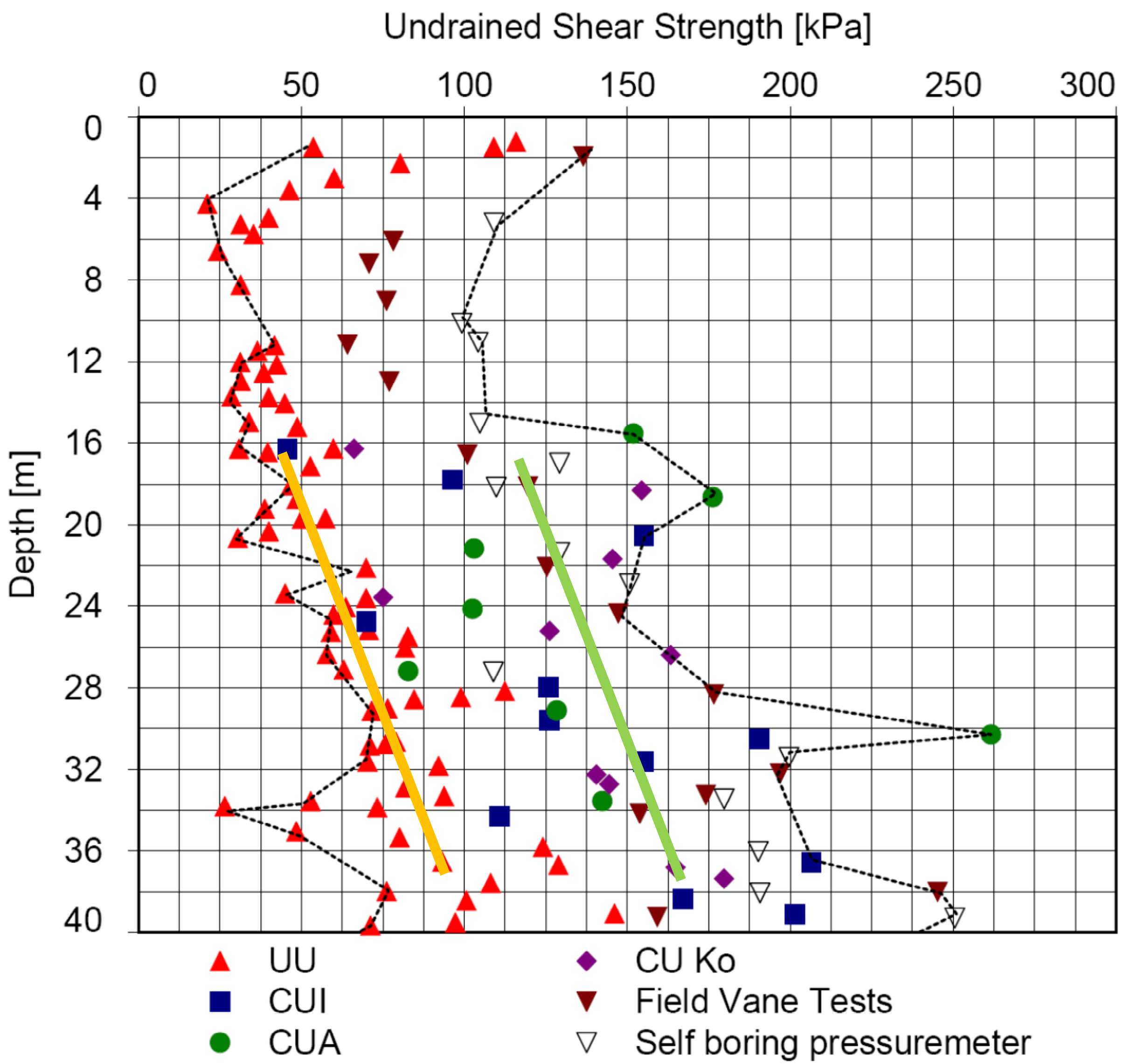


Interpreted s_u and D_r Profiles



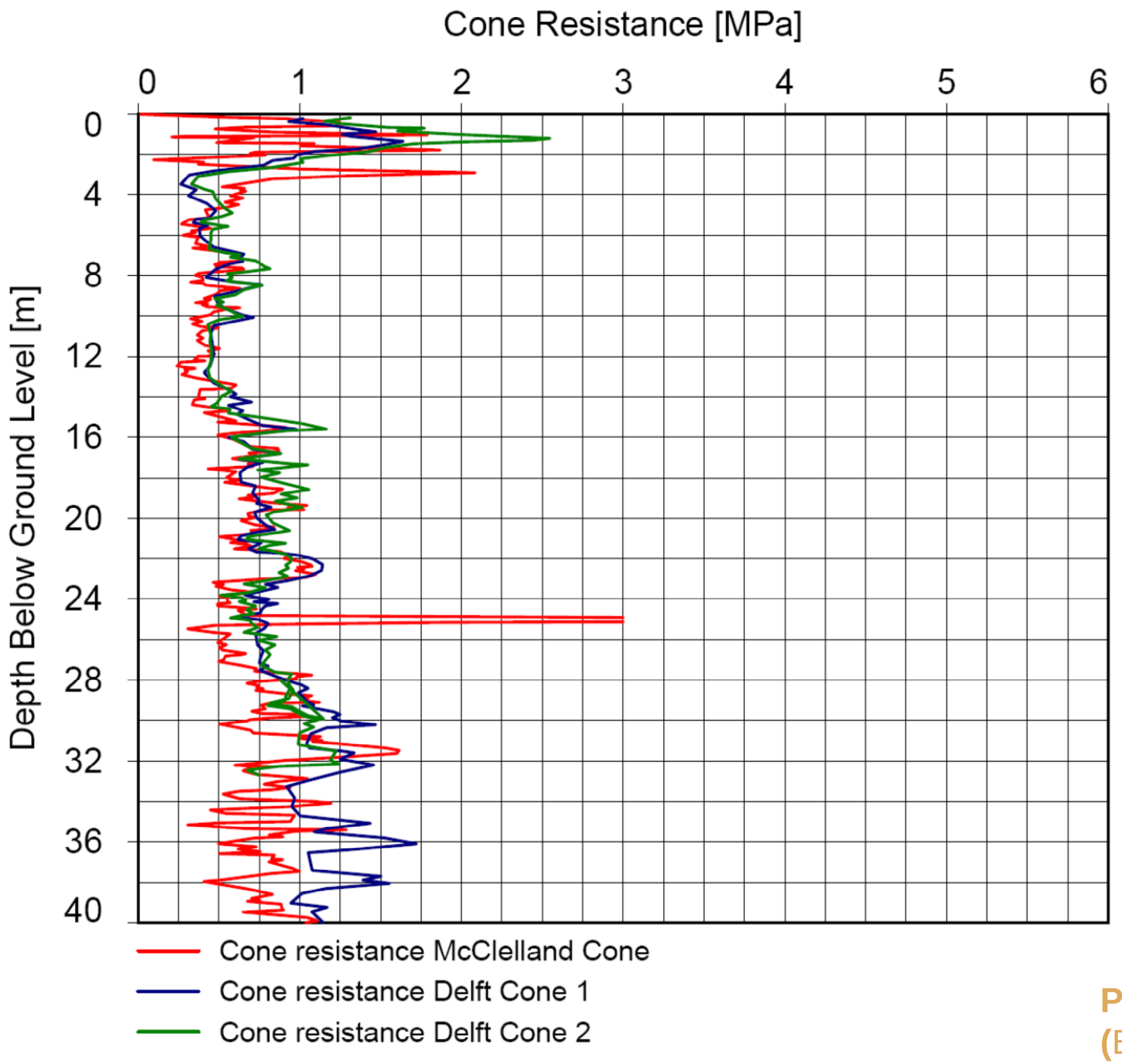


Why Use CPT for Profiling?



Pentre,
Lab Testing
(Lambson et al)

Why Use CPT for Profiling?

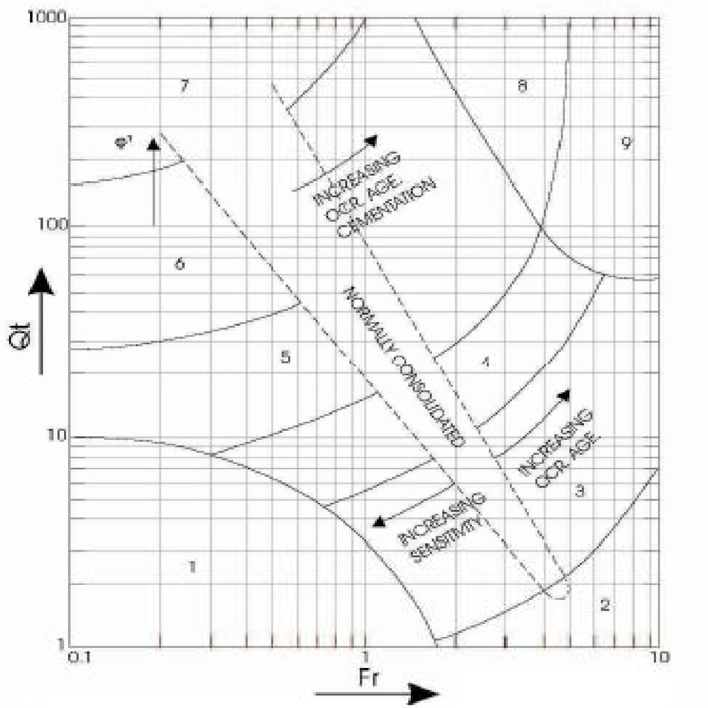


Pentre CPT Profiles
(BRE, 1985)

Soil Behaviour Type (SBT) Chart – Robertson (1990)

Soil Behaviour Type (SBT) Profiles

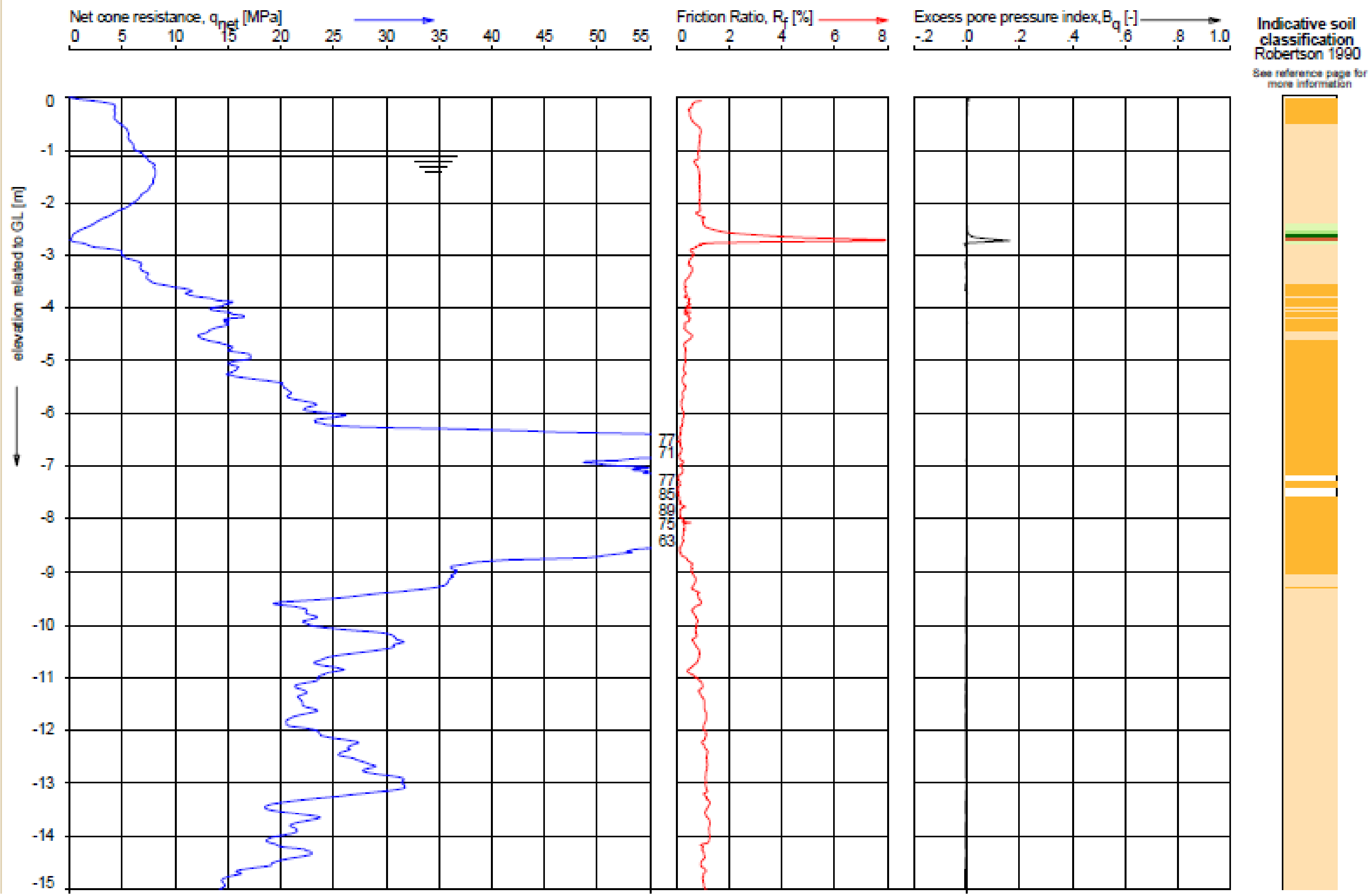
Soil Behaviour Type (SBT) profiles presented on report figures are automatically generated from the CPT data using the chart below (Robertson, 1990).



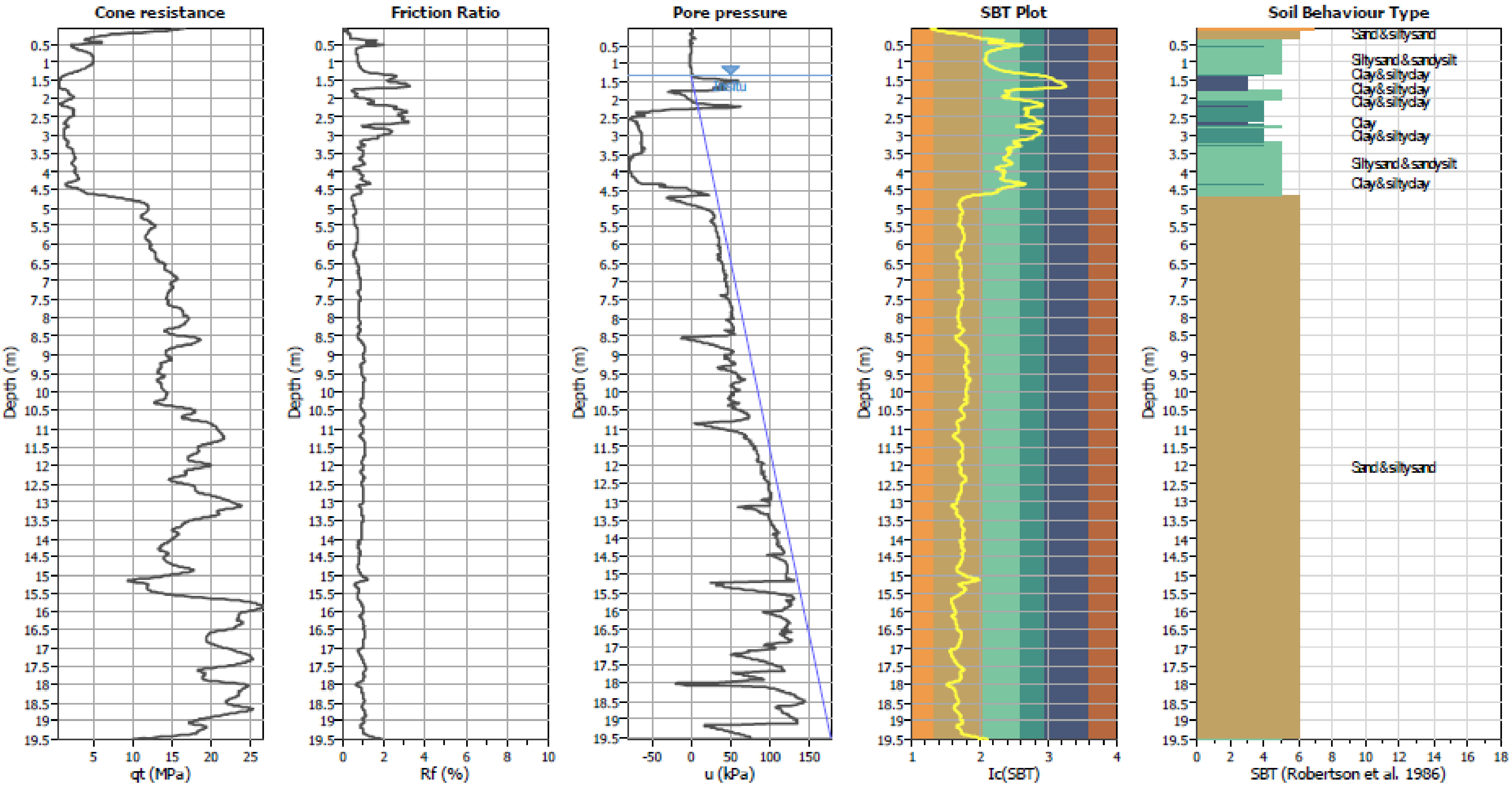
(1)	Sensitive, fine grained	(6)	SANDS – clean sand to silty sand
(2)	Organic soils – PEATS	(7)	Gravelly sand to sand
(3)	CLAYS – clay to silty clay	(8)	Very stiff sand to clayey sand
(4)	Silt mixtures – clayey SILT to silty CLAY	(9)	Very stiff, fine grained
(5)	SAND mixtures – silty sand to sandy silt		

CPeT-IT software

Soil Behaviour Type Profiles Inferred from CPT

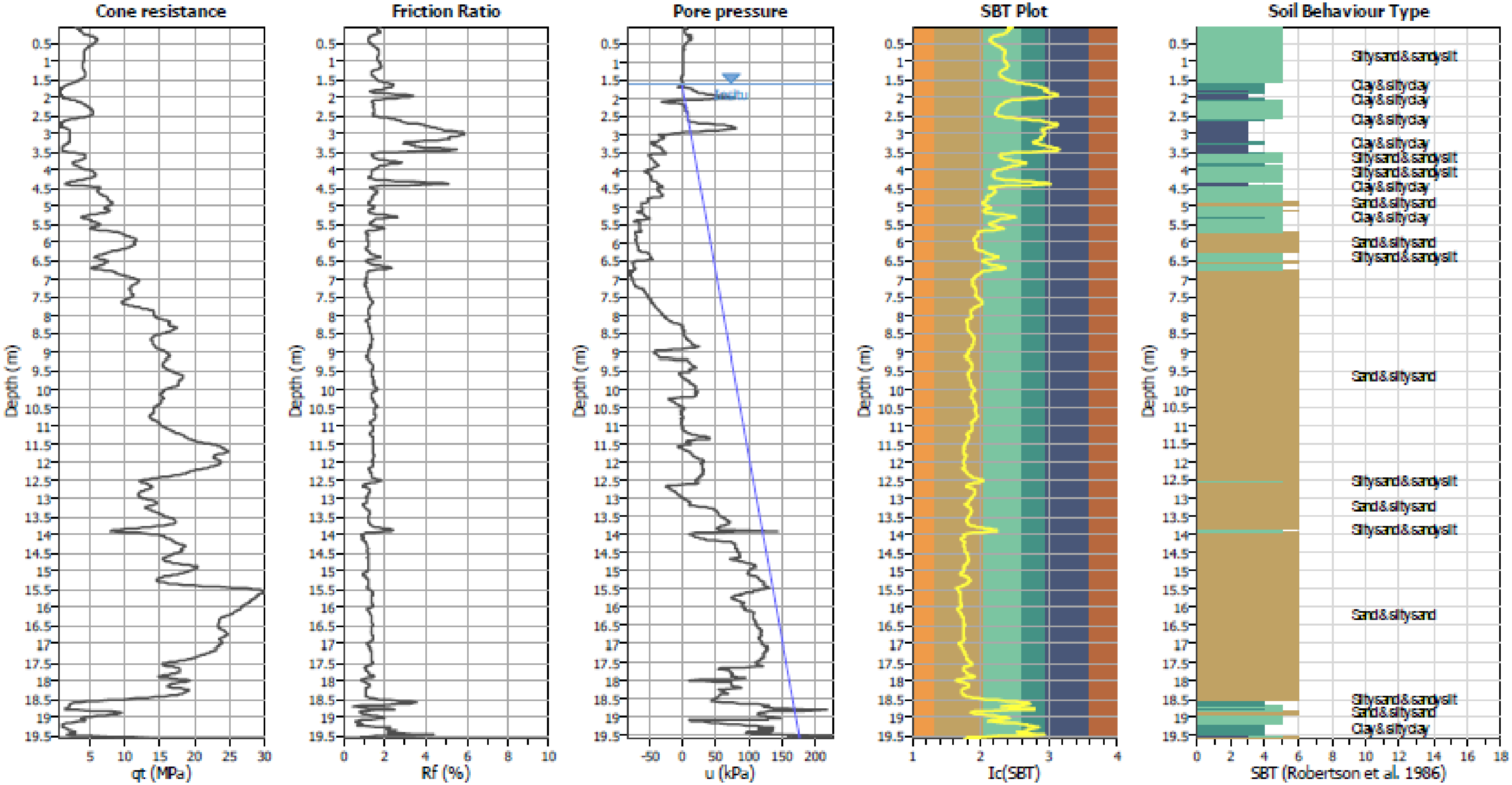


Example Site in Christchurch



CPeT-IT software

Example Site in Christchurch



CPeT-IT software

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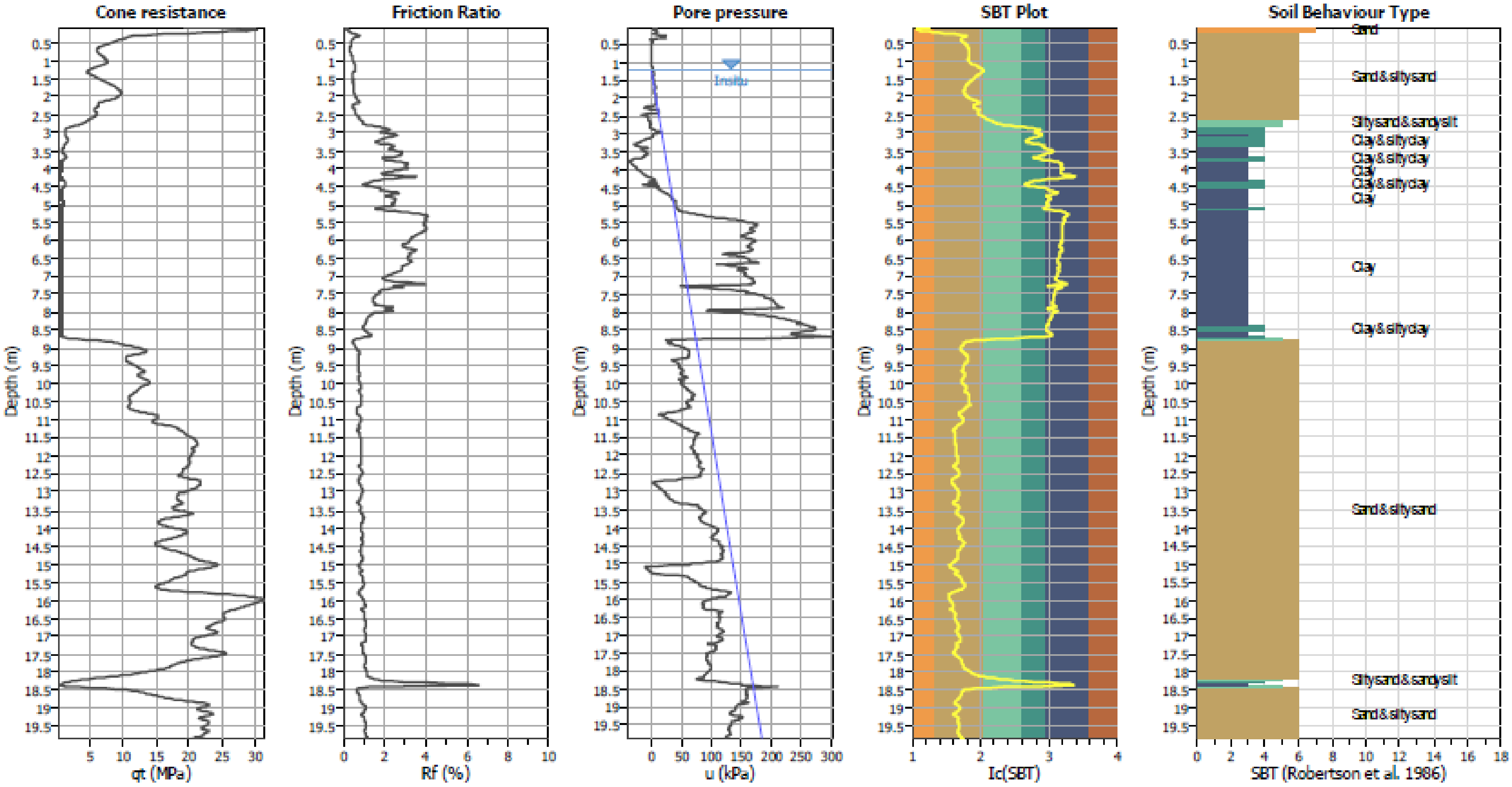

CPeT-IT software

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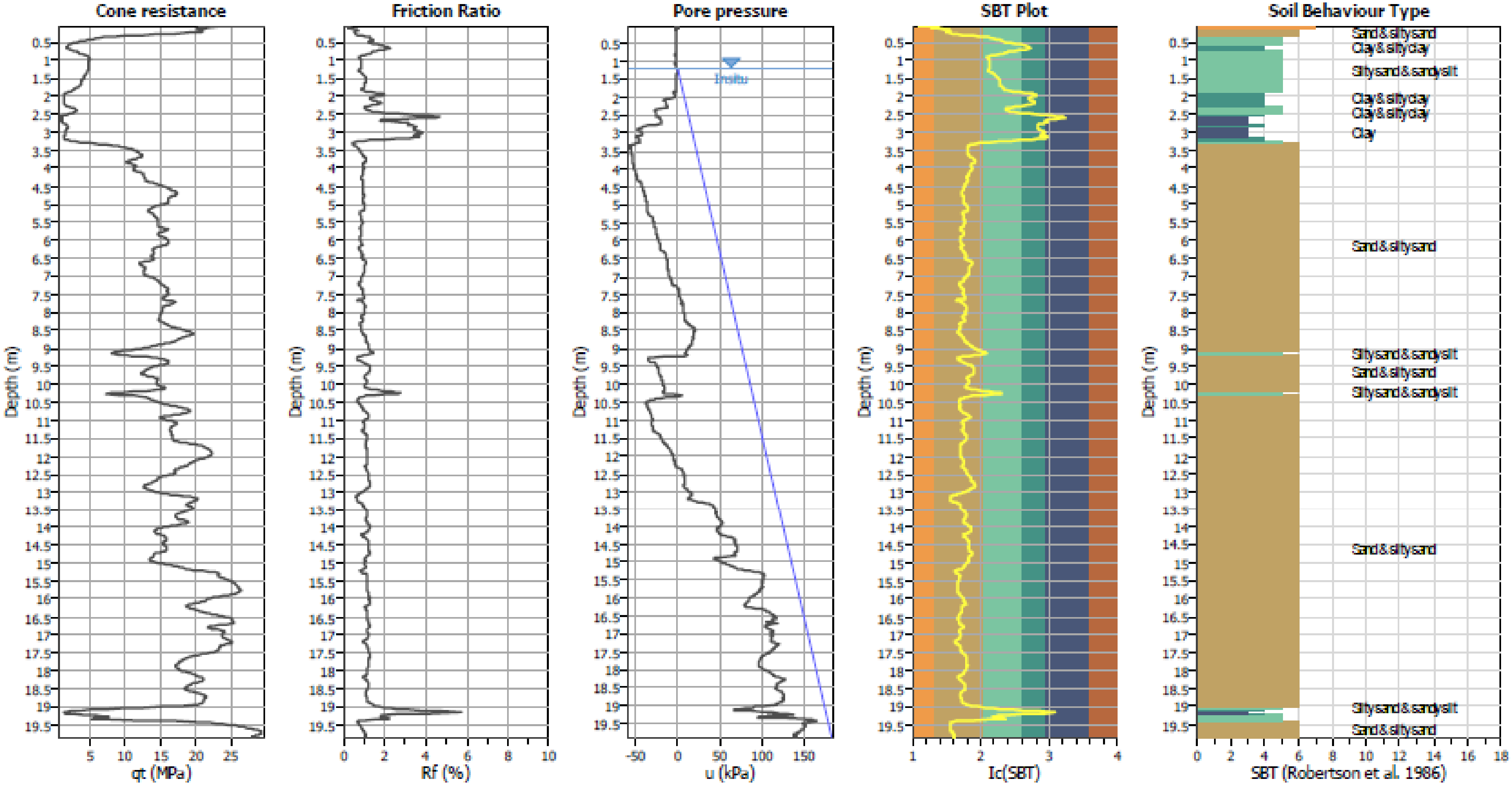
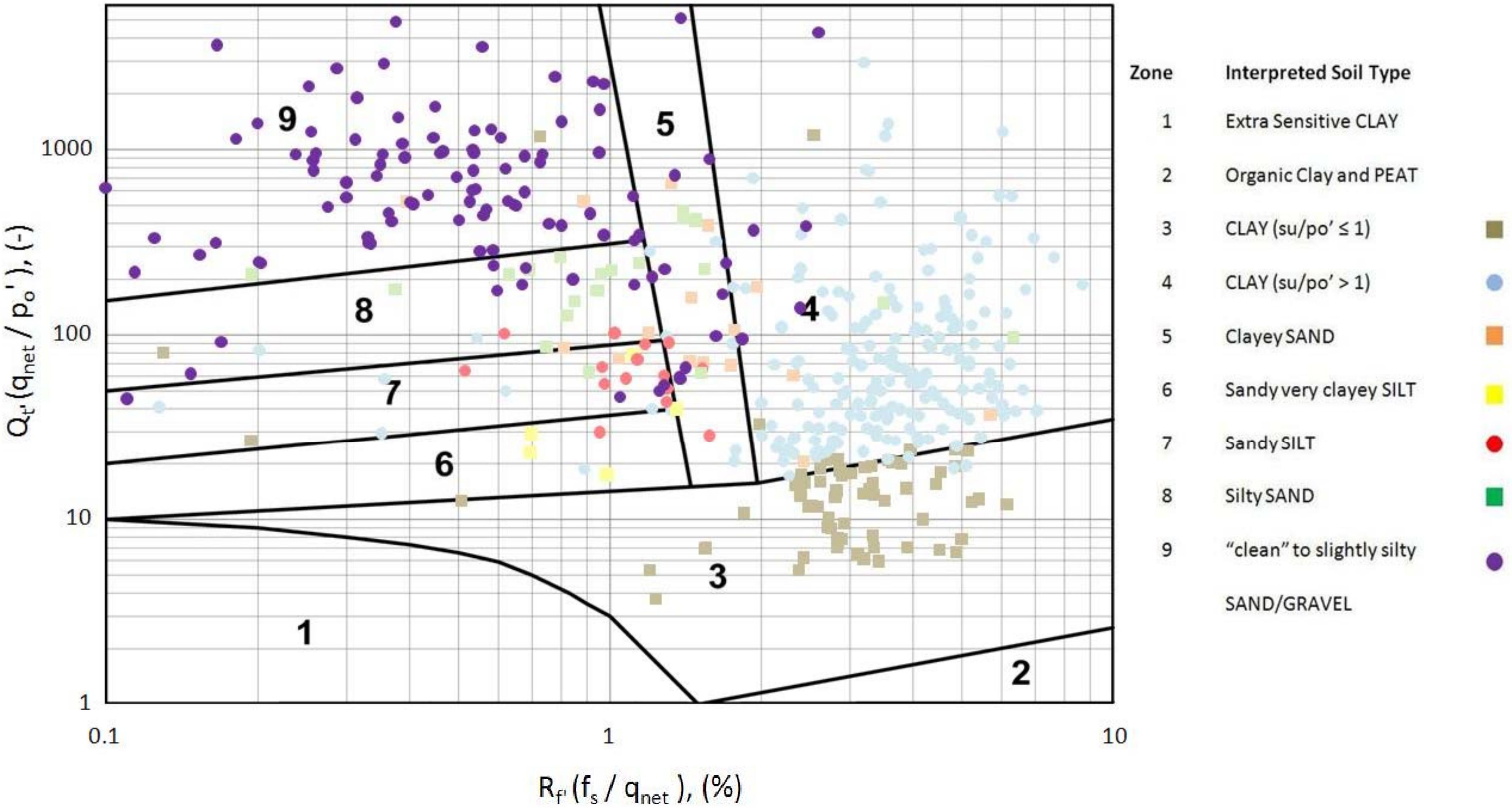


CPeT-IT software

Cat	General Description	S_t	Org	s_u / p_o'	Fines %	Clay %	'A' Line
3	Clay soils with a ratio of s_u / p_o' ≤ 1	-	-	≤ 1	>35	>12	Above

CPT SOIL TYPE INTERPRETATION GRAPH
(FRICTION RATIO versus NORMALIZED CONE RESISTANCE)



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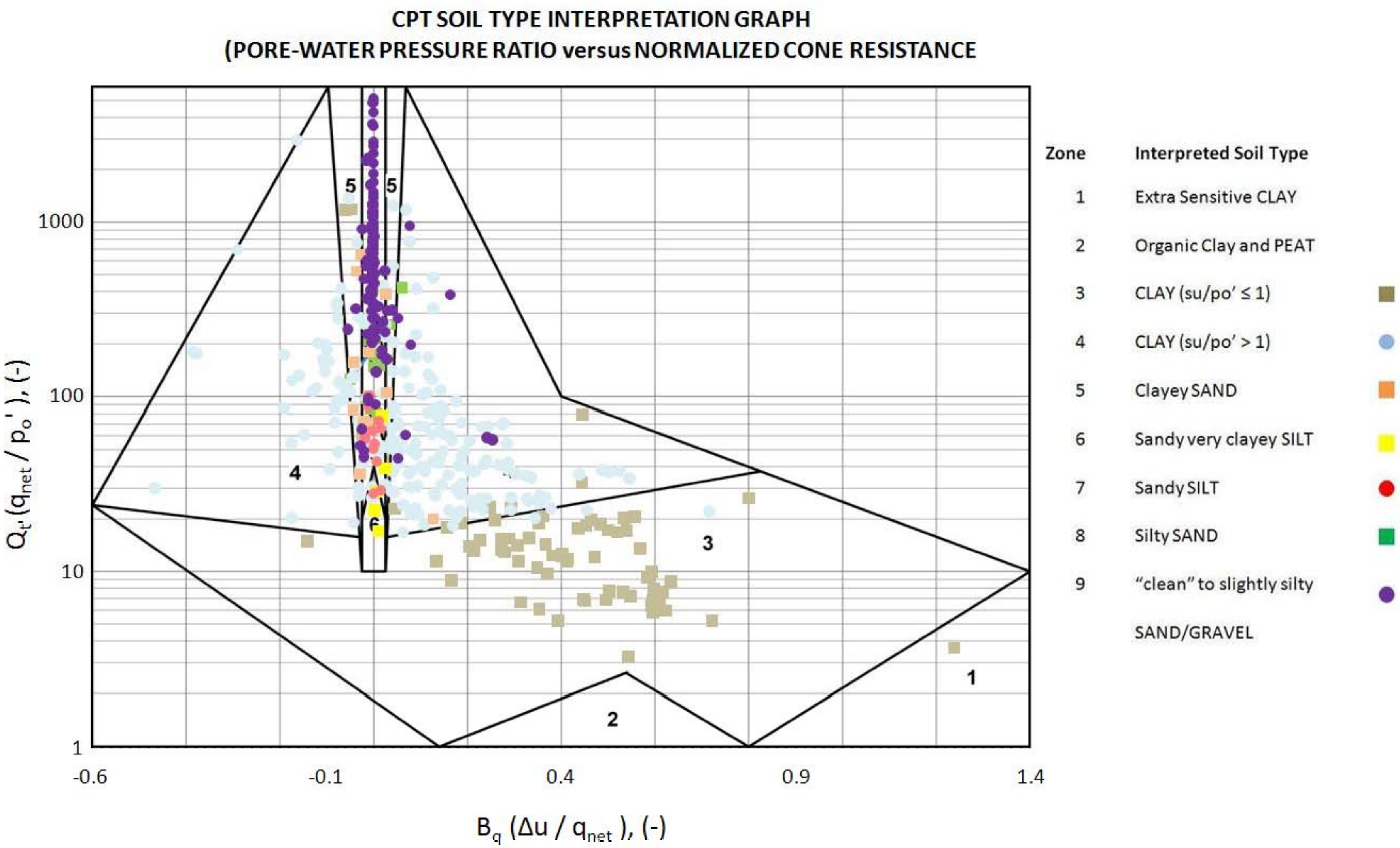
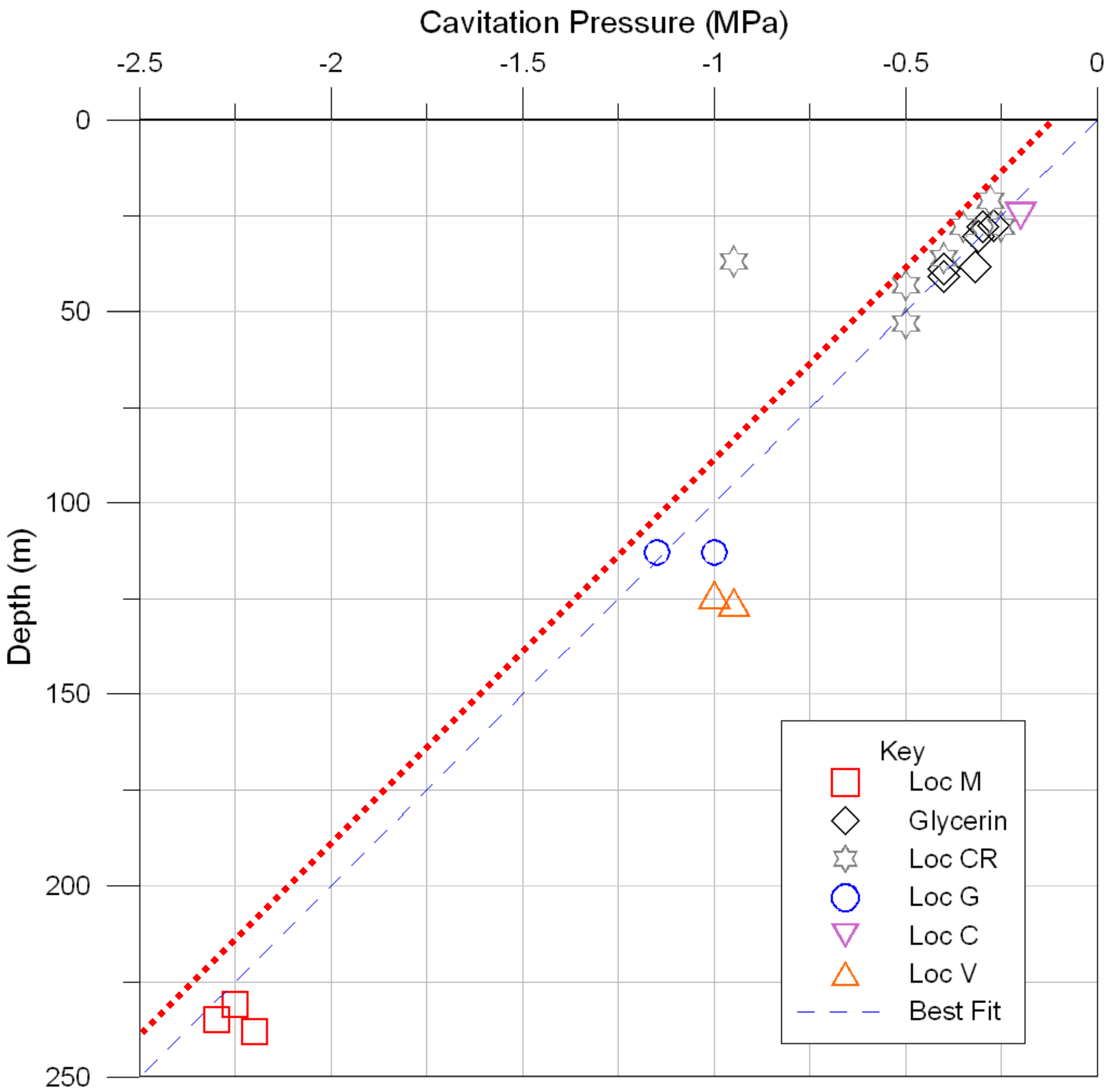
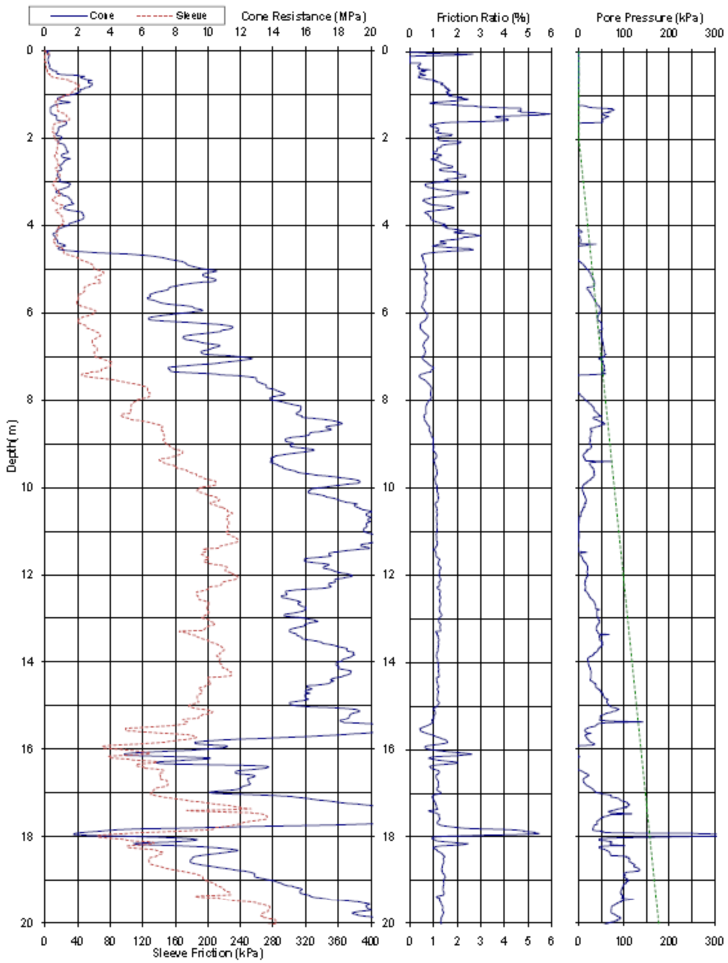


Beware of Cavitation



Pre- and Post-Earthquake Assessments

Pre 2011 Feb earthquake



Separation distance:

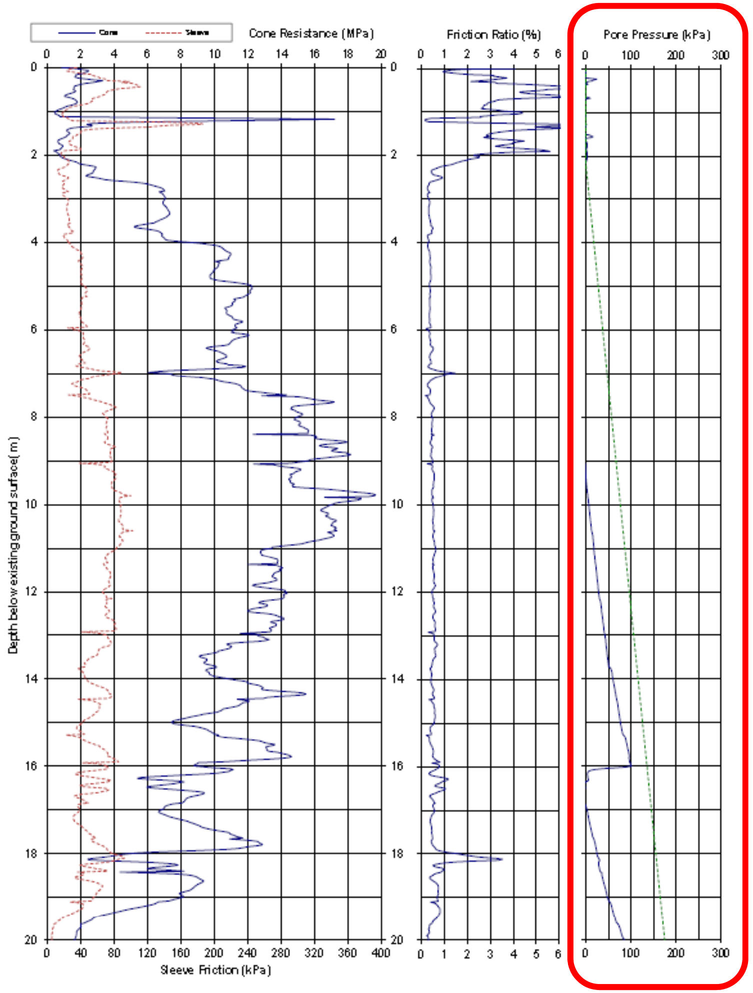
E: 6.4m

N :0.31m

Total:6.4m

ORBIT database

Post 2011 Feb earthquake



Pre- and Post-Earthquake Assessments

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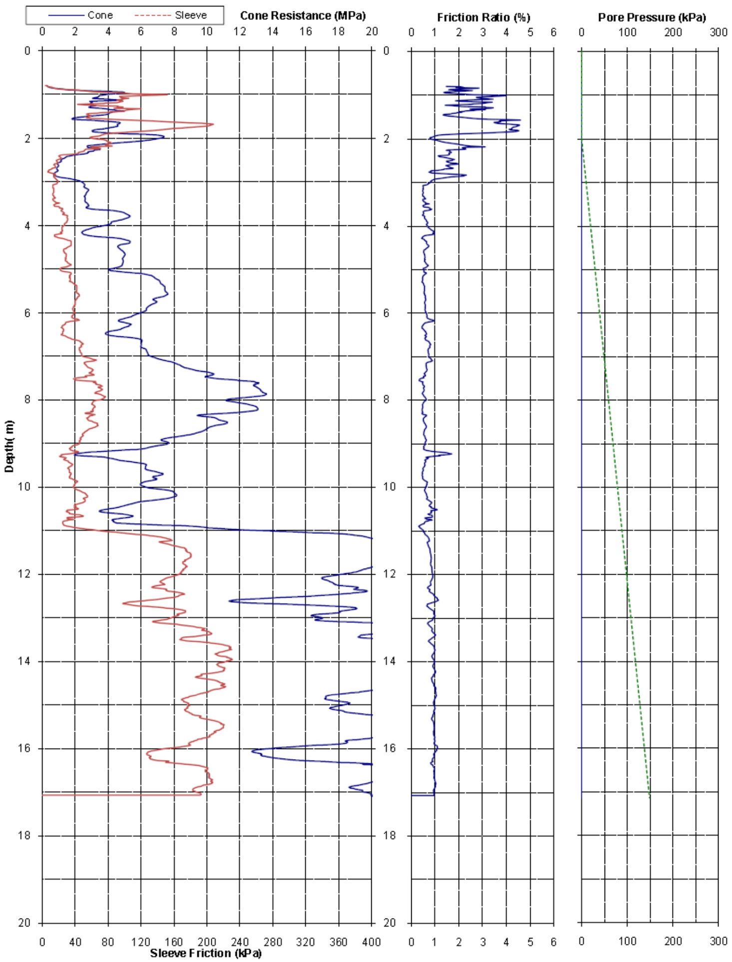


Separation distance:

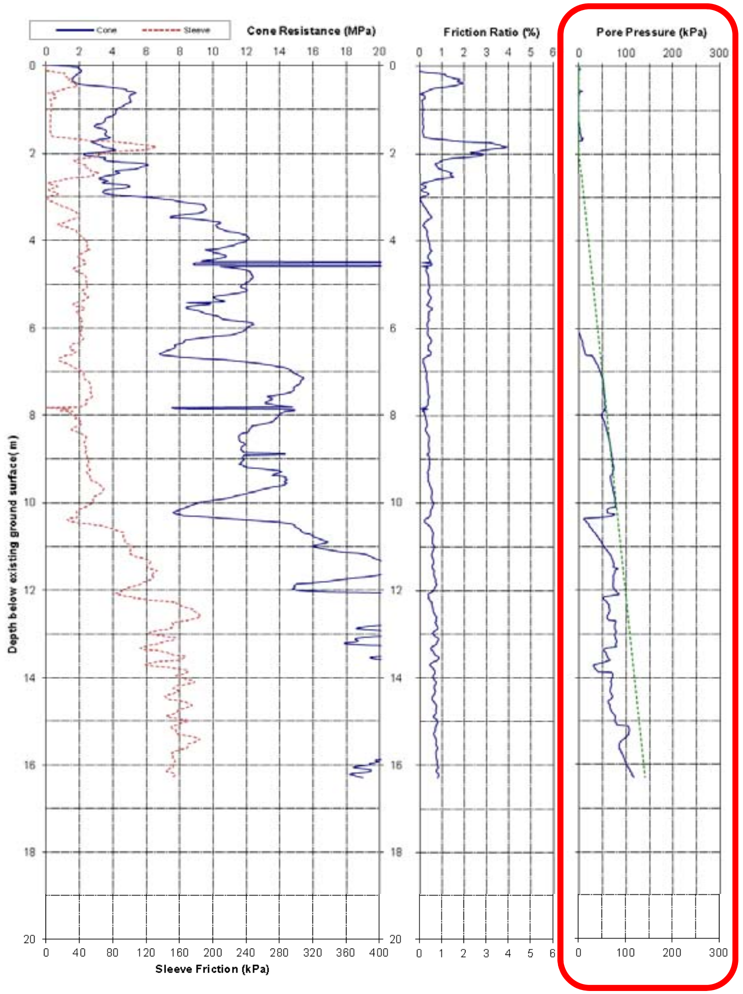
E: 2.8m

N :4.87m

Total:5.6m

ORBIT database

Post 2011 Feb earthquake



Pre- and Post-Earthquake Assessments

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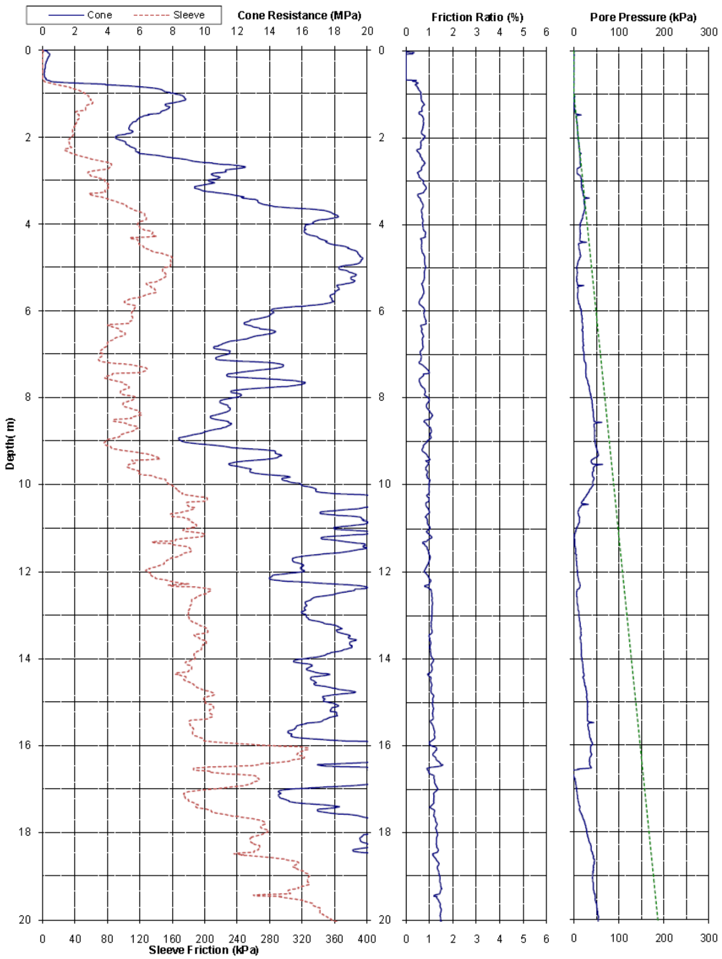


Separation distance:

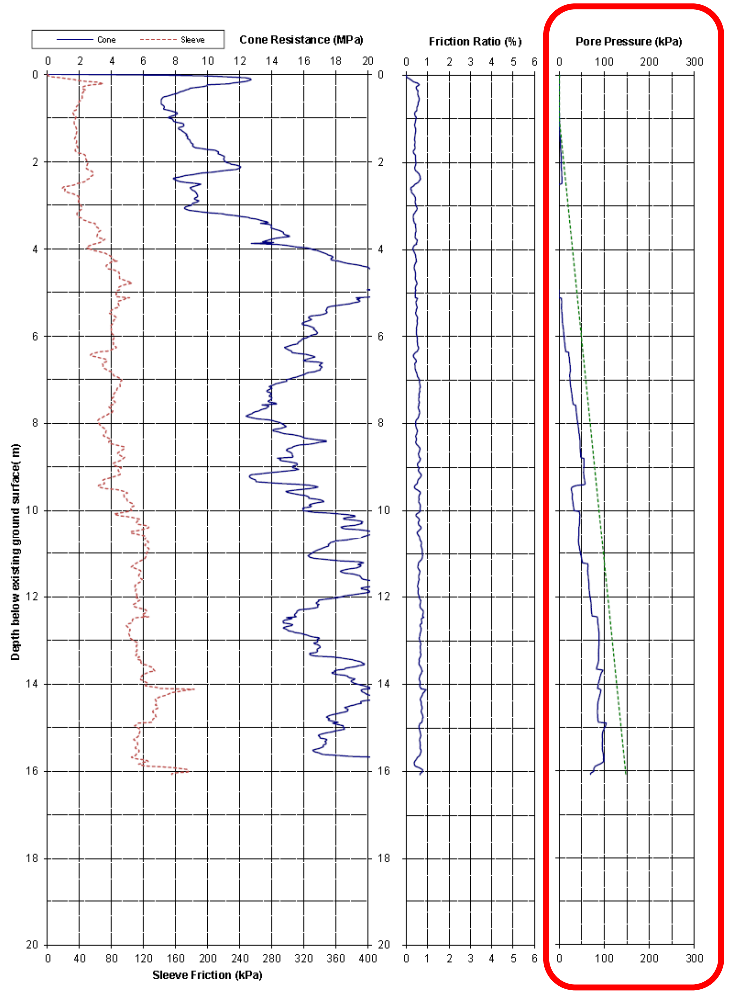
E: 10.12m

N :7.65m

Total:12.7 m

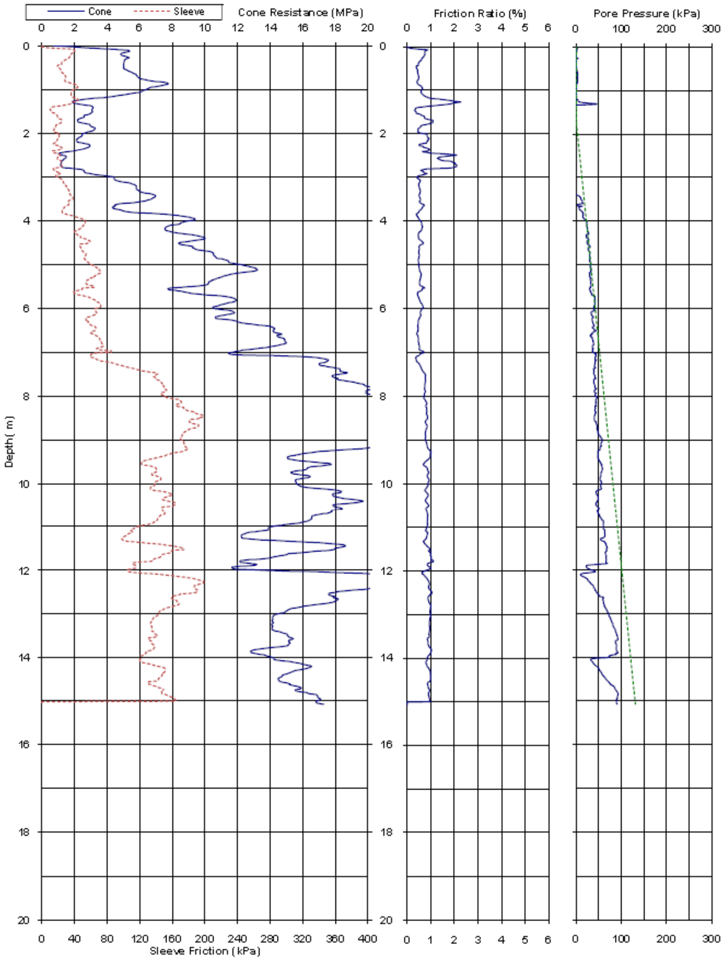
ORBIT database

Post 2011 Feb earthquake



Pre- and Post-Earthquake Assessments

Pre 2011 Feb earthquake



Separation distance:

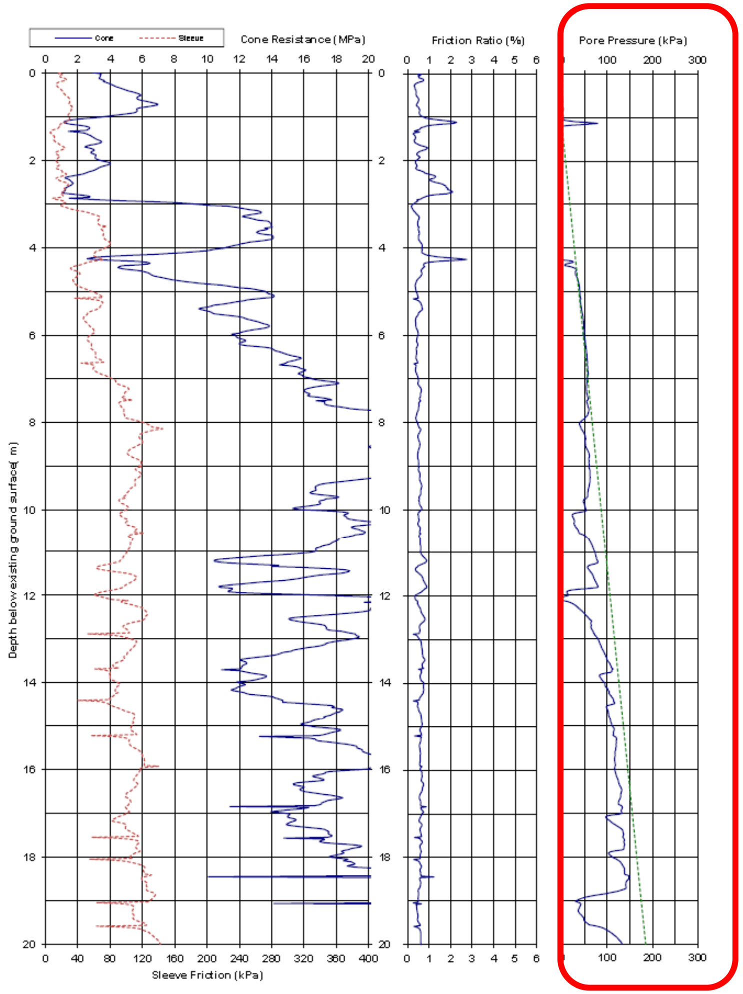
E: 4.58m

N :24.65m

Total:25m

ORBIT database

Post 2011 Feb earthquake



Summary

The CPT is an excellent interpretive tool for assessing soil layers and soil variability.

The pore-pressure sensor, in particular, provides valuable information on thin layers of more, or less, permeable material, within a soil matrix.

The choice of soil classification model has a significant bearing on the interpreted soils – over-reliance on a single model should be avoided.

Approaches that take into account both friction and PWP information are likely to be more reliable (if reliable PWP is available).

Granular inclusions, within a generally fine-grained soil matrix, can cause unreliable pore-pressure sensor readings

Complementary laboratory testing significantly enhances the benefits of CPT.

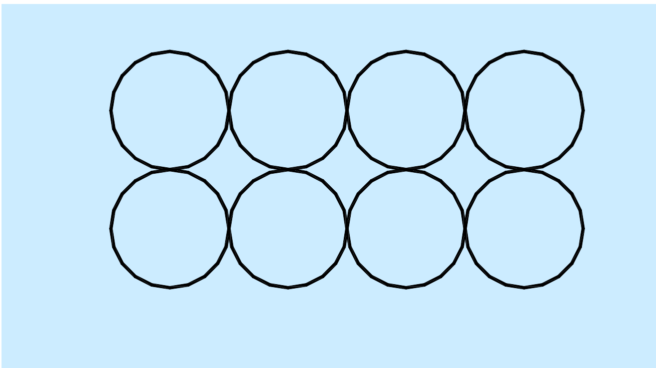
Beware cavitation – and if it occurs, then take it into account.

Relative Density

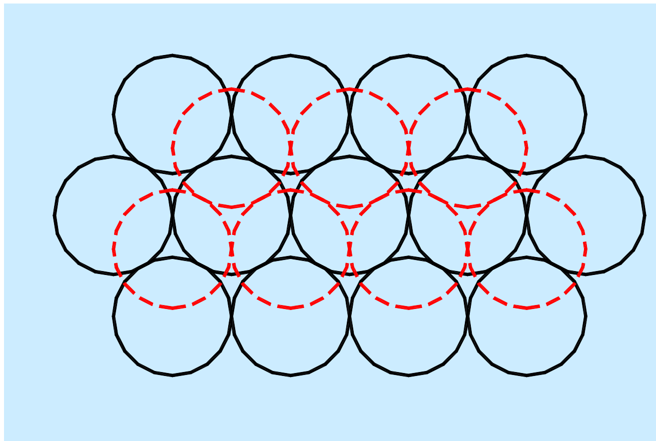
Voids Ratio, e, is the ratio of the volume of voids to the volume of solids

D_r (%) = $(e_{max} - e) / (e_{max} - e_{min})$ x 100

D_r (%) = $(\rho_{d(max)}/\rho_d)$ x $(\rho_d - \rho_{d(min)})/(\rho_{d(max)} - \rho_{d(min)})$ x 100



D_r = 0%



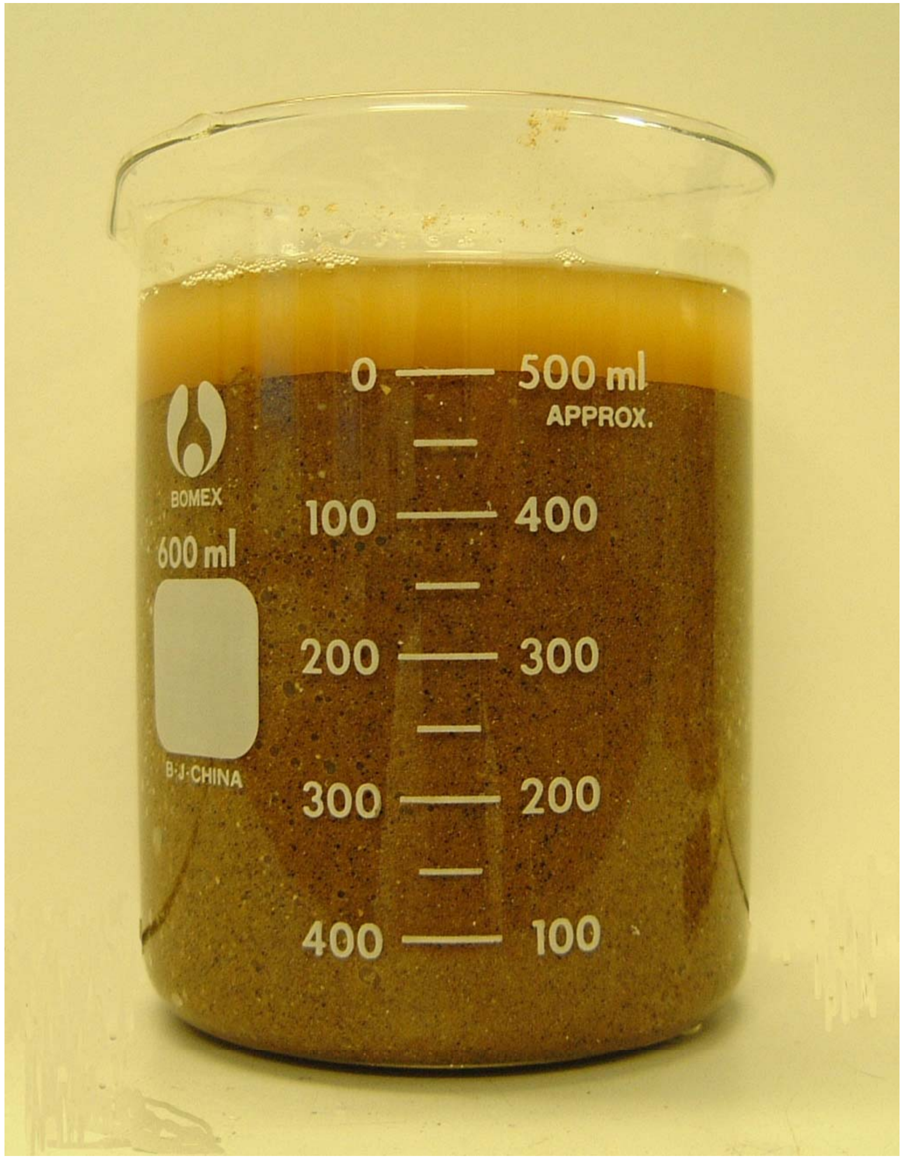
D_r = 100%

Relative Density Video Clip

- Video clip –

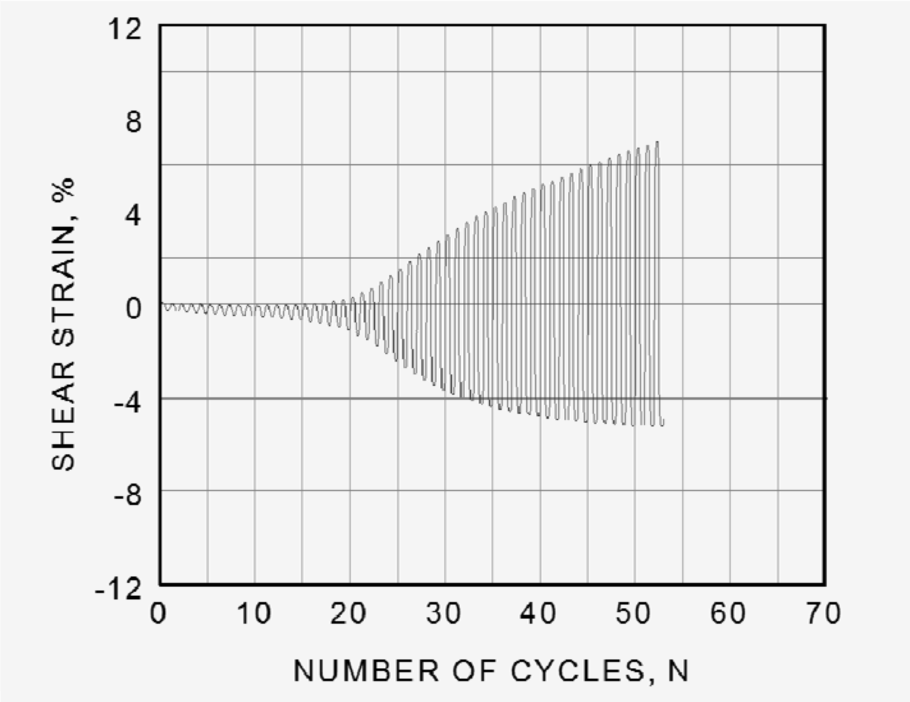
Increasing the Relative Density of a sand by moderate vibration

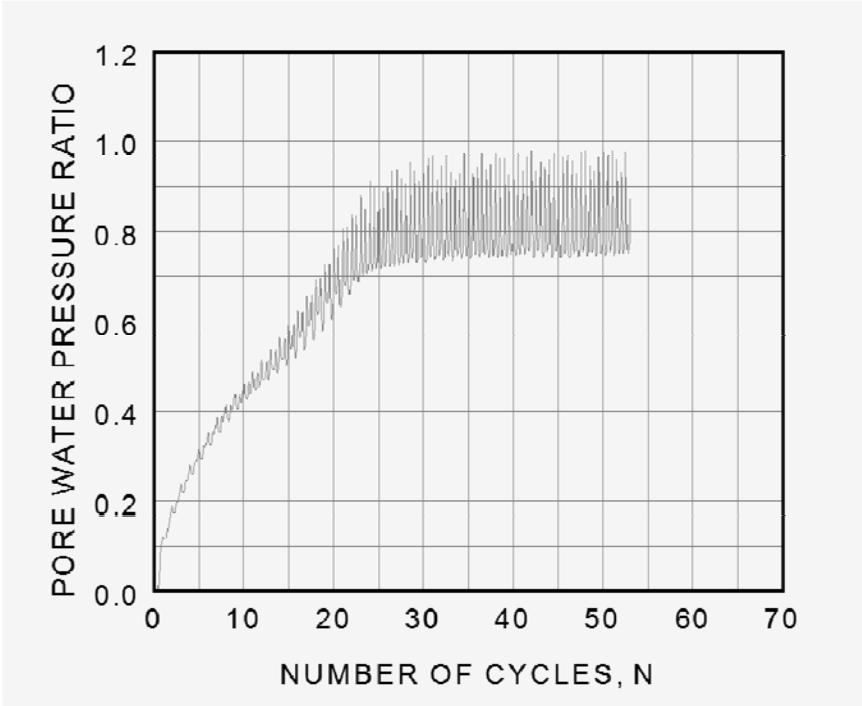
Final Condition



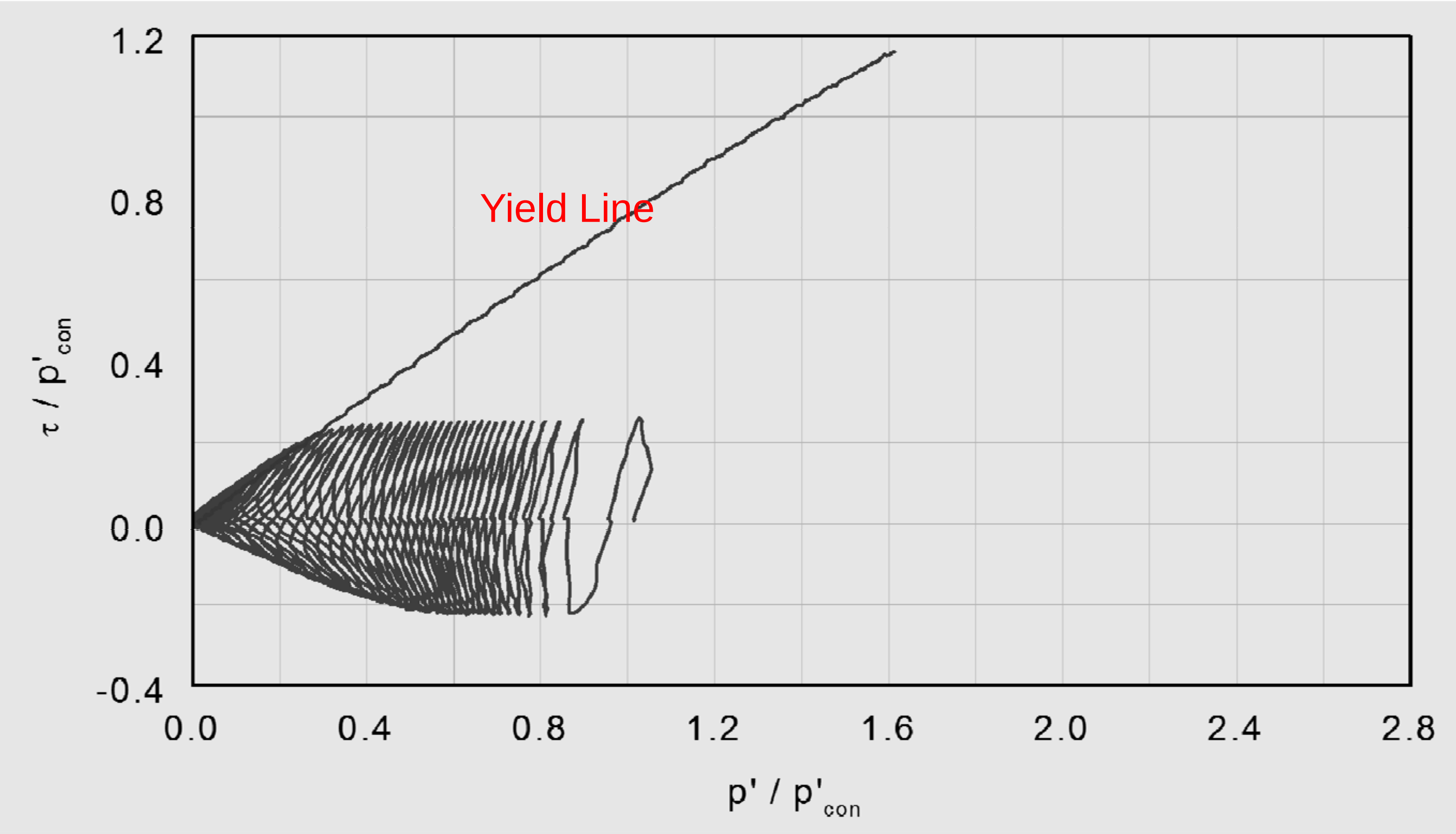
Cyclic Strength and Degradation

Development of Cyclic Strains and Pore-water Pressure



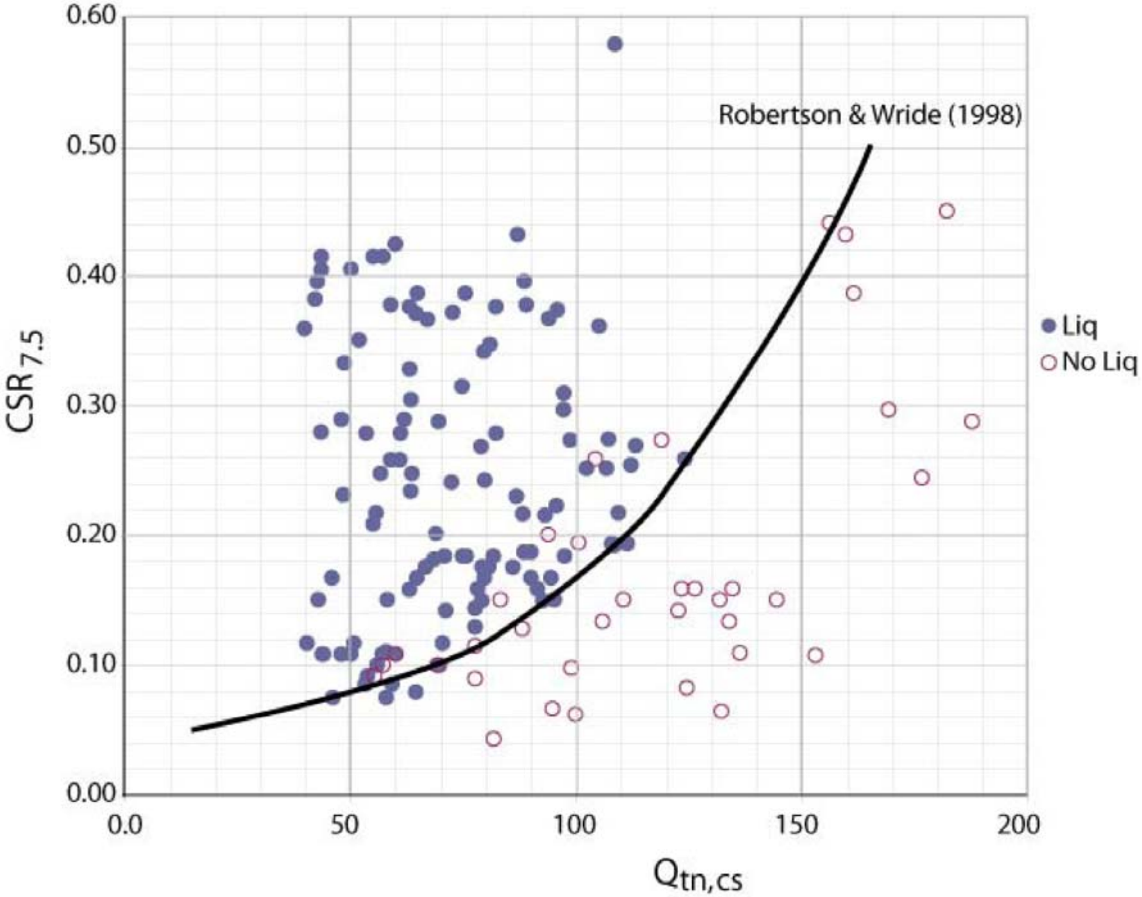


Stress Path During Cyclic Loading to Liquefaction



Robertson – Liquefaction Assessment Using CPT Results

$CSR_{7.5}$ = Cyclic Stress Ratio for Magnitude 7.5 earthquake



$Q_{tn,cs}$ = qc, normalised wrt effective overburden pressure and fines content

Liquefaction Assessment Using CPT Results - Robertson (2009)

$$CSR = \frac{\tau_{av}}{\sigma'_{vo}} = 0.65\left[\frac{a_{max}}{g}\right]\left(\frac{\sigma_{vo}}{\sigma'_{vo}}\right) r_d$$

$$r_d = 1.0 - 0.00765z \quad \text{if } z < 9.15 \text{ m}$$

$$= 1.174 - 0.0267z \quad \text{if } z = 9.15 \text{ to } 23 \text{ m}$$

$$= 0.744 - 0.008z \quad \text{if } z = 23 \text{ to } 30 \text{ m}$$

$$= 0.5 \quad \text{if } z > 30 \text{ m}$$

$$CRR_{7.5} = 93\left[\frac{(Q_{tn,cs})}{1000}\right]^3 + 0.08$$

if $50 \leq Q_{tn,cs} \leq 160$

$$CRR_{7.5} = 0.833\left[\frac{(Q_{tn,cs})}{1000}\right] + 0.05$$

if $(Q_{tn,cs} < 50$

$$\textit{Factor of Safety, FS} = \frac{CRR_{7.5}}{CSR} MSF$$

$$MSF = \frac{174}{M^{2.56}}$$

Liquefaction Assessment Using CPT Results - Robertson (2009)

$$Q_{tn} = \left(\frac{q_t - \sigma_{vo}}{P_{a2}}\right)\left(\frac{P_a}{\sigma'_{vo}}\right)^n$$

$$n = 0.381\ (I_c) + 0.05\ (\sigma'_{vo}/p_a) - 0.15$$

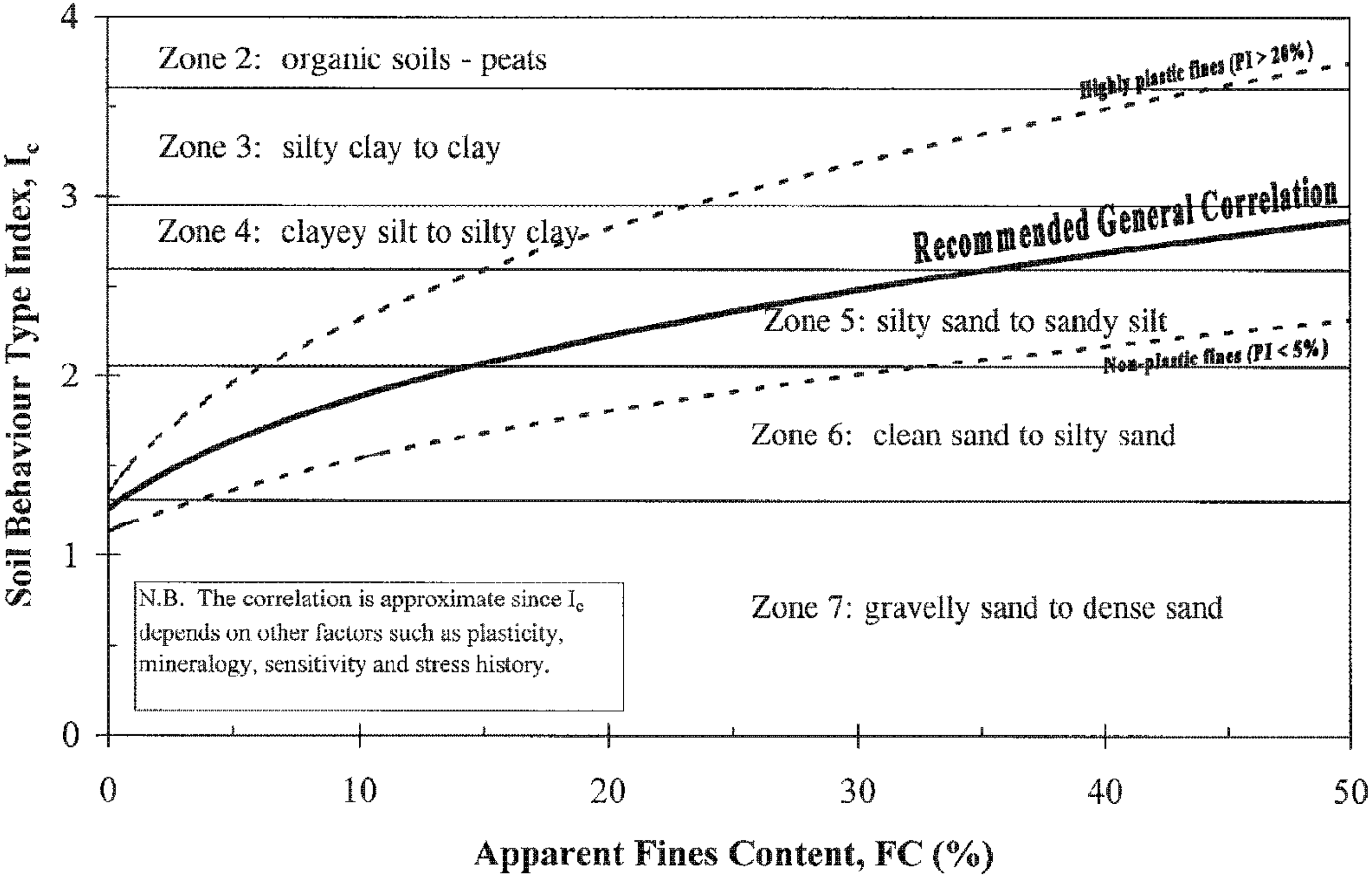
$$I_c = \left[(3.47 - \log Q_{tn})^2 + (\log F + 1.22)^2\right]^{0.5}$$

$$(Q_{tn})_{cs} = K_c\ Q_{tn}$$

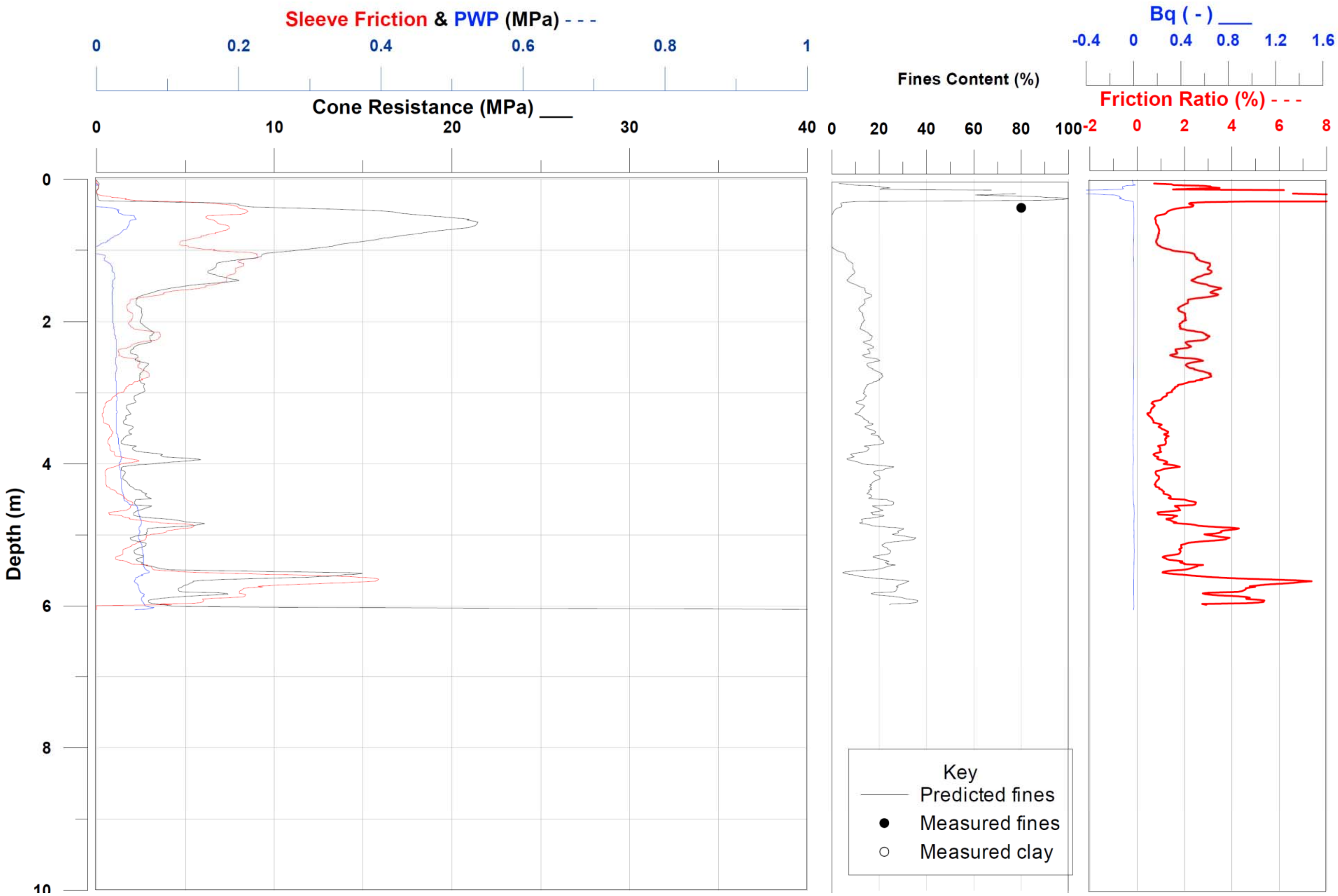
$$K_c = 1.0 \qquad \text{if } I_c \leq 1.64$$

$$K_c = 5.581\ I_c^3 - 0.403\ I_c^4 - 21.63\ I_c^2 + 33.75\ I_c - 17.88 \qquad \text{if } I_c > 1.64$$

Liquefaction Assessment Using CPT Results - Robertson (2009)



Example – Liquefaction Assessment



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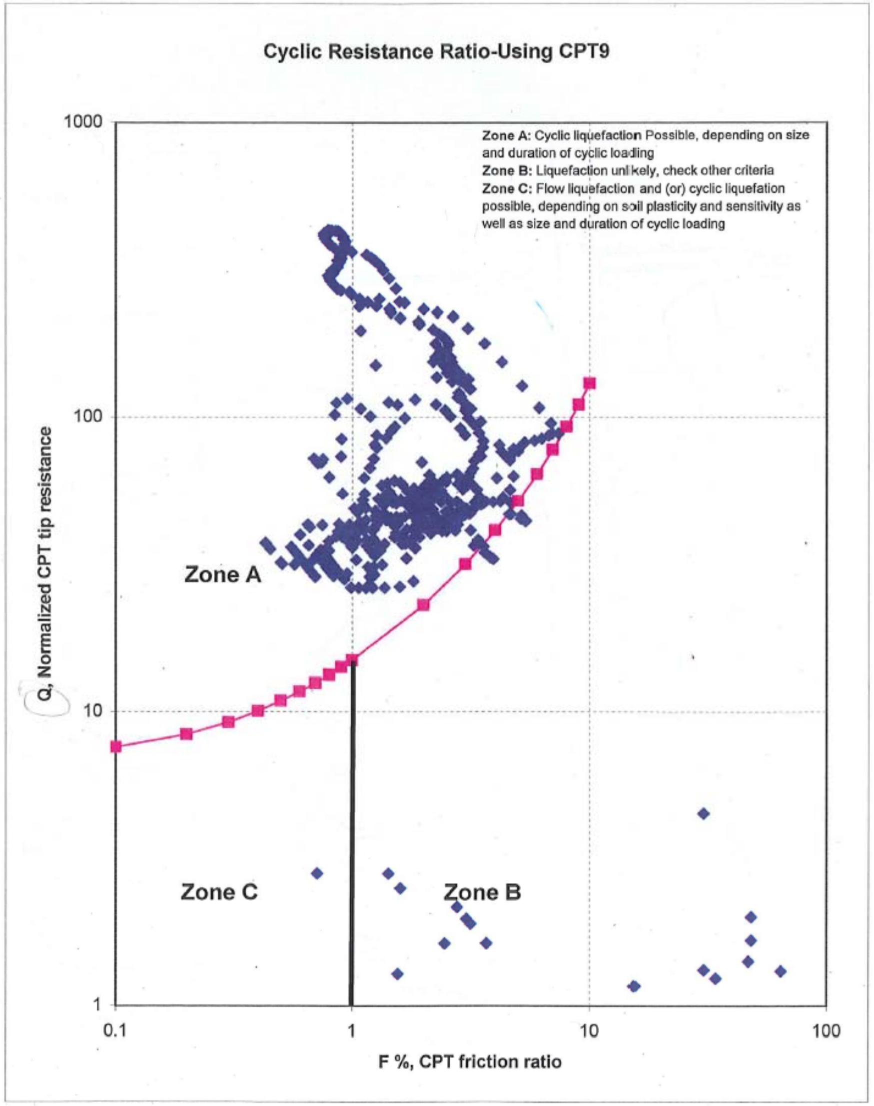
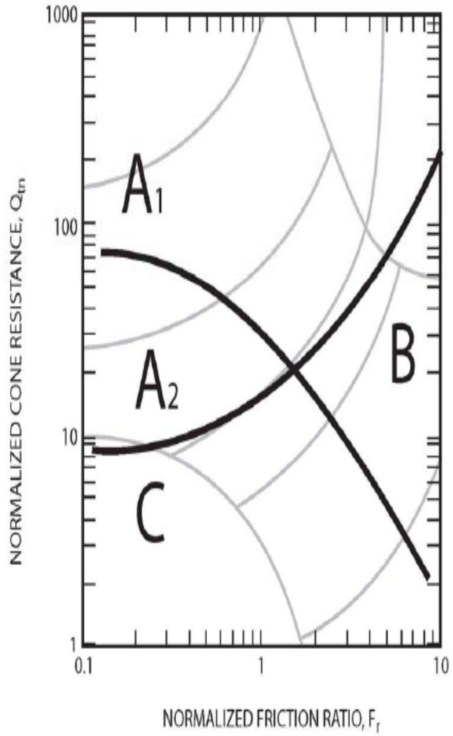




Cohesionless soils (A_1 & A_2) - Evaluate potential behavior using CPT-based case-history liquefaction correlations.

A_1 Cyclic liquefaction possible depending on level and duration of cyclic loading.

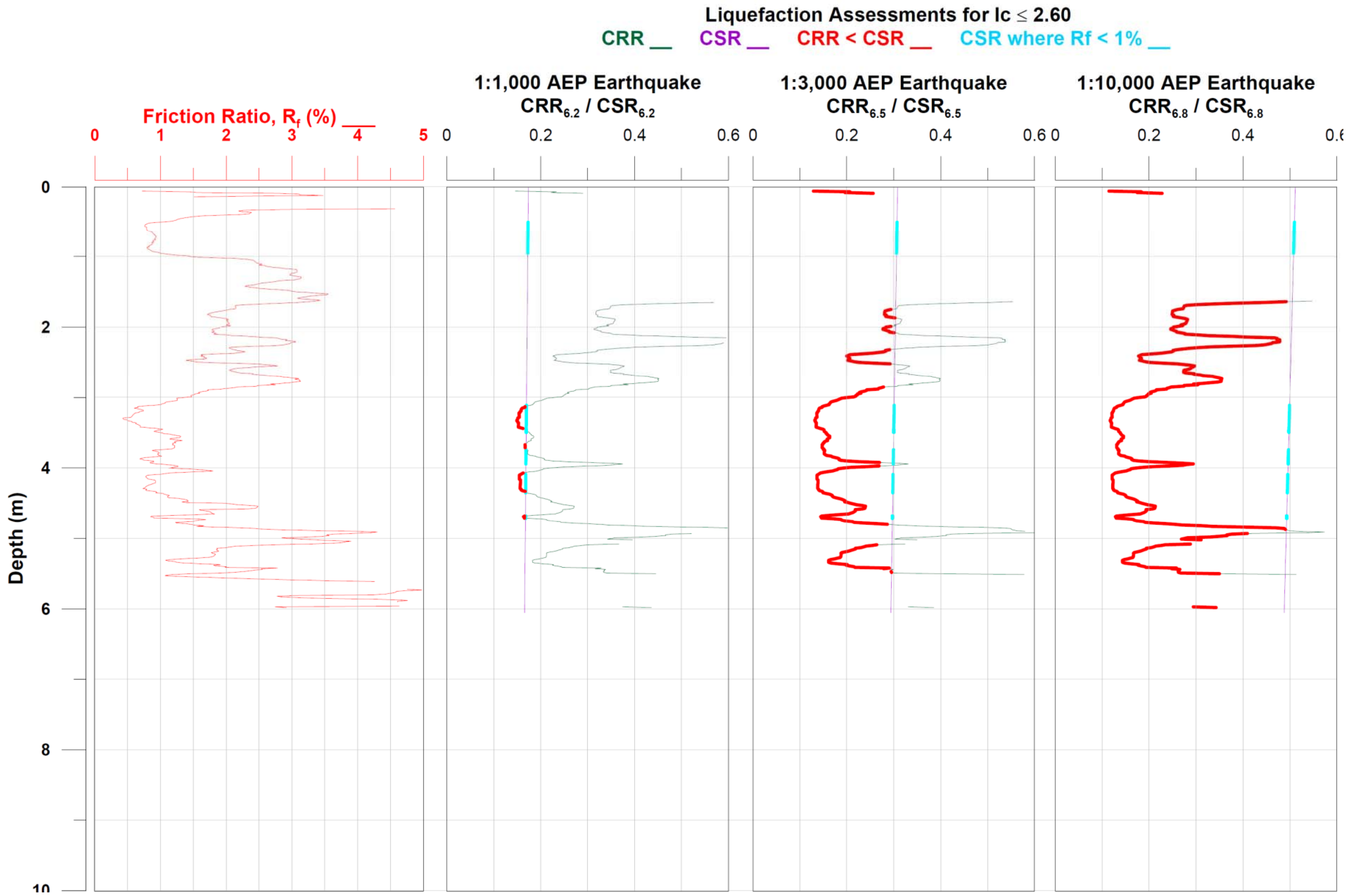
A_2 Cyclic liquefaction and post earthquake strength loss possible depending on loading and ground geometry.

Cohesive soils (B & C) – Evaluate potential behavior based on in-situ or laboratory test measurements or estimates of monotonic and cyclic undrained shear strengths.

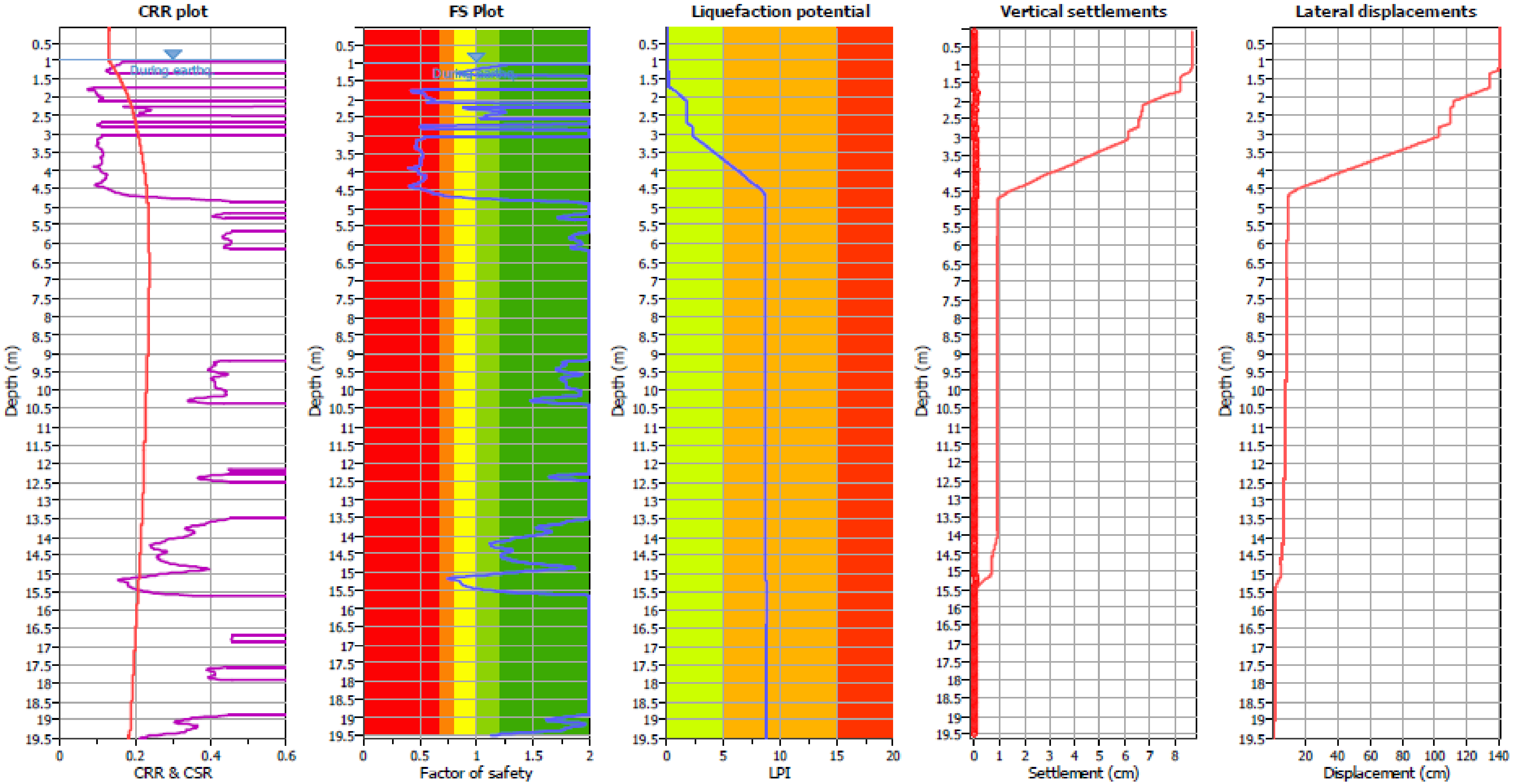
B Cyclic softening possible depending on level and duration of cyclic loading.

C Cyclic softening and post earthquake strength loss possible depending on soil sensitivity, loading and ground geometry.

Example – Liquefaction Assessment



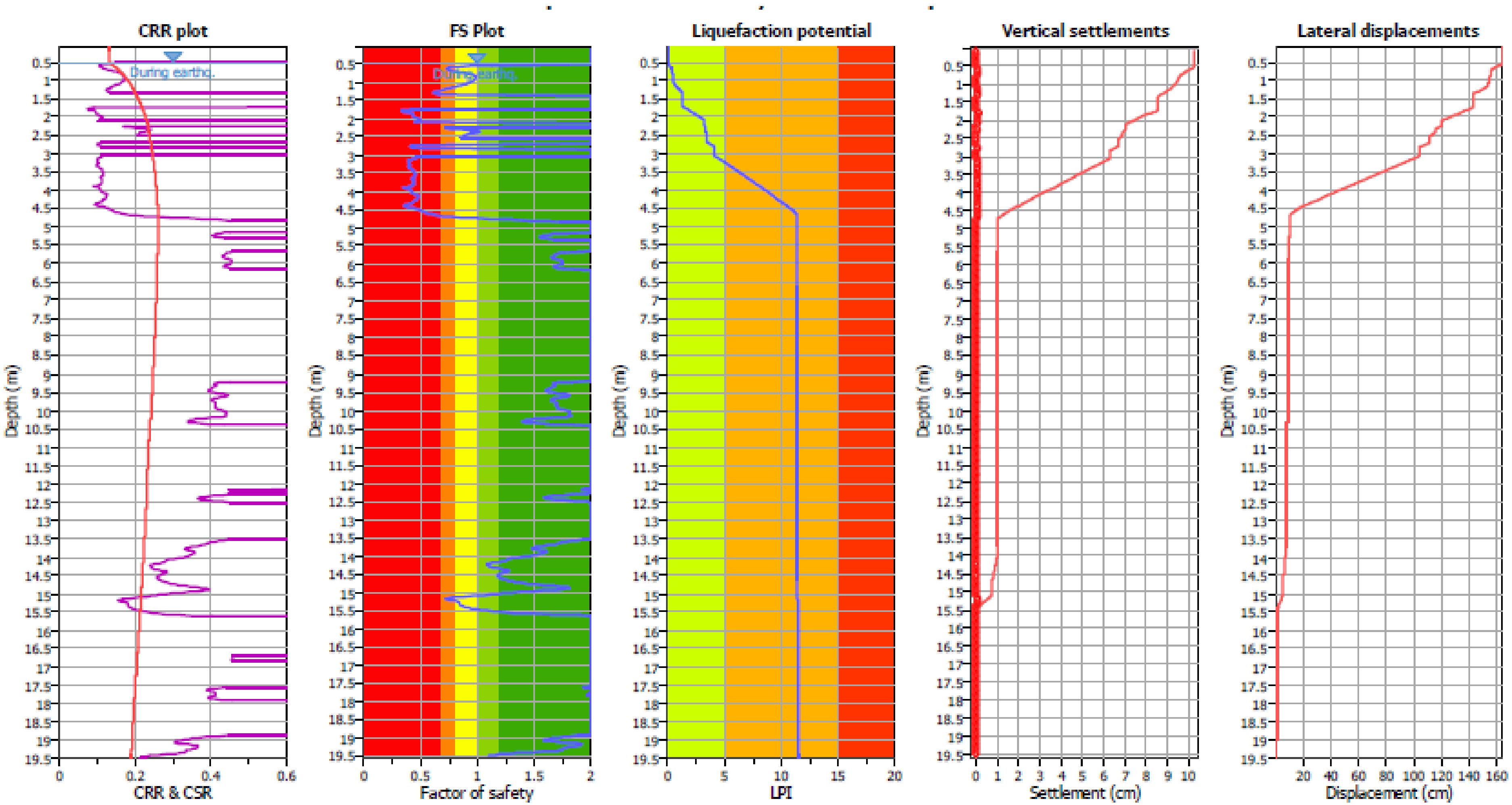
Effect of Water Table in Liquefaction Assessment



Water Table at 1.0m below ground level

CLiq software

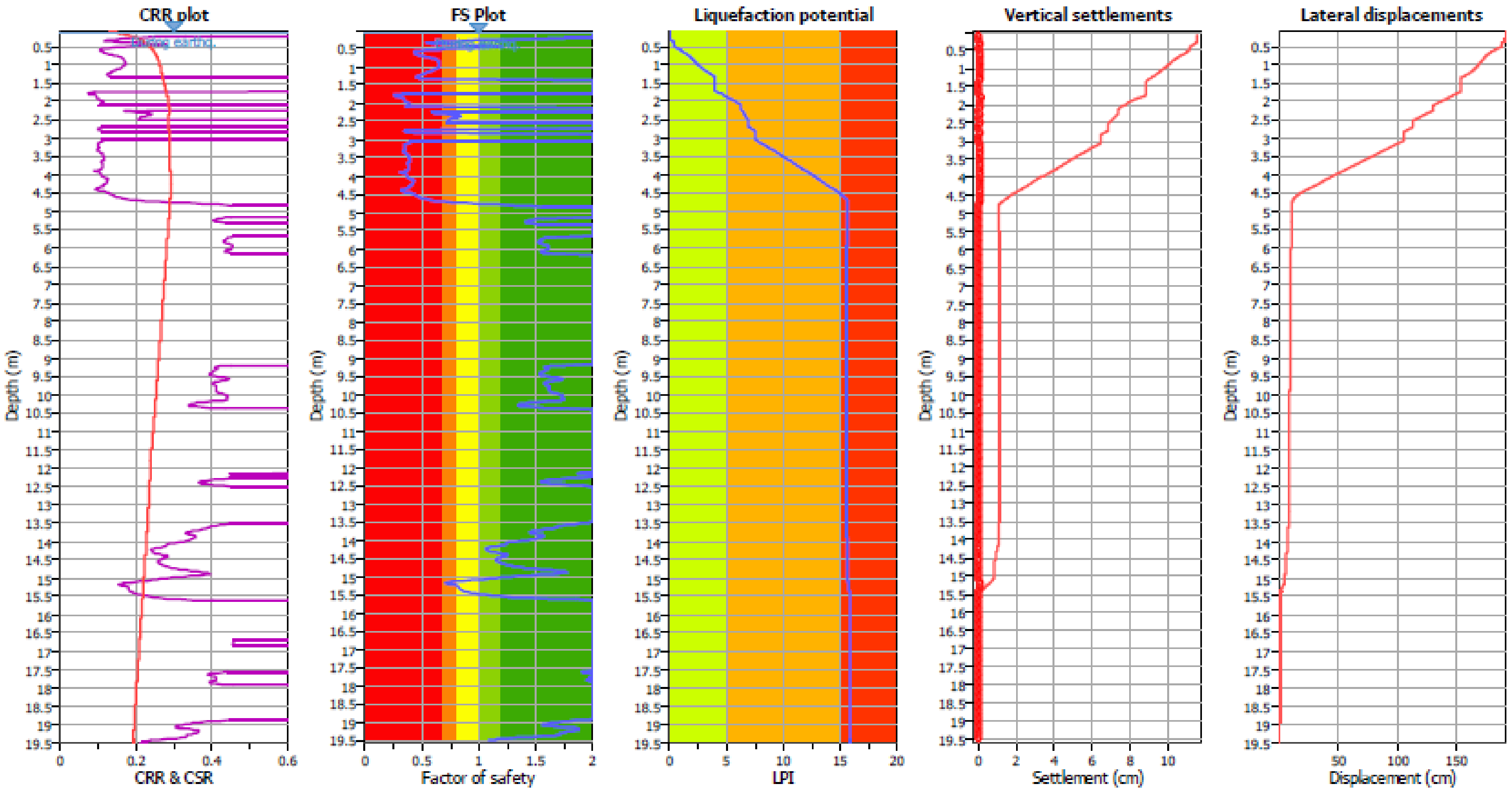
Effect of Water Table in Liquefaction Assessment



Water Table at 0.5m below ground level

CLiq software

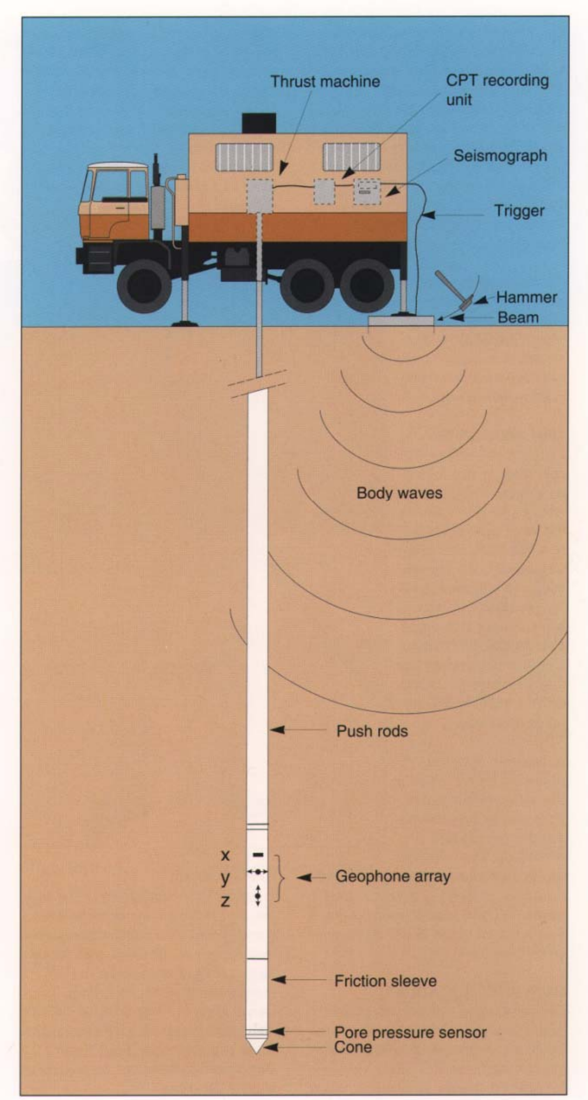
Effect of Water Table in Liquefaction Assessment



Water Table at 0.1m below ground level

CLiq software

Interpreting Low Strain Shear Modulus



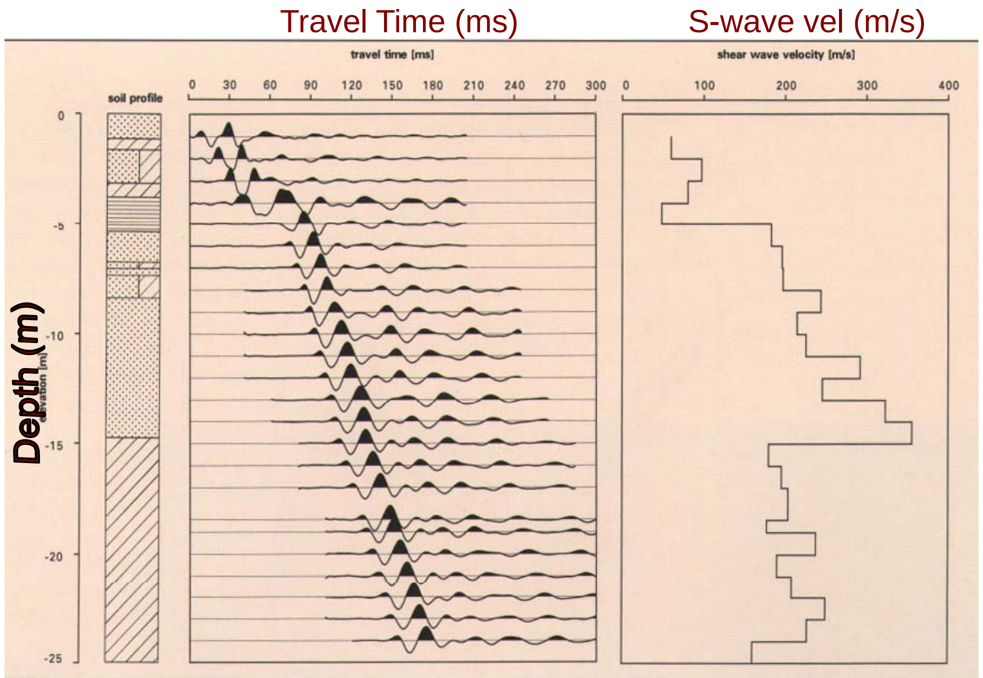
$$G_0 = G_{max} = \rho \ . \ v_s^2$$

where:

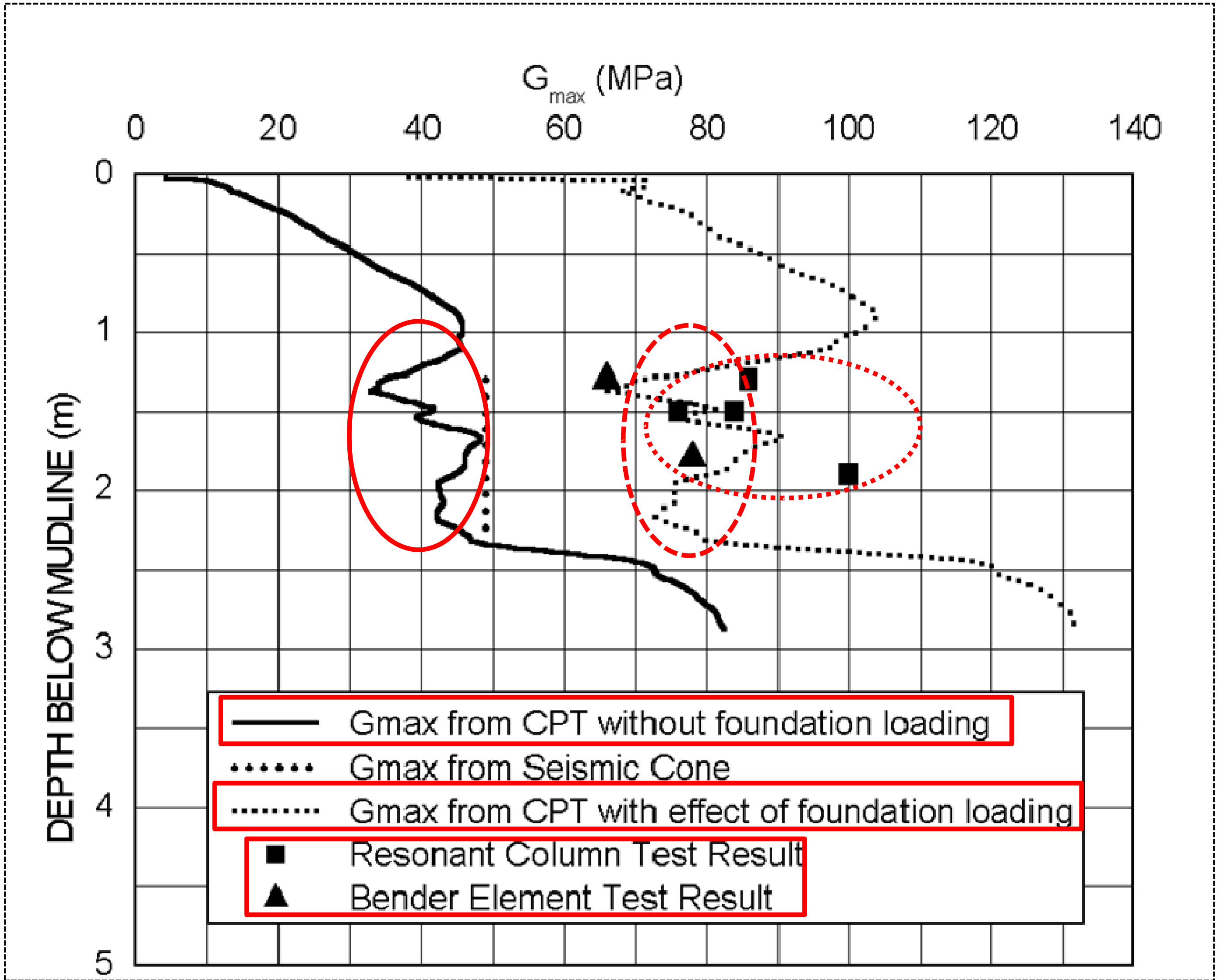
$G_0 = G_{max}$ = Low strain shear modulus (MPa)

ρ = mass density (Mg/m^3)

v_s = shear (S-wave) velocity (m/s)



Interpreting Low Strain Shear Modulus – Example



Some References

- Lunne T, Robertson P K and Powell JJM (1997) "Cone Penetration Testing in Geotechnical Practice", *Blackie Academic & Professional, ISBN 0 751 40393 8*.

- Meigh P. W (2001), Technical Note, "Monotonic & Dilatory Piezocone Dissipation in NC and OC Geomaterials"

- Ramsey, N (2010), "Some issues related to applications of the CPT", CPT'10, International Conference on Cone Penetration Testing, Huntington Beach, California, May 2010

- Robertson, P. K. (1990) "Soil Classification Using the Cone Penetration Test", Canadian Geotechnical Journal, 27(1), 151-158.

- Robertson, P. K. (2012) "Guide to Cone Penetration Testing for Geotechnical Engineering, 5th Edition". Can be downloaded from www.greggdrilling.com.

Thank You

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Meeting the challenge every day, worldwide.