CPT GENERAL NOTES

DESCRIPTION OF MEASUREMENTS AND CALIBRATIONS

To be reported per ASTM D5778:

Uncorrected Tip Resistance, q_c
Measured force acting on the cone divided by the cone's projected area

Corrected Tip Resistance, q_t
Cone resistance corrected for porewater and net area ratio effects
$q_t = q_c + U2(1 - a)$
Where a is the net area ratio, a lab calibration of the cone typically between 0.70 and 0.85

Pore Pressure, U1/U2
Pore pressure generated during penetration
U1 - sensor on the face of the cone
U2 - sensor on the shoulder (more common)

Sleeve Friction, fs
Frictional force acting on the sleeve divided by its surface area

Normalized Friction Ratio, FR
The ratio as a percentage of fs to q_t, accounting for overburden pressure

To be reported per ASTM D7400, if collected:

Shear Wave Velocity, Vs
Measured in a Seismic CPT and provides direct measure of soil stiffness

DESCRIPTION OF GEOTECHNICAL CORRELATIONS

Normalized Tip Resistance, Q_t
$Q_t = (q_t - \sigma_{v0})/\sigma'_{v0}$

Over Consolidation Ratio, OCR
OCR (1) = $0.25(Q_t)^{1.25}$
OCR (2) = $0.33(Q_t)$

Undrained Shear Strength, Su
$Su = Q_t \times \sigma'_{v0}/N_{kt}$
N_{kt} is a geographical factor (shown on Su plot)

Sensitivy, St
$St = (q_t - \sigma_{v0}/N_{kt}) \times (1/fs)$

Effective Friction Angle, ϕ'
ϕ' (1) = $\tan^{-1}(0.373[\log(q_t/\sigma'_{v0}) + 0.29])$
ϕ' (2) = $17.6 + 11[\log(Q_t)]$

Unit Weight
$UW = (0.27[\log(FR)]+0.36[\log(q_t/atm)]+1.236) \times UW_{water}$
σ_{v0} is taken as the incremental sum of the unit weights

SPT N_{60}
$N_{60} = (q_t/atm) / 10^{(1.1268 - 0.2817Ic)}$

Soil Behavior Type Index, Ic
$Ic = [(3.47 - \log(Q_t))^2 + (\log(FR) + 1.22)^2]^{0.5}$

Small Strain Modulus, G_0
$G_0 = \rho Vs^2$

Elastic Modulus, Es (assumes $q/q_{ultimate}$ ~ 0.3, i.e. FS = 3)
Es (1) = $2.6\Psi G_0$
where $\Psi = 0.56 - 0.33\log Q_{t,clean\ sand}$
Es (2) = G_0
Es (3) = $0.015 \times 10^{(0.55Ic + 1.68)}(q_t - \sigma_{v0})$
Es (4) = $2.5q_t$

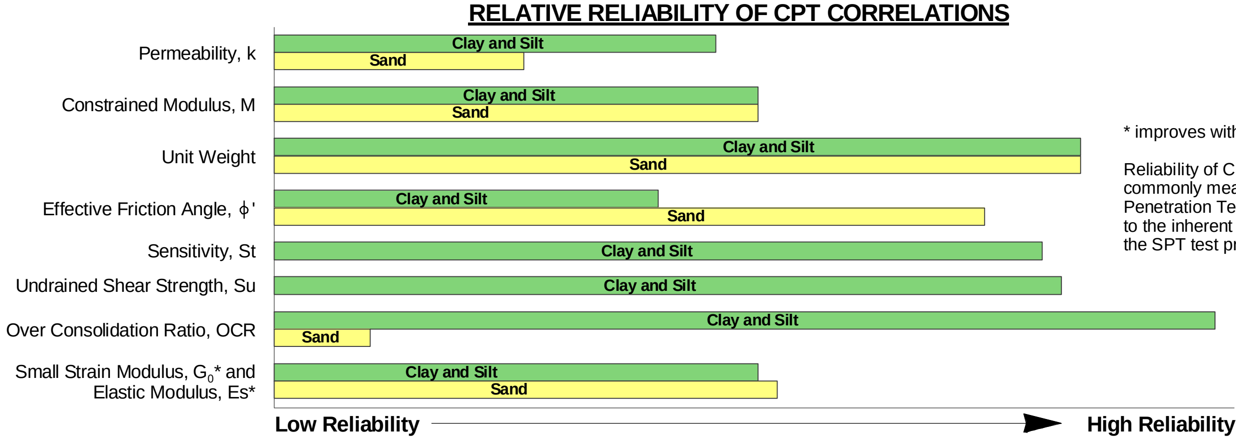
Constrained Modulus, M
$M = \alpha_M(q_t - \sigma_{v0})$
For Ic > 2.2 (fine-grained soils)
$\alpha_M = Q_t$ with maximum of 14
For Ic < 2.2 (coarse-grained soils)
$\alpha_M = 0.0188 \times 10^{(0.55Ic + 1.68)}$

Hydraulic Conductivity, k
For 1.0 < Ic < 3.27 $k = 10^{(0.952 - 3.04Ic)}$
For 3.27 < Ic < 4.0 $k = 10^{(-4.52 - 1.37Ic)}$

REPORTED PARAMETERS

CPT logs as provided, at a minimum, report the data as required by ASTM D5778 and ASTM D7400 (if applicable). This minimum data include tip resistance, sleeve resistance, and porewater pressure. Other correlated parameters may also be provided. These other correlated parameters are interpretations of the measured data based upon published and reliable references, but they do not necessarily represent the actual values that would be derived from direct testing to determine the various parameters. The following chart illustrates estimates of reliability associated with correlated parameters based upon the literature referenced below.

RELATIVE RELIABILITY OF CPT CORRELATIONS



* improves with seismic Vs measurements

Reliability of CPT-predicted N_{60} values as commonly measured by the Standard Penetration Test (SPT) is not provided due to the inherent inaccuracy associated with the SPT test procedure.

WATER LEVEL

The groundwater level at the CPT location is used to normalize the measurements for vertical overburden pressures and as a result influences the normalized soil behavior type classification and correlated soil parameters. The water level may either be "measured" or "estimated:"

Measured - Depth to water directly measured in the field

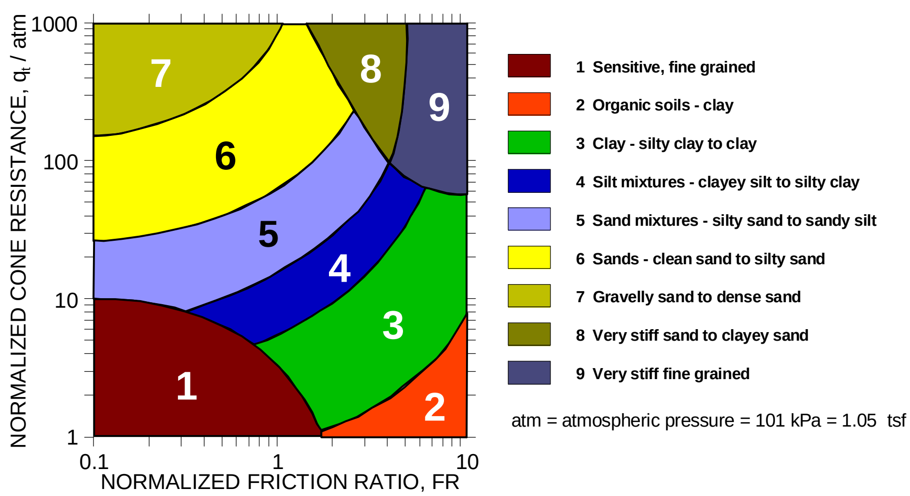
Estimated - Depth to water interpolated by the practitioner using pore pressure measurements in coarse grained soils and known site conditions

While groundwater levels displayed as "measured" more accurately represent site conditions at the time of testing than those "estimated," in either case the groundwater should be further defined prior to construction as groundwater level variations will occur over time.

CONE PENETRATION SOIL BEHAVIOR TYPE

The estimated stratigraphic profiles included in the CPT logs are based on relationships between corrected tip resistance (q_t), friction resistance (fs), and porewater pressure (U2). The normalized friction ratio (FR) is used to classify the soil behavior type.

Typically, silts and clays have high FR values and generate large excess penetration porewater pressures; sands have lower FRs and do not generate excess penetration porewater pressures. Negative pore pressure measurements are indicative of fissured fine-grained material. The adjacent graph (Robertson et al.) presents the soil behavior type correlation used for the logs. This normalized SBT chart, generally considered the most reliable, does not use pore pressure to determine SBT due to its lack of repeatability in onshore CPTs.



atm = atmospheric pressure = 101 kPa = 1.05 tsf

REFERENCES

Kulhawy, F.H., Mayne, P.W., (1997). "Manual on Estimating Soil Properties for Foundation Design," Electric Power Research Institute, Palo Alto, CA.

Mayne, P.W., (2013). "Geotechnical Site Exploration in the Year 2013," Georgia Institute of Technology, Atlanta, GA.

Robertson, P.K., Cabal, K.L. (2012). "Guide to Cone Penetration Testing for Geotechnical Engineering," Signal Hill, CA.

Schmertmann, J.H., (1970). "Static Cone to Compute Static Settlement over Sand," *Journal of the Soil Mechanics and Foundations Division*, 96(SM3), 1011-1043.

If no prior CPT experience exists in a given geologic environment it is advisable to obtain samples from appropriate locations to verify the soil type. If significant CPT experience is available and the charts have been evaluated based on this experience, samples may not always be required.

Soil behavior type can be improved if pore pressure measurements are also collected, as shown on Figure 23. In soft clays and silts the penetration pore pressures can be very large, whereas, in stiff heavily over-consolidated clays or dense silts and silty sands the penetration pore pressures (u_2) can be small and sometimes negative relative to the equilibrium pore pressures (u_0). The rate of pore pressure dissipation during a pause in penetration can also guide in the soil type. In sandy soils any excess pore pressures will dissipate very quickly, whereas, in clays the rate of dissipation can be very slow.

To simplify the application of the CPT $SBT_{\mathbf{n}}$ chart shown in Figure 22, the normalized cone parameters Q_t and F_r can be combined into one Soil Behavior Type index, I_c, where I_c is the radius of the essentially concentric circles that represent the boundaries between each SBT_n zone. I_c can be defined as follows;

$$I_c = ((3.47 - \log Q_t)^2 + (\log F_r + 1.22)^2)^{0.5}$$

where:

Q_t = normalized cone penetration resistance (dimensionless)

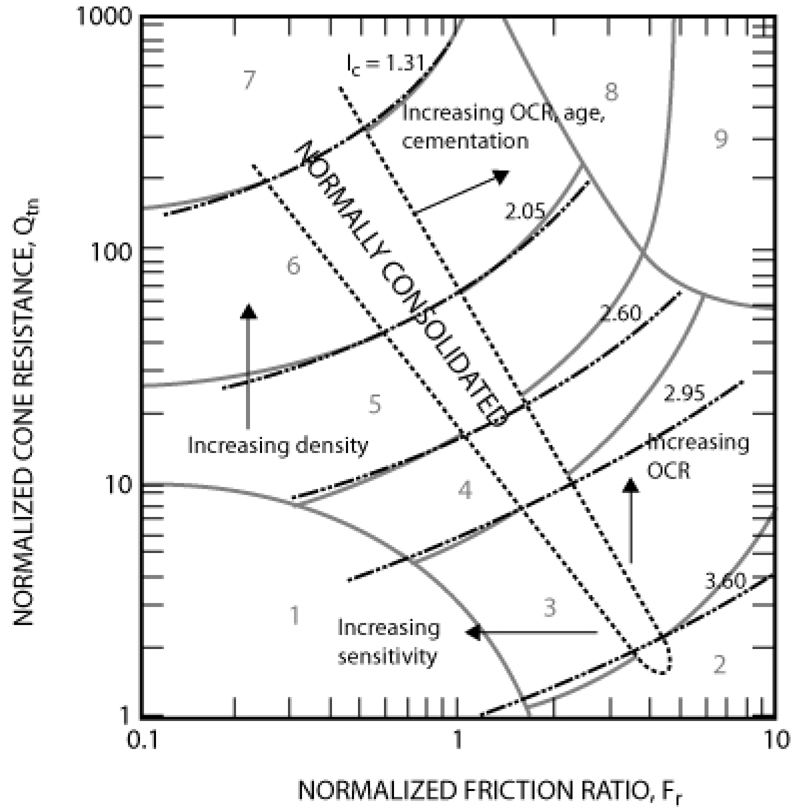
= $(q_t - \sigma_{vo})/\sigma'_{vo}$

F_r = normalized friction ratio, in %

= $(f_s/(q_t - \sigma_{vo}))$ x 100%

The term Q_t represents the simple normalization with a stress exponent (n) of 1.0, which applies well to clay-like soils. Robertson (2009) suggested that the normalized SBT_n charts shown in Figures 22 and 23 should be used with the normalized cone resistance (Q_{tn}) calculated using a stress exponent that varies with soil type via I_c (i.e. Q_{tn}, see Figure 46 for details).

The approximate boundaries of soil behavior types are then given in terms of the SBT_n index, I_c, as shown in Figure 22. The soil behavior type index does not apply to zones 1, 8 and 9. Profiles of I_c provide a simple guide to the continuous variation of soil behavior type in a given soil profile based on CPT results. Independent studies have shown that the normalized SBT_n chart shown in Figure 22 typically has greater than 80% reliability when compared with samples.



Zone	*Soil Behavior Type*	I_c
1	*Sensitive, fine grained*	N/A
2	*Organic soils – clay*	> 3.6
3	*Clays – silty clay to clay*	2.95 – 3.6
4	*Silt mixtures – clayey silt to silty clay*	2.60 – 2.95
5	*Sand mixtures – silty sand to sandy silt*	2.05 – 2.6
6	*Sands – clean sand to silty sand*	1.31 – 2.05
7	*Gravelly sand to dense sand*	< 1.31
8	*Very stiff sand to clayey sand**	N/A
9	*Very stiff, fine grained**	N/A

** Heavily overconsolidated or cemented*

Figure 22 Normalized CPT Soil Behavior Type (SBT_n) chart, Q_t - F
(Robertson, 1990, updated by Robertson, 2010).