

# CALCULATED CPT GEOTECHNICAL PARAMETERS

## A Detailed Description of the Methods Used in ConeTec's CPT Geotechnical Parameter Calculation and Plotting Software



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### Limitations

The geotechnical parameter output was prepared specifically for the site and project named in the accompanying report subject to objectives, site conditions and criteria provided to ConeTec by the client. The output may not be relied upon by any other party or for any other site without the express written permission of ConeTec Group (ConeTec) or any of its affiliates. For this project, ConeTec has provided site investigation services, prepared factual data reporting and produced geotechnical parameter calculations consistent with current best practices. No other warranty, expressed or implied, is made.

To understand the calculations that have been performed and to be able to reproduce the calculated parameters the user is directed to the basic descriptions for the methods in this document and the detailed descriptions and their associated limitations and appropriateness in the technical references cited for each parameter.

## ConeTec's Calculated CPT Geotechnical Parameters as of November 26, 2019

ConeTec's CPT parameter calculation and plotting routine provides a tabular output of geotechnical parameters based on current published CPT correlations and is subject to change to reflect the current state of practice. Due to drainage conditions and the basic assumptions and limitations of the correlations, not all geotechnical parameters provided are considered applicable for all soil types. The results are presented only as a guide for geotechnical use and should be carefully examined for consideration in any geotechnical design. Reference to current literature is strongly recommended. ConeTec does not warranty the correctness or the applicability of any of the geotechnical parameters calculated by the program and does not assume liability for any use of the results in any design or review. For verification purposes we recommend that representative hand calculations be done for any parameter that is critical for design purposes. The end user of the parameter output should also be fully aware of the techniques and the limitations of any method used by the program. The purpose of this document is to inform the user as to which methods were used and to direct the end user to the appropriate technical papers and/or publications for further reference.

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The CPT calculations are based on values of tip resistance, sleeve friction and pore pressures considered at each data point or averaged over a user specified layer thickness (e.g. 0.20 m). Note that  $q_t$  is the tip resistance corrected for pore pressure effects and  $q_c$  is the recorded tip resistance. The corrected tip resistance (corrected using  $u_2$  pore pressure values) is used for all of the calculations. Since all ConeTec cones have equal end area friction sleeves pore pressure corrections to sleeve friction,  $f_s$ , are not required.

The tip correction is:  $q_t = q_c + (1-a) \cdot u_2$  (consistent units are implied)

where:  $q_t$  is the corrected tip resistance

$q_c$  is the recorded tip resistance

$u_2$  is the recorded dynamic pore pressure behind the tip ( $u_2$  position)

$a$  is the Net Area Ratio for the cone (typically 0.80 for ConeTec cones)

The total stress calculations are based on soil unit weight values that have been assigned to the Soil Behavior Type (SBT) zones, from a user defined unit weight profile, by using a single uniform value throughout the profile, through unit weight estimation techniques described in various technical papers or from a combination of these methods. The parameter output files indicate the method(s) used.

Effective vertical overburden stresses are calculated based on a hydrostatic distribution of equilibrium pore pressures below the water table or from a user defined equilibrium pore pressure profile (typically obtained from CPT dissipation tests) or a combination of the two. For over water projects the stress effects of the column of water above the mudline have been taken into account as has the appropriate unit weight of water. How this is done depends on where the instruments were zeroed (i.e. on deck or at the mudline). The parameter output files indicate the method(s) used.

A majority of parameter calculations are derived or driven by results based on material types as determined by the various soil behavior type charts depicted in Figures 1 through 5. The parameter output files indicate the method(s) used.

The Soil Behavior Type classification chart shown in Figure 1 is the classic non-normalized SBT Chart developed at the University of British Columbia and reported in Robertson, Campanella, Gillespie and Greig (1986). Figure 2 shows the original normalized (linear method) SBT chart developed by Robertson (1990). The Bq classification charts shown in Figures 3a and 3b incorporate pore pressures into the SBT classification and are based on the methods described in Robertson (1990). Many of these charts have been summarized in Lunne, Robertson and Powell (1997). The



Jefferies and Davies SBT chart shown in Figure 3c is based on the techniques discussed in Jefferies and Davies (1993) which introduced the concept of the Soil Behavior Type Index parameter,  $I_c$ . Please note that the  $I_c$  parameter developed by Robertson and Fear (1995) and Robertson and Wride (1998) is similar in concept but uses a slightly different calculation method than that used by Jefferies and Davies (1993) as the latter incorporates pore pressure in their technique through the use of the  $B_q$  parameter. The normalized  $Q_{tn}$  SBT chart shown in Figure 4 is based on the work by Robertson (2009) utilizing a variable stress ratio exponent,  $n$ , for normalization based on a slightly modified redefinition and iterative approach for  $I_c$ . The boundary curves drawn on the chart are based on the work described in Robertson (2010).

Figure 5 shows a revised behavior based chart by Robertson (2016) depicting contractive-dilative zones. As the zones represent material behavior rather than soil gradation ConeTec has chosen a set of zone colors that are less likely to be confused with material type colors from previous SBT charts. These colors differ from those used by Dr. Robertson.

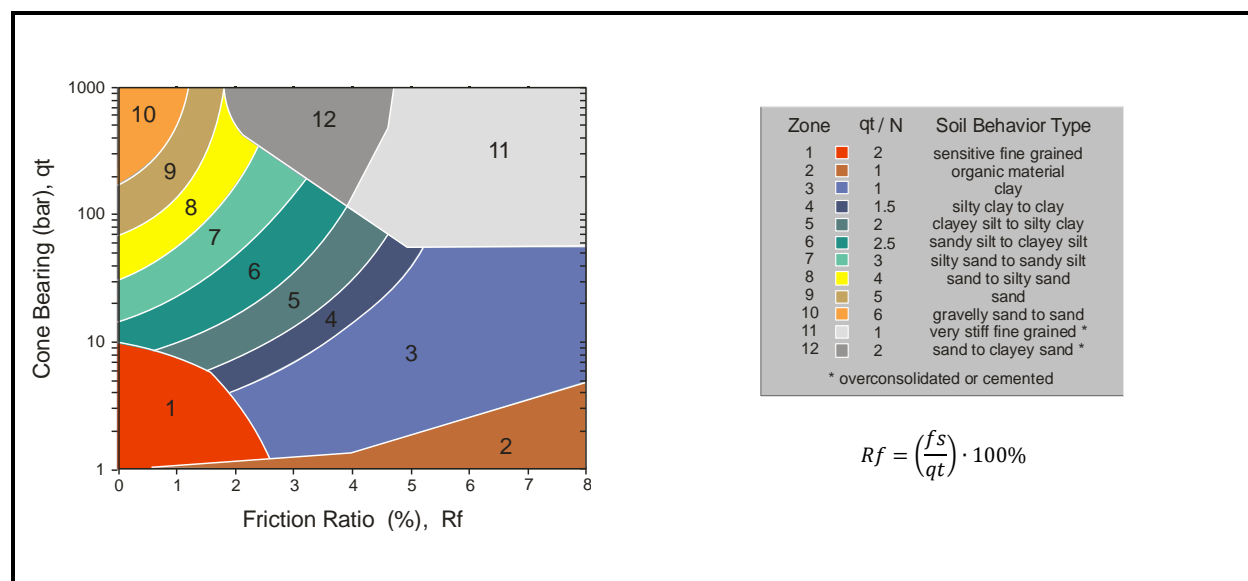


Figure 1. Non-Normalized Soil Behavior Type Classification Chart (SBT)

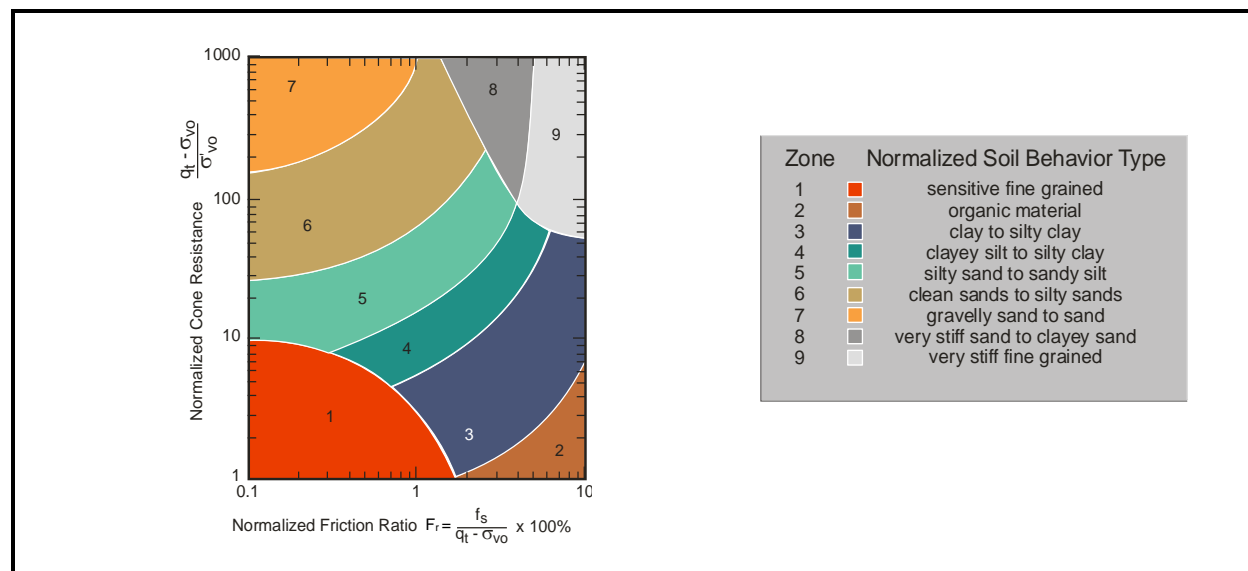


Figure 2. Normalized Soil Behavior Type Classification Chart (SBTn)

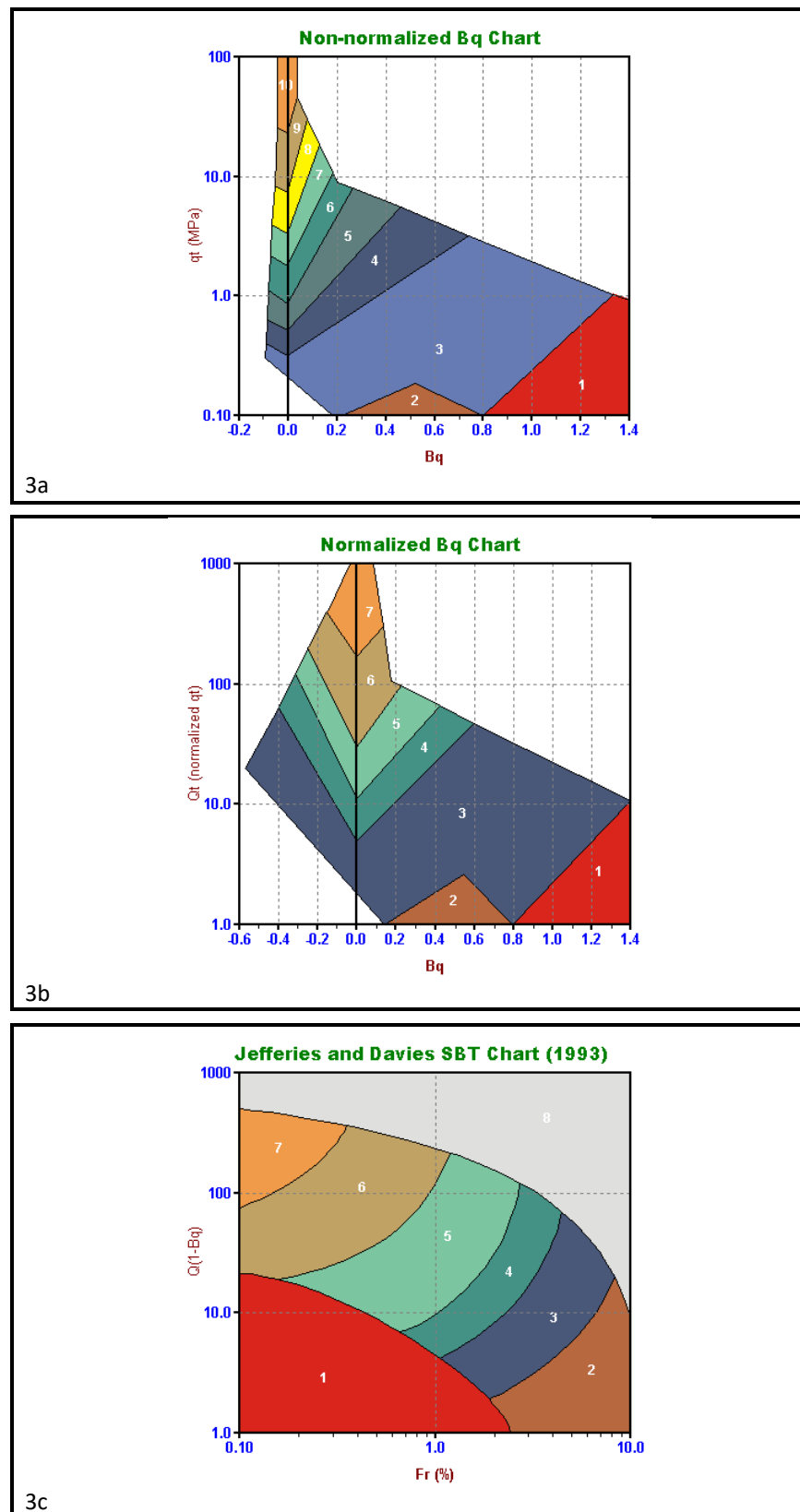


Figure 3. Alternate Soil Behavior Type Charts

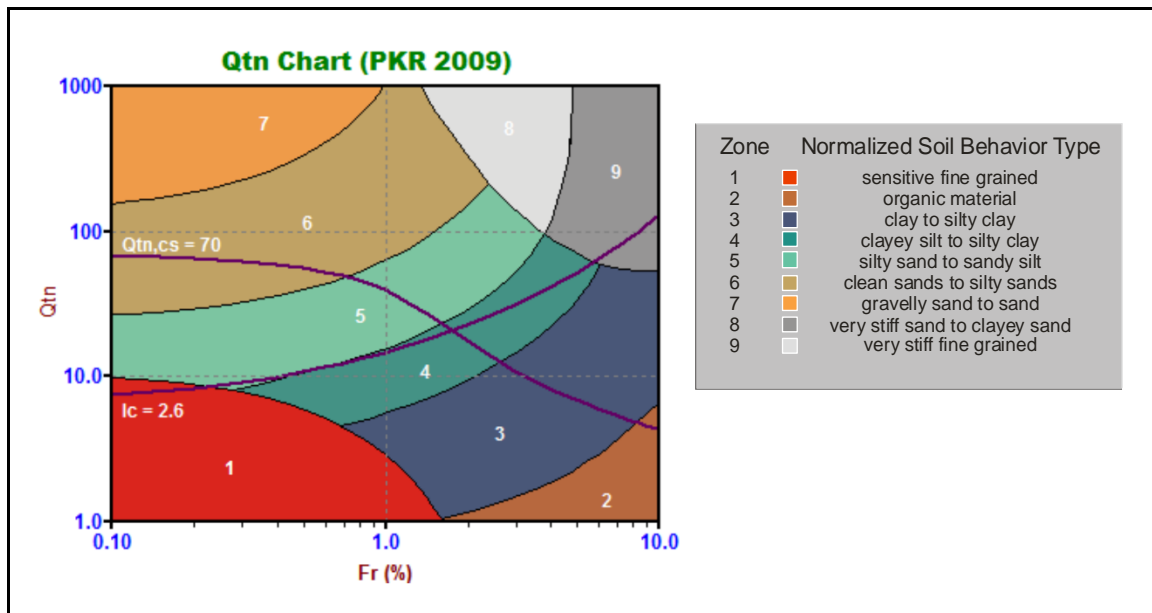
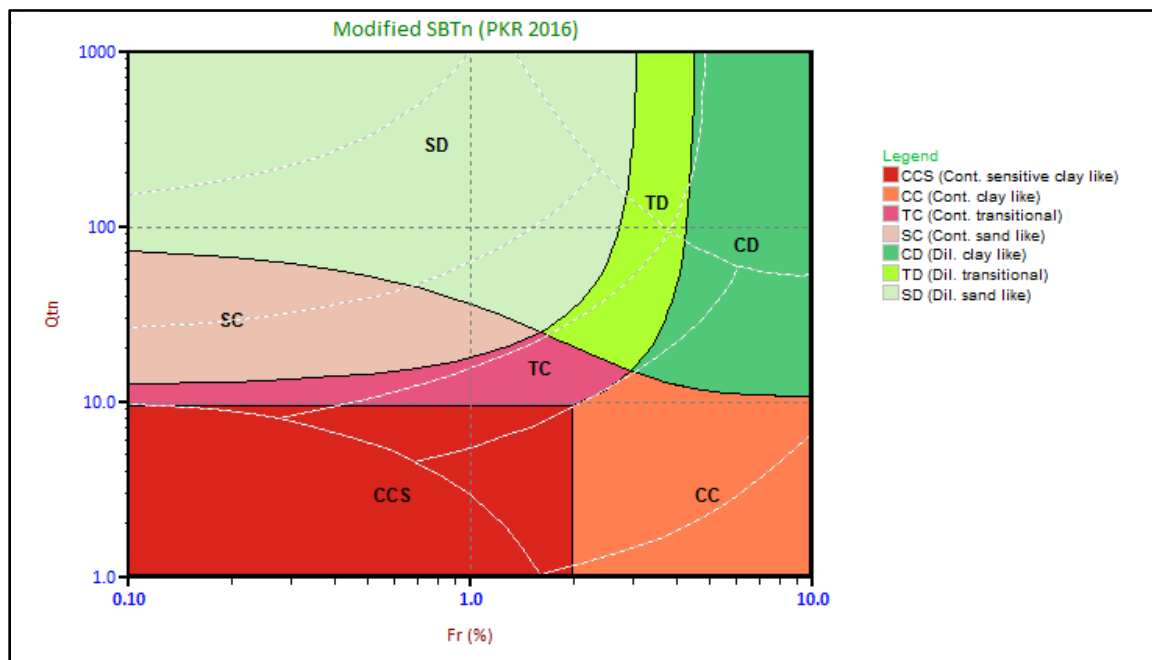
Figure 4. Normalized Soil Behavior Type Chart using  $Q_{tn}$  (SBT  $Q_{tn}$ )

Figure 5. Modified SBTn Behavior Based Chart

Details regarding the geotechnical parameter calculations are provided in Tables 1a and 1b. The appropriate references cited are listed in Table 2. Non-liquefaction specific parameters are detailed in Table 1a and liquefaction specific parameters are detailed in Table 1b.

Where methods are based on charts or techniques that are too complex to describe in this summary the user should refer to the cited material. Specific limitations for each method are described in the cited material.

Where the results of a calculation/correlation are deemed 'invalid' the value will be represented by the text strings "-9999", "-9999.0", the value 0.0 (Zero) or an empty cell. Invalid results will occur because of (and not limited to) one or a combination of:

1. Invalid or undefined CPT data (e.g. drilled out section or data gap).
2. Where the calculation method is inappropriate, for example, drained parameters in a material behaving as an undrained material (and vice versa).
3. Where input values are beyond the range of the referenced charts or specified limitations of the correlation method.
4. Where pre-requisite or intermediate parameter calculations are invalid.

The parameters selected for output from the program are often specific to a particular project. As such, not all of the calculated parameters listed in Table 1 may be included in the output files delivered with this report.

The output files are typically provided in Microsoft Excel XLS or XLSX format. The ConeTec software has several options for output depending on the number or types of calculated parameters desired or requested by the client. Each output file is named using the original COR file base name followed by a three or four letter indicator of the output set selected (e.g. BSC, TBL, NLI, NL2, IFI, IFI2) and possibly followed by an operator selected suffix identifying the characteristics of the particular calculation run.

**Table 1a. CPT Parameter Calculation Methods – Non liquefaction Parameters**

Calculated Parameter	Description	Equation	Ref
Depth	Mid Layer Depth <i>(where calculations are done at each point then Mid Layer Depth = Recorded Depth)</i>	$[Depth (Layer Top) + Depth (Layer Bottom)] / 2.0$	CK*
Elevation	Elevation of Mid Layer based on sounding collar elevation supplied by client or through site survey	Elevation = Collar Elevation - Depth	CK*
Avg qc	Averaged recorded tip value ( $q_c$ )	$Avg qc = \frac{1}{n} \sum_{i=1}^n q_c$ <i>n=1 when calculations are done at each point</i>	CK*
Avg qt	Averaged corrected tip ( $q_t$ ) where: $q_t = q_c + (1 - \alpha) \bullet u_2$	$Avg qt = \frac{1}{n} \sum_{i=1}^n q_t$ <i>n=1 when calculations are done at each point</i>	1
Avg fs	Averaged sleeve friction ( $f_s$ )	$Avg fs = \frac{1}{n} \sum_{i=1}^n f_s$ <i>n=1 when calculations are done at each point</i>	CK*
Avg Rf	Averaged friction ratio ( $R_f$ ) where friction ratio is defined as: $R_f = 100\% \bullet \frac{f_s}{q_t}$	$Avg Rf = 100\% \bullet \frac{Avg fs}{Avg qt}$ <i>n=1 when calculations are done at each point</i>	CK*
Avg u	Averaged dynamic pore pressure ( $u$ )	$Avg u = \frac{1}{n} \sum_{i=1}^n u_i$ <i>n=1 when calculations are done at each point</i>	CK*

Calculated Parameter	Description	Equation	Ref
Avg Res	Averaged Resistivity (this data is not always available since it is a specialized test requiring an additional module)	$AvgRes = \frac{1}{n} \sum_{i=1}^n Resistivity_i$ <i>n=1 when calculations are done at each point</i>	CK*
Avg UVIF	Averaged UVIF ultra-violet induced fluorescence (this data is not always available since it is a specialized test requiring an additional module)	$AvgUVIF = \frac{1}{n} \sum_{i=1}^n UVIF_i$ <i>n=1 when calculations are done at each point</i>	CK*
Avg Temp	Averaged Temperature (this data is not always available since it requires specialized calibrations)	$AvgTemp = \frac{1}{n} \sum_{i=1}^n Temperature_i$ <i>n=1 when calculations are done at each point</i>	CK*
Avg Gamma	Averaged Gamma Counts (this data is not always available since it is a specialized test requiring an additional module)	$AvgGamma = \frac{1}{n} \sum_{i=1}^n Gamma_i$ <i>n=1 when calculations are done at each point</i>	CK*
SBT	Soil Behavior Type as defined by Robertson et al 1986 (often referred to as Robertson and Campanella, 1986)	See Figure 1	1, 5
SBTn	Normalized Soil Behavior Type as defined by Robertson 1990 (linear normalization)	See Figure 2	2, 5
SBT-Bq	Non-normalized Soil Behavior type based on the Bq parameter	See Figure 3	1, 2, 5
SBT-Bqn	Normalized Soil Behavior based on the Bq parameter	See Figure 3	2, 5
SBT-JandD	Soil Behavior Type as defined by Jeffries and Davies	See Figure 3	7
SBT Qtn	Soil Behavior Type as defined by Robertson (2009) using a variable stress ratio exponent for normalization based on $I_c$	See Figure 4	15
Modified SBTn (contractive /dilative)	Modified SBTn chart as defined by Robertson (2016) indicating zones of contractive/dilative behavior.	See Figure 5	30
Unit Wt.	<p>Unit Weight of soil determined from one of the following user selectable options:</p> <ol style="list-style-type: none"> <li>1) uniform value</li> <li>2) value assigned to each SBT zone</li> <li>3) value assigned to each SBTn zone</li> <li>4) value assigned to SBTn zone as determined from Robertson and Wride (1998) based on <math>q_{c1n}</math></li> <li>5) values assigned to SBT Qtn zones</li> <li>6) Mayne <math>f_s</math> (sleeve friction) method</li> <li>7) Robertson 2010 method</li> <li>8) user supplied unit weight profile</li> </ol> <p>The last option may co-exist with any of the other options</p>	See references	3, 5, 15, 21, 24, 29

Calculated Parameter	Description	Equation	Ref
<p>TStress</p> <p><math>\sigma_v</math></p>	<p>Total vertical overburden stress at Mid Layer Depth</p> <p><i>A layer is defined as the averaging interval specified by the user where depths are reported at their respective mid-layer depth.</i></p> <p><i>For data calculated at each point layers are defined using the recorded depth as the mid-point of the layer. Thus, a layer starts half-way between the previous depth and the current depth unless this is the first point in which case the layer start is at zero depth. The layer bottom is half-way from the current depth to the next depth unless it is the last data point.</i></p> <p><i>Defining layers affects how stresses are calculated since the unit weight attributed to a data point is used throughout the entire layer. This means that to calculate the stresses the total stress at the top and bottom of a layer are required. The stress at mid layer is determined by adding the incremental stress from the layer top to the mid-layer depth. The stress at the layer bottom becomes the stress at the top of the subsequent layer. Stresses are NOT calculated from mid-point to mid-point.</i></p> <p><i>For over-water work the total stress due to the column of water above the mud line is taken into account where appropriate.</i></p>	$TStress = \sum_{i=1}^n \gamma_i h_i$ <p>where <math>\gamma_i</math> is layer unit weight <math>h_i</math> is layer thickness</p>	CK*
<p>EStress</p> <p><math>\sigma_v'</math></p>	Effective vertical overburden stress at mid-layer depth	$\sigma_v' = \sigma_v - u_{eq}$	CK*
<p>Equil u</p> <p><math>u_{eq}</math> or <math>u_0</math></p>	<p>Equilibrium pore pressure determined from one of the following user selectable options:</p> <ol style="list-style-type: none"> <li>1) hydrostatic below water table</li> <li>2) user supplied profile</li> <li>3) combination of those above</li> </ol> <p>When a user supplied profile is used/provided a linear interpolation is performed between equilibrium pore pressures defined at specific depths. If the profile values start below the water table then a linear transition from zero pressure at the water table to the first defined pointed is used.</p> <p>Equilibrium pore pressures may come from dissipation tests, adjacent piezometers or other sources. Occasionally, an extra equilibrium point ("assumed value") will be provided in the profile that does not come from a recorded value to smooth out any abrupt changes or to deal with material interfaces. These "assumed" values will be indicated on our plots and in tabular summaries.</p>	<p>For hydrostatic option:</p> $u_{eq} = \gamma_w \cdot (D - D_{wt})$ <p>where <math>u_{eq}</math> is equilibrium pore pressure <math>\gamma_w</math> is unit weight of water <math>D</math> is the current depth <math>D_{wt}</math> is the depth to the water table</p>	CK*
$K_0$	Coefficient of earth pressure at rest, $K_0$	$K_0 = (1 - \sin \Phi') OCR^{\sin \Phi'}$	17
$C_n$	Overburden stress correction factor used for $(N_1)_{60}$ and older CPT parameters	$C_n = (P_a / \sigma_v')^{0.5}$ <p>where <math>0.0 &lt; C_n &lt; 2.0</math> (user adjustable, typically 1.7) <math>P_a</math> is atmospheric pressure (100 kPa)</p>	12
$C_q$	Overburden stress normalizing factor	$C_q = 1.8 / (0.8 + (\sigma_v' / P_a))$ <p>where <math>0.0 &lt; C_q &lt; 2.0</math> (user adjustable) <math>P_a</math> is atmospheric pressure (100 kPa)</p>	3, 12



Calculated Parameter	Description	Equation	Ref
$N_{60}$	SPT N value at 60% energy calculated from $q_t/N$ ratios assigned to each SBT zone. This method has abrupt N value changes at zone boundaries.	<i>See Figure 1</i>	5
$(N_1)_{60}$	SPT $N_{60}$ value corrected for overburden pressure	$(N_1)_{60} = C_n \cdot N_{60}$	4
$N_{60lc}$	SPT $N_{60}$ values based on the $I_c$ parameter [as defined by Roberston and Wride 1998 (5), or by Robertson 2009 (15)].	$(q_t/P_a)/N_{60} = 8.5 (1 - I_c/4.6)$ $(q_t/P_a)/N_{60} = 10^{(1.1268 - 0.2817I_c)}$ $P_a$ being atmospheric pressure	5 15, 31
$(N_1)_{60lc}$	SPT $N_{60}$ value corrected for overburden pressure (using $N_{60lc}$ ). User has 3 options.	1) $(N_1)_{60lc} = C_n \cdot (N_{60lc})$ 2) $q_{c1n}/(N_1)_{60lc} = 8.5 (1 - I_c/4.6)$ 3) $(Q_{tn})/(N_1)_{60lc} = 10^{(1.1268 - 0.2817I_c)}$	4 5 15, 31
$S_u$ or $S_u$ (Nkt)	Undrained shear strength based on $q_t$ $S_u$ factor $N_{kt}$ is user selectable	$S_u = \frac{q_t - \sigma_v}{N_{kt}}$	1, 5
$S_u$ or $S_u$ (Ndu)	Undrained shear strength based on pore pressure $S_u$ factor $N_{du}$ is user selectable	$S_u = \frac{u_2 - u_{eq}}{N_{du}}$	1, 5
$D_r$	Relative Density determined from one of the following user selectable options: a) Ticino Sand b) Høksund Sand c) Schmertmann (1978) d) Jamiolkowski (1985) - All Sands e) Jamiolkowski et al (2003) (various compressibilities, $K_o$ )	See reference (methods a through d) Jamiolkowski et al (2003) reference	5 14
$\Phi$ $\phi$	Friction Angle determined from one of the following user selectable options (methods a through d are for sands and method e is for silts and clays): a) Campanella and Robertson b) Durgunoglu and Mitchel c) Janbu d) Kulhawy and Mayne e) NTH method (clays and silts)	See appropriate reference	5 5 5 11 23
Delta U/ $q_t$	Differential pore pressure ratio (older parameter used before $B_q$ was established)	$= \frac{\Delta u}{q_t}$  where: $\Delta u = u - u_{eq}$ and $u$ = dynamic pore pressure $u_{eq}$ = equilibrium pore pressure	CK*
$B_q$	Pore pressure parameter	$B_q = \frac{\Delta u}{q_t - \sigma_v}$  where: $\Delta u = u - u_{eq}$ and $u$ = dynamic pore pressure $u_{eq}$ = equilibrium pore pressure	1, 2, 5
Net $q_t$ or $q_{tNet}$	Net tip resistance (used in many subsequent correlations)	$q_t - \sigma_v$	CK*
$q_e$	Effective tip resistance (using the dynamic pore pressure $u_2$ and not equilibrium pore pressure)	$q_t - u_2$	CK*

Calculated Parameter	Description	Equation	Ref
qeNorm	Normalized effective tip resistance	$\frac{qt - u_2}{\sigma_v}$	CK*
$Q_t$ or Norm: $Q_t$	Normalized $q_t$ for Soil Behavior Type classification as defined by Robertson (1990) using a linear stress normalization. Note this is different from $Q_{tn}$ .	$Q_t = \frac{qt - \sigma_v}{\sigma_v}$	2, 5
$F_r$ or Norm: $F_r$	Normalized Friction Ratio for Soil Behavior Type classification as defined by Robertson (1990)	$Fr = 100\% \cdot \frac{fs}{qt - \sigma_v}$	2, 5
$Q(1-Bq)$	$Q(1-Bq)$ grouping as suggested by Jefferies and Davies for their classification chart and the establishment of their $I_c$ parameter	$Q \cdot (1 - Bq)$  <i>where <math>Bq</math> is defined as above and <math>Q</math> is the same as the normalized tip resistance, <math>Q_t</math>, defined above</i>	6, 7
qc1	Normalized tip resistance, $q_{c1}$ , using a fixed stress ratio exponent, $n$ (this method has stress units)	$q_{c1} = q_t \cdot (P_a / \sigma_v')^{0.5}$ where: $P_a$ = atmospheric pressure	21
qc1 (0.5)	Normalized tip resistance, $q_{c1}$ , using a fixed stress ratio exponent, $n$ (this method is unit-less)	$q_{c1} (0.5) = (q_t / P_a) \cdot (P_a / \sigma_v')^{0.5}$ where: $P_a$ = atmospheric pressure	5
qc1 ( $C_n$ )	Normalized tip resistance, $q_{c1}$ , based on $C_n$ (this method has stress units)	$q_{c1}(C_n) = C_n \cdot q_t$	5, 12
qc1 ( $C_q$ )	Normalized tip resistance, $q_{c1}$ , based on $C_q$ (this method has stress units)	$q_{c1}(C_q) = C_q \cdot q_t$ (some papers use $q_c$ )	5, 12
qc1n	normalized tip resistance, $q_{c1n}$ , using a variable stress ratio exponent, $n$ (where $n=0.0, 0.70, 1.0$ ) (this method is unit-less)	$q_{c1n} = (q_t / P_a)(P_a / \sigma_v')^n$ where: $P_a$ = atm. Pressure and $n$ varies as described below	3, 5
$I_c$ or $I_c$ (RW1998)	Soil Behavior Type Index as defined by Robertson and Fear (1995) and Robertson and Wride (1998) for estimating grain size characteristics and providing smooth gradational changes across the SBTn chart	$I_c = [(3.47 - \log_{10} Q)^2 + (\log_{10} Fr + 1.22)^2]^{0.5}$  <i>Where:</i> $Q = \left( \frac{qt - \sigma_v}{P_a} \right) \left( \frac{P_a}{\sigma_v'} \right)^n$  <i>Or</i> $Q = q_{c1n} = \left( \frac{qt}{P_a} \right) \left( \frac{P_a}{\sigma_v'} \right)^n$  <i>depending on the iteration in determining <math>I_c</math></i>  <i>And <math>Fr</math> is in percent <math>P_a</math> = atmospheric pressure</i>  <i><math>n</math> varies between 0.5, 0.70 and 1.0 and is selected in an iterative manner based on the resulting <math>I_c</math></i>	3, 5, 21
$I_c$ (PKR 2009)	Soil Behavior Type Index, $I_c$ (PKR 2009) based on a variable stress ratio exponent $n$ , which itself is based on $I_c$ (PKR 2009). An iterative calculation is required to determine $I_c$ (PKR 2009) and its corresponding $n$ (PKR 2009).	$I_c \text{ (PKR 2009)} = [(3.47 - \log_{10} Q_{tn})^2 + (1.22 + \log_{10} Fr)^2]^{0.5}$	15

Calculated Parameter	Description	Equation	Ref
n (PKR 2009)	Stress ratio exponent n, based on $I_c$ (PKR 2009). An iterative calculation is required to determine n (PKR 2009) and its corresponding $I_c$ (PKR 2009).	$n \text{ (PKR 2009)} = 0.381 (I_c) + 0.05 (\sigma'_v/P_a) - 0.15$	15
Qtn (PKR 2009)	Normalized tip resistance using a variable stress ratio exponent based on $I_c$ (PKR 2009) and n (PKR 2009). An iterative calculation is required to determine Qtn (PKR 2009).	$Q_{tn} = [(q_t - \sigma_v)/P_a](P_a/\sigma'_v)^n$ where $P_a$ = atmospheric pressure (100 kPa) $n$ = stress ratio exponent described above	15
FC	Apparent fines content (%)	$FC = 1.75(I_c^{3.25}) - 3.7$ $FC = 100$ for $I_c > 3.5$ $FC = 0$ for $I_c < 1.26$ $FC = 5\%$ if $1.64 < I_c < 2.6$ AND $F_r < 0.5$	3
$I_c$ Zone	This parameter is the Soil Behavior Type zone based on the $I_c$ parameter (valid for zones 2 through 7 on SBTn or SBT Qtn charts)	$I_c < 1.31$ Zone = 7 $1.31 < I_c < 2.05$ Zone = 6 $2.05 < I_c < 2.60$ Zone = 5 $2.60 < I_c < 2.95$ Zone = 4 $2.95 < I_c < 3.60$ Zone = 3 $I_c > 3.60$ Zone = 2	3
State Param or State Parameter or $\psi$	The state parameter index, $\psi$ , is defined as the difference between the current void ratio, $e$ , and the critical void ratio, $e_c$ . Positive $\psi$ - contractive soil Negative $\psi$ - dilative soil  This is based on the work by Been and Jefferies (1985) and Plewes, Davies and Jefferies (1992)  - vertical effective stress is used rather than a mean normal stress	See reference	6, 8
Yield Stress $\sigma'_p$	Yield stress is calculated using the following methods  a) General method  b) 1 <sup>st</sup> order approximation using $q_t$ Net (clays) c) 1 <sup>st</sup> order approximation using $\Delta u_2$ (clays) d) 1 <sup>st</sup> order approximation using $q_e$ (clays)	All stresses in kPa  a) $\sigma'_p = 0.33 \cdot (q_t - \sigma_v)^{m'} (\sigma_{atm}/100)^{1-m'}$  where $m' = 1 - \frac{0.28}{1 + (I_c/2.65)^{2.5}}$  b) $\sigma'_p = 0.33 \cdot (q_t - \sigma_v)$ c) $\sigma'_p = 0.54 \cdot (\Delta u_2)$ $\Delta u_2 = u_2 - u_0$ d) $\sigma'_p = 0.60 \cdot (q_t - u_2)$	19  20 20 20
OCR  OCR(JS1978)  OCR(Mayne2014) OCR (qtNet) OCR (deltaU) OCR (qe) OCR (Vs) OCR (PKR2015)	Over Consolidation Ratio based on  a) Schmertmann (1978) method involving a plot of $S_u/\sigma'_v$ / ( $S_u/\sigma'_v$ ) <sub>NC</sub> and OCR  b) based on Yield stresses described above c) approximate version based on qtNet d) approximate version based on $\Delta u$ e) approximate version based on effective tip, $q_e$ f) approximate version based on shear wave velocity, $V_s$ g) based on $Q_t$	a) requires a user defined value for NC $S_u/P_c'$ ratio  b through f) based on yield stresses  g) $OCR = 0.25 \cdot (Q_t)^{1.25}$	9  19 20 20 20 18 32

Calculated Parameter	Description	Equation	Ref
Es/qt	Intermediate parameter for calculating Young's Modulus, E, in sands. It is the Y axis of the reference chart.	Based on Figure 5.59 in the reference	5
Es Young's Modulus E	<p>Young's Modulus based on the work done in Italy. There are three types of sands considered in this technique. The user selects the appropriate type for the site from:</p> <p>a) OC Sands b) Aged NC Sands c) Recent NC Sands</p> <p>Each sand type has a family of curves that depend on mean normal stress. The program calculates mean normal stress and linearly interpolates between the two extremes provided in the Es/qt chart. Es is evaluated for an axial strain of 0.1%.</p>	<p>Mean normal stress is evaluated from:</p> $\sigma'_m = \frac{1}{3}(\sigma'_v + \sigma'_h + \sigma'_h)$ <p>where <math>\sigma'_v</math> = vertical effective stress <math>\sigma'_h</math> = horizontal effective stress</p> <p>and <math>\sigma_h = K_o \cdot \sigma'_v</math> with <math>K_o</math> assumed to be 0.5</p>	5
Delta U/TStress	Differential pore pressure ratio with respect to total stress	$= \frac{\Delta u}{\sigma_v}$ where: $\Delta u = u - u_{eq}$	CK*
Delta U/Estress, P Value, Excess Pore Pressure Ratio	Differential pore pressure ratio with respect to effective stress. Key parameter (P, Normalized Pore Pressure Parameter, Excess Pore Pressure Ratio) in the Winckler et. al. static liquefaction method.	$= \frac{\Delta u}{\sigma'_v}$ where: $\Delta u = u - u_{eq}$	25, 25a, CK*
Su/Estress	Undrained shear strength ratio with respect to vertical effective overburden stress using the $S_u (N_{kt})$ method	$= S_u (N_{kt}) / \sigma'_v$	CK*
Gmax	$G_{max}$ determined from SCPT shear wave velocities (not estimated values)	$G_{max} = \rho V_s^2$ where $\rho$ is the mass density of the soil determined from the estimated unit weights at each test depth	27
qtNet/Gmax	Net tip resistance ratio with respect to the small strain modulus $G_{max}$ determined from SCPT shear wave velocities (not estimated values)	$= (qt - \sigma_v) / G_{max}$ where $G_{max} = \rho V_s^2$ and $\rho$ is the mass density of the soil determined from the estimated unit weights at each test depth	15, 28, 30

\*CK – common knowledge

**Table 1b. CPT Parameter Calculation Methods – Liquefaction Parameters**

Calculated Parameter	Description	Equation	Ref
$K_{SPT}$	Equivalent clean sand factor for $(N_1)_{60}$	$K_{SPT} = 1 + ((0.75/30) \cdot (FC - 5))$	10
$K_{CPT}$ or $K_c$ (RW1998)	Equivalent clean sand correction for $q_{c1N}$	$K_{cpt} = 1.0$ for $l_c \leq 1.64$ $K_{cpt} = f(l_c)$ for $l_c > 1.64$ (see reference) $K_c = -0.403 l_c^4 + 5.581 l_c^3 - 21.63 l_c^2 + 33.75 l_c - 17.88$	3, 10
$K_c$ (PKR 2010)	Clean sand equivalent factor to be applied to $Q_{tn}$	$K_c = 1.0$ for $l_c \leq 1.64$ $K_c = -0.403 l_c^4 + 5.581 l_c^3 - 21.63 l_c^2 + 33.75 l_c - 17.88$ for $l_c > 1.64$	16
$(N_1)_{60cs} I_c$	Clean sand equivalent SPT $(N_1)_{60} I_c$ . User has 3 options.	1) $(N_1)_{60cs} I_c = \alpha + \beta((N_1)_{60} I_c)$ 2) $(N_1)_{60cs} I_c = K_{SPT} * ((N_1)_{60} I_c)$ 3) $(q_{c1ncs}) / (N_1)_{60cs} I_c = 8.5 (1 - I_c/4.6)$  FC $\leq$ 5%: $\alpha = 0, \beta = 1.0$ FC $\geq$ 35%: $\alpha = 5.0, \beta = 1.2$ 5% < FC < 35%: $\alpha = \exp[1.76 - (190/FC^2)]$ $\beta = [0.99 + (FC^{1.5}/1000)]$	10 10 5
$q_{c1ncs}$	Clean sand equivalent $q_{c1n}$	$q_{c1ncs} = q_{c1n} \cdot K_{cpt}$	3
$Q_{tn,cs}$ (PKR 2010)	Clean sand equivalent for $Q_{tn}$ described above - $Q_{tn}$ being the normalized tip resistance based on a variable stress exponent as defined by Robertson (2009)	$Q_{tn,cs} = Q_{tn} \cdot K_c$ (PKR 2016)	16
$Su(Liq)/ESv$	Liquefied shear strength ratio as defined by Olson and Stark	$\frac{Su(Liq)}{\sigma_v'} = 0.03 + 0.0143(q_{c1})$  Note: $\sigma_v'$ and $s_v'$ are synonymous	13
$Su(Liq)/ESv$ (PKR 2010)	Liquefied shear strength ratio as defined by Robertson (2010)	$\frac{Su(Liq)}{\sigma_v'}$ Based on a function involving $Q_{tn,cs}$	16
$Su(Liq)$ (PKR 2010)	Liquefied shear strength derived from the liquefied shear strength ratio and effective overburden stress		16
Cont/Dilat Tip	Contractive / Dilative qc1 Boundary based on $(N_1)_{60}$	$(\sigma_v')_{boundary} = 9.58 \times 10^{-4} [(N_1)_{60}]^{4.79}$ $qc1$ is calculated from specified qt(MPa)/N ratio	13
CRR	Cyclic Resistance Ratio (for Magnitude 7.5)	$q_{c1ncs} < 50$ : $CRR_{7.5} = 0.833 [q_{c1ncs}/1000] + 0.05$  $50 \leq q_{c1ncs} < 160$ : $CRR_{7.5} = 93 [q_{c1ncs}/1000]^3 + 0.08$	10
$K_g$	Small strain Stiffness Ratio Factor, $K_g$	$[G_{max}/qt]/[q_{c1n}^{-m}]$ $m$ = empirical exponent, typically 0.75	26

Calculated Parameter	Description	Equation	Ref
SP Distance	State Parameter Distance, Winckler static liquefaction method	Perpendicular distance on Qtn chart from plotted point to state parameter $\Psi = -0.05$ curve	25
URS NP Fr	Normalized friction ratio point on $\Psi = -0.05$ curve used in SP Distance calculation		25
URS NP Qtn	Normalized tip resistance (Qtn) point on $\Psi = -0.05$ curve used in SP Distance calculation		25

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