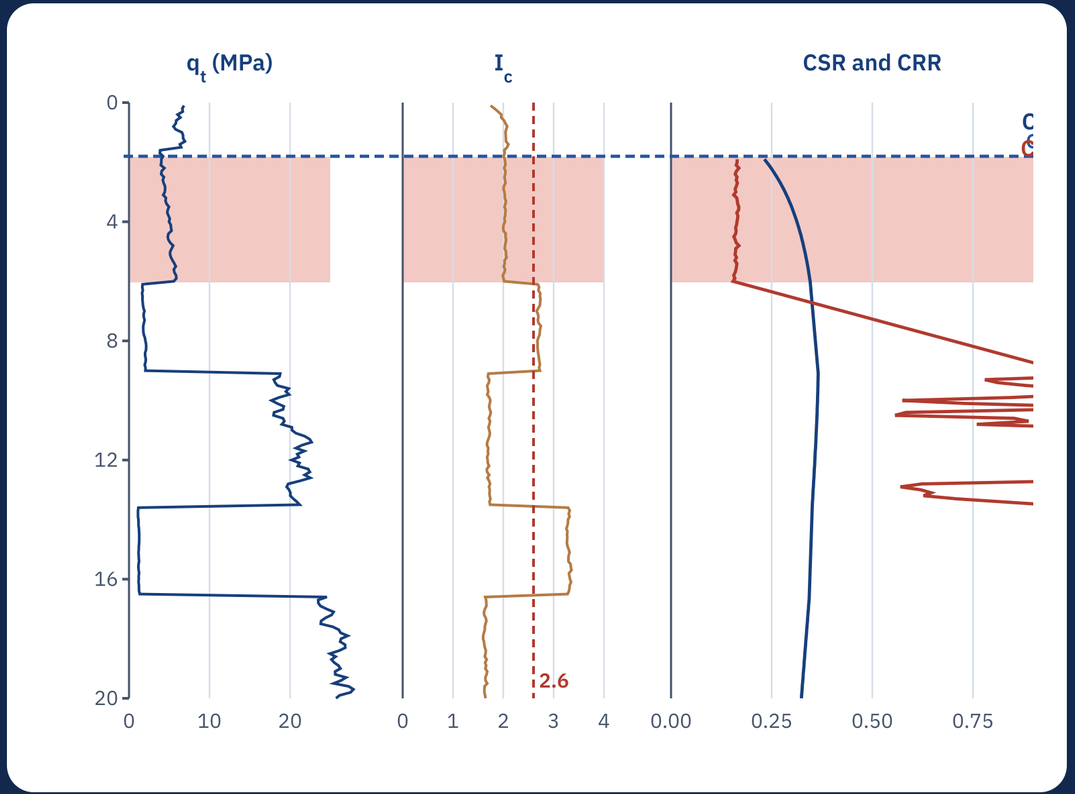
Geotechnical lecture presentation · Liquefaction

Liquefaction triggering by CPT

Lecture: liquefaction triggering by CPT; one cone reading is solved by hand end to end with two methods (Boulanger–Idriss, Robertson–Wride), the remaining readings with tables.

Cone data · Ic | Two methods | CSR · CRR · FS | Zones | Can be solved by hand



Based on the GeoTerva Theory page · geoterva.com

What will we learn in this lecture?

Determination of the **corrected cone resistance q_t**, the **friction ratio R_f**, and the **soil behavior index I_c** from the cone record (q_c, f_s, u_2)

To **estimate the soil type, unit weight and fines content from cone data** (no layer table is entered)

Two complete packages: Boulanger–Idriss (2014) and Robertson–Wride (1998, NCEER); each one's normalization, CRR curve, MSF and K_σ are internally consistent

CSR, **FS = CRR/CSR**, screened readings, **zones** and liquefiable thickness

A single reading (4.00 m) in a borehole by hand with two methods; the other readings in the table with the same steps

LECTURE FLOW

Each topic is covered in **three steps**:

1 · **Theory**: formula and rationale

2 · **Problem statement**: given and required

3 · **Solution**: step by step, with numbers

Example: CPT-1 (GWT 1.80 m; 20 m depth, 5 cm interval); a_{max} = 0.35 g, M = 7.5, net area ratio a = 0.80, $FS_{required}$ = 1.20.

q_t, R_f and units

THEORY

Since the **cone** provides an almost continuous record (reading interval 1–5 cm), there is no layer table to enter.

Soil type, unit weight and fines content are estimated **from cone data**.

Consequences of liquefaction — settlement, lateral spreading, loss of bearing capacity — are outside the scope of this version.

The corrected cone resistance is calculated from the relation $q_t = q_c + (1 - a)\cdot u_2$, where a is the net area ratio of the cone (0.65–0.85; typical value 0.80).

In soft clays and silts where the u_2 value is much above the hydrostatic value, the correction is significant, whereas in sands it remains small; if u_2 is not recorded, $q_t = q_c$ is taken.

$$q_t = q_c + (1 - a)\, u_2 \qquad R_f = \frac{f_s}{q_t} \times 100\,\%$$

γ from CPT; two GWT depths

THEORY

Unit weight is estimated from the CPT data at every reading; **R_f** is in % and its value is kept between 1.5 γ_w and 2.5 γ_w.

Unit weight is integrated from the surface; alternatively, two constant values are used: γ above the groundwater level and γ_{sat} below it.

Pore water pressure is assumed hydrostatic from the groundwater level; for **C_N** and **I_c** the groundwater level at the time of testing is used, while for CSR and K_σ the design groundwater level is used.

$$\frac{\gamma}{\gamma_w} = 0.27 \log R_f + 0.36 \log \frac{q_t}{P_a} + 1.236 \qquad \sigma_v = \int \gamma \, dz \qquad u = \gamma_w (z - z_w) \qquad \sigma'_v = \sigma_v - u$$

I_c and exponent n

THEORY

The soil behaviour type index is calculated with I_c = [(3.47 – log Q)² + (log F + 1.22)²]^0.5.

The exponent n takes the value 0.5 in sands and 1.0 in clays and is determined by the Robertson & Wride (1998) iteration.

The soil log in the drawings is based on this classification; a series shorter than h_{min} is merged with its longer neighbour.

$$I_c = \left[(3.47 - \log Q)^2 + (\log F + 1.22)^2\right]^{0.5} \qquad Q = \frac{q_t - \sigma_v}{P_a}\left(\frac{P_a}{\sigma'_v}\right)^n \qquad F = \frac{f_s}{q_t - \sigma_v} \times 100\,\%$$

I_c range	< 1.31	1.31 – 2.05	2.05 – 2.60	2.60 – 2.95	2.95 – 3.60	> 3.60
Soil (Robertson 1990)	gravelly – dense sand	sand: clean – silty	sand mixture	silt mixture	clay	organic

Which reading is evaluated?

THEORY

A reading is evaluated when it lies below the design groundwater level, no deeper than depth z_{max}, and in soil that behaves like sand.

Soils with an I_c value above $I_{c,lim}$ (default 2.6) are treated as clay-like; these soils are left to the cyclic softening check.

The boundary between sand-like and clay-like behaviour is not sharp; it is recommended to repeat the analysis with $I_{c,lim}$ = 2.4, 2.6 and 2.8.

In a reading where the net cone resistance $q_t - \sigma_v$ is not positive, the soil behaviour index cannot be defined and the reading is not evaluated; the eliminated readings remain in all tables together with their reasons.

$q_t \rightarrow q_{c1N} \rightarrow q_{c1Ncs}$

THEORY

Since in the Boulanger & Idriss (2014) normalization the exponent depends on the result, C_N is found by iteration and in the m relation the value of q_{c1Ncs} is kept between 21 and 254.

In the relation FC = 80(I_c + C_{FC}) − 137, C_{FC} is the fit parameter of the correlation between I_c and the fines content; 0 corresponds to the general correlation, and ±0.29 is one standard deviation of this correlation.

Because the scatter of the correlation is large, a site-specific C_{FC} value determined from laboratory fines contents of samples from boreholes adjacent to the CPT points is more appropriate and should be determined separately for each geological unit.

$$q_{c1N} = C_N \frac{q_t}{P_a} \qquad C_N = \left(\frac{P_a}{\sigma'_v}\right)^m \leq 1.7 \qquad m = 1.338 - 0.249\, q_{c1Ncs}^{0.264}$$

$$FC = 80\,(I_c + C_{FC}) - 137 \qquad \Delta q_{c1N} = \left(11.9 + \frac{q_{c1N}}{14.6}\right) \exp\left[1.63 - \frac{9.7}{FC+2} - \left(\frac{15.7}{FC+2}\right)^2\right] \qquad q_{c1Ncs} = q_{c1N} + \Delta q_{c1N}$$

CRR, MSF and K_σ

THEORY

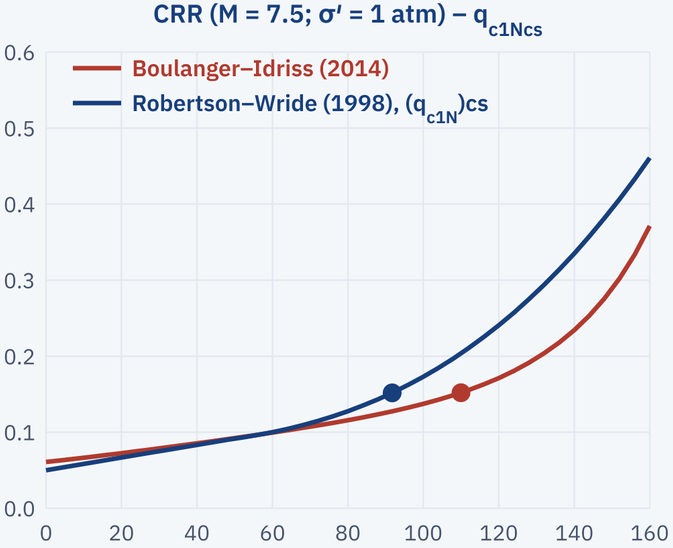
The Boulanger & Idriss (2014) resistance curve is the deterministic curve given in the report and is based on the 16th percentile of the case data (constant 2.80).

The CRR(M=7.5; σ′=1) curve is obtained from the q_{c1Ncs} value; when q_{c1Ncs} is above 211, the value 211 is taken because the C_σ limit is reached.

σ'_v in the K_σ relation is the effective stress corresponding to the design groundwater level.

$$CRR_{7.5,1} = \exp\left[\frac{q}{113} + \left(\frac{q}{1000}\right)^2 - \left(\frac{q}{140}\right)^3 + \left(\frac{q}{137}\right)^4 - 2.80\right] \qquad q = q_{c1Ncs}$$

$$MSF = 1 + (MSF_{max} - 1)(8.64e^{-M/4} - 1.325) \qquad MSF_{max} = 1.09 + \left(\frac{q}{180}\right)^3 \qquad K_\sigma = 1 - C$$



Kc, CRR and MSF

THEORY

The corrected cone resistance $(q_{c1N})_{cs}$ is calculated with the relation $(q_{c1N})_{cs} = K_c\, q_{c1N}$; K_c depends on Ic and takes the value 1 for Ic ≤ 1.64.

For clean sand with 1.64 < Ic < 2.36 and a friction ratio below 0.5%, $K_c = 1$ is taken and no fines correction is applied.

The clean sand curve ends at $(q_{c1N})_{cs} = 160$; the module continues the same cubic relation up to 250 ($CRR_{7.5} = 1.5$) and marks the reading.

$$q_{c1N} = C_Q \frac{q_t}{P_a} \quad C_Q = \left(\frac{P_a}{\sigma'_v}\right)^n \le 1.7 \qquad (q_{c1N})_{cs} = K_c\, q_{c1N} \qquad K_c = -0.403 I_c^4 + 5.581 I_c^3 - 21.63 I_c^2 + 33.75 I_c - 17.88$$

$$CRR_{7.5} = 0.833 \frac{(q_{c1N})_{cs}}{1000} + 0.05 \; (< 50) \quad 93 \left(\frac{(q_{c1N})_{cs}}{1000}\right)^3 + 0.08 \; (50 \ldots 160) \qquad MSF = \frac{102.24}{M^{2.56}} \quad K_\sigma = \left(\frac{\sigma'_v}{P_a}\right)^{f-1}$$

CSR and the r_d relation of the two methods

THEORY

The cyclic stress ratio is expressed as CSR = 0.65 (σ_v/σ'_v) a_{max} r_d, where σ_v and σ'_v are the stresses computed with respect to the design groundwater level.

For the depth reduction coefficient r_d, the B&I; method uses the Idriss relation and the R&W; method the Liao–Whitman relation; the magnitude and overburden corrections are applied to the resistance, not to the demand.

$$CSR = 0.65\,\frac{\sigma_v}{\sigma'_v}\,a_{max}\,r_d \qquad r_d^{BI} = \exp[\alpha + \beta M] \qquad r_d^{RW} = 1.0 - 0.00765 z \;(z \le 9.15\ \mathrm{m})$$

z (m)	2	4	6	8	10	15	20
r_d Boulanger–Idriss (M = 7.5)	0.991	0.972	0.949	0.924	0.896	0.822	0.750
r_d Robertson–Wride	0.985	0.969	0.954	0.939	0.907	0.773	0.640

FS = CRR / CSR

THEORY

Each reading represents half the distance to the reading above and below it; this representative distance does not exceed 0.25 m in either direction, or 3/4 of the usual reading interval if larger.

A gap in the record is not extrapolated to the results; it remains a series not evaluated as "no reading" and is listed in a warning.

Consecutive readings with the same result form a series; a series thinner than h_{min} (default 0.10 m) takes the result of its longer neighbor, and adjacent series with the same result form zones.

Each method is a whole; the stress-reduction coefficient, normalization, clean-sand correction, magnitude and overburden coefficients, and the resistance curve are derived together from a case database.

The sources of the two methods prescribe that the components of one method are not mixed with those of the other; in the module, the method selection changes all of these components together.

$$FS = \frac{CRR}{CSR} \qquad \text{FS} < 1 : \text{ liquefies} \qquad 1 \leq FS < FS_{req}\,(1.20) : \text{ at the boundary}$$

Problem statement

EXAMPLE

Given

Reading	$q_c = 4.956$ **MPa,** $f_s = 46.2$ **kPa,** $u_2 = 21.6$ **kPa; net area ratio** $a = 0.80$
Site	**GWT** $z_w = 1.80$ **m (the design GWT is the same); unit weight from the CPT (80 readings from 0 to 4 m)**
Earthquake	$a_{max} = 0.35g$, $M = 7.5$; $C_{FC} = 0$; **Robertson–Wride** $f = 0.7$; $FS_{req} = 1.20$

REQUIRED

q_t, σ'_v, I_c; with Boulanger–Idriss and Robertson–Wride, **q_{c1Ncs}, CRR, CSR, FS**.

Solution (1/8)

SOLUTION

1 Corrected tip resistance and friction ratio

$$q_t = q_c + (1-a)u_2 = 4956 + (1-0.80)(21.6) = \mathbf{4{,}960.32}\ \text{kPa}$$

$$R_f = \frac{f_s}{q_t} \times 100 = \frac{46.2}{4{,}960.32} \times 100 = \mathbf{0.9314}\ \%$$

2 Unit weight (Robertson–Cabal)

$$\gamma = (0.27 \log R_f + 0.36 \log \tfrac{q_t}{P_a} + 1.236)\gamma_w = (1.8360)(9.81) = \mathbf{18.01}\ \text{kN/m}^3$$

3 Stresses

$$\sigma_v = \sum \tfrac{1}{2}(\gamma_{k-1} + \gamma_k)\Delta z = \mathbf{73.64}\ \text{kPa} \qquad u = 9.81(4.00 - 1.80) = 21.58\ \text{kPa}$$

$$\sigma'_v = \sigma_v - u = 73.64 - 21.58 = \mathbf{52.05}\ \text{kPa}$$

Effective vertical stress **σ′$_V$ = 52.05 kPa**.

Solution (2/8)

SOLUTION

4 Net end bearing and F

$$q_t - \sigma_v = 4{,}960.32 - 73.64 = \mathbf{4{,}886.68}\ \mathrm{kPa}$$

$$F = \frac{f_s}{q_t - \sigma_v} \times 100 = \frac{46.2}{4{,}886.68} \times 100 = \mathbf{0.9454}\ \%$$

5 Iteration of the exponent n (Robertson–Wride): first n = 1.0 (clay trial)

$$Q = \frac{q_t - \sigma_v}{P_a}\left(\frac{P_a}{\sigma'_v}\right)^{1} = 93.88$$

$$I_c = \sqrt{(3.47 - \log 93.88)^2 + (\log 0.9454 + 1.22)^2} = \mathbf{1.9162} \le 2.6 \ \Rightarrow\ \text{not clay}$$

Solution (3/8)

SOLUTION

6 n = 0.5 (sand) is tried

$$Q = 48.2278 \left(\frac{101.325}{52.05} \right)^{0.5} = 67.29$$

$$I_c = \sqrt{(3.47 - \log 67.29)^2 + (\log 0.9454 + 1.22)^2} = \mathbf{2.0312} \leq 2.6 \;\Rightarrow\; n = 0.5$$

I_c = 2.031 ≤ 2.6: not clay-like, the reading is evaluated.

Solution (4/8)

SOLUTION

7 Fines content ($C_{FC} = 0$)

$$FC = 80\,(I_c + C_{FC}) - 137 = 80(2.0312) - 137 = \mathbf{25.50\ \%}$$

8 m and C_N are coupled: iteration with q_{c1Ncs} ($x = q_t/P_a = 48.955$, $\sigma'_v = 52.05$)

Iteration	q_{c1Ncs} (input)	m	C_N	$q_{c1N} = C_N q_t/P_a$	Δq_{c1N}	q_{c1Ncs} (output)
1	48.955	0.6425	1.5341	75.100	44.128	119.227
2	119.227	0.4582	1.3569	66.427	42.590	109.017
3	109.017	0.4788	1.3756	67.342	42.752	110.094
4	110.094	0.4766	1.3736	67.242	42.734	109.977
…	…	…	…	…	…	…
13	109.988	0.4768	1.3738	67.252	42.736	109.988

Converges in 13 iterations: **m = 0.4768, C_N = 1.3738, q_{c1N} = 67.252, Δq_{c1N} = 42.736 → q_{c1Ncs} = 109.988**.

Solution (5/8)

SOLUTION

9 Base resistance (M = 7.5; 1 atm), MSF and K_σ (q_{c1Ncs} = 109.99)

$$CRR_{7.5,1} = \exp[q/113 + (q/1000)^2 - (q/140)^3 + (q/137)^4 - 2.80] \quad (q = 109.99)$$

$$CRR_{7.5,1} = \exp[-1.8840] = \mathbf{0.1520}$$

$$MSF_{max} = 1.09 + (109.99/180)^3 = 1.3181$$

$$MSF = 1 + (1.3181 - 1)(8.64e^{-7.5/4} - 1.325) = \mathbf{1.0000}$$

$$C_\sigma = 1/(37.3 - 8.27(109.99)^{0.264}) = 0.1150$$

$$K_\sigma = 1 - 0.1150 \ln(52.05/101.325) = \mathbf{1.0766}$$

$CRR_{7.5;1}$ = **0.1520**; MSF = **1.0000**; K_σ = **1.0766** → CRR = **0.1636**.

Solution (6/8)

SOLUTION

10 Demand (Idriss r_d) and factor of safety

$$r_d = \exp[\alpha + \beta M] = \exp[-0.1971 + 0.0225(7.5)] = 0.9718$$

$$CSR = 0.65\,\frac{\sigma_v}{\sigma'_v}\,a_{max}\,r_d = 0.65\left(\frac{73.64}{52.05}\right)(0.35)(0.9718) = \mathbf{0.3127}$$

$$CRR = CRR_{7.5,1} \cdot MSF \cdot K_\sigma = 0.1520(1.0000)(1.0766) = 0.1636$$

$$FS = \frac{CRR}{CSR} = \frac{0.1636}{0.3127} = \mathbf{0.523}$$

Boulanger–Idriss: **FS = 0.523 < 1**, liquefaction is triggered.

Solution (7/8)

SOLUTION

11 C_Q and q_{c1N} (n = 0.5 the same)

$$C_Q = (P_a/\sigma'_v)^{0.5} = (101.325/52.05)^{0.5} = 1.3952$$

$$q_{c1N} = C_Q \frac{q_t}{P_a} = 1.3952(48.955) = 68.300$$

12 K_c (I_c = 2.031: 1.64 < I_c < 2.36 but F = 0.945% ≥ 0.5: fines correction PRESENT)

$$K_c = -0.403 I_c^4 + 5.581 I_c^3 - 21.63 I_c^2 + 33.75 I_c - 17.88 = \mathbf{1.3430}$$

$$(q_{c1N})_{cs} = K_c \, q_{c1N} = 1.3430(68.300) = \mathbf{91.727}$$

In Robertson–Wride the fines effect is the **K_c multiplier** (1.343); in Boulanger–Idriss Δq_{c1N} is **added** (+42.7); $(q_{c1N})cs$ = 91.73, q_{c1Ncs} = 109.99.

Solution (8/8)

SOLUTION

13 Resistance, demand (Liao–Whitman r_d; $K_\sigma = 1$ since $\sigma'_v < P_a$) and FS

$$CRR_{7.5} = 93\left(\frac{91.727}{1000}\right)^3 + 0.08 = 0.1518 \qquad MSF = \frac{102.24}{7.5^{2.56}} = 0.9996$$

$$r_d = 1 - 0.00765(4) = 0.9694 \qquad CSR = 0.65\left(\frac{73.64}{52.05}\right)(0.35)(0.9694) = 0.3120$$

$$FS = \frac{CRR_{7.5}}{CSR}\,MSF\,K_\sigma = \frac{0.1518}{0.3120}(0.9996)(1) = \mathbf{0.486}$$

Both packages reach the same conclusion: **Boulanger–Idriss FS = 0.523**, **Robertson–Wride FS = 0.486**; both < 1. The difference between them comes from the fines correction and r_d.

Check the solution in GeoTerva ↗

Problem statement

EXAMPLE

Given

Borehole	**CPT-1: 20 m, 400 readings at 5 cm intervals; GWT** 1.80 **m**
Methods	**Boulanger–Idriss and Robertson–Wride; each reading is solved with the steps in Example 1**

REQUIRED

For the reading at each metre: **q_t, R_f, I_c, soil, σ'_v, q_{c1Ncs}, CSR, CRR, FS** (two methods) and the decision.

Solution (1/2)

SOLUTION

z (m)	q_t (MPa)	R_f %	I_c	Soil	σ'_v	q_{c1Ncs} (BI)	CSR (BI)	FS (BI)	$(q_{c1N})cs$ (RW)	FS (RW)	Decision (BI / RW)
1	6.58	2.27	2.04	sand	19.4	–	–	–	–	–	*above GWT*
2	4.02	0.93	2.04	sand	36.0	108.4	0.238	0.691	90.1	0.626	Liquefies / Liquefies
3	4.46	0.87	2.02	sand	43.9	107.1	0.283	0.569	88.8	0.514	Liquefies / Liquefies
4	**4.96**	**0.93**	**2.03**	**sand**	**52.1**	**110.0**	**0.313**	**0.523**	**91.7**	**0.486**	**Liquefies / Liquefies**
5	5.12	0.95	2.05	sand	60.3	109.7	0.332	0.483	90.2	0.445	Liquefies / Liquefies
6	5.57	0.84	2.02	sand	68.6	107.2	0.346	0.445	88.4	0.415	Liquefies / Liquefies
7	1.92	2.43	2.66	silt mixture	76.4	–	–	–	–	–	*clay-like*
8	2.03	2.40	2.68	silt mixture	84.3	–	–	–	–	–	*clay-like*
9	2.03	2.55	2.73	silt mixture	92.3	–	–	–	–	–	*clay-like*
10	17.69	1.00	1.74	sand	102.5	173.9	0.364	1.579	184.9	1.808	Safe / Safe
11	20.25	1.03	1.72	sand	112.8	192.7	0.361	3.455	199.1	2.187	Safe / Safe
12	20.21	0.88	1.69	sand	123.3	186.2	0.357	2.527	186.1	1.821	Safe / Safe
13	19.88	0.95	1.73	sand	133.8	177.5	0.353	1.758	180.8	1.689	Safe / Safe
14	1.17	3.85	3.28	clay	142.9	–	–	–	–	–	*clay-like*
15	1.21	3.91	3.30	clay	150.6	–	–	–	–	–	*clay-like*
16	1.22	3.91	3.33	clay	158.3	–	–	–	–	–	*clay-like*
17	24.54	0.77	1.63	sand	167.3	206.1	0.341	6.842	188.5	1.951	Safe / Safe
18	26.33	0.71	1.60	sand	177.7	218.9	0.335	9.233	196.2	2.212	Safe / Safe
19	26.27	0.79	1.64	sand	188.3	213.7	0.330	9.199	189.9	2.069	Safe / Safe
20	25.71	0.76	1.65	sand	198.9	203.9	0.324	5.959	181.1	1.868	Safe / Safe

Solution (2/2)

SOLUTION

1 From reading to zone: each reading represents up to the neighbouring midpoints (at most 0.25 m); identical results are combined

Method	Liquefiable zone (m)	Thickness (m)	At the limit (m)	Minimum FS	z (m)
Boulanger–Idriss	1.83 – 6.03	**4.20**	0.00	0.445	6.00
Robertson–Wride	1.83 – 6.03	**4.20**	0.00	0.415	6.00

Both methods count the range **1.83 – 6.03 m** (4.20 m) as liquefiable in CPT-1; the smallest FS is at 6.0 m in both. The 4.0 m row is Example 1, solved by hand. The silt-like layer between 6 – 9 m ($I_c > 2.6$) is treated as clay-like and screened out in the 7 – 9 m rows.

Check the solution in GeoTerva ↗

Problem statement

EXAMPLE

Given

Boreholes	**CPT-1 (GWT 1.80 m), CPT-2 (2.40 m), CPT-3 (3.10 m); same parameters**
Comparison	**each method with its own package**

REQUIRED

Each borehole's **minimum FS**, **liquefied** and **borderline** thicknesses.

Solution

SOLUTION

Borehole	GWT (m)	Method	Minimum FS	z (m)	Liquefied zones (m)	Thickness (m)	At the limit (m)
CPT-1	1.80	Boulanger–Idriss	**0.445**	6.00	1.83 – 6.03	4.20	0.00
		Robertson–Wride	**0.415**	6.00	1.83 – 6.03	4.20	0.00
CPT-2	2.40	Boulanger–Idriss	**0.605**	7.10	2.62 – 7.53	4.90	0.85
		Robertson–Wride	**0.640**	7.10	2.67 – 7.53	4.85	0.25
CPT-3	3.10	Boulanger–Idriss	**0.655**	8.50	5.03 – 10.03	5.00	0.00
		Robertson–Wride	**0.683**	8.50	5.03 – 10.03	5.00	0.00

In every borehole both methods trigger liquefaction; the liquefied thicknesses are almost identical (4.2 – 5.0 m). The differences are in the marginal thicknesses (CPT-2: 0.85 / 0.25 m) and in the minimum FS. The minimum FS is **sensitive to noise**; thickness is the more stable value.

Check the solution in GeoTerva ↗

Problem statement

EXAMPLE

Given

Base case	**CPT-1:** $a_{max} = 0.35g$, $M = 7.5$, $I_{c,lim} = 2.6$, $C_{FC} = 0$, **design GWT = test GWT** (1.80 **m**)
Variables	**only one at a time:** $I_{c,lim}$ **2.4 / 2.8;** C_{FC} ∓ 0.29; a_{max} **0.25g / 0.45g; design GWT 1.0 m**

REQUIRED

The **minimum FS** and the **liquefied thickness** of CPT-1 (two methods); hand check of FC for C_{FC}.

Example 4 · Sensitivity table

Solution (1/2)

SOLUTION

Condition	Change	FS_{min} (BI)	z (m)	Thickness (m)	FS_{min} (RW)	z (m)	Thickness (m)
Base	–	0.445	6.00	**4.20**	0.415	6.00	**4.20**
$I_{c,lim}$ decreases	2.4	0.445	6.00	**4.20**	0.415	6.00	**4.20**
$I_{c,lim}$ increases	2.8	0.318	8.80	**7.20**	0.391	8.45	**7.20**
C_{FC}	−0.29	0.318	6.00	**4.20**	–	–	–
C_{FC}	+0.29	0.579	6.00	**4.20**	–	–	–
a_{max} decreases	0.25g	0.624	6.00	**4.20**	0.582	6.00	**4.20**
a_{max} increases	0.45g	0.346	6.00	**4.20**	0.323	6.00	**4.20**
Design GWT rises	1.0 m	0.400	6.00	**4.50**	0.368	6.00	**4.50**

$I_{c,lim}$ = 2.8 is the most influential input: the silty sand between 6 and 9 m (I_c 2.6 – 2.8) is included, the liquefiable thickness goes from 4.2 → **7.2 m**, and $FS_{min} \approx 0.32$. C_{FC} exists only in B&I and shifts FS between 0.32 and 0.58; a_{max} and the design GWT do not change the thickness much.

Solution (2/2)

SOLUTION

1 Effect of C_{FC} on the fines content at the sample reading (I_c = 2.031)

$$C_{FC} = -0.29: \; FC = 80(2.0312 - 0.29) - 137 = \mathbf{2.30\ \%}$$

$$C_{FC} = 0: \; FC = 80(2.0312) - 137 = \mathbf{25.50\ \%}$$

$$C_{FC} = +0.29: \; FC = 80(2.0312 + 0.29) - 137 = \mathbf{48.70\ \%}$$

FC 2.3 → 25.5 → 48.7 % (uncertainty in I_c moves FC a great deal): the fines correction Δq_{c1N} is therefore uncertain, and a **site-specific C_{FC}** requires laboratory fines contents beside the borehole.

Check the solution in GeoTerva ↗

Summary

Key points

Cone record → $q_t = q_c + (1 - a)u_2$, R_f, γ (from CPT), σ'_v, $\mathbf{I_c}$ (n iterations); $I_c > 2.6$ clay-like, screened out

Two packages: Boulanger–Idriss ($FC = 80(I_c + C_{FC}) - 137$, q_{c1Ncs}, CRR, MSF, K_σ) and Robertson–Wride (multiplies K_c, cubic CRR); their components are not mixed

Example (4.00 m): σ'_v 52.05 kPa, I_c 2.031; B&I q_{c1Ncs} 109.99, CRR 0.1636, CSR 0.3127 → **FS 0.523**; R&W $(q_{c1N})cs$ 91.73, $CRR_{7.5}$ 0.1518, CSR 0.3120 → **FS 0.486**

Zone: merges up to neighboring midpoints (≤ 0.25 m), below h_{min} = 0.10 m; CPT-1 liquefiable 1.83 – 6.03 m (4.20 m)

Sensitivity: $I_{c,lim}$ and C_{FC} are influential; the minimum FS is sensitive to noise, the thickness is more stable; results are triggering only, the consequences (settlement, lateral spreading) require a separate analysis

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NOTE

All numerical examples have been produced with the module's own calculation engine; the module gives the same values. The module's opening project is these three boreholes (a_{max} = 0.35g, M = 7.5).

GeoTerva

Online geotechnical analysis

From theory to practice

Paste your own cone penetration tests (q_c, f_s, u_2) or read them from a file; enter the GWT and the earthquake parameters. For each reading, the module provides I_c, CSR, CRR, FS, the zones, the liquefiable thickness, the results of the two methods, the colour-banded section, the step-by-step solution and the report together.

Open the module → | **Theory page →**

Open on your phone
The example modules need no registration.

If you would like to use them in your lectures: info@geoterva.com