

Chapter 3

3.1 Eq. (3.3): $A_R (\%) = \frac{D_o^2 - D_i^2}{D_i^2} \times 100 = \frac{76.2^2 - 73^2}{73^2} \times 100 = \mathbf{8.96\%}$

3.2

Depth from ground surface (m)	N_{60}	c_u (kN/m ²) [Eq. (3.8)]	σ'_o (MN/m ²)	OCR [Eq. 3.9]
3.0	5	92.4	$\frac{1}{1000} [(1.5)(16.5) + (1.5)(19 - 9.81)]$ = 0.03854	5.51
4.5	8	129.6	$0.03854 + \frac{1}{1000} (1.5)(16.8 - 9.81)$ = 0.0490	6.46
6.0	8	92.4	$0.0490 + \frac{1}{1000} (1.5)(16.8 - 9.81)$ = 0.0595	5.65
7.5	9	141.1	$0.0595 + \frac{1}{1000} (1.5)(16.8 - 9.81)$ = 0.07	5.48
9.0	10	152.2	$0.07 + \frac{1}{1000} (1.5)(16.8 - 9.81)$ = 0.0805	5.35
Average $c_u = \mathbf{121.5 \text{ kN/m}^2}$			Average OCR = 5.69	

3.3

Depth from ground surface (m)	N_{60}	σ'_o ^a (kN/m ²)	OCR [Eq. 3.10]	σ'_c (kN/m ²) [Eq. (3.11)]
3.0	5	38.54	7.52	235
4.5	8	49.0	9.47	376
6.0	8	59.5	8.0	376
7.5	9	70.0	7.46	423
9.0	10	80.5	7.2	470

^a See Problem 3.2

3.4

Depth (m)	σ'_o (kN/m ²)
1.5	$18 \times 1.5 = 27$
3.0	$18 \times 3.0 = 54$
4.5	$18 \times 4.5 = 81$
6.0	$18 \times 6.0 = 108$
7.5	$108 + (1.5)(20.2 - 9.81) = 123.6$
9.0	$123.6 + (1.5)(20.2 - 9.81) = 139.2$

Eq. (3.13):
$$C_N = \left[\frac{1}{\left(\frac{\sigma'_o}{p_a} \right)} \right]^{0.5}$$

Depth (m)	N_{60}	σ'_o (kN/m ²)	C_N	$(N_1)_{60}$ ^a
1.5	6	27	1.92	12
3.0	8	54	1.36	11
4.5	9	81	1.11	10
6.0	8	108	0.96	8
7.5	13	123.6	0.9	12
9.0	14	139.2	0.85	12

^a Rounded off to nearest whole number

$$3.5 \quad C_N = \frac{2}{1 + \left(\frac{\sigma'_o}{p_a} \right)}$$

Depth (m)	N_{60}	σ'_o ^a (kN/m ²)	C_N	$(N_1)_{60}$ ^b
1.5	6	27	1.57	9
3.0	8	54	1.3	10
4.5	9	81	1.1	10
6.0	8	108	0.96	8
7.5	13	123.6	0.89	12
9.0	14	139.2	0.84	12

^a See Problem 3.4

^b Rounded off to nearest whole number

3.6 From Problem 3.4, the average value of

$$(N_1)_{60} = \frac{1}{6}(12 + 11 + 10 + 8 + 12 + 12) = 10.83 \approx 11$$

$$\text{Eq. (3.31): } \phi' = \sqrt{20(N_1)_{60}} + 20 = \sqrt{(20)(11)} + 20 = 34.83^\circ \approx \mathbf{35^\circ}$$

3.7 From Problem 3.4

Depth (m)	σ'_o (kN/m ²)	p_a (kN/m ²)	N_{60}	ϕ' (deg) [Eq. (3.30)]
1.5	27	100	6	34.7
3.0	54	100	8	34.9
4.5	81	100	9	34.0
6.0	108	100	8	31.4
7.5	123.6	100	13	34.9
9.0	139.2	100	14	34.9

Average $\phi' = 34.1^\circ \approx \mathbf{34^\circ}$

3.8 Eq. (3.29): $\phi' = 27.1 + 0.3N_{60} - 0.00054(N_{60})^2$

Depth (m)	N_{60}	ϕ' (deg) [Eq. (3.29)]
1.5	6	28.88
3.0	8	29.47
4.5	9	29.76
6.0	8	29.47
7.5	13	30.9
9.0	14	31.19

Average $\phi' = 29.93^\circ \approx 30^\circ$

3.9

Depth (m)	σ'_o (kN/m ²)	p_a (kN/m ²)	N_{60}	D_r (%) [Eq. (3.22)]
1.5	27	100	6	50.6
3.0	54	100	8	51.8
4.5	81	100	9	49.7
6.0	108	100	8	43.2
7.5	123.6	100	13	52.8
9.0	139.2	100	14	52.7

Average $D_r = 50.13\% \approx 50\%$

3.10 Eq. (3.13): $C_N = \left[\frac{1}{\left(\frac{\sigma'_o}{p_a} \right)} \right]^{0.5}$; $(N_1)_{60} = C_N N_{60}$

Depth (m)	σ'_o (kN/m ²)	p_a (kN/m ²)	N_{60}	C_N	$1.08(N_1)_{60}$	$D_r = \left(\frac{1.08(N_1)_{60}}{60} \right)^{0.5}$ [Eq. (3.28)]
1.5	27	100	6	1.92	12.44	45.3
3.0	54	100	8	1.36	11.75	42.3
4.5	81	100	9	1.11	10.78	42.4
6.0	108	100	8	0.96	8.29	37.2
7.5	123.6	100	13	0.9	12.64	45.9
9.0	139.2	100	14	0.85	12.85	46.3

Average = 43.23% $\approx 43\%$

3.11

Depth (m)	σ'_o (kN/m ²)	p_o (kN/m ²)	$\left(0.23 + \frac{0.06}{D_{50}}\right)^{1.7}$	N_{60}	D_r (%) [Eq. (3.23)]
1.5	26.4	100	0.133	5	52.9
3.0	52.8	100	0.133	11	55.5
4.5	79.2	100	0.133	14	51.1
6.0	105.6	100	0.133	18	50.2
7.5	132.0	100	0.133	16	42.3
9.0	158.4	100	0.133	21	44.3

3.12

Depth (m)	γ (kN/m ³)	σ'_o (kN/m ²)	p_a (kN/m ²)	N_{60}	ϕ' (deg) ^a [Eq. (3.30)]
3.0	16.66	49.98	100	7	34
4.5	16.66	74.97	100	9	34
6.0	16.66	99.66	100	11	35
7.5	18.55	127.49	100	16	37
9.0	18.55	155.31	100	18	36
10.5	18.55	183.14	100	20	36
12.0	18.55	210.97	100	22	36

^a rounded to nearest whole number

$$\text{Average } \phi' = \frac{1}{7}(34 + 34 + 35 + 37 + 36 + 36 + 36) = 35.4^\circ \approx \mathbf{36^\circ}$$

3.13 Between depths 6 m and 9 m, average $N_{60} = \frac{1}{3}(11 + 16 + 18) = 15$.

$$\text{Eq. (3.32): } E_s = p_a \alpha N_{60} = (100)(10)(15) = \mathbf{15,000 \text{ kN/m}^2}$$

3.14 Eq. (3.21):

$$D_r (\%) = 12.2 + 0.75 \left[222N_{60} + 2311 - 711(\text{OCR}) - 779 \left(\frac{\sigma'_o}{p_a} \right) - 50C_u^2 \right]^{0.5}$$

At a depth of 3.0 m:

$$D_r(\%) = 12.2 + 0.75 \left[222(9) + 2311 - (711)(2) - (779) \left(\frac{55}{100} \right) - (50)(2.8)^2 \right]^{0.5}$$
$$= 46.3\%$$

At a depth of 4.5 m:

$$D_r(\%) = 12.2 + 0.75 \left[222(11) + 2311 - (711)(2) - (779) \left(\frac{82}{100} \right) - (50)(2.8)^2 \right]^{0.5}$$
$$= 48.2\%$$

At a depth of 6.0 m:

$$D_r(\%) = 12.2 + 0.75 \left[222(12) + 2311 - (711)(2) - (779) \left(\frac{98}{100} \right) - (50)(2.8)^2 \right]^{0.5}$$
$$= 48.9\%$$

$$\text{Average } D_r = \frac{1}{3}(46.3 + 48.2 + 48.9) = 48.7\% \approx \mathbf{48\%}$$

3.15 Eq. (3.34): $c_u = \frac{T}{K}$

$$\text{Eq. (3.38): } K = \frac{\pi d^2}{12} \left(\frac{d}{\cos i_T} + \frac{d}{\cos i_B} + 6h \right)$$
$$= \frac{\pi(0.0635)^2}{12} \left[\frac{0.0635}{\cos 45} + \frac{0.0635}{\cos 45} + (6)(0.127) \right]$$
$$= 0.000994$$

$$c_{u(\text{VST})} = \frac{51}{0.000994} = 51,308 \text{ N/m}^2 \approx 51.3 \text{ kN/m}^2$$

Eqs. (3.39) and (3.40a):

$$c_{u(\text{corrected})} = \lambda c_{u(\text{VST})} = [1.7 - 0.54 \log(\text{PI})](51.3)$$

$$= [1.7 - 0.54 \log(46 - 21)](51.3) = \mathbf{48.48 \text{ kN/m}^2}$$

3.16 Eq. (3.42): $\text{OCR} = \beta \frac{c_{u(\text{field})}}{\sigma'_o}$

$$\sigma'_o = 59.5 \text{ kN/m}^2 \text{ (from Problem 3.2)}$$

$$\text{Eq. (3.43): } \beta = 22(\text{PI})^{-0.48} = (22)(25)^{-0.48} = 4.69$$

$$\text{OCR} = (4.69) \left(\frac{51.3}{59.5} \right) = \mathbf{4.04}$$

3.17 a. $\frac{h}{d} = \frac{101.6}{50.8} = 2$

$$\text{From Eq. (3.36): } K = \frac{7\pi d^3}{6} = \frac{(7)(\pi)(0.0508 \text{ m})^3}{6} = 0.00048 \text{ m}^3$$

$$c_{u(\text{VST})} = \frac{T}{K} = \frac{280}{0.00048} = 583,333 \text{ N/m}^2 \approx \mathbf{58.3 \text{ kN/m}^2}$$

b. From Eqs. (3.39) and (3.40a):

$$c_{u(\text{corrected})} = [1.7 - 0.54 \log(\text{PI})](1129)]$$

$$= [1.7 - 0.54 \log(58 - 29)](58.3) = \mathbf{53.07 \text{ kN/m}^2}$$

3.18 Eq. (3.45): $\beta = \frac{1}{0.08 + 0.0055(\text{PI})} = \frac{1}{0.08 + 0.0055(29)} = 4.18$

$$\text{Eq. (3.42): } \text{OCR} = \beta \frac{c_{u(\text{field})}}{\sigma'_o} = (4.18) \left(\frac{58.3}{64.2} \right) = \mathbf{3.8}$$

3.19

Depth (m)	σ'_o (MN/m ²)	q_c (MN/m ²)	ϕ' (deg)
1.5	0.024	2.06	42.06
3.0	0.048	4.23	42.15
4.5	0.072	6.01	41.98
6.0	0.096	8.18	42.03
7.5	0.120	9.97	41.93
9.0	0.144	12.42	42.07

ϕ' (average) $\approx 42^\circ$

3.20 Note: OCR = 1; $Q_c = 1$

Depth (m)	q_c (kN/m ²)	σ'_o (kN/m ²)	D_r (%) [Eq. (3.51)]
1.5	2060	24	37.1
3.0	4230	48	44.7
4.5	6010	72	48.2
6.0	8180	96	52.3
7.5	9970	120	54.6
9.0	12420	144	58.3

3.21 From Eq. (3.55):
$$\frac{\left(\frac{q_c}{P_a}\right)}{N_{60}} = 5.44D_{50}^{0.26} = 5.44(0.2)^{0.26} = 3.58$$

$P_a \approx 100 \text{ kN/m}^2$

Depth (m)	q_c (MN/m ²)	N_{60}
1.5	2.06	5.75 \approx 6
3.0	4.23	11.8 \approx 12
4.5	6.01	16.78 \approx 17
6.0	8.18	22.85 \approx 23
7.5	9.97	27.85 \approx 28
9.0	12.42	34.69 \approx 35

3.22 a. $\sigma_o = (2)(18) + (20)(4) = 116 \text{ kN/m}^2$

$$\text{Eq. (3.56): } c_u = \frac{q_c - \sigma_o}{N_k} = \frac{800 - 116}{15} \approx \mathbf{45.6 \text{ kN/m}^2}$$

b. $\sigma'_o = (2)(18) + (20 - 9.81)(4) = 76.76 \text{ kN/m}^2$

$$\text{Eq. (3.60): } \text{OCR} = 0.37 \left(\frac{q_c - \sigma_o}{\sigma'_o} \right)^{1.01} = (0.37) \left(\frac{800 - 116}{76.76} \right)^{1.01} \approx \mathbf{3.37}$$

3.23 Eq. (3.61):

$$\begin{aligned} E_p &= 2(1 + \mu_s)(V_o + v_m) \left(\frac{\Delta p}{\Delta v} \right) = (2)(1 + 0.5) \left(535 + \frac{46 + 180}{2} \right) \left(\frac{326.5 - 42.4}{180 - 46} \right) \\ &= \mathbf{4121.6 \text{ kN/m}^2} \end{aligned}$$

3.24 a. $K_D = \frac{p_o - u_o}{\sigma'_o} = \frac{280 - (9.81)(8 - 3)}{95} = 2.43$

$$\text{Eq. (3.68): } K_o = \left(\frac{K_D}{1.5} \right)^{0.47} - 0.6 = \left(\frac{2.43}{1.5} \right)^{0.47} - 0.6 = \mathbf{0.65}$$

b. Eq. (3.69): $\text{OCR} = (0.5K_D)^{1.6} = (0.5 \times 2.43)^{1.6} = \mathbf{1.37}$

c. Eq. (3.72): $E_s = (1 - \mu_s^2)E_D = (1 - \mu_s^2)(34.7)(p_1 - p_o)$
 $= (1 - 0.35^2)(34.7)(350 - 280) = \mathbf{2131 \text{ kN/m}^2}$

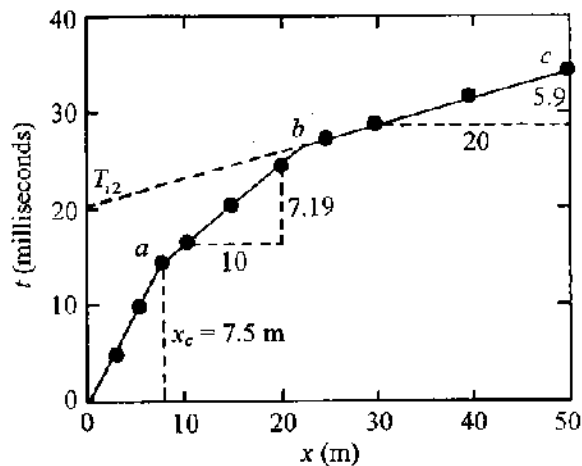
3.25 $K_D = \frac{p_o - u_o}{\sigma'_o} = \frac{260 - (4)(9.81)}{(2)(14.5) + (4)(19.8 - 9.81)} = 3.2$

$$\text{Eq. (3.74a): } \phi' = 31 + \frac{K_D}{0.236 + 0.066K_D} = 31 + \frac{3.2}{0.236 + (0.066)(3.2)} = \mathbf{38.2^\circ}$$

$$3.26 \quad \text{Eq. (3.79): } v = \sqrt{\frac{E_s}{\gamma} \frac{1 - \mu_s}{(1 - 2\mu_s)(1 + \mu_s)}}; \quad \mu_s = 0.32$$

$$105 = \sqrt{\frac{E_s}{18} \times \frac{0.68}{(0.36)(1.32)}}; \quad E_s = \mathbf{14.136 \text{ kN/m}^2}$$

3.27 A time-distance plot is shown.



$$\text{Slope of } 0a = \frac{1}{v_1} = \frac{15.24 \times 10^{-3}}{7.5}$$

$$v_1 = \frac{7.5 \times 10^3}{15.24} = \mathbf{492 \text{ m/s (top layer)}}$$

$$v_2 = \text{slope of } ab = \frac{10 \times 10^3}{7.19} \approx \mathbf{1390 \text{ m/s}}$$

$$v_3 = \text{slope of } bc = \frac{20 \times 10^3}{5.9} = \mathbf{3390 \text{ m/s}}$$

$$x_c = 7.5 \text{ m}$$

$$Z_1 = \frac{1}{2} \sqrt{\frac{v_2 - v_1}{v_2 + v_1}} x_c = \frac{1}{2} \sqrt{\frac{1390 - 492}{1390 + 492}} (7.5) = \mathbf{2.6 \text{ m}}$$

$$\text{Eq. (3.81): } Z_2 = \frac{1}{2} \left[T_{i2} - \frac{2Z_1 \sqrt{v_3^2 - v_1^2}}{(v_3)(v_1)} \right] \left[\frac{v_3 v_2}{\sqrt{v_3^2 - v_2^2}} \right]; \quad T_{i2} \approx 20 \times 10^{-3} \text{ s}$$

$$\frac{2Z_1 \sqrt{v_3^2 - v_1^2}}{(v_3)(v_1)} = \frac{(2)(2.6) \sqrt{(3390)^2 - (492)^2}}{(3390)(492)} = 0.0105$$

$$\frac{v_3 v_2}{\sqrt{v_3^2 - v_2^2}} = \frac{(3390)(1390)}{\sqrt{(3390)^2 - (1390)^2}} = 1524$$

$$\text{So, } Z_2 = \frac{1}{2} (0.02 - 0.0105)(1524) = \mathbf{7.24 \text{ m}}$$

