

# SOLUTIONS MANUAL

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SEVENTH EDITION

PRINCIPLES OF

**FOUNDATION ENGINEERING**



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# Chapter 2

2.1 Eq. (2.3):  $A_R (\%) = \frac{D_o^2 - D_i^2}{D_i^2} \times 100 = \frac{(76.2)^2 - (73)^2}{(73)^2} \times 100 = \mathbf{8.96\%}$

2.2

Depth from ground surface (m)	$N_{60}$	$c_u$ (kN/m <sup>2</sup> ) [Eq. (2.8)]	$\sigma'_o$ (MN/m <sup>2</sup> )	OCR [Eq. (2.9)]
3.0	5	<b>92.4</b>	$\frac{1}{1000} [(1.5)(16.5) + (1.5)(19 - 9.81)]$ = 0.03854	<b>5.51</b>
4.5	8	<b>129.6</b>	$0.03854 + \frac{1}{1000} (1.5)(16.8 - 9.81)$ = 0.0490	<b>6.46</b>
6.0	8	<b>92.4</b>	$0.0490 + \frac{1}{1000} (1.5)(16.8 - 9.81)$ = 0.0595	<b>5.65</b>
7.5	9	<b>141.1</b>	$0.0595 + \frac{1}{1000} (1.5)(16.8 - 9.81)$ = 0.07	<b>5.48</b>
9.0	10	<b>152.2</b>	$0.07 + \frac{1}{1000} (1.5)(16.8 - 9.81)$ = 0.0805	<b>5.35</b>
Average $c_u = \mathbf{121.5 \text{ kN/m}^2}$			Average OCR = <b>5.69</b>	

2.3

Depth (m)	$\sigma'_o$ (kN/m <sup>2</sup> )
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	$123.6 + (1.5)(20.2 - 9.81) = 139.2$

$$\text{Eq. (2.11): } C_N = \frac{2}{1 + \left(\frac{\sigma'_o}{p_a}\right)}; p_a \approx 100 \text{ kN/m}^2$$

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

<sup>a</sup>Rounded off to nearest whole number

2.4 From Problem 2.3, the average value of

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

$$\text{Eq. (2.28): } \phi' = \sqrt{20(N_1)_{60}} + 20 = \sqrt{(20)(11)} + 20 = 34.83^\circ \approx \mathbf{35^\circ}$$

2.5 From Problem 2.3

Depth (m)	$\sigma'_o$ (kN/m <sup>2</sup> )	$p_a$ (kN/m <sup>2</sup> )	$N_{60}$	$\phi'$ (deg) [Eq. (2.27)]
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 $\phi' = 34.1^\circ \approx \mathbf{34^\circ}$				

2.6

Depth (m)	$\sigma'_o$ (kN/m <sup>2</sup> )	$p_a$ (kN/m <sup>2</sup> )	$N_{60}$	$D_r$ (%) [Eq. (2.20)]
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 $D_r = 50.13\% \approx \mathbf{50\%}$				

2.7

Depth (m)	$\sigma'_o$ (kN/m <sup>2</sup> )	$p_o$ (kN/m <sup>2</sup> )	$\left(0.23 + \frac{0.06}{D_{50}}\right)^{1.7}$	$N_{60}$	$D_r$ (%) [Eq. (2.21)]
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
Average $D_r \approx \mathbf{49.4\%}$					

2.8

Depth (m)	$\gamma$ (kN/m <sup>3</sup> )	$\sigma'_o$ (kN/m <sup>2</sup> )	$p_a$ (kN/m <sup>2</sup> )	$N_{60}$	$\phi'$ (deg) <sup>a</sup> [Eq. (2.27)]
3.0	16.66	49.98	100	7	34
4.5	16.66	74.97	100	9	34
6.0	10.66	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
<sup>a</sup> rounded to nearest whole number					

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

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

$$\text{Eq. (2.29): } E_s = p_a \alpha N_{60} = (100)(10)(15) = \mathbf{15,000 \text{ kN/m}^2}$$

2.10 Eq. (2.19):

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

**At a depth of 3.0 m:**

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

**At a depth of 4.5 m:**

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

**At a depth of 6.0 m:**

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

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

2.11 Eq. (2.31):  $c_u = \frac{T}{K}$

$$\text{Eq. (2.32b): } K = 366 \times 10^{-8} D^3 = 366 \times 10^{-8} (6.35)^3 = 93.7 \times 10^{-5}$$

$$c_{u(\text{VST})} = \frac{0.051}{93.7 \times 10^{-5}} = 54.4 \text{ kN/m}^2$$

Eqs. (2.34) and (2.35a):

$$\begin{aligned} c_{u(\text{corrected})} &= \lambda c_{u(\text{VST})} = [1.7 - 0.54 \log(\text{PI})](54.4) \\ &= [1.7 - 0.54 \log(46 - 21)](54.4) = \mathbf{51.4 \text{ kN/m}^2} \end{aligned}$$

2.12 Eq. (2.37):  $OCR = \beta \frac{c_{u(\text{field})}}{\sigma'_o}$

$\sigma'_o = 59.5 \text{ kN/m}^2$  (From Problem 2.2)

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

$OCR = (4.69) \left( \frac{54.4}{59.5} \right) = \mathbf{4.29}$

2.13 a. From Eq. (2.33):  $K = 366 \times 10^{-8} D^3 = 366 \times 10^{-8} (5.08 \text{ cm})^3 = 4.8 \times 10^{-4}$

$c_{u(\text{VST})} = \frac{T}{K} = \frac{16.81}{4.8 \times 10^{-4}} = \mathbf{35,020.8 \text{ N/m}^2} \approx \mathbf{35 \text{ kN/m}^2}$

b. From Eqs. (2.34) and (2.35a):

$c_{u(\text{corrected})} = [1.7 - 0.54 \log(\text{PI})](35)$   
 $= [1.7 - 0.54 \log(58 - 29)](35) = \mathbf{31.86 \text{ kN/m}^2}$

2.14 Eq. (2.40):  $\beta = \frac{1}{0.08 + 0.0055(\text{PI})} = \frac{1}{0.08 + 0.0055(29)} = 4.18$

Eq. (2.37):  $OCR = \beta \frac{c_{u(\text{field})}}{\sigma'_o} = (4.18) \left( \frac{35}{64.2} \right) = \mathbf{2.28}$

2.15

Depth (m)	$\sigma'_o$ (MN/m <sup>2</sup> )	$q_c$ (MN/m <sup>2</sup> )	$\phi'$ (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
			$\phi'$ (average) $\approx \mathbf{42^\circ}$

2.16 Note: OCR = 1

Depth (m)	$q_c$ (kN/m <sup>2</sup> )	$\sigma'_o$ (kN/m <sup>2</sup> )	$D_r$ (%) [Eq. (2.46)]
1.5	2060	24	<b>37.1</b>
3.0	4230	48	<b>44.7</b>
4.5	6010	72	<b>48.2</b>
6.0	8180	96	<b>52.3</b>
7.5	9970	120	<b>54.6</b>
9.0	12420	144	<b>58.3</b>

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

$$\text{Eq. (2.51): } c_u = \frac{q_c - \sigma_o}{N_k} = \frac{800 - 116}{15} \approx \mathbf{45.6 \text{ kN/m}^2}$$

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

$$\text{Eq. (2.55): } \text{OCR} = 0.37 \left( \frac{q_c - \sigma_o}{\sigma'_o} \right)^{1.01} = (0.37) \left( \frac{800 - 116}{76.76} \right)^{1.01} \approx \mathbf{3.37}$$

2.18 Eq. (2.56):

$$E_p = 2(1 + \mu_s)(V_o + v_m) \left( \frac{\Delta p}{\Delta v} \right) = (2)(1 + 0.5) \left( 535 + \frac{46 + 180}{2} \right) \left( \frac{326.5 - 42.4}{180 - 46} \right)$$

$$= \mathbf{4121.6 \text{ kN/m}^2}$$

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

$$\text{Eq. (2.63): } K_o = \left( \frac{K_D}{1.5} \right)^{0.47} - 0.6 = \left( \frac{2.43}{1.5} \right)^{0.47} - 0.6 = \mathbf{0.65}$$

b. Eq. (2.64):  $\text{OCR} = (0.5K_D)^{1.6} = (0.5 \times 2.43)^{1.6} = \mathbf{1.37}$

c. Eq. (2.67):  $E_s = (1 - \mu_s^2)E_D = (1 - \mu_s^2)(34.7)(p_1 - p_o)$   
 $= (1 - 0.35^2)(34.7)(350 - 280) = \mathbf{2131 \text{ kN/m}^2}$

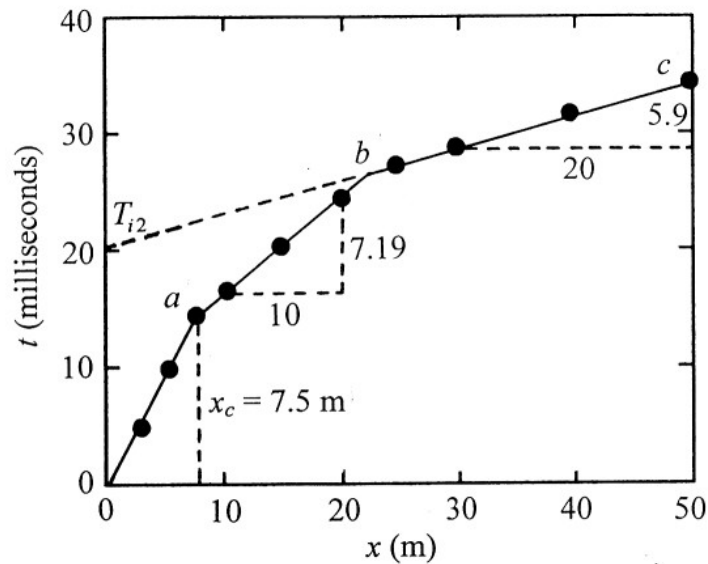
2.20  $K_D = \frac{p_o - u_o}{\sigma'_o} = \frac{260 - (4)(9.81)}{(2)(14.5) + (4)(19.8 - 9.81)} = 3.2$

Eq. (2.69a):  $\phi' = 31 + \frac{K_D}{0.236 + 0.066K_D} = 31 + \frac{3.2}{0.236 + (0.066)(3.2)} = \mathbf{38.2^\circ}$

2.21 Eq. (2.72):  $v = \sqrt{\frac{E_s}{\gamma} \frac{1 - \mu_s}{(1 - 2\mu_s)(1 + \mu_s)g}}$ ;  $\mu_s = 0.32$

$1900 = \sqrt{\frac{E_s}{18} \times \frac{0.68}{(0.36)(1.32)g}}$ ;  $E_s = \mathbf{3125 \text{ kN/m}^2}$

2.22 A time-distance plot is shown.





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

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

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

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

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

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

$$\text{Eq. (2.74): } Z_2 = \frac{1}{2} \left[ T_{i2} - \frac{2Z_1 \sqrt{v_3^2 - v_1^2}}{(v_3)(v_1)} \right] \left[ \frac{v_3 v_2}{\sqrt{v_3^2 - v_2^2}} \right]; \quad T_{i2} \approx 20 \times 10^{-3} \text{ s}$$

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

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

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