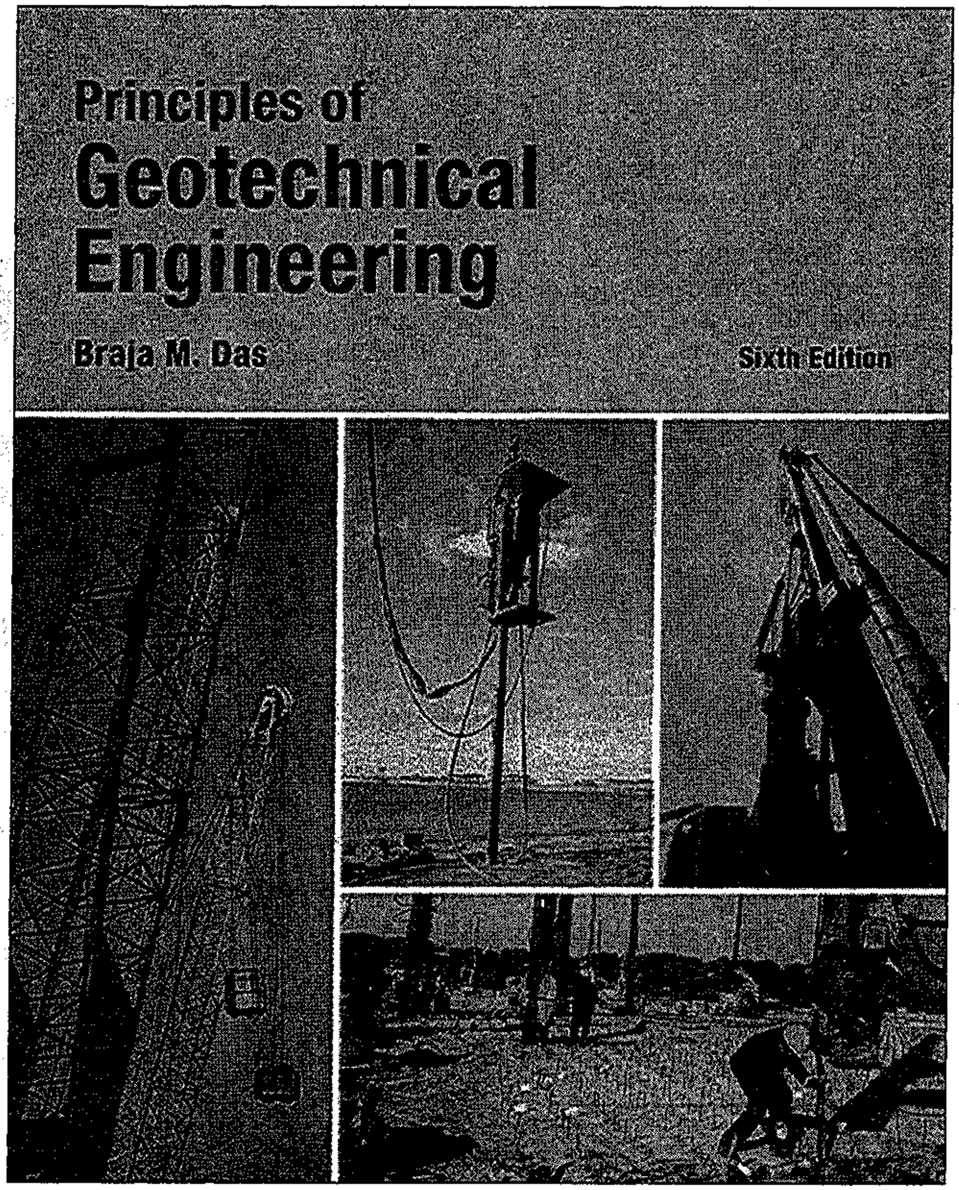
INSTRUCTOR'S SOLUTIONS MANUAL

to accompany



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ENGINEERING

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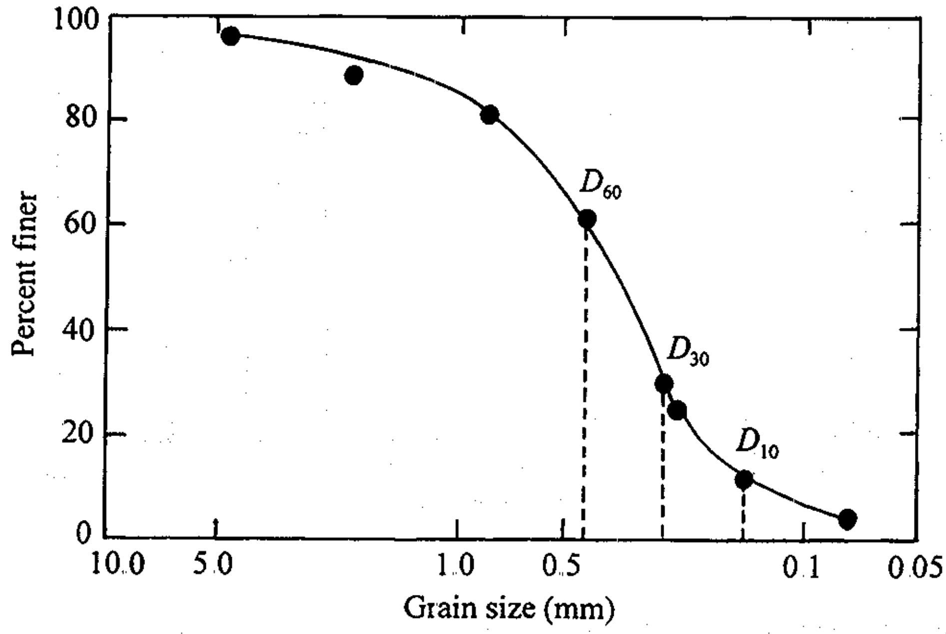
CONTENTS

CHAPTER 2

2.1 a.

Sieve No.	Mass retained (g)	Percent retained on each sieve	Percent finer
4	28	4.54	95.46
10	42	6.81	88.65
20	48	7.78	80.87
40	128	20.75	60.12
60	221	35.82	24.3
100	86	13.94	10.36
200	40	6.48	3.88
Pan	24	3.88	0
	$\sum 617$ g		

The graph for percent finer versus grain size is shown.



b. From the graph, D_{10} = **0.14 mm**, D_{30} = **0.27 mm**, D_{60} = **0.42 mm**.

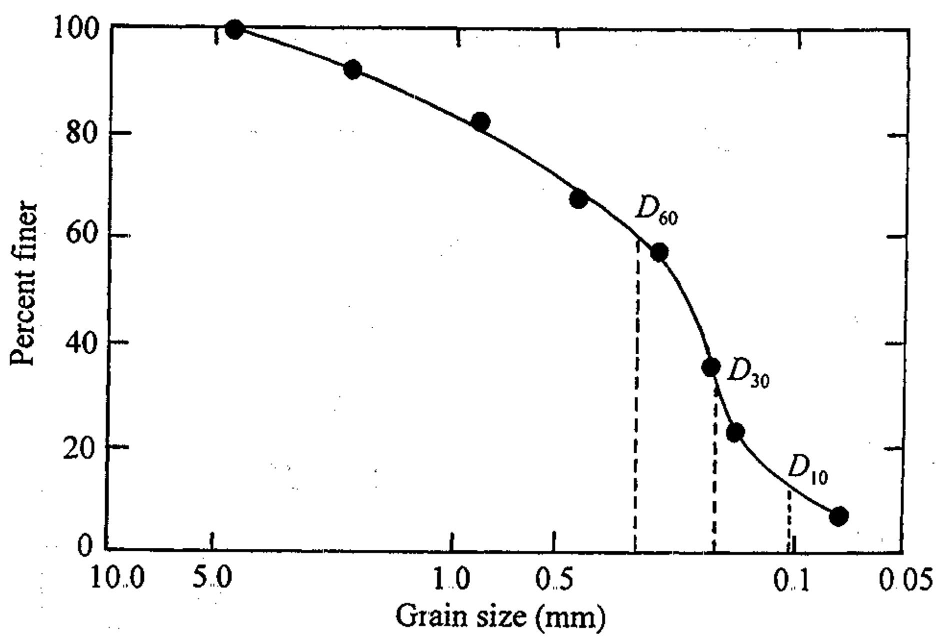
c. $C_u = \frac{D_{60}}{D_{10}} = \frac{0.42}{0.14} = \mathbf{3}$

d. $C_c = \frac{(D_{30})^2}{(D_{60})(D_{10})} = \frac{(0.27)^2}{(0.42)(0.14)} = \mathbf{1.24}$

2.2 a.

Sieve No.	Mass retained (g)	Percent retained on each sieve	Percent finer
4	0	0	100
10	44	7.99	92.01
20	56	10.16	81.85
40	82	14.88	66.97
60	51	9.26	57.71
80	106	19.24	38.47
100	92	16.70	21.77
200	85	15.43	6.34
Pan	35	6.34	0
	$\sum 551$ g		

The grain-size distribution curve is shown.



b. From the graph, D_{60} = **0.3 mm**, D_{30} = **0.17 mm**, D_{10} = **0.11 mm**.

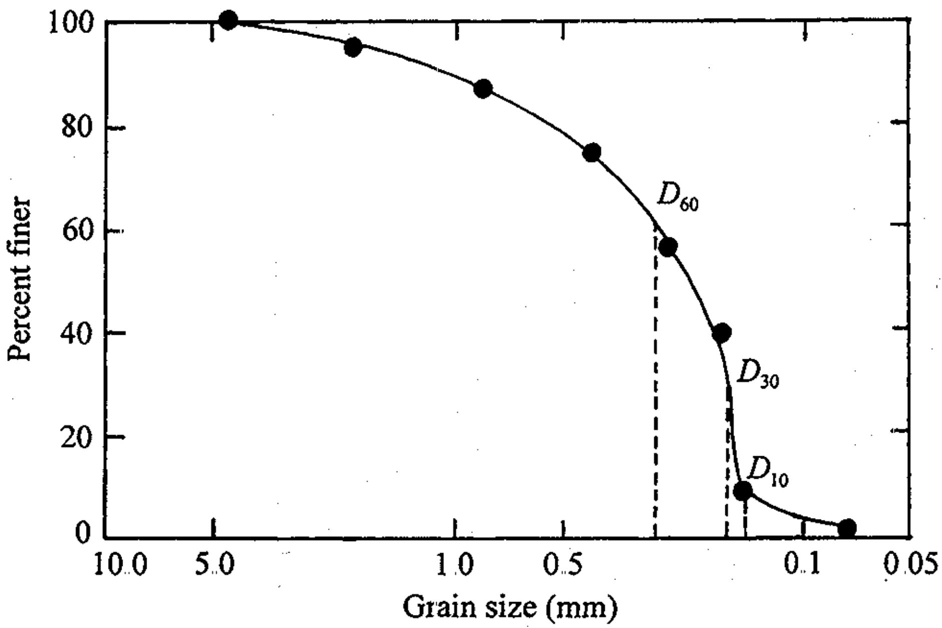
c. $C_u = \dfrac{0.3}{0.11} = \mathbf{2.73}$

d. $C_c = \dfrac{(0.17)^2}{(0.11)(0.3)} = \mathbf{0.88}$

2.3 a.

Sieve No.	Mass retained (g)	Percent retained on each sieve	Percent finer
4	0	0	100
10	40	5.49	94.51
20	60	8.23	86.28
40	89	12.2	74.08
60	140	19.2	54.88
80	122	16.74	38.14
100	210	28.81	9.33
200	56	7.68	1.65
Pan	12	1.65	0
	$\sum 729$ g		

The grain-size distribution curve is shown.



b. From the graph, D_{60} = **0.27 mm**, D_{30} = **0.17 mm**, D_{10} = **0.15 mm**.

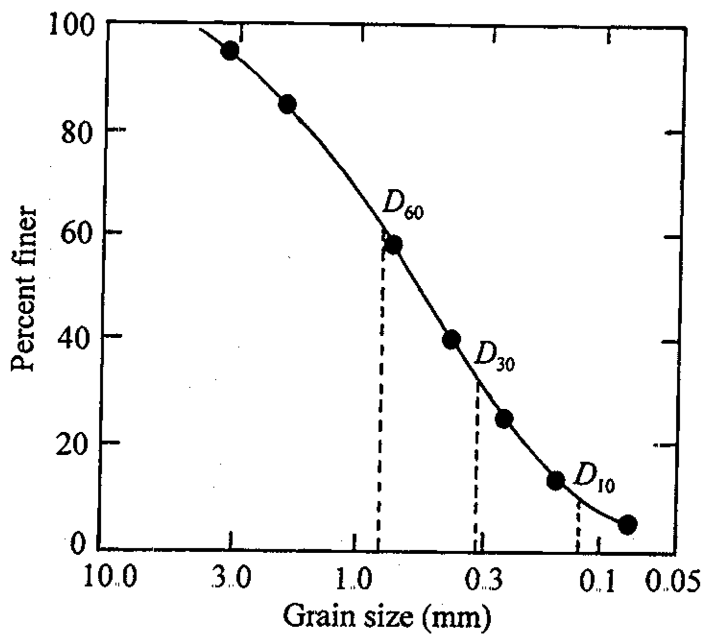
c. $C_u = \frac{0.27}{0.15} = \mathbf{1.8}$

d. $C_c = \frac{(0.17)^2}{(0.15)(0.27)} = \mathbf{0.714}$

2.4 a.

Sieve No.	Mass retained (g)	Percent retained on each sieve	Percent finer
4	0	0	100
6	30.0	6.0	94
10	48.7	9.74	84.26
20	127.3	25.46	58.8
40	96.8	19.36	39.44
60	76.6	15.32	24.12
100	55.2	11.04	13.08
200	43.4	8.68	4.40
Pan	22.0	4.4	0
	$\sum$500 g		

The grain-size distribution curve is shown.



b. From the graph, D_{60} = **0.82 mm**, D_{30} = **0.31 mm**, D_{10} = **0.12 mm**.

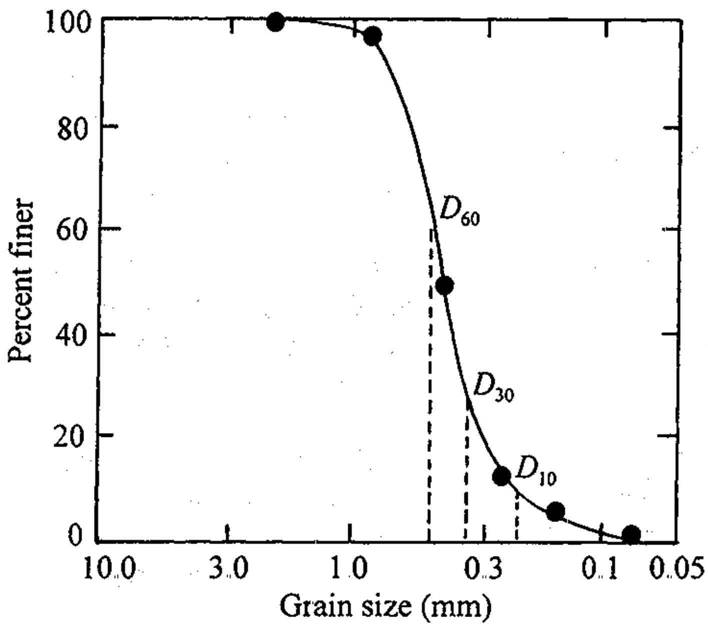
c. $C_u = \frac{0.82}{0.12} = \mathbf{6.83}$

d. $C_c = \frac{(0.31)^2}{(0.81)(0.12)} = \mathbf{0.98}$

2.5 a.

Sieve No.	Mass retained (g)	Percent retained on each sieve	Percent finer
4	0	0	100
6	0	0	100
10	0	0	100
20	9.1	1.82	98.18
40	249.4	49.88	48.3
60	179.8	35.96	12.34
100	22.7	4.54	7.8
200	15.5	3.10	4.7
Pan	23.5	4.70	0
	$\sum 500$ g		

The grain-size distribution curve is shown.

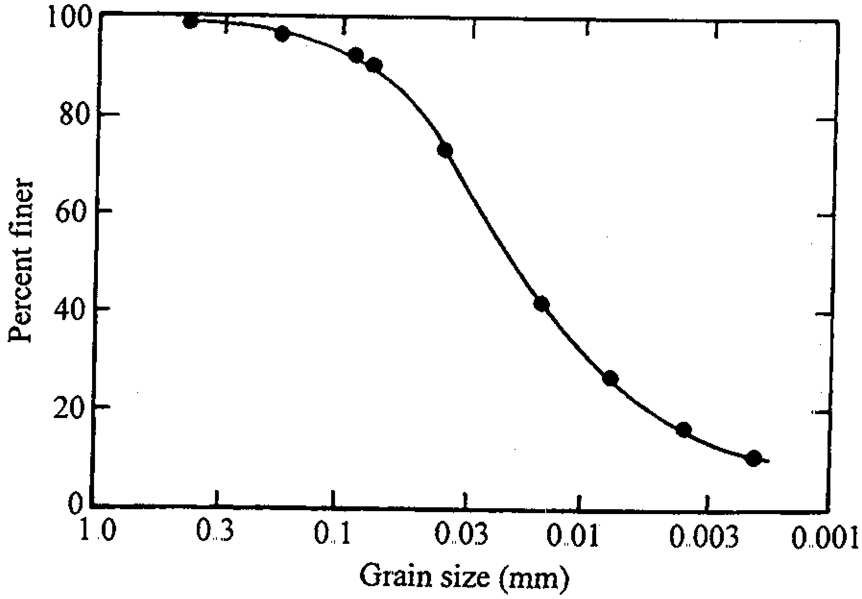


b. From the graph, D_{60} = **0.48 mm**, D_{30} = **0.33 mm**, D_{10} = **0.23 mm**.

c. $C_u = \frac{0.48}{0.23} = \mathbf{2.09}$

d. $C_c = \frac{(0.33)^2}{(0.48)(0.23)} = \mathbf{0.99}$

2.6 a. The grain-size distribution curve is shown.



b. Percent passing 2 mm = 100
Percent passing 0.06 mm = 84
Percent passing 0.002 mm = 11

GRAVEL: 100 - 100 = **0%**
SAND: 100 - 84 = **16%**
SILT: 84 - 11 = **73%**
CLAY: 11 - 0 = **11%**

c. Percent passing 2 mm = 100
Percent passing 0.05 mm = 80
Percent passing 0.002 mm = 11

GRAVEL: 100 - 100 = **0%**
SAND: 100 - 80 = **20%**
SILT: 80 - 11 = **69%**
CLAY: 11 - 0 = **11%**

d. Percent passing 2 mm = 100
Percent passing 0.075 mm = 90
Percent passing 0.002 mm = 11

GRAVEL: 100 - 100 = **0%**
SAND: 100 - 90 = **10%**
SILT: 90 - 11 = **79%**
CLAY: 11 - 0 = **11%**

2.7 a. The grain-size distribution is shown in the figure on the next page.

b. Percent passing 2 mm = 100
Percent passing 0.06 mm = 74
Percent passing 0.002 mm = 9

GRAVEL: 100 - 100 = **0%**
SAND: 100 - 74 = **26%**
SILT: 74 - 9 = **65%**
CLAY: 9 - 0 = **9%**

c. Percent passing 2 mm = 100
Percent passing 0.05 mm = 70
Percent passing 0.002 mm = 9

GRAVEL: 100 - 100 = **0%**
SAND: 100 - 70 = **30%**
SILT: 70 - 9 = **61%**
CLAY: 9 - 0 = **9%**

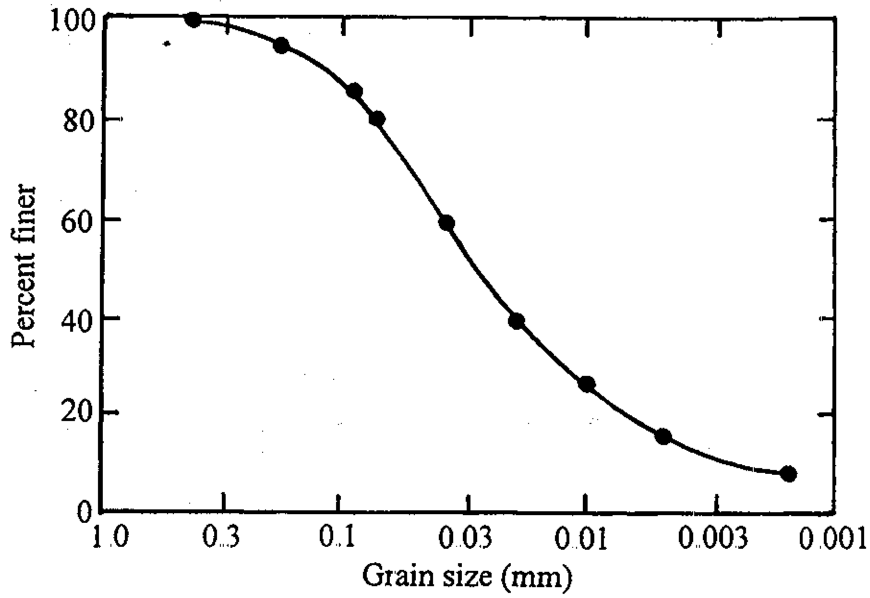
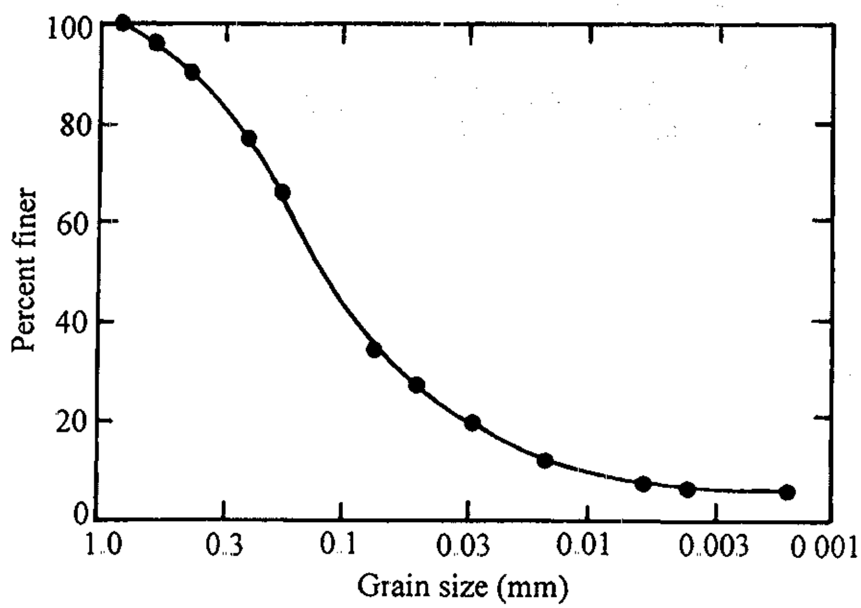


Figure 2.7a.

d. Percent passing 2 mm = 100
Percent passing 0.075 mm = 80
Percent passing 0.002 mm = 9

GRAVEL: 100 - 100 = **0%**
SAND: 100 - 80 = **20%**
SILT: 80 - 9 = **71%**
CLAY: 9 - 0 = **9%**

2.8 a. The grain-size distribution is shown.



b. Percent passing 2 mm = 100
Percent passing 0.06 mm = 30
Percent passing 0.002 mm = 6

GRAVEL: 100 - 100 = **0%**
SAND: 100 - 30 = **70%**
SILT: 30 - 6 = **24%**
CLAY: 6 - 0 = **6%**

c. Percent passing 2 mm = 100
Percent passing 0.05 mm = 26
Percent passing 0.002 mm = 9

GRAVEL: 100 - 100 = **0%**
SAND: 100 - 26 = **74%**
SILT: 26 - 6 = **20%**
CLAY: 6 - 0 = **6%**

d. Percent passing 2 mm = 100
Percent passing 0.075 mm = 34
Percent passing 0.002 mm = 6

GRAVEL: 100 - 100 = **0%**
SAND: 100 - 34 = **66%**
SILT: 34 - 6 = **28%**
CLAY: 6 - 0 = **6%**

2.9 $G_s = 2.7$; temperature = 24°; $L = 9.2$ cm; time, $t = 60$ minutes after the start of sedimentation

Equation (2.5): $D\text{ (mm)} = K\sqrt{\frac{L\text{ (cm)}}{t\text{ (min)}}}$

From Table 2.6, for $G_s = 2.7$ and temperature = 24°, $K = 0.01282$. So

$$D = 0.01282\sqrt{\frac{9.2}{60}} = \mathbf{0.005\ mm}$$

2.10 For $G_s = 2.7$ and temperature = 23°, $K = 0.01279$ (Table 2.6)

$$D\text{ (mm)} = K\sqrt{\frac{L\text{ (cm)}}{t\text{ (min)}}} = 0.01279\sqrt{\frac{12.8}{100}} = \mathbf{0.0046\ mm}$$

CHAPTER 3

3.1 $\gamma_{sat} = \frac{G_s\gamma_w + e\gamma_w}{1+e} = \frac{G_s\gamma_w}{1+e} + \frac{e}{1+e}\gamma_w = \gamma_d + \frac{e}{1+e}\gamma_w$

$(1 + e)(\gamma_{sat} - \gamma_d) = e\gamma_w$

$e\gamma_w = \gamma_{sat} - \gamma_d + e\gamma_{sat} - e\gamma_d$

$e(\gamma_w - \gamma_{sat} + \gamma_d) = \gamma_{sat} - \gamma_d$

$$e = \frac{\gamma_{sat} - \gamma_d}{\gamma_d - \gamma_{sat} + \gamma_w}$$

3.2 $\gamma_{sat} = \frac{(1+w_{sat})G_s\gamma_w}{1+w_{sat}G_s}$

$\gamma_{sat} + w_{sat}G_s\,\gamma_{sat} = G_s\,\gamma_w + w_{sat}G_s\,\gamma_w$

$G_s(\gamma_w + w_{sat}\,\gamma_w - w_{sat}\,\gamma_{sat}) = \gamma_{sat}$

$$G_s = \frac{\gamma_{sat}}{\gamma_w + w_{sat}\gamma_w - w_{sat}\gamma_{sat}} = \frac{\gamma_{sat}}{\gamma_w - w_{sat}(\gamma_{sat} - \gamma_w)}$$

3.3 a. $\gamma = \frac{W}{V} = \frac{12.2}{0.1} = \mathbf{122\ lb/ft^3}$

b. $\gamma_d = \frac{\gamma}{1+w} = \frac{122}{1+\frac{12}{100}} = \mathbf{108.93\ lb/ft^3}$

c. $\gamma_d = \frac{G_s\gamma_w}{1+e}$

$108.93 = \frac{(2.72)(62.4)}{1+e}$; $e = \mathbf{0.56}$

d. $n = \frac{e}{1+e} = \frac{0.56}{1+0.56} = \mathbf{0.36}$

e. $S = \frac{wG_s}{e} = \frac{(0.12)(2.72)}{0.56} \times 100 = \mathbf{58.3\%}$

f. $W_s = \frac{W}{1+w} = \frac{12.2}{1+\frac{12}{100}} = 10.89 \text{ lb}$

$W_w = W - W_s = 12.2 - 10.89 = 1.31 \text{ lb}$

$V_w = \frac{1.31}{62.4} = \mathbf{0.021\ ft^3}$

3.4 a. $\gamma_d = \frac{\gamma}{1+w} = \frac{19.2}{1+\frac{9.8}{100}} = \mathbf{17.5\ kN/m^3}$

b. $\gamma_d = 17.5 = \frac{G_s\gamma_w}{1+e} = \frac{(2.69)(9.81)}{1+e}; \quad e = \mathbf{0.51}$

c. $n = \frac{e}{1+e} = \frac{0.51}{1+0.51} = \mathbf{0.338}$

d. $S = \frac{wG_s}{e} = \frac{(0.098)(2.69)}{0.51} \times 100 = \mathbf{51.7\%}$

3.5 a. $\gamma = \frac{W}{V} = \frac{30.75}{0.25} = \mathbf{123\ lb/ft^3}$

b. $\gamma_d = \frac{\gamma}{1+w} = \frac{123}{1+0.098} = \mathbf{112.02\ lb/ft^3}$

c. $e = \frac{G_s\gamma_w}{\gamma_d} - 1 = \frac{(2.66)(62.4)}{112.02} - 1 = \mathbf{0.482}$

d. $n = \frac{e}{1+e} = \frac{0.482}{1+0.482} = \mathbf{0.325}$

e. $S = \frac{wG_s}{e} = \frac{(0.098)(2.66)}{0.482} \times 100 = \mathbf{54.1\%}$

f. $W_s = \frac{30.75}{1+\frac{9.8}{100}} = 28 \text{ lb}$

$$W_w = W - W_s = 30.75 - 28 = 2.75 \text{ lb}$$

$$V_w = \frac{W_w}{\gamma_w} = \frac{2.75}{62.4} = \mathbf{0.044\ ft^3}$$

3.6 a. $\gamma_d = \dfrac{\gamma}{1+w} = \dfrac{20.6}{1+0.166} = \mathbf{17.67\ kN/m^3}$

b. $e = \dfrac{G_s\gamma_w}{\gamma_d} - 1 = \dfrac{(2.74)(9.81)}{17.67} - 1 = \mathbf{0.52}$

c. $n = \dfrac{e}{1+e} = \dfrac{0.52}{1+0.52} = \mathbf{0.34}$

d. $S = \dfrac{wG_s}{e} = \dfrac{(0.166)(2.74)}{0.52} \times 100 = \mathbf{87.5\%}$

3.7 a. At 90% saturation,

$$\gamma = \frac{G_s\gamma_w + Se\gamma_w}{1+e} = \frac{(G_s + Se)\gamma_w}{1+e} = \frac{(2.74 + 0.9 \times 0.52)(9.81)}{1+0.52} = 20.7 \text{ kN/m}^3$$

Water to be added = 20.7 − 20.6 = **0.1 kN / m³**

b. At 100% saturation,

$$\gamma_{sat} = \frac{(G_s + e)\gamma_w}{1+e} = \frac{(2.74 + 0.52)(9.81)}{1+0.52} = 21.04 \text{ kN/m}^3$$

Water to be added = 21.04 − 20.6 = **0.44 kN / m³**

3.8 a. $\gamma = \dfrac{G_s\gamma_w + wG_s\gamma_w}{1+e}; \quad G_s = \dfrac{Se}{w}; \quad G_s w = Se$

$$\gamma = \frac{\left(\frac{Se}{w}\right)\gamma_w + Se\gamma_w}{1+e}; \quad 96 = \frac{\left[\frac{(0.6)(e)}{0.17} + (0.6)(e)\right](62.4)}{1+e}$$

$e = \mathbf{0.59}$

b. $G_s = \dfrac{Se}{w} = \dfrac{(0.6)(0.59)}{0.17} = \mathbf{2.08}$

c. $\gamma_{sat} = \frac{(G_s + e)\gamma_w}{1+e} = \frac{(2.08 + 0.59)(62.4)}{1.59} = \mathbf{104.8\ lb/ft^3}$

3.9 a. $e = wG_s = (0.23)(2.67) = 0.614$

$$\gamma_{sat} = \frac{(G_s + e)\gamma_w}{1+e} = \frac{(2.67 + 0.614)(62.4)}{1 + 0.614} = \mathbf{126.97\ lb/ft^3}$$

b. $\gamma_d = \frac{\gamma_{sat}}{1+w} = \frac{126.97}{1+0.23} = \mathbf{103.2\ lb/ft^3}$

c. $\gamma = \frac{(G_s + Se)\gamma_w}{1+e} = \frac{(2.67 + 0.7 \times 0.614)(62.4)}{1.614} = \mathbf{119.8\ lb/ft^3}$

3.10 $\gamma_d = \frac{(1820)(9.81)}{1000} = 17.85\ \text{kN/m}^3$

$$e = \frac{G_s\gamma_w}{\gamma_d} - 1 = \frac{(2.68)(9.81)}{17.85} - 1 = 0.473$$

$$w = \frac{e}{G_s} = \frac{0.473}{2.68} \times 100 = \mathbf{17.65\%}$$

3.11 a. $e = \frac{0.35}{1 - 0.35} = 0.538$

$$\gamma_{sat} = \frac{(G_s + e)\gamma_w}{1+e} = \frac{(2.69 + 0.538)(9.81)}{1.538} = \mathbf{20.59\ kN/m^3}$$

b. $\gamma = \frac{G_s\gamma_w(1+w)}{1+e}$; $\quad 18 = \frac{(2.69)(9.81)(1+w)}{1+0.538}$

$$w = 0.049 = \mathbf{4.9\%}$$

3.12 a. $\gamma = \frac{\gamma_w(G_s + Se)}{1+e}$; $\quad 105.73 = \frac{(62.4)(G_s + 0.5e)}{1+e}$

$G_s = 1.694 + 1.194e$ (a)

$$112.67 = \frac{(62.4)(G_s + 0.75e)}{1+e} \qquad \text{(b)}$$

From Equations (a) and (b),

$$112.67 = \frac{(62.4)(1.694 + 1.194e + 0.75e)}{1+e}; \quad e = \mathbf{0.81}$$

b. From Equation(a),

$$G_s = 1.694 + (1.194)(0.82) = \mathbf{2.66}$$

3.13 $$\gamma_d = \frac{G_s \gamma_w}{1+e} = \frac{(2.66)(62.4)}{1+0.81} = 91.7 \text{ lb/ft}^3$$

$$\gamma_{sat} = \frac{\gamma_w (G_s + e)}{1+e} = \frac{(62.4)(2.66+0.81)}{1+0.81} = 119.6 \text{ lb/ft}^3$$

$$\text{Water} = (4.5)(\gamma_{sat} - \gamma_d) = (4.5)(119.6 - 91.7) = \mathbf{125.55\ lb}$$

3.14 $$e = e_{max} - D_r(e_{max} - e_{min}) = 0.86 - (0.56)(0.86 - 0.43) = \mathbf{0.619}$$

$$\gamma = \frac{G_s \gamma_w (1+w)}{1+e} = \frac{(2.66)(62.4)(1+0.7)}{1.619} = \mathbf{109.7\ lb/ft^3}$$

3.15 $$e = e_{max} - D_r(e_{max} - e_{min}) = 0.75 - (0.65)(0.75 - 0.52) = \mathbf{0.6}$$

$$\gamma_d = \frac{G_s \gamma_w}{1+e} = \frac{(2.7)(62.4)}{1.6} = \mathbf{105.3\ lb/ft^3}$$

3.16 a. $$D_r = \frac{e_{max} - e_1}{e_{max} - e_{min}}$$

$$e_1 = e_{max} - D_r(e_{max} - e_{min}) = 0.9 - (0.4)(0.9 - 0.46) = 0.724$$

$$\gamma_d = \frac{G_s \gamma_w}{1+e_1} = \frac{(2.65)(9.81)}{1+0.724} = \mathbf{15.08\ kN/m^3}$$

b. $$e_2 = e_{max} - D_r(e_{max} - e_{min}) = 0.9 - (0.75)(0.9 - 0.46) = 0.57$$

$$\frac{\Delta H}{H}=\frac{\Delta e}{1+e_1}=\frac{e_1-e_2}{1+e_1};\quad \frac{\Delta H}{2}=\frac{0.724-0.57}{1+0.724}$$

$\Delta H = 0.1787$ m = **178.7 mm**

3.17 $\gamma_d=\dfrac{G_s\gamma_w}{1+\dfrac{wG_s}{S}}$

$$92.1=\frac{G_s\gamma_w}{1+\dfrac{wG_s}{0.4}} \qquad \text{(a)}$$

$$113.7=\frac{G_s\gamma_w}{1+\dfrac{wG_s}{0.7}} \qquad \text{(b)}$$

From Equations (a) and (b), $\dfrac{113.7}{92.1}=\dfrac{1+2.5wG_s}{1+1.429wG_s}$

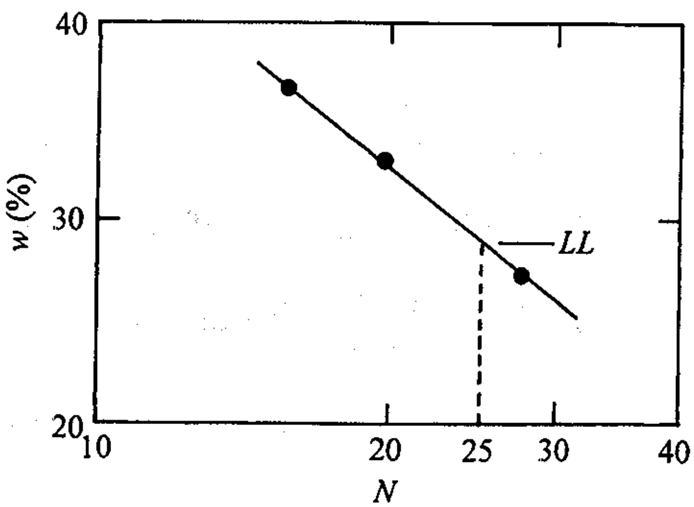
$$G_s=\frac{0.32}{w} \qquad \text{(c)}$$

From Equations (a) and (c),

$$92.1=\frac{\left(\dfrac{0.32}{w}\right)(62.4)}{1+\left(\dfrac{w}{0.4}\right)\left(\dfrac{0.32}{w}\right)};\quad w=0.12=\mathbf{12\%}$$

3.18 a. Refer to the plot of w versus N.

$LL = 28.5$



b. $PI = LL - PL = 28.5 - 12.2 = \mathbf{16.3}$

3.19 $LI = \dfrac{w - PL}{LL - PL} = \dfrac{31 - 12.2}{16.3} = \mathbf{1.15}$

3.20 $SL = \left(\dfrac{M_1 - M_2}{M_2}\right)(100) - \left(\dfrac{V_i - V_f}{M_2}\right)(\rho_w)(100)$

$= \left(\dfrac{36 - 25}{25}\right)(100) - \left(\dfrac{19.65 - 13.5}{25}\right)(1)(100) = \mathbf{19.4\%}$

$SR = \dfrac{M_2}{V_f \rho_w} = \dfrac{25}{(13.5)(1)} = \mathbf{1.85}$

3.21 $SL = \left(\dfrac{M_1 - M_2}{M_2}\right)(100) - \left(\dfrac{V_i - V_f}{M_2}\right)(\rho_w)(100)$

$= \left(\dfrac{44 - 30.1}{30.1}\right)(100) - \left(\dfrac{24.6 - 15.9}{30.1}\right)(1)(100) = 46.18 - 28.9 = \mathbf{17.28\%}$

$SR = \dfrac{M_2}{V_f \rho_w} = \dfrac{30.1}{(15.9)(1)} = \mathbf{1.89}$

CHAPTER 4

4.1 SOIL A: From Table 4.1, the soil is A-2-4. The GI for A-2-4 is zero. So, the classification is **A-2-4(0)**.

SOIL B: Table 4.1. Soil is A-3. $GI = 0$. Classification: **A-3(0)**

SOIL C: Table 4.1. Soil is A-2-6. Equation (4.2):

$$GI = 0.01(F_{200} - 15)(PI - 10) = 0.01(12 - 15)(13 - 10) = -0.09 \approx 0$$

Classification: **A-2-6(0)**

SOIL D: Table 4.1. Soil is A-2-7. Equation (4.2):

$$GI = 0.01(F_{200} - 15)(PI - 10) = 0.01(30 - 15)(18 - 10) = 1.2 \approx 1$$

Classification: **A-2-7(1)**

SOIL E: Table 4.1. Soil is A-1-b. The group index for A-1-b is 0.

Classification: **A-1-b(0)**

4.2 SOIL A: Table 4.1. Soil is A-7-5.

Note: $PI = 21$, which is less than $LL - 30 = 52 - 30 = 22$

$$GI = (F_{200} - 35)[0.2 + 0.005(LL - 40)] + 0.01(F_{200} - 15)(PI - 10)$$
$$= (72 - 35)[0.2 + 0.005(52 - 40)] + 0.01(72 - 15)(21 - 10) = 15.89 \approx 16$$

Classification: **A-7-5(16)**

SOIL B: Table 4.1. Soil is A-6.

$$GI = (F_{200} - 35)[0.2 + 0.005(LL - 40)] + 0.01(F_{200} - 15)(PI - 10)$$
$$= (58 - 35)[0.2 + 0.005(38 - 40)] + 0.01(58 - 15)(12 - 10) = 5.23 \approx 5$$

Classification: **A-6(5)**

SOIL C: Table 4.1. Soil is A-7-6.

Note: $PI = 14$ is greater than $LL - 30 = 11$

$$GI = (F_{200} - 35)[0.2 + 0.005(LL - 40)] + 0.01(F_{200} - 15)(PI - 10)$$
$$= (64 - 35)[0.2 + 0.005(41 - 40)] + 0.01(64 - 15)(14 - 10) = 7.905 \approx 8$$

Classification: **A-7-6(8)**

SOIL D: Table 4.1. Soil is A-6.

$$GI = (F_{200} - 35)[0.2 + 0.005(LL - 40)] + 0.01(F_{200} - 15)(PI - 10)$$
$$= (82 - 35)[0.2 + 0.005(32 - 40)] + 0.01(82 - 15)(12 - 10) = 8.86 \approx 9$$

Classification: **A-6(9)**

SOIL E: Table 4.1. Soil is A-6.

$$GI = (F_{200} - 35)[0.2 + 0.005(LL - 40)] + 0.01(F_{200} - 15)(PI - 10)$$
$$= (48 - 35)[0.2 - 0.005(30 - 40)] + 0.01(48 - 15)(11 - 10) = 2.28 \approx 2$$

Classification: **A-6(2)**

4.3 SOIL 1: Fine fraction = % passing No. 200 sieve = 30%
Coarse fraction = 100 - 30 = 70%
Gravel fraction = 100 - 70 = 30%
Sand fraction: 70 - 30 = 40%

More than 50% of coarse fraction passing No. 4 sieve, so sandy soil.

Table 4.2 and Figure 4.2: **SC**

Figure 4.3; more than 15% gravel. **Clayey sand with gravel**

SOIL 2: Coarse fraction = 200 - 20 = 80%
Gravel fraction = 100 - 48 = 52%
Sand fraction = 80 - 52 = 28%

Table 4.2. Gravelly soil.

Table 4.2 and Figure 4.2: **GC**

Figure 4.3, ≥15% sand, so **clayey gravel with sand**

SOIL 3: Coarse fraction = 100 - 70 = 30%
Gravel fraction = 100 - 95 = 5%
Sand fraction = 95 - 70 = 25%

$LL = 52$; $PI = 28$. From Table 4.2, it is a fine-grained soil.

Table 4.2 and Figure 4.2: **CH**

From Figure 4.4, ≥30% plus 200, % sand > % gravel, < 15% gravel, so **sandy fat clay**

SOIL 4: Coarse fraction = 100 - 82 = 18%
Gravel fraction = 100 - 100 = 0%
Sand fraction = 18 - 0 = 18%

$LL = 30$; $PI = 19$. From Table 4.2 and Figure 4.2: **CL**

Figure 4.4: **lean clay with sand**

SOIL 5: Coarse fraction = 100 - 74 = 26%
Gravel fraction = 100 - 100= 0%
Sand fraction = 26%

Fine-grained soil. $LL = 35$; $PI = 21$

From Table 4.2 and Figure 4.2: **CL**

Figure 4.4: **lean clay with sand**

SOIL 6: Coarse fraction = 100 - 26 = 74%
Gravel fraction = 100 - 87 = 13%
Sand fraction = 74 - 13 = 61%

Table 4.2: coarse-grained soil; $LL = 38$, $PI = 18$

Table 4.2 and Figure 4.2: **SC**

Figure 4.3: <15% gravel: **clayey sand**

SOIL 7: Coarse fraction = 100 - 78 = 22%
Gravel fraction = 100 - 88 = 12%
Sand fraction = 22 - 12 = 10%

Table 4.2: fine-grained soil. $LL = 69$; $PI = 38$

Table 4.2 and Figure 4.2: **CH**

Figure 4.4: <30% plus 200; %sand < % gravel: **fat clay with gravel**

SOIL 8: Coarse fraction = 100 - 57 = 43%
Gravel fraction = 100 - 99 = 1%
Sand fraction = 43 - 1 = 42%

$LL = 54$; $PI = 26$. Table 4.2 and Figure 4.2: **CH**

Figure 4.4: ≥30% plus 200; % sand > % gravel: **sandy fat clay**

SOIL 9: Coarse fraction = 100 - 11 = 89%
Gravel fraction = 100 - 71 = 29%
Sand fraction = 89 - 29 = 70%

$LL = 32$; $PI = 16$; $C_u = 4.8$; $C_c = 2.9$. Table 4.2 and Figure 4.2: **SP-SC**

Figure 4.3: **poorly graded sand with clay and gravel**

SOIL 10: Coarse fraction = 100 - 2 = 98%
Gravel fraction = 100 - 100 = 0%
Sand fraction = 98 - 0 = 98%

$C_u = 7.2$; $C_c = 2.2$; Table 4.2: **SW**

Figure 4.3: <15% gravel: **well graded sand**

SOIL 11: Coarse fraction = 100 - 65 = 35%
Gravel fraction = 100 - 89 = 11%
Sand fraction = 35 - 11 = 24%

$LL = 44$; $PI = 21$. Table 4.2 and Figure 4.2: **CL**

Figure 4.4: **sandy lean clay**

SOIL 12: Coarse fraction = 100 − 8 = 92%
Gravel fraction = 100 − 90 = 10%
Sand fraction = 92 − 10 = 82%

$LL = 39$; $PI = 31$; $C_u = 3.9$; $C_c = 2.1$

Table 4.2 and Figure 4.2: **SP-SC**

Figure 4.3: **poorly graded sand with clay**

4.4 a. Percent passing No. 10 sieve = 90
Percent passing No. 40 sieve = 38
Percent passing No. 200 sieve = 13

$PI = 23 - 19 = 4$

Referring to Table 4.1, the soil is A-1-b. $GI = 0$. So the soil is **A-1-b(0)**.

b. Coarse fraction = 100 − 23 = 77%
Gravel fraction = 100 − 100 = 0%
Sand fraction = 77 − 0 = 77%

$LL = 23$; $PI = 19$

From Table 4.2 and Figure 4.2: **SC**

From Figure 4.3: **clayey sand**

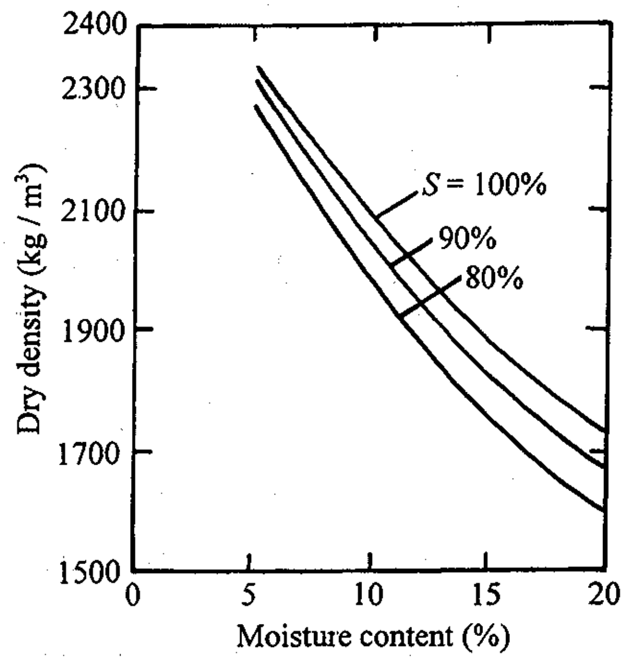
CHAPTER 5

5.1 From Equation (5.3):

$$\rho_d = \frac{G_s \rho_w}{1+\frac{G_s w}{S}} = \frac{(2.65)(1000)}{1+\frac{2.65w}{S}}$$

$$= \frac{2650}{1+\frac{2.65w}{S}}$$

w (%)	ρ_d @ S (%) in kg/m^3		
	80	90	100
5	2273.5	2309.9	2340.0
10	1990.6	2047.2	2094.9
15	1770.4	1838.2	1896.2
20	1594.0	1667.8	1732.0



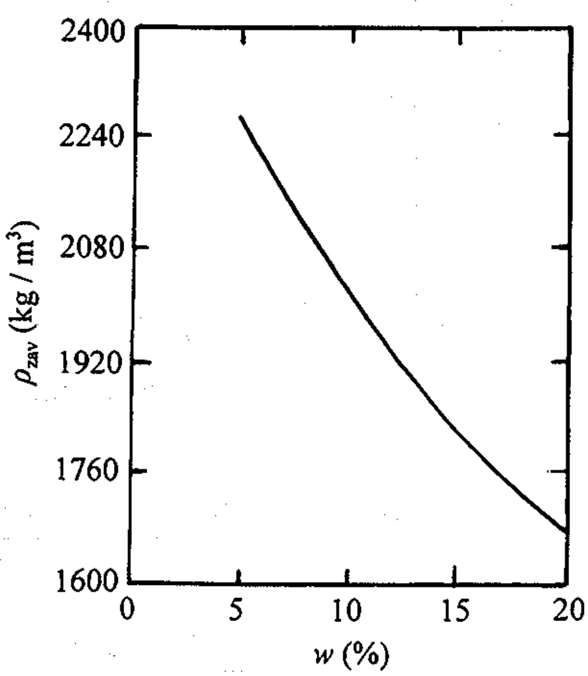
The plot between ρ_d versus w is shown.

5.2 Equation (5.4):

$$\rho_{zav} = \frac{\rho_w}{w+\frac{1}{G_s}} = \frac{1000}{w+\frac{1}{2.54}}$$

$$= \frac{1000}{w+0.3937}$$

w (%)	ρ_{zav} (kg/m^3)
5	**2253.7**
10	**2025.5**
15	**1839.2**
20	**1648.4**



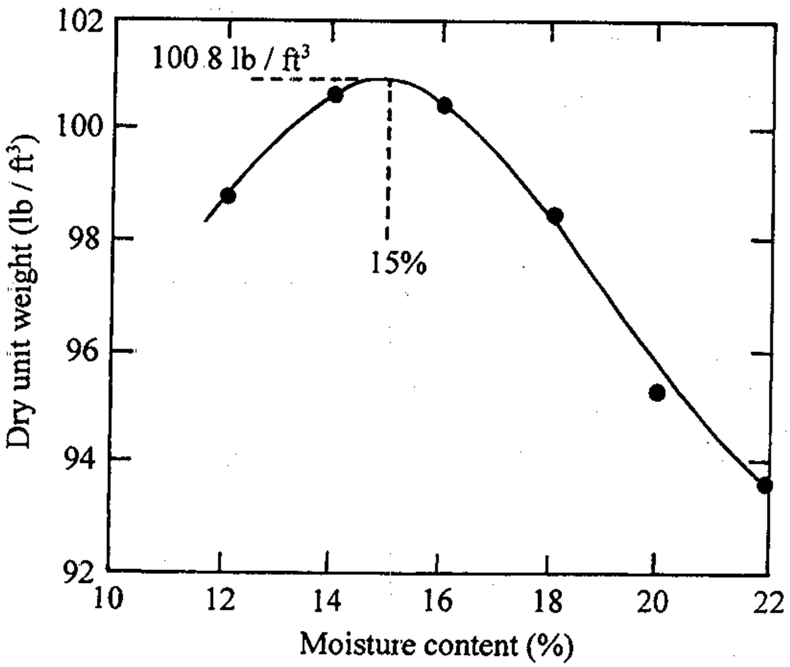
5.3 Refer to the following table.

Volume, V (ft^3)	Weight of wet soil, W (lb)	Moist unit weight, γ[a] (lb/ft^3)	Moisture content, w (%)	Dry unit weight, γ_d[b] (lb/ft^3)
1/30	3.69	110.7	12	98.84
1/30	3.82	114.6	14	100.53
1/30	3.88	116.4	16	100.34
1/30	3.87	116.1	18	98.39
1/30	3.81	114.3	20	95.25
1/30	3.77	113.1	21	93.47

[a] $\gamma = \dfrac{W}{V}$; [b] $\gamma_d = \dfrac{\gamma}{1+\dfrac{w(\%)}{100}}$

The plot of γ_d vs. w is shown. From the plot,

Maximum dry unit weight = **100.8 lb / ft³**; Optimum moisture content = **15%**



$$\gamma_d = \frac{G_s\gamma_w}{1+e}; \quad e = \frac{G_s\gamma_w}{\gamma_d} - 1 = \frac{(2.68)(62.4)}{100.8} - 1 = \mathbf{0.66}$$

$$S = \frac{wG_s}{e} = \frac{(0.15)(2.68)}{0.66} = \mathbf{60.9\%}$$

5.4 Refer to the following table.

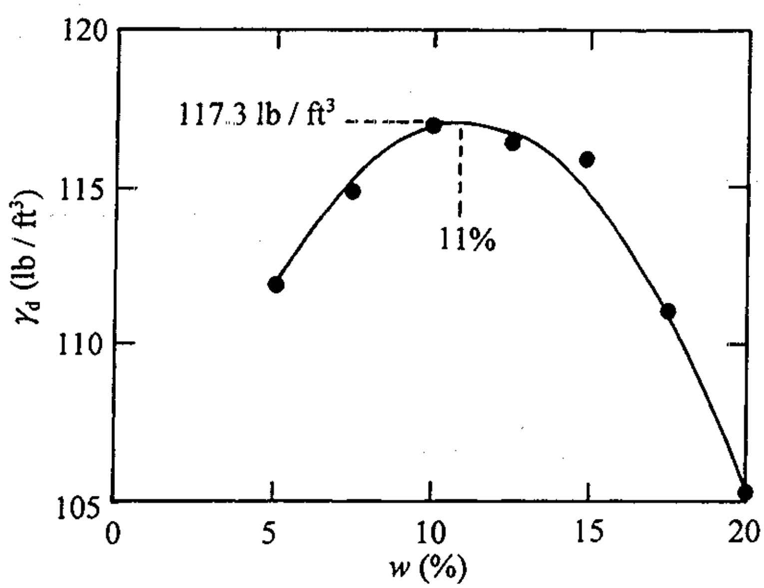
Volume, V (ft^3)	Weight of wet soil in the mold, W (lb)	Moist unit weight, γ [a] (lb / ft^3)	Moisture content, w (%)	Dry unit weight, γ_d [b] (lb / ft^3)
1/30	3.92	117.6	5.0	112
1/30	4.12	123.6	7.5	114.98
1/30	4.29	128.7	10.0	117.0
1/30	4.37	131.1	12.5	116.5
1/30	4.45	133.5	15.0	116.1
1/30	4.35	130.5	17.5	111.1
1/30	4.20	126.0	20.0	105

[a] $\gamma = \dfrac{W}{V}$; [b] $\gamma_d = \dfrac{\gamma}{1 + \dfrac{w(\%)}{100}}$

The plot of γ_d vs. w is shown. From the plot,

Maximum dry unit weight = **117.3 lb / ft^3**

Optimum moisture content = **11%**



$$e = \frac{G_s \gamma_w}{\gamma_d} - 1 = \frac{(2.67)(62.4)}{117.3} - 1 = \mathbf{0.42}$$

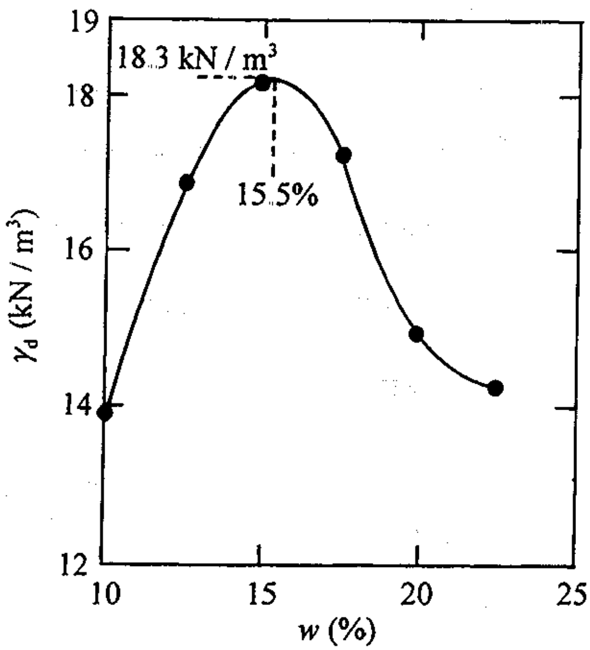
$$S = \frac{wG_s}{e} = \frac{(0.11)(2.67)}{0.42} = 0.699 = \mathbf{69.9\%}$$

5.5

Volume of mold, V (cm^3)	Weight of wet soil, W (N)	Moist unit weight, γ (kN/m^3)	w (%)	γ_d (kN/m^3)
943.3	14.42	15.29	10.0	13.9
943.3	17.95	19.03	12.5	16.92
943.3	19.82	21.01	15.0	18.27
943.3	19.13	20.28	17.5	17.26
943.3	16.97	17.99	20.0	14.99
943.3	16.58	17.58	22.5	14.35

W = mass in kg × 9.81; $\gamma = W/V$

The plot of γ_d vs. w is shown.



From the graph,

$$\gamma_{d(\max)} = \mathbf{18.3\ kN/m^3}$$

$$w_{opt} = \mathbf{15.5\%}$$

$$\gamma_d = 0.95\,\gamma_{d(\max)} = (0.95)(18.3)$$

$$= 17.39\ kN/m^3$$

From the graph,

$$w = \mathbf{13\%\ at\ 0.95\,\gamma_{d(\max)}}$$

5.6 $\gamma_{(insitu)} = 17.3\ kN/m^3$; $\gamma_{d(insitu)} = \dfrac{17.3}{1+\dfrac{16}{100}} = 14.91\ kN/m^3$

$$\gamma_{d(compacted)} = 18.1\ kN/m^3$$

$$\text{Volume of soil to be excavated} = (2000)\left(\frac{18.1}{14.91}\right) = \mathbf{2427.9\ m^3}$$

5.7 Dry unit weight of solids required: $5000\gamma_d$ kN $= (5000)\left(\frac{G_s \times 9.81}{1.7}\right) = 28{,}853G_s$ kN

Borrow pit	γ_d at borrow pit (kN / m³)	Volume to be excavated from borrow pit = [28,853G_s / $\gamma_{d\,(\text{borrow pit})}$]	Cost / m³ ($)	Total cost ($)
A	$\frac{G_s \times 9.81}{1+0.8} = 5.45G_s$	5294.1 m³	9	47,647
B	$\frac{G_s \times 9.81}{1+0.9} = 5.16G_s$	5591.7 m³	6	33,550
C	$\frac{G_s \times 9.81}{1+1.1} = 4.67G_s$	6178.4 m³	7	43,249
D	$\frac{G_s \times 9.81}{1+0.85} = 5.3G_s$	5444 m³	10	54,440

Borrow pit B

5.8 Mass of sand used to fill the hole and cone = 6.08 - 2.86 = 3.22 kg

Sand used to fill the hole = 3.22 - 0.118 = 3.102 kg

Volume of the hole $= \frac{3.102}{1731} = 0.00179 \text{ m}^3$

$$\rho = \frac{3.34}{0.00179} = 1865.9 \text{ kg/m}^3$$

$$\rho_d = \frac{1865.9}{1+\left(\frac{12.1}{100}\right)} = \mathbf{1664.5\ kg/m^3}$$

5.9 $$D_r = \left[\frac{\gamma_{d(\text{field})} - \gamma_{d(\min)}}{\gamma_{d(\max)} - \gamma_{d(\min)}}\right]\left[\frac{\gamma_{d(\max)}}{\gamma_{d(\text{field})}}\right]$$

$$0.72 = \left[\frac{\gamma_{d(\text{field})} - 14.6}{17.8 - 14.6}\right]\left[\frac{17.8}{\gamma_{d(\text{field})}}\right]$$

$\gamma_{d\,(\text{field})} = 16.77 \text{ kN/m}^3$

$$R(\%) = \frac{\gamma_{d(\text{field})}}{\gamma_{d(\max)}} \times 100 = \frac{16.77}{17.8} \times 100 = \mathbf{94.2\%}$$

5.10 $R = 0.935 = \frac{\gamma_{d(\text{field})}}{\gamma_{d(\max)}} = \frac{\gamma_{d(\text{field})}}{16.98}$; $\gamma_{d(\text{field})} = \mathbf{15.88\ kN/m^3}$

$$D_r = \left[\frac{\gamma_{d(\text{field})} - \gamma_{d(\min)}}{\gamma_{d(\max)} - \gamma_{d(\min)}}\right]\left[\frac{\gamma_{d(\max)}}{\gamma_{d(\text{field})}}\right] = \left(\frac{15.88 - 14.46}{16.98 - 14.46}\right)\left(\frac{16.98}{15.88}\right) = \mathbf{60.3\%}$$

5.11 a. $R = 0.94 = \frac{\gamma_{d(\text{field})}}{\gamma_{d(\max)}} = \frac{\gamma_{d(\text{field})}}{18.6}$; $\gamma_{d(\text{field})} = \mathbf{17.48\ kN/m^3}$

b. $D_r = \left[\frac{\gamma_{d(\text{field})} - \gamma_{d(\min)}}{\gamma_{d(\max)} - \gamma_{d(\min)}}\right]\left[\frac{\gamma_{d(\max)}}{\gamma_{d(\text{field})}}\right] = \left[\frac{17.48 - 15.1}{18.6 - 15.1}\right]\left[\frac{18.6}{17.48}\right] = \mathbf{72.4\%}$

c. $\gamma = \gamma_d(1 + w) = (17.48)(1 + 0.08) = \mathbf{18.88\ kN/m^3}$

5.12 Equation (5.17):

$$S_N = 1.7\sqrt{\frac{3}{D_{50}^2} + \frac{1}{D_{20}^2} + \frac{1}{D_{10}^2}} = 1.7\sqrt{\frac{3}{1.98^2} + \frac{1}{0.31^2} + \frac{1}{0.18^2}} = \mathbf{11.02}$$

5.13 Equation (5.17):

$$S_N = 1.7\sqrt{\frac{3}{0.72^2} + \frac{1}{0.47^2} + \frac{1}{0.17^2}} = \mathbf{11.39}$$

5.14 Refer to Figure 5.39. For 1-m distance from the vibroflot, $IC \approx 8$. There are 3 vibroflots. So, combined $IC = 8 \times 3 = 24$.

With $IC = 24$, the probable relative density to be achieved is about **98%**.

CHAPTER 6

6.1 $k = \frac{QL}{Aht} = \frac{(20)(20)}{(4.6)(35)(180 \text{ sec})} = \mathbf{0.0138 \text{ in./sec}}$

6.2 a. $k = \frac{QL}{Aht} = \frac{(580 \text{ cm}^3)(35 \text{ cm})}{(125 \text{ cm}^2)(42 \text{ cm})(180 \text{ sec})} = \mathbf{2.15 \times 10^{-2} \text{ cm / sec}}$

b. $v_s = v\left(\frac{1+e}{e}\right);\ v = ki$

$$v_s = ki\left(\frac{1+e}{e}\right) = (0.0215)\left(\frac{42 \text{ cm}}{35 \text{ cm}}\right)\left(\frac{1+0.61}{0.61}\right) = \mathbf{0.068 \text{ cm / sec}}$$

6.3 $k = \frac{QL}{Aht};\ 0.014 = \frac{(120)\left(\frac{250}{10}\right)}{(105)(h)(60)}$

$h = \mathbf{34 \text{ cm}}$

$$v = ki = (0.014)\left(\frac{34}{25}\right) = \mathbf{0.019 \text{ cm / sec}}$$

6.4 a. $k = 2.303\left(\frac{aL}{At}\right)\log_{10}\left(\frac{h_1}{h_2}\right) = (2.303)\left[\frac{(0.15)(15)}{(3)(8)}\right]\log_{10}\left(\frac{25}{12}\right) = \mathbf{6.88 \times 10^{-2} \text{ in. / min}}$

b. $k = 2.303\left(\frac{aL}{At}\right)\log_{10}\left(\frac{h_1}{h_2}\right)$

$$0.0688 = (2.303)\left[\frac{(0.15)(15)}{(3)(4)}\right]\log_{10}\left(\frac{25}{h_2}\right) = 0.4318\log\left(\frac{25}{h_2}\right)$$

$$0.1593 = \log_{10}\left(\frac{25}{h_2}\right);\ 1.433 = \left(\frac{25}{h_2}\right)$$

$h_2 = \mathbf{17.3 \text{ in.}}$

6.5 $k = 2.303\left(\frac{aL}{At}\right)\log_{10}\left(\frac{h_1}{h_2}\right)$; $0.175 = (2.303)\left(\frac{a \times 38}{6.5 \times 8}\right)\log\left(\frac{650}{300}\right)$

$a =$ **0.31 cm²**

6.6 a. $k = 2.303\left(\frac{aL}{At}\right)\log_{10}\left(\frac{h_1}{h_2}\right)$

$$= 2.303\left(\frac{0.97 \times 50}{16 \times 8}\right)\log_{10}\left(\frac{760}{410}\right) = 0.234 \text{ cm/min} = 0.0039 \text{ cm/sec}$$

$$\overline{K} = \frac{k\eta}{\gamma_w} = \frac{(0.0039 \text{ cm/sec})(1.005 \times 10^{-3} \text{ N} \cdot \text{s/m}^2)}{9.789 \times 10^3 \text{ N/m}^3} = \mathbf{4 \times 10^{-10} \text{ m}^2}$$

b. $k = 2.303\left(\frac{aL}{At}\right)\log_{10}\left(\frac{h_1}{h_2}\right)$

$$0.234 \text{ cm/min} = 2.303\left(\frac{0.97 \times 50}{16 \times 6}\right)\log_{10}\left(\frac{760}{h_2}\right)$$

$h_2 =$ **478.3 mm**

6.7 $q = kiA$

$$i = \frac{160 - 150}{125} = 0.08$$

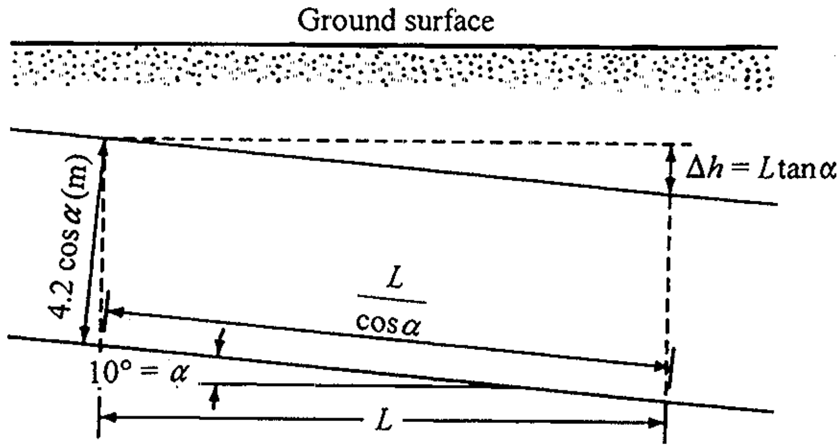
$$k = 3 \text{ m/day} = \frac{3}{24 \times 60} = 0.00208 \text{ m/min}$$

$A = 2 \times 500 = 1000 \text{ m}^2$

$q = (0.00208)(0.08)(1000) =$ **0.166 m³/min**

6.8 From the figure on the following page, $i = \frac{\text{head loss}}{\text{length}} = \frac{L\tan\alpha}{\left(\frac{L}{\cos\alpha}\right)} = \sin\alpha$

$q = kiA = (k)(\sin\alpha)(4.2\cos\alpha)(1)$; $k = 6.8 \times 10^{-4}$ cm/sec $= 6.8 \times 10^{-6}$ m/sec



$$q = (6.8 \times 10^{-6})(\sin 10°)(4.2 \cos 10°)\underbrace{(3600)}_{\text{to change to m/h}} = 0.0176 \text{ m}^3/\text{hr}/\text{m}$$

$$\approx \mathbf{17.6 \times 10^{-3}\ m^3/hr/m}$$

6.9 $$i = \frac{h}{\left(\frac{L}{\cos\alpha}\right)}$$

$$q = kiA = k\left(\frac{h\cos\alpha}{L}\right)(H_1 \cos\alpha \times 1) = \left(\underbrace{\frac{0.05}{10^2}}_{\text{m/sec}}\right)\left(\frac{2.8\cos 5}{52}\right)(3\cos 5)$$

$$= (0.0005)(0.0536)(2.99) = \mathbf{8.01 \times 10^{-5}\ m^3/s/m}$$

6.10 From Equation (6.31a):

$$\frac{k_1}{k_2} = \frac{\frac{e_1^3}{1+e_1}}{\frac{e_2^3}{1+e_2}}; \quad \frac{0.022}{k_2} = \frac{\left(\frac{0.48^3}{1+0.48}\right)}{\left(\frac{0.7^3}{1+0.7}\right)} = \frac{0.0747}{0.2018}$$

$$k_2 = \mathbf{0.059\ cm/sec}$$

6.11 $n_1 = 0.31,\ e_1 = \dfrac{n_1}{1-n_1} = \dfrac{0.31}{1-0.31} = 0.449$

$n_2 = 0.4,\ e_2 = \dfrac{0.4}{1-0.4} = 0.667$

Equation (6.31a):

$$k_2 = k_1\left(\frac{e_2^3}{1+e_2}\right)\left(\frac{1+e_1}{e_1^3}\right) = k_1\left(\frac{1+e_1}{1+e_2}\right)\left(\frac{e_2}{e_1}\right)^3 = 0.13\left(\frac{1.449}{1.667}\right)\left(\frac{0.667}{0.449}\right)^3 = \mathbf{0.37\ ft/min}$$

6.12 $\rho_{d(\text{field})} = R\rho_{d(\max)} = (0.8)(1720) = 1376\ \text{kg/m}^3$

$e_1 = \dfrac{G_s\rho_w}{\rho_{d(\max)}} - 1 = \dfrac{(2.66)(1000)}{1720} - 1 = 0.547$

$e_s = \dfrac{G_s\rho_w}{\rho_{d(\text{field})}} - 1 = \dfrac{(2.66)(1000)}{1376} - 1 = 0.933$

$$k_2 = k_1\left(\frac{e_2^3}{1+e_2}\right)\left(\frac{1+e_1}{e_1^3}\right) = 0.04\left(\frac{0.933}{0.547}\right)^3\left(\frac{1.547}{1.933}\right) = \mathbf{0.159\ cm/sec}$$

6.13 $e_1 = e_{\max} - (e_{\max} - e_{\min})D_r = 0.7 - (0.7 - 0.46)(0.8) = 0.508$

$e_2 = 0.7 - (0.7 - 0.46)(0.5) = 0.58$

$$k_2 = k_1\left(\frac{e_2}{e_1}\right)^3\left(\frac{1+e_1}{1+e_2}\right) = 0.006\left(\frac{0.58}{0.508}\right)^3\left(\frac{1.508}{1.58}\right) = \mathbf{8.52\times10^{-3}\ cm/sec}$$

6.14

Sieve No.	Opening (cm)	Percent passing	Fraction between two consecutive sieves (%)
30	0.06	100	
			----20
40	0.0425	80	
			----12
60	0.02	68	
			----40
100	0.015	28	
			----28
200	0.0075	0	

For fraction between sieve Nos. 30 and 40 $\left.\right\rangle$ $\dfrac{f_i}{D_{li}^{0.404}\times D_{si}^{0.595}}=\dfrac{20}{0.06^{0.404}\times 0.0425^{0.595}}=407.98$

For fraction between sieve Nos. 40 and 60 $\left.\right\rangle$ $\dfrac{f_i}{D_{li}^{0.404}\times D_{si}^{0.595}}=\dfrac{12}{0.0425^{0.404}\times 0.02^{0.595}}=441.03$

For fraction between sieve Nos. 60 and 100 $\left.\right\rangle$ $\dfrac{f_i}{D_{li}^{0.404}\times D_{si}^{0.595}}=\dfrac{40}{0.02^{0.404}\times 0.015^{0.595}}=2362.8$

For fraction between sieve No.s 100 and 200 $\left.\right\rangle$ $\dfrac{f_i}{D_{li}^{0.404}\times D_{si}^{0.595}}=\dfrac{28}{0.015^{0.404}\times 0.0075^{0.595}}=2812.2$

$$\Sigma\frac{\Sigma 100\%}{D_{li}^{0.404}\times D_{si}^{0.595}}=\frac{100}{404.98+441.03+2362.8+2812.2}=0.0166$$

$$k=(1.99\times 10^{4})(0.0166)^2\left(\frac{1}{6.5}\right)^2\left(\frac{0.5^3}{1+0.5}\right)=\mathbf{0.0108\ cm/sec}$$

6.15 $\dfrac{k_1}{k_2}=\left(\dfrac{e_1^n}{1+e_1}\right)\left(\dfrac{1+e_2}{e_2^n}\right)=\left(\dfrac{1+e_2}{1+e_1}\right)\left(\dfrac{e_1}{e_2}\right)^n$

$$\frac{1.2\times 10^{-6}}{3.6\times 10^{-6}}=\left(\frac{2.4}{1.8}\right)\left(\frac{0.8}{1.4}\right)^n;\quad 0.25=0.571^n$$

$$n=\frac{\log 0.25}{\log 0.571}=\frac{-0.602}{-0.243}=2.477$$

$$k_1=C\frac{e_1^n}{1+e_1};\quad C=\frac{1.2\times 10^{-6}(1+0.8)}{0.8^{2.477}}=3.754\times 10^{-6}\ \text{cm/sec}$$

$$k_3=\left(\frac{0.62^{2.477}}{1.62}\right)(3.754\times 10^{-6})=\mathbf{0.709\times 10^{-6}\ cm/sec}$$

6.16 $\log k = A'\log e + B'$

$$A'=\frac{\log k_1-\log k_2}{\log e_1-\log e_2}=\frac{\log(1.2\times 10^{-6})-\log(3.6\times 10^{-6})}{\log(0.8)-\log(1.4)}=1.96$$

$$B'=\log k_1 - A'\log e_1=\log(1.2\times 10^{-6})-(1.96)\log(0.8)=-5.73$$

$$\log k_3 = (1.96)\log(0.62) - 5.73 = -6.1369$$

$$k_3 = \mathbf{0.7 \times 10^{-6}\ cm / sec}$$

6.17 $$\frac{k_1}{k_2} = \left(\frac{1+e_2}{1+e_1}\right)\left(\frac{e_1}{e_2}\right)^n$$

$$\frac{0.2 \times 10^{-6}}{0.91 \times 10^{-6}} = \left(\frac{2.9}{2.2}\right)\left(\frac{1.2}{1.9}\right)^n; \quad 0.1667 = 0.6316^n$$

$$n = \frac{\log(0.1667)}{\log(0.6316)} = \frac{-0.778}{-0.1996} = 3.898$$

$$C = \frac{k_1(1+e_1)}{e_1^n} = \frac{(0.2 \times 10^{-6})(2.2)}{1.2^{3.898}} = 0.216 \times 10^{-6}$$

$$k_3 = C\left(\frac{e^n}{1+e}\right) = \left(\frac{0.9^{3.898}}{1.9}\right)(0.216 \times 10^{-6}) = \mathbf{0.075 \times 10^{-6}\ cm / sec}$$

6.18 $$\log k = \log k_0 - \frac{e_0 - e}{0.5e_0} = \log(0.86 \times 10^{-6}) - \left(\frac{2.1 - 1.3}{0.5 \times 2.1}\right)$$

$$= \mathbf{0.1 \times 10^{-6}\ cm / sec}$$

6.19 $$k_{H(\mathrm{eq})} = \frac{1}{H}(k_1 H_1 + k_2 H_2 + \dots)$$

$$k_{H(\mathrm{eq})} = \frac{1}{7}\left[(10^{-5})(1.5) + (300 \times 10^{-5})(2.5) + (3.5 \times 10^{-5})(3)\right]$$

$$= \frac{10^{-5}}{7}(1.5 + 750 + 10.5) = 108.86 \times 10^{-5}\ \mathrm{cm/sec}$$

$$k_{V(\mathrm{eq})} = \frac{H}{\frac{H_1}{k_1} + \frac{H_2}{k_2} + \dots} = \frac{7}{\frac{1.5}{10^{-5}} + \frac{2.5}{300 \times 10^{-5}} + \frac{3}{3.5 \times 10^{-5}}} = 2.96 \times 10^{-5}\ \mathrm{cm/sec}$$

$$\frac{k_{H(\mathrm{eq})}}{k_{V(\mathrm{eq})}} = \frac{108.86 \times 10^{-5}}{2.96 \times 10^{-5}} = \mathbf{36.8}$$

6.20 $$k_{V(\text{eq})} = \frac{H}{\frac{H_1}{k_1}+\frac{H_2}{k_2}+\frac{H_3}{k_3}+\frac{H_4}{k_4}} = \frac{4}{\frac{1}{20\times10^{-4}}+\frac{1}{2\times10^{-4}}+\frac{1}{10^{-4}}+\frac{1}{3\times10^{-4}}}$$

$$= 2.124\times10^{-4}\ \text{cm/sec}$$

$$k_{H(\text{eq})} = \frac{1}{H}(H_1k_1 + H_2k_2 + H_3k_3 + H_4k_4)$$

$$= \frac{1}{4}(20\times10^{-4} + 2\times10^{-4} + 1\times10^{-4} + 3\times10^{-4}) = 6.5\times10^{-4}\ \text{cm/sec}$$

$$\frac{k_{H(\text{eq})}}{k_{V(\text{eq})}} = \frac{6.5\times10^{-4}}{2.124\times10^{-4}} = \mathbf{3.06}$$

6.21 Equation (6.37): $v = v_1 = v_2 = v_3 = \ldots$

$$k_{\text{eq}}\, i = k_1\, i_1 = k_2\, i_2 = k_3\, i_3 = \ldots$$

$$k_{\text{eq}}\left(\frac{300}{450}\right) = 10^{-2}\left(\frac{\Delta h_A}{150}\right)$$

$$0.1213\times10^{-2}\left(\frac{300}{450}\right) = 10^{-2}\left(\frac{\Delta h_A}{150}\right);\quad \Delta h_A = 12.13\ \text{mm}$$

$$h_A = 300 - \Delta h_A = \mathbf{287.87\ mm}$$

Similarly, $k_{eq}\dfrac{300}{450} = 3\times10^{-3}\left(\dfrac{\Delta h_B}{150}\right)$

$$1.213\times10^{-3}\left(\frac{300}{450}\right) = 3\times10^{-3}\left(\frac{\Delta h_B}{150}\right);\quad \Delta h_B = 40.43\ \text{mm}$$

$$h_B = h_A - \Delta h_B = 287.87 - 40.43 = \mathbf{247.44\ mm}$$

CHAPTER 7

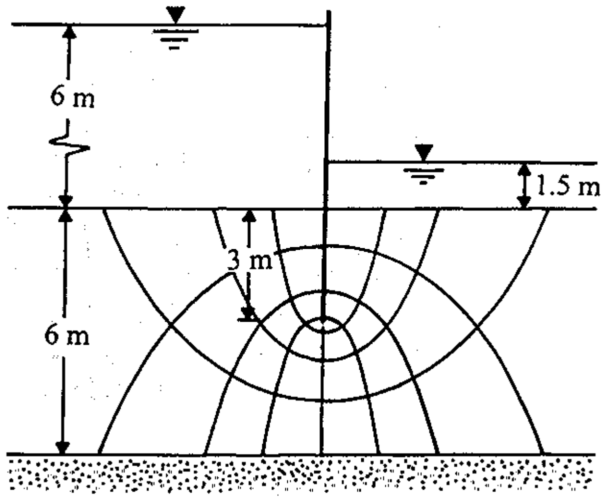
7.1 Equation (7.14):

$$h_2 = \frac{h_1 k_1}{H_1\left(\frac{k_1}{H_1} + \frac{k_2}{H_2}\right)}$$

$$6 \text{ cm} = \frac{(18 \text{ cm})(0.002 \text{ cm/sec})}{(7 \text{ cm})\left(\frac{0.002 \text{ cm/sec}}{7 \text{ cm}} + \frac{k_2 \text{ cm/sec}}{10 \text{ cm}}\right)}$$

$$k_2 = \mathbf{0.0057\ cm\ /\ sec}$$

7.2 The flow net is shown.



$k = 4 \times 10^{-4}$ cm / sec

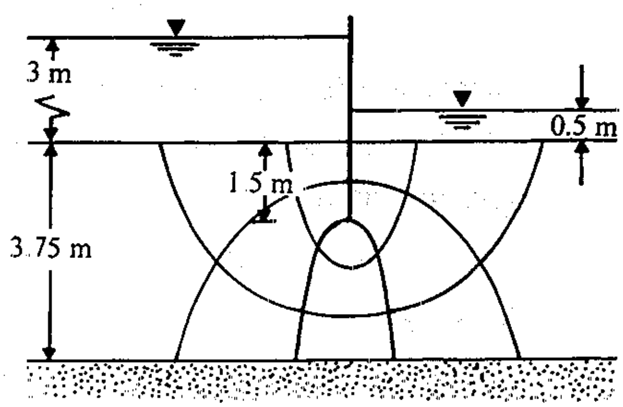
$H = H_1 - H_2 = 6 - 1.5 = 4.5$ m. So

$$q = \left(\frac{4\times10^{-4}}{10^2}\right)\left(\frac{4.5\times4}{8}\right)$$

$$= 9\times10^{-6} \text{ m}^3/\text{m/sec}$$

$$= \mathbf{77.76\times10^{-2}\ m^3/m/day}$$

7.3 The flow net is shown. $N_f = 3$; $N_d = 5$



$$q = kH\left(\frac{N_f}{N_d}\right)$$

$$= \left(\frac{4\times10^{-4}}{10^2} \text{ m/sec}\right)(3-0.5)\left(\frac{3}{5}\right)$$

$$= 6\times10^{-6} \text{ m}^3/\text{m/sec}$$

$$= \mathbf{0.518\ m^3/m/day}$$

7.4 Based on the notations in Figure 7.12,

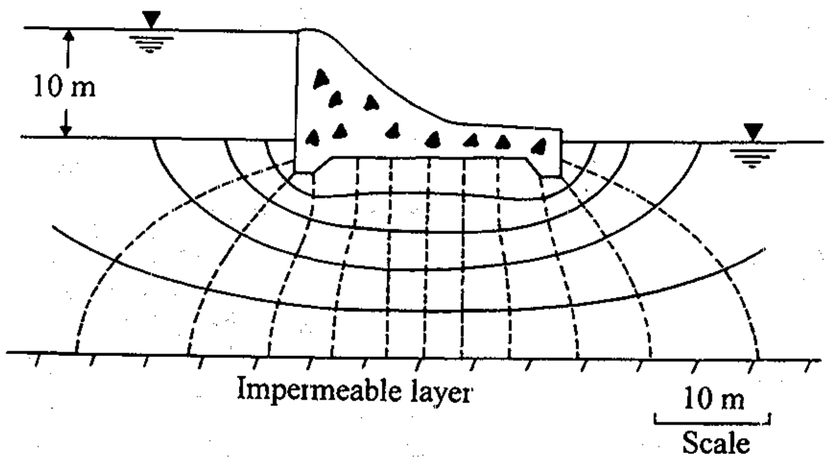
$H = (4 - 1.5)\text{m} = 2.5\text{ m}$ $\quad S = D = 3.6\text{ m}$ $\quad T' = D_1 = 6\text{ m}$

$$\frac{S}{T'} = \frac{3.6}{3} = 0.6$$

From the figure, $\dfrac{q}{KH} \approx 0.44$

$$q = (0.44)(2.5)\left(\frac{4 \times 10^{-4}}{10^2} \times 60 \times 60 \times 24\text{ m/day}\right) = \mathbf{0.38\ m^3\ /\ day\ /\ m}$$

7.5 The flow net is shown.



$$q = kH\left(\frac{N_f}{N_d}\right) = \left(\frac{0.002}{10^2} \times 60 \times 60 \times 24\text{ m/day}\right)(10)\left(\frac{5}{12}\right) = \mathbf{7.2\ m^3\ /\ day\ /\ m}$$

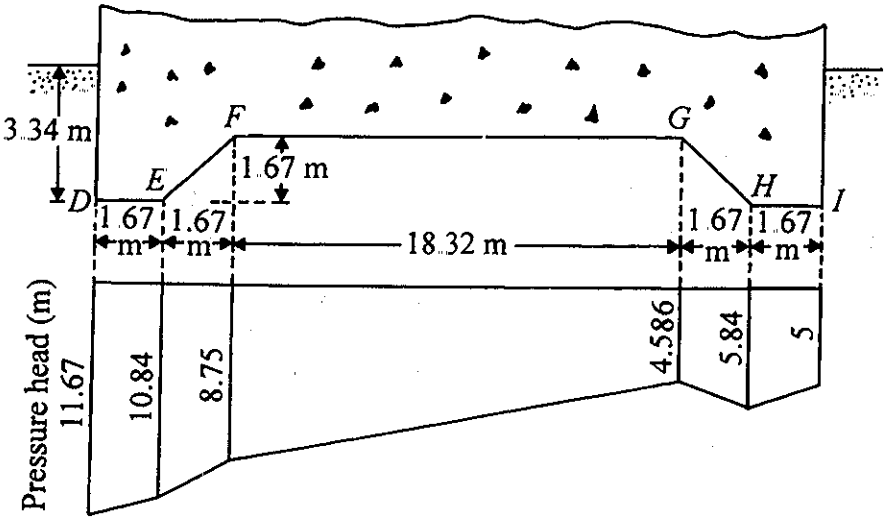
7.6 Refer to the flow net shown in Problem 7.5 and the figure on the following page. The flow net has 12 potential drops. Also $H = 10$ m. So the head loss for each drop = (10/12)m. Thus,

Pressure head at $D = (10 + 3.34) - 2(10/12) = 11.67$ m

Similarly,

Pressure head at $E = (10 + 3.34) - 3(10/12) = 10.84$ m

Pressure head at $F = (10 + 1.67) - 3.5(10/12) = 8.75$ m



Pressure head at $G = (10 + 1.67) - 8.5(10/12) = 4.586$ m

Pressure head at $H = (10 + 3.34) - 9(10/12) = 5.84$ m

Pressure head at $I = (10 + 3.34) - 10(10/12) = 5$ m

The pressure heads calculated above are shown in the above figure. The hydraulic uplift force per unit length of the structure can now be calculated to be

$= \gamma_w$ (area of the pressure head diagram)(1)

$$= 9.81\left[\begin{array}{l}\left(\frac{11.67+10.84}{2}\right)(1.67)+\left(\frac{10.84+8.75}{2}\right)(1.67) \\ +\left(\frac{8.75+4.586}{2}\right)(18.32)+\left(\frac{4.586+5.84}{2}\right)(1.67)+\left(\frac{5.84+5}{2}\right)(1.67)\end{array}\right]$$

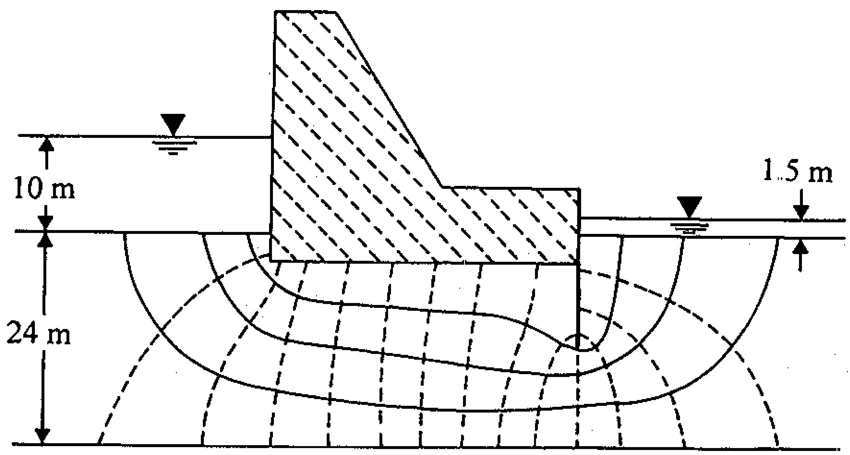
$$= 9.81(18.8+16.36+122.16+8.71+9.05)$$

$$= \mathbf{1717.5\ kN/m}$$

7.7 The flow net is shown on the next page. $N_f = 4$; $N_d = 14$

$$q = kH\left(\frac{N_f}{N_d}\right) = \left(\frac{10^{-3}}{10^2}\right)(10-1.5)\left(\frac{4}{14}\right) = (10^{-5})(8.5)\left(\frac{4}{14}\right)$$

$$= 2.429\times10^{-5}\ \text{m}^3/\text{m}/\text{sec} \approx \mathbf{2.1\ m^3/m/day}$$



Problem 7.7

7.8 Refer to the flow net shown for Problem 7.7. At the bottom left-hand side of the weir, the number of drops is about 1.5. At the bottom right-hand side of the weir, the number of drops is 10.

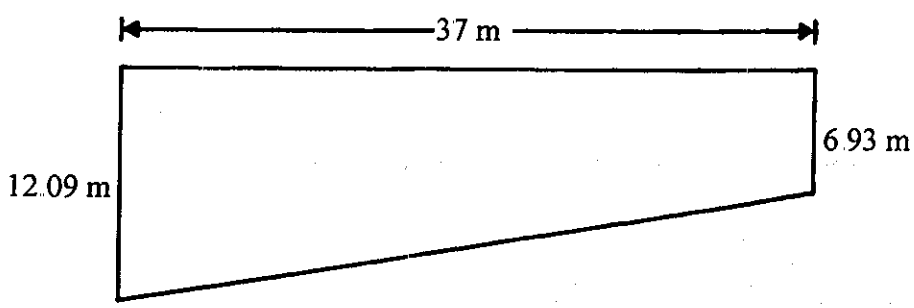
$$\Delta h = \frac{H_1 - H_2}{N_d} = \frac{10 - 1.5}{14} = 0.607 \text{ m / drop}$$

So, at the bottom left-hand side of the weir, the uplift head is

$(10 + 3) - (\Delta h)(1.5) = 13 - (0.607)(1.5) = 12.09$ m

At the bottom of the right-hand side of the weir, the uplift head is

$(10 + 3) - (\Delta h)(10) = 13 - (0.607)(10) = 6.93$ m



So, uplift force $\approx 9.81 \times (37)\left(\frac{12.09 + 6.93}{2}\right) \approx$ **3452 kN / m**

7.9 For this case, $T' = 8$ m; $S = 4$ m; $H = H_1 - H_2 = 6$ m; $B = 8$ m; $b = B/2 = 4$ m

a. $\frac{S}{T'} = \frac{4}{8} = 0.5$

$x = b - x' = 4 - 1 = 3$ m

$\frac{x}{b} = \frac{3}{4} = 0.75$

$\frac{b}{T'} = \frac{4}{8} = 0.5$

From Figure 7.13, $q/kH = 0.37$

$$q = (0.37)\left(\frac{0.001}{10^2} \times 60 \times 60 \times 24\right)(6) \approx \mathbf{1.92\ m^3/day/m}$$

b. $\frac{S}{T'} = 0.5$; $\frac{b}{T'} = 0.5$

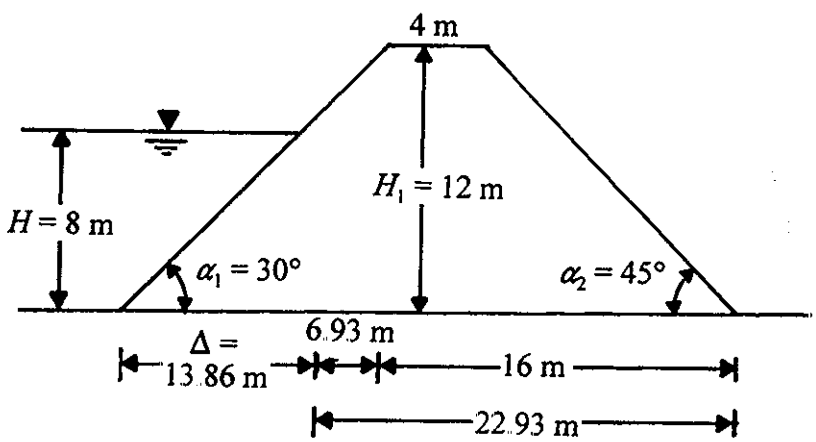
$x = b - x' = 4 - 2 = 2$ m

$\frac{x}{b} = \frac{2}{4} = 0.5$

So, $q/kH \approx 0.4$

$$q = (0.4)\left(\frac{0.001}{10^2} \times 60 \times 60 \times 24\right)(6) \approx \mathbf{2.07\ m^3/day/m}$$

7.10 $\alpha_1 = 30°$; $\alpha_2 = 45°$; $H = 8$ m; and $\Delta = 8\cot 30 = 13.86$ m. $0.3\Delta = 4.16$ m.



$$d = H_1 \cot\alpha_2 + L_1 + (H_1 - H)\cot\alpha_1 + 0.3\Delta$$

$$= (12)(\cot 45) + 4 + (12 - 8)\cot 30 + 4.16 \approx 27.09 \text{ m}$$

$$L = \frac{d}{\cos\alpha_2} - \sqrt{\frac{d^2}{\cos^2\alpha_2} - \frac{H^2}{\sin^2\alpha_2}} = \frac{27.09}{\cos 45}\sqrt{\left(\frac{27.09}{\cos 45}\right)^2 - \left(\frac{8}{\sin 45}\right)^2} = 1.71 \text{ m}$$

$$q = kL\tan\alpha_2 \sin\alpha_2 = \left[\left(\frac{2\times 10^{-4}}{10^2}\right)(1.71)\right][(\tan 45)(\sin 45)]$$

$$= 2.418\times 10^{-6} \text{ m}^3/\text{sec}/\text{m} \approx \mathbf{0.209\ m^3/day/m}$$

7.11 $\Delta = H\cot\alpha_1 = 8\cot 28 = 15.05$ m

$$d = H_1 \cot\alpha_2 + L_1 + (H_1 - H)\cot\alpha_1 + 0.3\Delta$$

$$= 12\cot 35 + 7 + (12 - 8)\cot 28 + (0.3)(15.05)$$

$$= 17.14 + 7 + 7.52 + 4.52 = 36.18 \text{ m}$$

$$L = \frac{d}{\cos\alpha_2} - \sqrt{\frac{d^2}{\cos^2\alpha_2} - \frac{H^2}{\sin^2\alpha_2}} = \frac{36.18}{\cos 35}\sqrt{\left(\frac{36.18}{\cos 35}\right)^2 - \left(\frac{8}{\sin 35}\right)^2} = 2.26 \text{ m}$$

$$q = kL\tan\alpha_2 \sin\alpha_2 = \left[\left(\frac{1.5\times 10^{-4}}{10^2}\right)(2.26)\right][(\tan 35)(\sin 35)]$$

$$= 1.36\times 10^{-6} \text{ m}^3/\text{sec}/\text{m} \approx \mathbf{0.118\ m^3/day/m}$$

7.12 From Problem 7.10, $d = 27.09$ m; $H = 8$ m; $\alpha_2 = 45°$

$$\frac{d}{H} = \frac{27.09}{8} = 3.39$$

$m \approx 0.2$ (Figure 7.17)

$$L = \frac{mH}{\sin\alpha_2} = \frac{(0.2)(8)}{\sin 45} = 2.26 \text{ m}$$

$$q = kL\sin^2\alpha_2 = \left(\frac{2\times10^{-4}}{10^2}\right)(2.26)(\sin^2 45)$$

$$= 2.26\times10^{-6}\ \text{m}^3/\text{sec}/\text{m} \approx \mathbf{0.195\ m^3/day/m}$$

7.13 From Problem 7.11, $d = 36.18$ m; $H = 8$ m; $\alpha_2 = 35°$

$$\frac{d}{H} = \frac{36.18}{8} = 4.52$$

$m \approx 0.2$

$$L = \frac{mH}{\sin\alpha_2} = \frac{(0.2)(8)}{\sin 35} = 2.8\ \text{m}$$

$$q = kL\tan\alpha_2\sin\alpha_2 = \left(\frac{2\times10^{-4}}{10^2}\right)(2.26)(\sin^2 45)$$

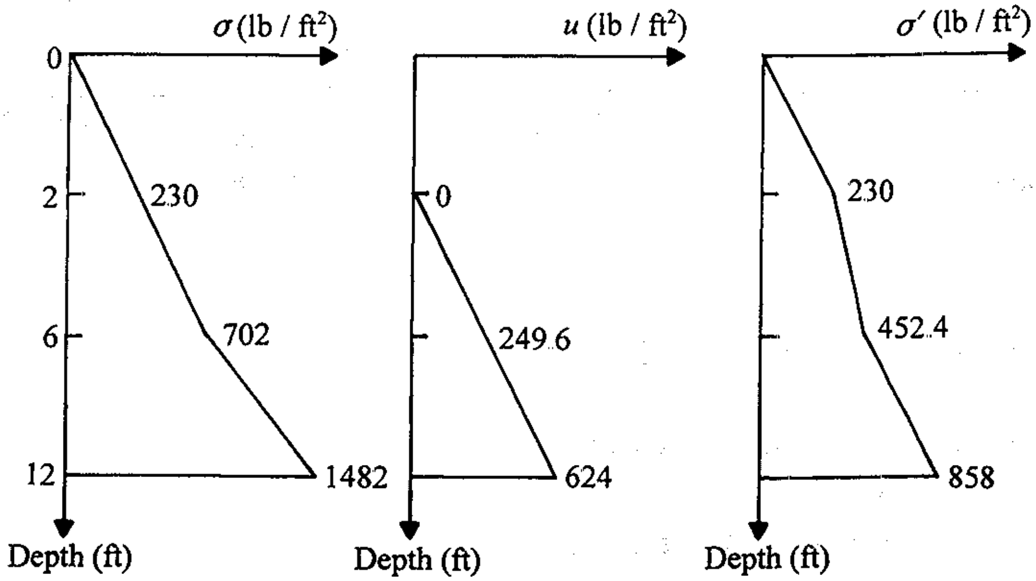
$$= 2.26\times10^{-6}\ \text{m}^3/\text{sec}/\text{m} \approx \mathbf{0.119\ m^3/day/m}$$

CHAPTER 8

8.1

Point	lb / ft²		
	σ	u	σ'
A	**0**	**0**	**0**
B	(2)(115) = **230**	**0**	**230**
C	230 + (118)(4) = **702**	(62.4)(4) = **249.6**	**452.4**
D	702 + (130)(6) = **1482**	(62.4)(4 + 6) = **624**	**858**

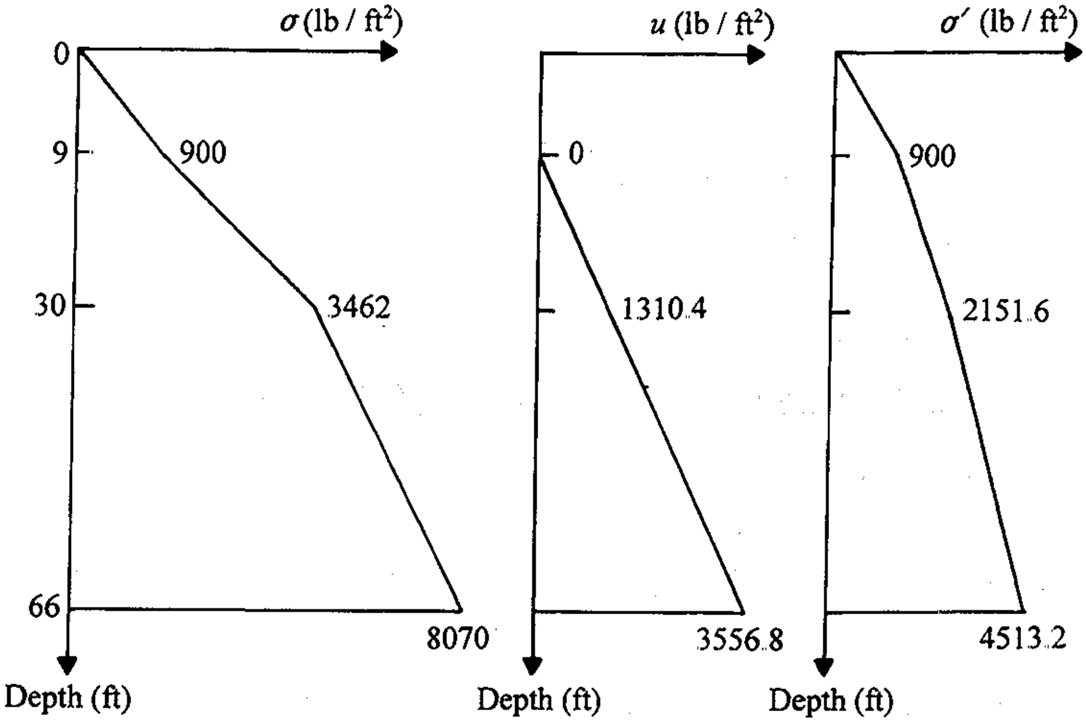
The plot is shown.



8.2

Point	lb / ft²		
	σ	u	σ'
A	**0**	**0**	**0**
B	(9)(100) = **900**	**0**	**900**
C	900 + (21)(122) = **3462**	(21)(62.4) = **1310.4**	**2151.6**
D	3462 + (36)(128) = **8070**	(21 + 36)(62.4) = **3556.8**	**4513.2**

The plot is shown.



8.3 Point A: $\sigma = \mathbf{0}$; $u = \mathbf{0}$; $\sigma' = \mathbf{0}$

Point B: $\sigma = (4)(16.2) = \mathbf{64.8\ kN/m^2}$

$u = \mathbf{0}$

$\sigma' = 64.8 - 0 = \mathbf{64.8\ kN/m^2}$

Point C: $\sigma = 64.8 + (1.5)(18.4) = \mathbf{92.4\ kN/m^2}$

$u = (1.5)(9.81) = \mathbf{14.72\ kN/m^2}$

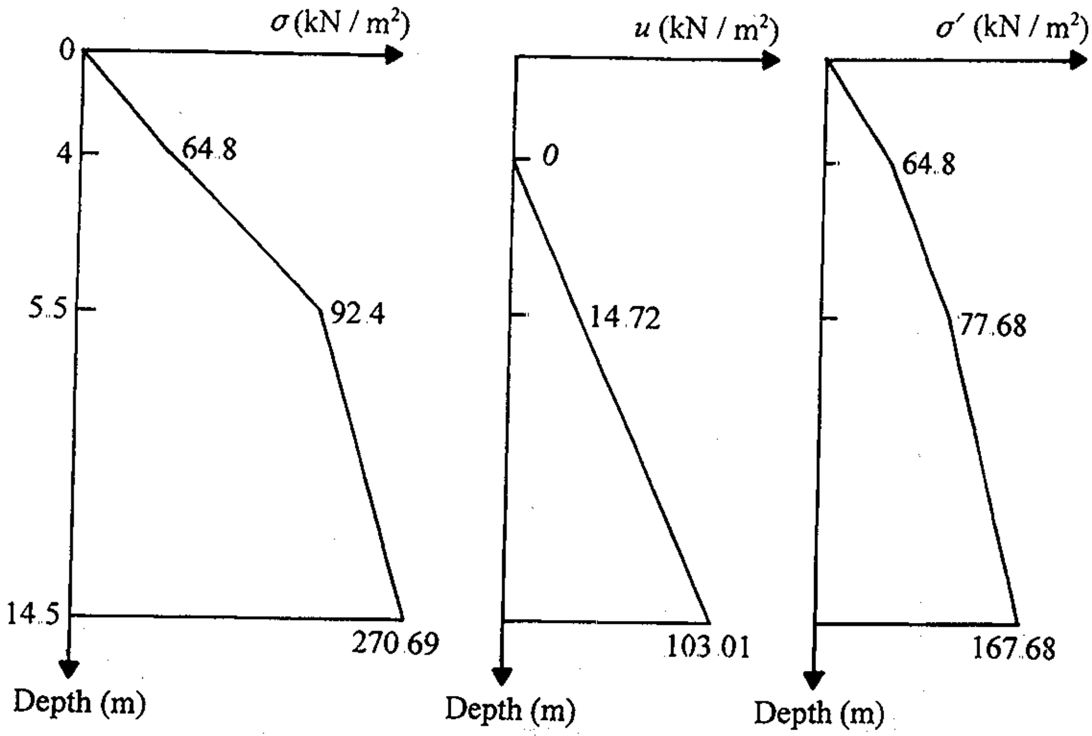
$\sigma' = 92.4 - 14.72 = \mathbf{77.68\ kN/m^2}$

Point D: $\sigma = 92.4 + (9)(19.81) = \mathbf{270.69\ kN/m^2}$

$u = 14.72 + (9)(9.81) = \mathbf{103.01\ kN/m^2}$

$\sigma' = 270.69 - 103.01 = \mathbf{167.68\ kN/m^2}$

The plot is shown on the next page.



Problem 8.3

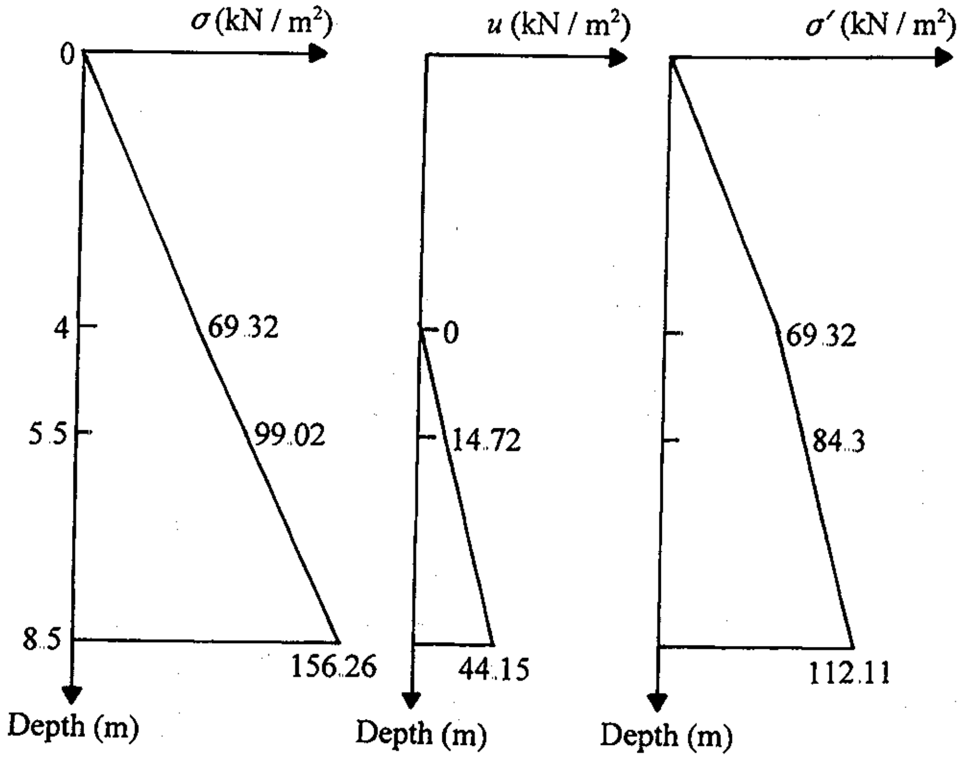
8.4 $$\gamma_{d(\text{sand})} = \frac{G_s\gamma_w}{1+e} = \frac{(2.65)(9.81)}{1+0.5} = 17.33\ \text{kN/m}^3$$

$$\gamma_{\text{sat(sand)}} = \frac{(G_s+e)\gamma_w}{1+e} = \frac{(2.68+0.65)(9.81)}{1+0.65} = 19.8\ \text{kN/m}^3$$

$$\gamma_{\text{sat(clay)}} = \frac{(G_s+e)\gamma_w}{1+e} = \frac{(2.71+0.81)(9.81)}{1+0.81} = 19.08\ \text{kN/m}^3$$

Point	kN / m²		
	σ	u	σ'
A	**0**	**0**	**0**
B	(4)(17.33) = **69.32**	**0**	**69.32**
C	69.31 + (1.5)(19.8) = **99.02**	(9.81)(1.5) = **14.72**	**84.3**
D	99.02 + (3)(19.08) = **156.26**	(9.81)(1.5 + 3) = **44.15**	**112.11**

The plot is shown on the next page.



Problem 8.4

8.5 $\gamma_{d(\text{sand})} = \dfrac{G_s \gamma_w}{1+e} = \dfrac{(2.65)(9.81)}{1+0.52} = 17.1 \text{ kN/m}^3$

$$\gamma_{\text{sat(sand)}} = \frac{G_s \gamma_w + e\gamma_w}{1+e} = \frac{(2.68+0.52)(9.81)}{1+1.52} = 20.46 \text{ kN/m}^3$$

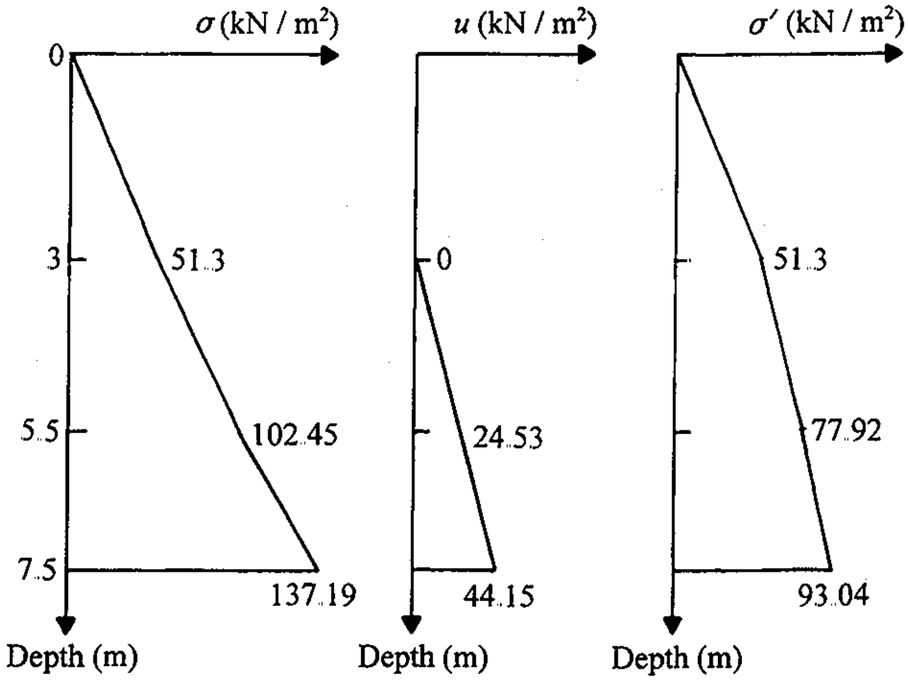
$$\gamma_{\text{sat(clay)}} = \frac{G_s \gamma_w + e\gamma_w}{1+e}$$

$$wG_s = e;\ G_s = \frac{e}{w} = \frac{1.22}{0.45} = 2.71$$

$$\gamma_{\text{sat(clay)}} = \frac{(2.71+1.22)(9.81)}{2.22} = 17.37 \text{ kN/m}^3$$

Point	kN / m²		
	σ	u	σ'
A	**0**	**0**	**0**
B	(17.1)(3) = **51.3**	**0**	**51.3**
C	51.3 + (20.46)(2.5) = **102.45**	(2.5)(9.81) = **24.53**	**77.92**
D	102.45 + (17.37)(2) = **137.19**	(2.5 + 2)(9.81) = **44.15**	**93.04**

The plot is shown.



8.6 a. $\gamma_{d(\text{sand})} = \dfrac{G_s \gamma_w}{1+e} = \dfrac{(2.68)(62.4)}{1+0.49} = 112.2 \text{ lb/ft}^3$

$$\gamma_{\text{sat(clay)}} = \frac{(G_s + e)\gamma_w}{1+e} = \frac{(2.75+0.9)(62.4)}{1+0.9} = 119.9 \text{ lb/ft}^3$$

Depth (ft)	lb / ft²		
	σ	u	σ'
0	**0**	**0**	**0**
15	(111.2)(15) = **1683**	**0**	**1683**
27	1683 + (119.9)(12) = **3121.8**	(62.4)(12) = **748.8**	**2373**

b. $\gamma_{\text{sat(sand)}} = \dfrac{(G_s + e)\gamma_w}{1+e} = \dfrac{(2.68+0.49)(62.4)}{1+0.49} = 132.8 \text{ lb/ft}^3$

$\sigma = (15)(132.8) + (12)(119.9) = 3430.8 \text{ lb / ft}^2$
$u = (27)(62.4) = 1684.8 \text{ lb / ft}^2$
$\sigma' = 3430.8 - 1684.8 = 1746 \text{ lb / ft}^2$

Change of σ': $2373 - 1746 = \mathbf{627\ lb / ft^2}$

c. Let the height of rise be h. So, at any time, at the bottom of the clay layer,
$\sigma = (15 - h)(112.2) + (h)(132.8) + (12)(119.9)$
$u = (12 + h)(62.4)$

Change of σ': $300 = 2373 - [(1683 - 112.2h + 132.8h + 1438.8) - (748.8 + 62.4h)]$

$h = \mathbf{7.18\ ft}$

8.7 $$i_{cr} = \frac{\gamma'}{\gamma_w} = \frac{G_s - 1}{1+e} = \frac{2.68-1}{1+e} = \frac{1.68}{1+e}$$

e	i_{cr}
0.4	**1.2**
0.5	**1.12**
0.6	**1.05**
0.7	**0.99**

8.8 $$\gamma_{sat(clay)} = \frac{(1+w)G_s\gamma_w}{1+wG_s} = \frac{(1+0.4)(2.7)(62.4)}{1+(0.4)(2.7)} = 113.4 \text{ lb / ft}^2$$

Let the depth of the excavation be H. So, $(25 - H)(113.4) - (18)(62.4) = 0 = \sigma'$

$H \approx \mathbf{15.1\ ft}$

8.9 Let the depth of excavation be H, and height of water be h. Given: $H = 18$ ft. So,

$(25 - H)(113.4) + (h)(62.4) - (18)(62.4) = 0$

$$h = \frac{(18)(62.4) - (25-18)(113.4)}{62.4} = \mathbf{5.28\ ft}$$

8.10 $i = \frac{h}{H_2} = \frac{0.4}{1} = 0.4$

$$q = kiA = \left(\frac{0.12}{100} \times 60 \text{ m/min}\right)(0.4)(0.45) = \mathbf{0.013\ m^3/min}$$

8.11 a. $i = \frac{h}{H_2} = \frac{1.2}{2} = 0.6$

$$q = kiA = (0.1)(0.6)(0.5 \times 100^2 \text{ cm}^2) = \mathbf{300\ cm^3/sec}$$

b. $i_{cr} = \frac{\gamma'}{\gamma_w} = \frac{G_s - 1}{1 + e} = \frac{2.68 - 1}{1 + 0.55} = 1.08$

Since $I < i_{cr}$, **no boiling**

c. $i = i_{cr} = \frac{h}{H_2}; \quad 1.08 = \frac{h}{2}$

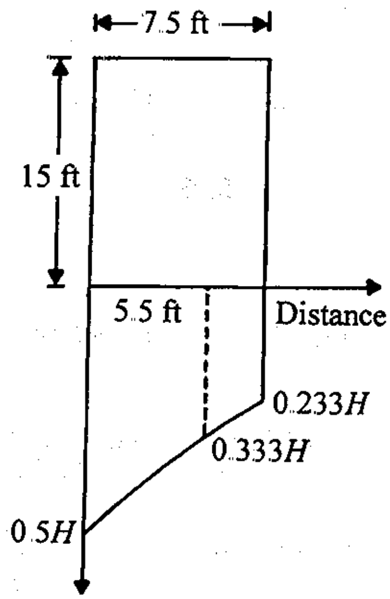
$h = \mathbf{2.16}$

8.12 Referring to Figure 7.9, the block to be considered on the downstream side is 7.5 ft (width) × 15 ft (depth) × 1 ft (length at right angle to the section).

$H_1 = 15$ ft; $H_2 = 5$ ft.

$H = H_1 - H_2 = 15 - 5 = 10$ ft

From the flow net, the hydraulic head can be estimated (see figure).



Area of the hydraulic head diagram under the block of soil shown in the figure is

$$A = H\left(\frac{0.5+0.333}{2}\right)(5.5) + H\left(\frac{0.333+0.233}{2}\right)(7.5-5.5) = 2.29H + 0.566H$$

$$\text{Average hydraulic head} = \frac{(2.29+0.566)(10)}{7.5} \approx 3.81 \text{ ft}$$

$$i_{av} = \frac{3.81}{15} = 0.254$$

Factor of safety:

$$\text{FS} = \frac{\gamma'}{i_{av}\gamma_w} = \frac{(120-62.4)}{(0.254)(62.4)} = \mathbf{3.63}$$

8.13 Equation (8.19): $W_F' = (5 \text{ ft})\left(\frac{D}{2}\right)(\gamma_F') + (1)\left(\frac{D}{2}\right)[\gamma_{d(F)}]$

$$\text{FS} = \frac{W' + W_F'}{U} = \frac{\frac{1}{2}D^2\gamma' + \frac{5}{2}\gamma_F' D + \frac{D}{2}\gamma_{d(F)}}{\frac{1}{2}D^2 i_{av}\gamma_w}$$

or

$$\text{FS} = \frac{\gamma' + \frac{5\gamma_F'}{D} + \frac{\gamma_{d(F)}}{D}}{i_{av}\gamma_w} = \frac{(120-62.4) + \frac{(5)(127-62.4)}{15} + \frac{105}{15}}{(0.254)(62.4)}$$

$$= \mathbf{5.43}$$

8.14 Equation (8.25): $h \text{ (mm)} = \frac{C}{eD_{10}}$

$$C = 10 \text{ mm}^2; \quad h = \frac{10}{(0.65)(0.18)} = 85.5 \text{ mm}$$

$$C = 50 \text{ mm}^2; \quad h = \frac{50}{(0.65)(0.18)} = 427.4 \text{ mm}$$

Range: **85.5 mm to 427.4 mm**

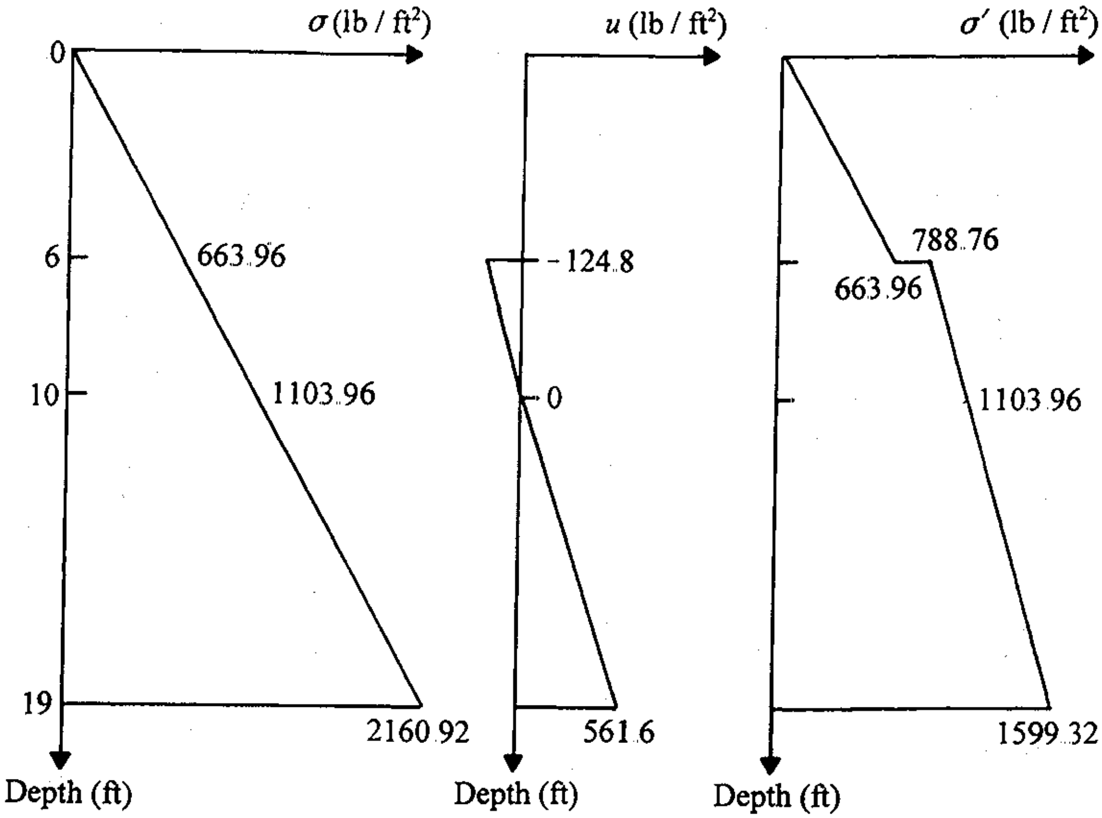
8.15 $\gamma_{d(\text{sand})} = \dfrac{G_s\gamma_w}{1+e} = \dfrac{(2.66)(62.4)}{1+0.5} = 110.66 \text{ lb/ft}^3$

$$\gamma_{(\text{clay})} = \frac{\gamma_w(G_s+Se)}{1+e} = \frac{(62.4)[2.71+(0.5)(0.75)]}{1+0.75} = 110 \text{ lb/ft}^3$$

$$\gamma_{\text{sat(clay)}} = \frac{\gamma_w(G_s+e)}{1+e} = \frac{(62.4)(2.72+0.95)}{1+0.95} = 117.44 \text{ lb/ft}^3$$

Depth (ft)	lb / ft²		
	σ	u	σ'
0	**0**	**0**	**0**
6	(110.66)(6) = **663.96**	**0**	**663.96**
		(−0.5)(62.4)(4) = **−124.8**	**788.76**
6 + 4 = 10	663.96 + (110)(4) = **1103.96**	**0**	**1103.96**
10 + 9 = 19	1103.96 + (117.44)(9) = **2160.92**	(9)(62.4) = **561.6**	**1599.32**

The plot is given.



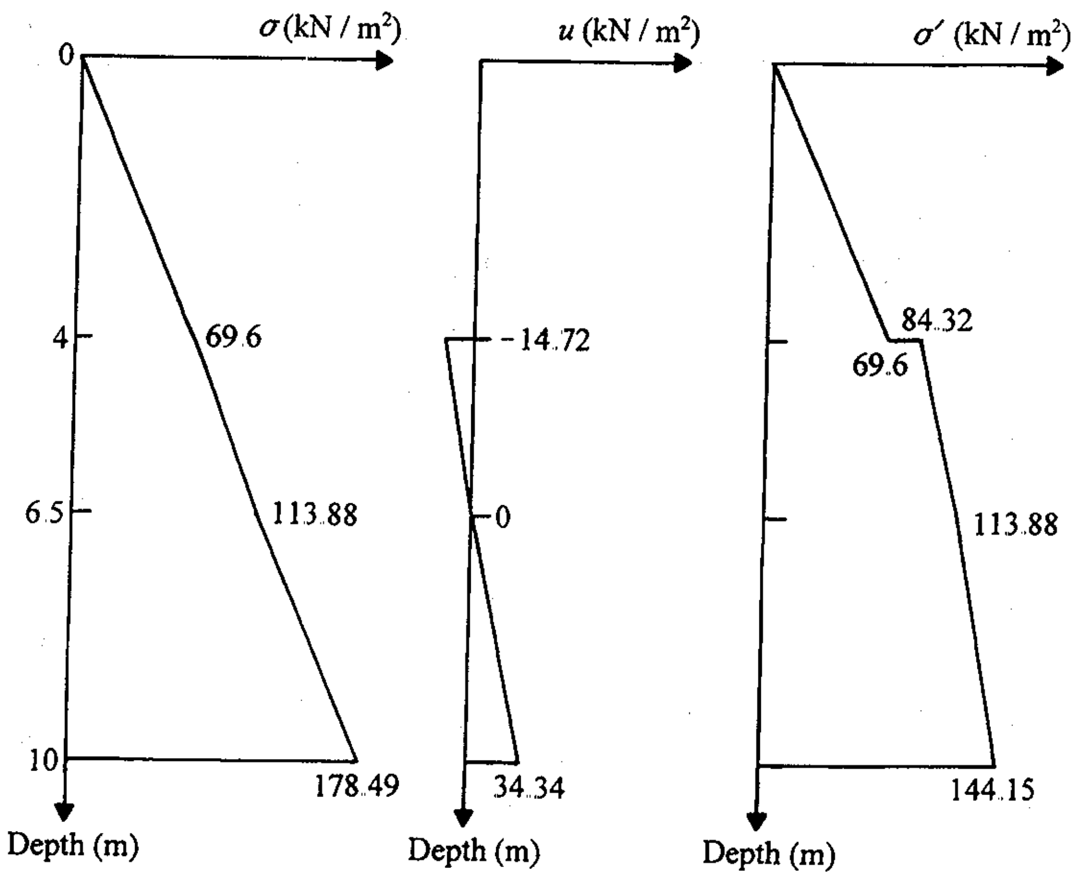
8.16 $\gamma_{d(\text{sand})} = \dfrac{(2.66)(9.81)}{1+0.5} = 17.4 \text{ kN/m}^3$

$$\gamma_{\text{clay}} = \frac{(9.81)[2.71+(0.6)(0.75)]}{1+0.75} = 17.71 \text{ kN/m}^3$$

$$\gamma_{\text{sat(clay)}} = \frac{(9.81)(2.72+0.95)}{1+0.95} = 18.46 \text{ kN/m}^3$$

Depth (m)	kN / m²		
	σ	u	σ'
0	**0**	**0**	**0**
4	(17.4)(4)=**69.6**	**0**	**69.6**
		(−0.6)(9.81)(2.5)=−**14.72**	**84.32**
4+2.5=6.5	69.6+(17.71)(2.5)=**113.88**	**0**	**113.88**
6.5+3.5=10	**113.88** + (18.46)(3.5)=**178.49**	(3.5)(9.81) = **34.34**	**144.15**

The plot is given.

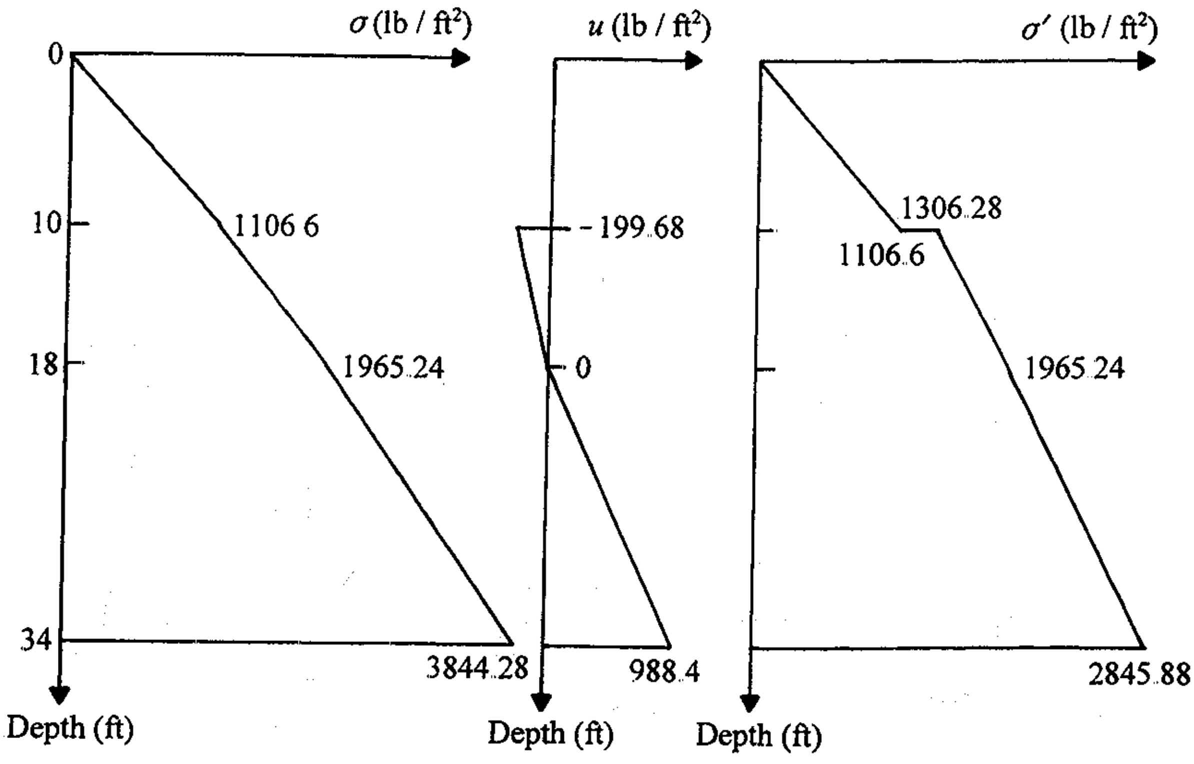


8.17 From Problem 8.15, $\gamma_{d\,(\text{sand})} = 110.66\ \text{lb}/\text{ft}^3$; $\gamma_{\text{sat}\,(\text{clay})} = 117.44\ \text{lb}/\text{ft}^3$

$$\gamma_{(\text{clay})} = \frac{(62.4)[2.71+(0.4)(0.75)]}{1+0.75} = 107.33\ \text{lb}/\text{ft}^3$$

Depth (ft)	lb / ft²		
	σ	u	σ'
0	**0**	**0**	**0**
10	(110.66)(10)=**1106.6**	**0**	**1106.6**
		(−0.4)(62.4)(8)=−**199.68**	**1306.28**
10+8=18	1106.6+(8)(107.33)=**1965.24**	**0**	**1965.24**
18+16=34	1965.24+(16)(117.44)=**3844.28**	(16)(62.4)=**998.4**	**2845.88**

The plot is given.

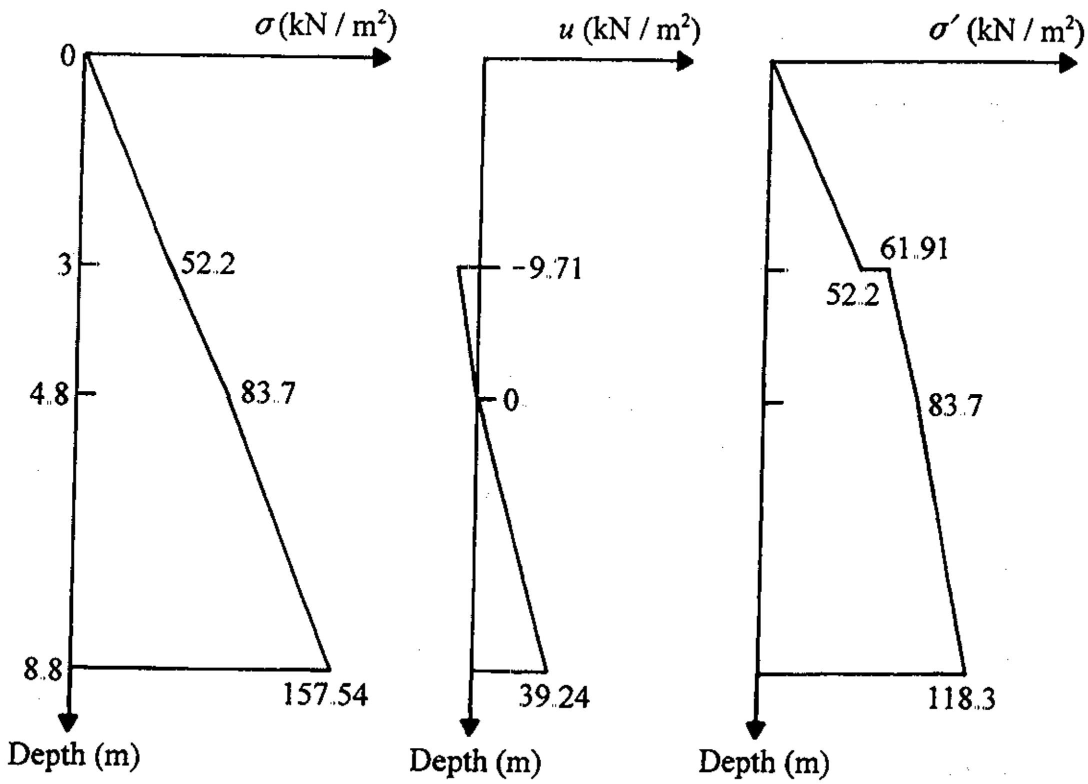


8.18 From Problem 8.16, $\gamma_{d\,(\text{sand})} = 17.4\ \text{kN/m}^3$; $\gamma_{\text{sat (clay)}} = 18.46\ \text{kN/m}^3$

$$\gamma_{(\text{clay})} = \frac{(9.81)[2.71+(0.55)(0.75)]}{1+0.75} = 17.5\ \text{kN/m}^3$$

Depth (m)	kN / m²		
	σ	u	σ'
0	**0**	**0**	**0**
3	(17.4)(3) = **52.2**	**0**	**52.2**
		(−0.55)(9.81)(1.8) = **−9.71**	**61.91**
4.8	52.2 + (1.8)(17.5) = **83.7**	**0**	**83.7**
8.8	83.7 + (4)(18.46) = **157.54**	(4)(9.81) = **39.24**	**118.3**

The plot is given.



CHAPTER 9

9.1 a. $$\left.\begin{matrix}\sigma_1\\ \sigma_3\end{matrix}\right\}=\frac{\sigma_y+\sigma_x}{2}\pm\sqrt{\left(\frac{\sigma_y-\sigma_x}{2}\right)^2+\tau_{xy}^2}$$

$\sigma_x = 80$ kN / m²; $\sigma_y = 120$ kN / m²; $\tau_{xy} = +40$ kN / m²; $\theta = 145°$

$$\left.\begin{matrix}\sigma_1\\ \sigma_3\end{matrix}\right\}=\frac{120+80}{2}\pm\sqrt{\left(\frac{120-80}{2}\right)^2+(40)^2}$$

$\sigma_1 = \mathbf{144.7\ kN / m^2}$; $\sigma_3 = \mathbf{55.3\ kN / m^2}$

b. $$\sigma_n=\frac{\sigma_y+\sigma_x}{2}+\frac{\sigma_y-\sigma_x}{2}\cos 2\theta+\tau_{xy}\sin 2\theta$$

$$=\frac{120+80}{2}+\frac{120-80}{2}\cos[(2)(145)]+40\sin[(2)(145)]=\mathbf{69.25\ kN/m^3}$$

$$\tau_n=\frac{\sigma_y-\sigma_x}{2}\sin 2\theta-\tau_{xy}\cos 2\theta$$

$$=\frac{120-80}{2}\sin[(2)(145)]-40\cos[(2)(145)]=\mathbf{-32.47\ kN/m^2}$$

9.2 a. $\sigma_x = 500$ lb / ft²; $\sigma_y = 250$ lb / ft²; $\tau_{xy} = -80$ lb / ft²; $\theta = 45°$

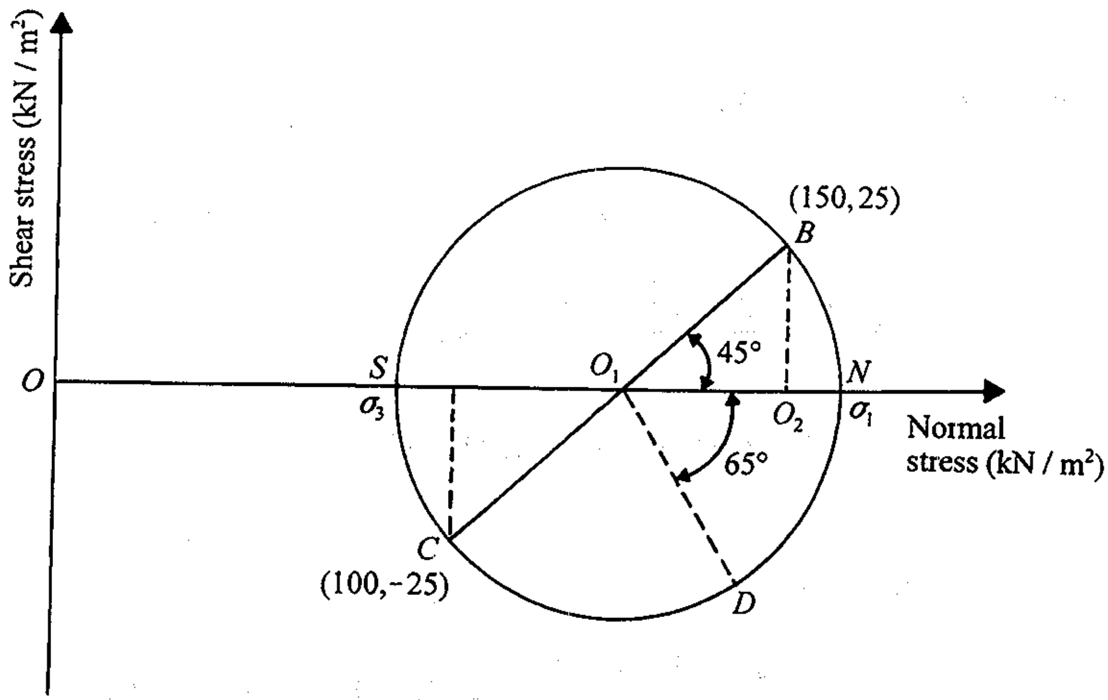
$$\left.\begin{matrix}\sigma_1\\ \sigma_3\end{matrix}\right\}=\frac{250+500}{2}\pm\sqrt{\left(\frac{250-500}{2}\right)^2+(-80)^2}$$

$\sigma_1 = \mathbf{523.4\ lb / ft^2}$; $\sigma_3 = \mathbf{226.6\ lb / ft^2}$

b. $$\sigma_n=\frac{250+500}{2}+\frac{250-500}{2}\cos 90-80\sin 90=\mathbf{295\ lb/ft^2}$$

c. $$\tau_n=\frac{250-500}{2}\sin 90-(-80)\cos 90=\mathbf{-125\ lb/ft^2}$$

9.3 a. The Mohr's circle is shown.



$$\overline{OO_1} = \frac{150+100}{2} = 125 \text{ kN / m}^2$$

$$\overline{O_1B} = \sqrt{\left(\frac{150-100}{2}\right)^2 + (25)^2} = 35.36 \text{ kN / m}^2$$

$\sigma_3 = \overline{OS} = 125 - 35.36 =$ **89.64 kN / m² (+)**

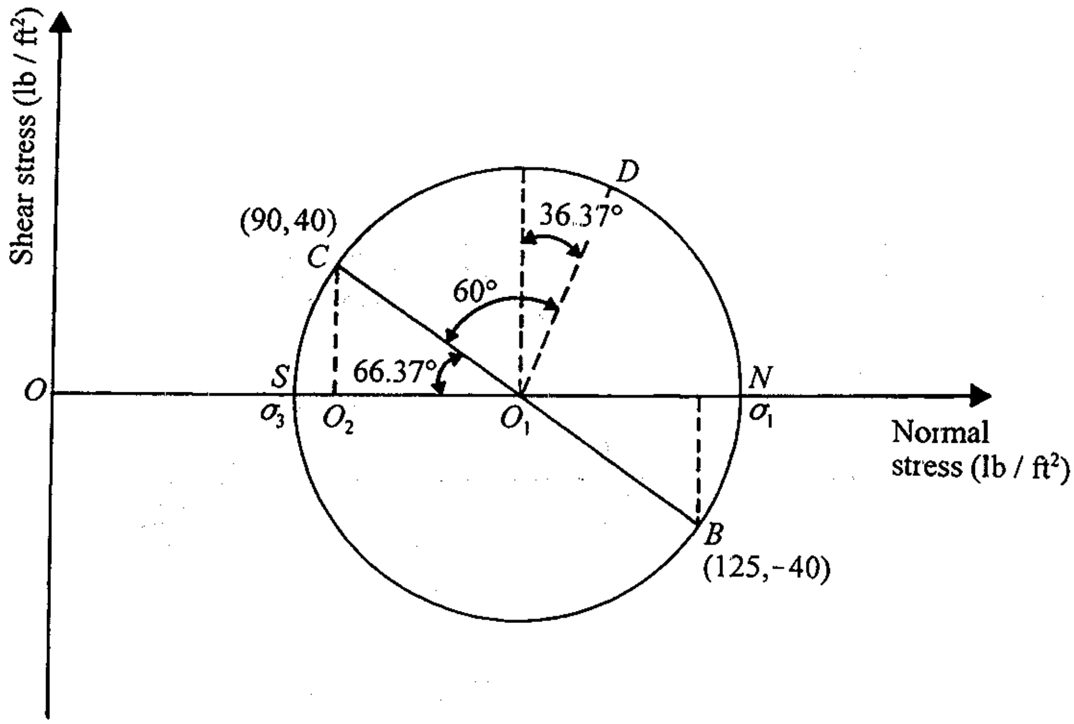
$\sigma_1 = \overline{ON} = 125 + 35.36 =$ **160.36 kN / m² (+)**

b. $\angle BO_1O_2 = \tan^{-1}\left(\frac{25}{25}\right) = 45°$

$\sigma_n = \overline{OO_1} + \overline{O_1D}\cos 65 = 125 + 35.36\cos 65 =$ **139.9 kN / m² (+)**

$\tau_n = \overline{O_1D}\sin 65 = 35.36\sin 65 =$ **32.05 kN / m² (-)**

9.4 a. The Mohr's circle is shown.



$$\overline{OO_1} = \frac{125+90}{2} = 107.5 \text{ lb / ft}^2$$

$$\overline{O_1O_2} = \frac{125-90}{2} = 17.5 \text{ lb / ft}^2$$

$$\overline{O_1B} = \sqrt{(17.5)^2 + (40)^2} = 43.66 \text{ lb / ft}^2$$

$\sigma_1 = \overline{ON} = 107.5 + 43.66 =$ **151.16 lb / ft²**

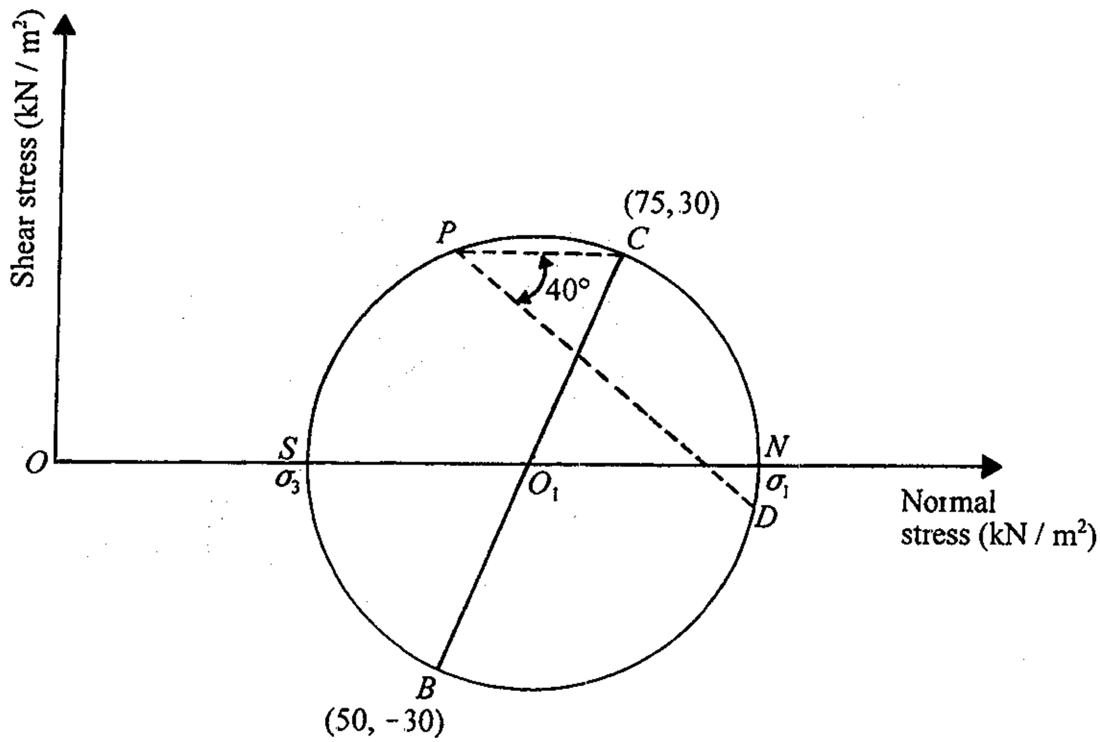
$\sigma_3 = \overline{OS} = 107.5 - 43.66 =$ **63.84 lb / ft² (+)**

b. $\angle CO_1O_2 = \tan^{-1}\left(\frac{40}{17.5}\right) = 66.37°$

$\sigma_n = \overline{OO_1} + \overline{O_1D}\sin(36.37) = 107.5 + 43.66\sin 36.37 =$ **133.4 lb / ft²**

$\tau_n = 43.66\cos 36.37 =$ **35.16 lb / ft²**

9.5 a. The Mohr's circle is shown.



$\sigma_1 = \overline{ON} = \mathbf{95\ kN/m^2}$; $\sigma_3 = \overline{OS} = \mathbf{30\ kN/m^2}$

b. σ_n and τ_n are coordinates of D. So

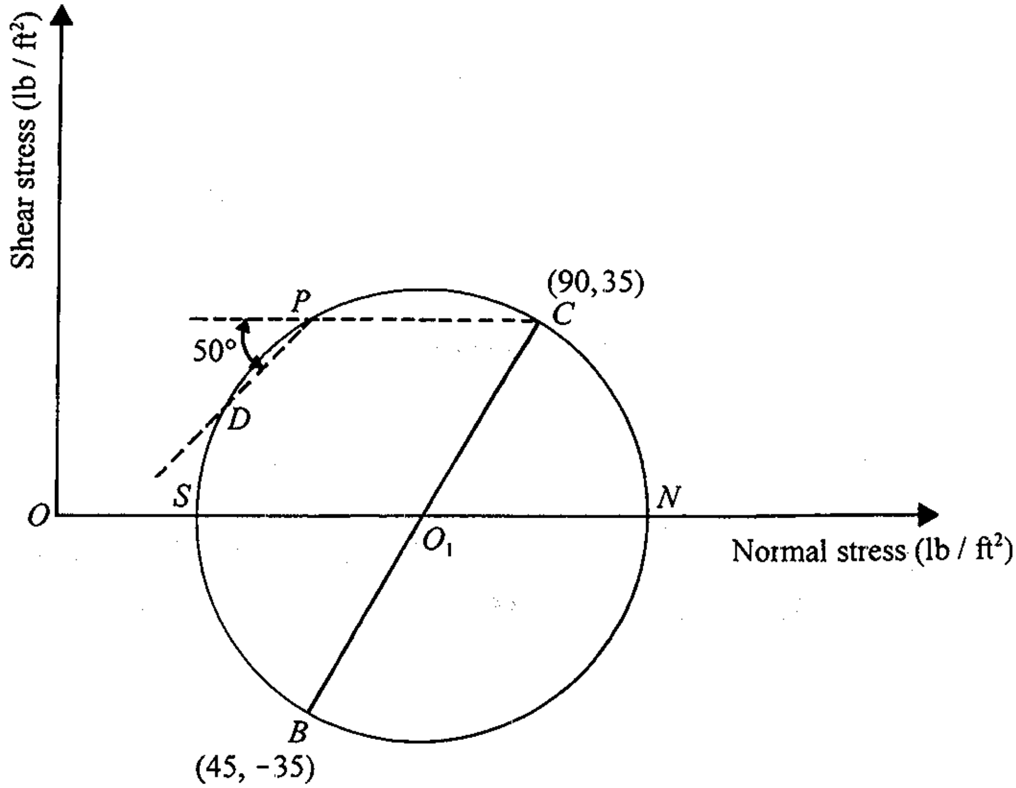
$\sigma_n \approx \mathbf{94.2\ kN/m^2}$; $\tau_n \approx \mathbf{7.1\ kN/m^2\ (-)}$

9.6 a. The Mohr's circle is shown on page 59.

$\sigma_1 = \overline{ON} \approx \mathbf{109.1\ kN/m^2}$; $\sigma_3 = \overline{OS} = \mathbf{25.9\ kN/m^2}$

b. σ_n and τ_n are coordinates of D. So

$\sigma_n \approx \mathbf{29.1\ kN/m^2}$; $\tau_n \approx \mathbf{16.08\ kN/m^2}$



Problem 9.6

9.7

Load @	P (lb)	r (ft)	z (ft)	$\frac{r}{z}$	I_1 (Table 9.1)	$\Delta\sigma_z = \frac{P}{z^2} I_1$ (lb / ft²)
A	2000	$(10^2 + 5^2)^{0.5} = 11.18$	10	1.12	0.0626	1.25
B	4000	$(10^2 + 5^2)^{0.5} = 11.18$	10	1.12	0.0626	2.5
C	6000	5	10	0.5	0.2733	16.4

$\Delta\sigma_z$ = Σ20.15 lb / ft²

9.8 Equation (9.16): $\eta = \sqrt{\dfrac{1-(2)(0.4)}{2-(2)(0.4)}} = 0.408$

Equation (9.15):

Load A: $\dfrac{(2000)(0.408)}{2\pi(10)^2}\left[\dfrac{1}{(0.408)^2+(1.12)^2}\right]^{\frac{3}{2}} = 0.77 \text{ lb/ft}^2$

Load B: $\dfrac{(4000)(0.408)}{2\pi(10)^2}\left[\dfrac{1}{(0.408)^2+(1.12)^2}\right]^{\frac{3}{2}} = 1.53 \text{ lb}/\text{ft}^2$

Load C: $\dfrac{(6000)(0.408)}{2\pi(10)^2}\left[\dfrac{1}{(0.408)^2+(0.5)^2}\right]^{\frac{3}{2}} = 14.5 \text{ lb}/\text{ft}^2$

$\Delta\sigma_z = 0.77 + 1.53 + 14.5 = \mathbf{16.8\ lb/ft^2}$

9.9 Equation (9.19):

$$\Delta\sigma_z = \frac{2q_1z^3}{\pi\left[(x_1+x_2)^2+z^2\right]^2} + \frac{2q_2z^3}{\pi\left(x_2^2+z^2\right)^2+z^2} = \frac{(2)(100)(2)^3}{\pi\left(5^2+2^2\right)^2} + \frac{(2)(200)(2)^3}{\pi\left(2^2+2^2\right)^2}$$

$= \mathbf{16.53\ kN/m^2}$

9.10 $$\Delta\sigma_z = \frac{2q_1z^3}{\pi\left[(x_1+x_2)^2+z^2\right]^2} + \frac{2q_2z^3}{\pi\left(x_2^2+z^2\right)^2+z^2}$$

$$= \frac{(2)(100)(2.5)^3}{\pi\left[(3+2.5)^2+(2.5)^2\right]^2} + \frac{(2)(260)(2.5)^3}{\pi\left[(2.5)^2+(2.5)^2\right]^2}$$

$= \mathbf{20.83\ kN/m^3}$

9.11 $$\Delta\sigma_z = \frac{2q_1z^3}{\pi\left[(x_1+x_2)^2+z^2\right]^2} + \frac{2q_2z^3}{\pi\left(x_2^2+z^2\right)^2+z^2}$$

$$35 = \frac{(2)(750)(3)^3}{\pi(12^2+3^2)^2} + \frac{2q_2(3)^3}{\pi(4^2+3^2)^2} = 0.55 + 0.0275q_2$$

$q_2 = \mathbf{1252.7\ lb/ft}$

9.12 $\Delta\sigma_z$ at A due to $q_1 = \dfrac{2q_1z^2}{\pi\left(x^2+z^2\right)^2}$

or

$$(\Delta\sigma_z)_1 = \frac{(2)(100)(2)^3}{\pi\left[(2)^2+(2)^2\right]^2} = 7.96 \text{ kN / m}^2$$

Vertical component of $q_2 = q_2 \sin 45$

$$(\Delta\sigma_z)_2 = \frac{2q_2(\sin 45)z^3}{\pi\left[(5)^2+(2)^2\right]^2}; \ (\Delta\sigma_z)_2 = 0.0043q_2$$

Horizontal component of $q_2 = q_2 \cos 45$

From Equation (9.21):

$$(\Delta\sigma_z)_3 = \frac{2q_2xz^2}{\pi\left(x^2+z^2\right)^2} = \frac{2q_2(\cos 45)(5)(2)^2}{\pi\left[(5)^2+(2)^2\right]^2} = 0.0107q_2$$

Total vertical stress,

$$\Delta\sigma_z = 10 \text{ kN / m}^2 = (\Delta\sigma_z)_1 + (\Delta\sigma_z)_2 + (\Delta\sigma_z)_3$$

$$10 = 7.96 + 0.0043q_2 + 0.0107q_2$$

$$q_2 = \frac{10-7.96}{0.015} = \mathbf{136 \text{ kN / m}}$$

9.13 $B = 10$ ft; $q = 200$ lb / ft^2; $x = 8$ ft; $z = 8$ ft

$\dfrac{2x}{B} = \dfrac{(2)(8)}{10} = 1.6; \ \dfrac{2z}{B} = \dfrac{(2)(8)}{10} = 1.6.$ From Table 9.4, $\dfrac{\Delta\sigma_z}{q} = 0.248$

$$\Delta\sigma_z = (0.248)(200) = \mathbf{49.6 \text{ lb / ft}^2}$$

9.14 $\dfrac{2x}{B} = \dfrac{(2)(1.5)}{3} = 1; \ \dfrac{2z}{B} = \dfrac{(2)(3)}{3} = 2.$ From Table 9.4, $\dfrac{\Delta\sigma_z}{q} = 0.409$

$$\Delta\sigma_z = (60)(0.409) = \mathbf{24.54 \text{ kN / m}^2}$$

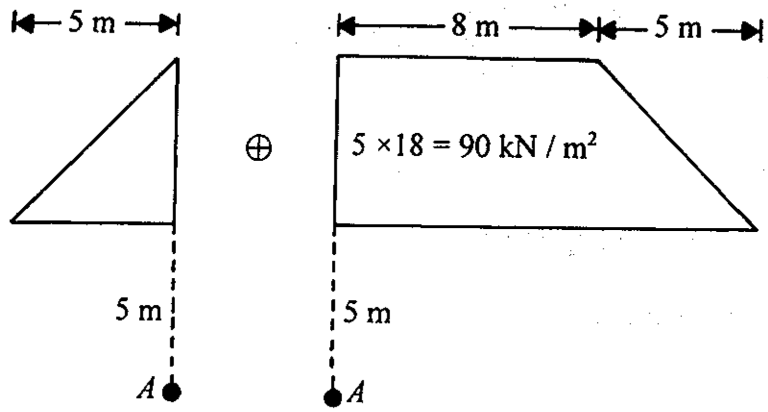
9.15 Equation (9.24):

$$\Delta\sigma_z = \frac{2Bqxz^2}{\pi\left\{\left[x^2 + z^2 - \left(\frac{B}{2}\right)^2\right]^2 + B^2z^2\right\}}$$

$$9 = \frac{(2)(1)(q)(1.5)(0.75)^2}{\pi\left\{\left[(1.5)^2 + (0.75)^2 - \left(\frac{1}{2}\right)^2\right]^2 + (1)^2(0.75)^2\right\}}$$

q = **119.4 kN / m²**

9.16 Refer to the figure below.



With the notations given in Figure 9.17, for the left side:

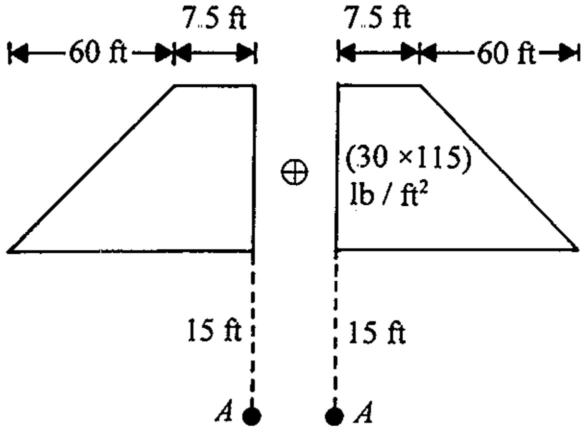
$\frac{B_1}{z} = \frac{0}{5} = 0$; $\frac{B_2}{z} = \frac{5}{5} = 1$. From Figure 9.18, $I_{3(L)} = 0.24$

For the right side,

$\frac{B_1}{z} = \frac{8}{5} = 1.6$; $\frac{B_2}{z} = \frac{5}{5} = 1$. From Figure 9.18, $I_{3(R)} = 0.48$

$$\Delta\sigma_z = q[I_{3(L)} + I_{3(R)}] = (90)(0.24 + 0.48) = \mathbf{64.8\ kN / m^2}$$

9.17 At A:



For the left side:

$$\frac{B_1}{z} = \frac{7.5}{15} = 0.5$$

$$\frac{B_2}{z} = \frac{60}{15} = 4$$

$$I_3 = 0.468$$

For the right side:

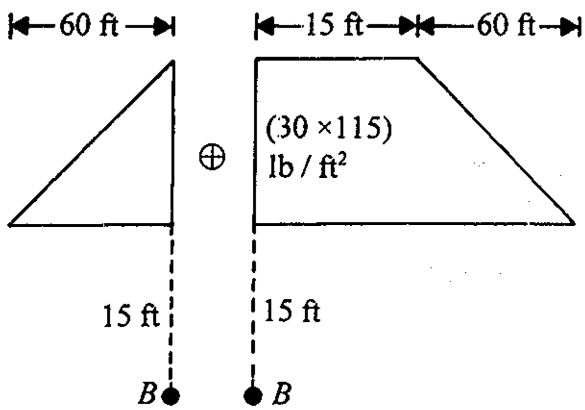
$$\frac{B_1}{z} = 0.5$$

$$\frac{B_2}{z} = 4$$

$$I_3 = 0.468$$

$$\Delta\sigma_z = (30)(115)(0.468 + 0.468) \approx \mathbf{3229\ lb/ft^2}$$

At B:



For the left side:

$$\frac{B_1}{z} = \frac{0}{15} = 0$$

$$\frac{B_2}{z} = \frac{60}{15} = 4$$

$$I_3 = 0.42$$

For the right side:

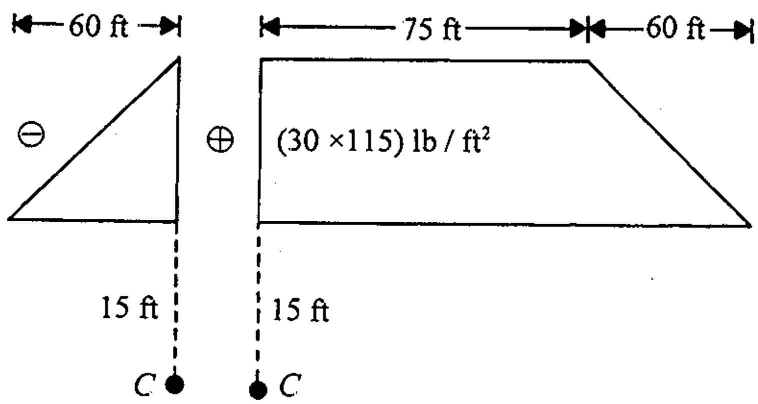
$$\frac{B_1}{z} = \frac{15}{15} = 1$$

$$\frac{B_2}{z} = \frac{60}{15} = 4$$

$$I_3 = 0.48$$

$$\Delta\sigma_z = (30)(115)(0.42 + 0.48) \approx \mathbf{3105\ lb/ft^2}$$

At C:



For the left side:

$\frac{B_1}{z} = 0$

$\frac{B_2}{z} = \frac{60}{15} = 4$

$I_3 = 0.42$

For the right side:

$\frac{B_1}{z} = \frac{75}{15} = 5$

$\frac{B_2}{z} = \frac{60}{15} = 4$

$I_3 = 0.5$

$$\Delta\sigma_z = (30)(115)(0.5 - 0.42) \approx \mathbf{276\ lb / ft^2}$$

9.18 Equation (9.30) and Table 9.6: $q = 3500\ \text{lb / ft}^2$

R (ft)	z (ft)	$\frac{z}{R}$	$\frac{\Delta\sigma_z}{q}$	$\Delta\sigma_z$ (lb / ft²)
6	1.5	0.4	0.9488	**3321**
6	3	0.5	0.9106	**3187**
6	6	1.0	0.6465	**2263**
6	9	1.5	0.4240	**1484**
6	12	2.0	0.2845	**996**

9.19 Equation (9.31) and Tables 9.7 and 9.8: $q = 300 \text{ kN / m}^2$

z (m)	r (m)	R (m)	$\frac{z}{R}$	$\frac{r}{R}$	A'	B'	$\Delta\sigma_z$ (kN / m²)
4.8	0	4	1.2	0	0.23178	0.31485	**164.0**
4.8	0.8	4	1.2	0.2	0.22795	0.30730	**160.6**
4.8	1.6	4	1.2	0.4	0.21662	0.28481	**150.4**
4.8	4.0	4	1.2	1.0	0.15101	0.14915	**90.1**
4.8	6.0	4	1.2	1.5	0.09192	0.04378	**40.7**
4.8	8.0	4	1.2	2.0	0.05260	0.00023	**15.8**

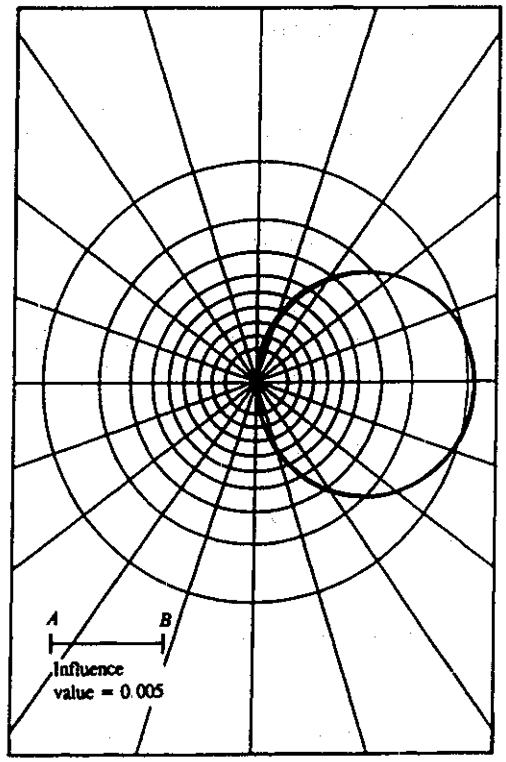
9.20 Refer to the Newmark's chart.

The plan is drawn to scale.

$\overline{AB} = 4$ m. $M \approx 65$.

$\Delta\sigma_z = (IV)qM = (0.005)(300)(65)$

$= \mathbf{97.5\ kN / m^2}$

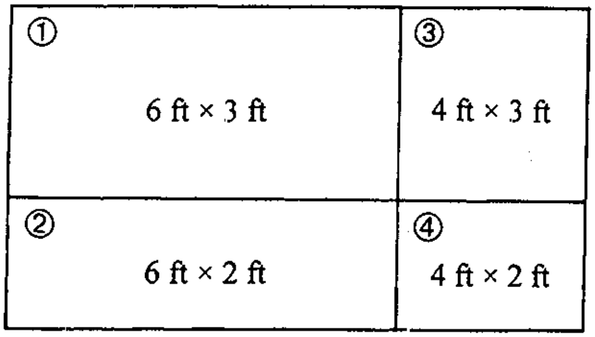


9.21 a. Equations (9.36) and (9.37): $n = \frac{L}{z} = \frac{10}{5} = 2; \quad m = \frac{B}{z} = \frac{5}{5} = 1$

Equation (9.34): $\Delta\sigma_z = qI_4; \; I_4 = 0.1999$

$\Delta\sigma_z = (1800)(0.1999) = \mathbf{359.8\ lb / ft^2}$

b. Refer to the figure below.



For rectangle 1: $m = \frac{3}{5} = 0.6; \quad n = \frac{6}{5} = 1.2; \quad I_4 = 0.1431$

For rectangle 2: $m = \frac{2}{5} = 0.4; \quad n = \frac{6}{5} = 1.2; \quad I_4 = 0.1063$

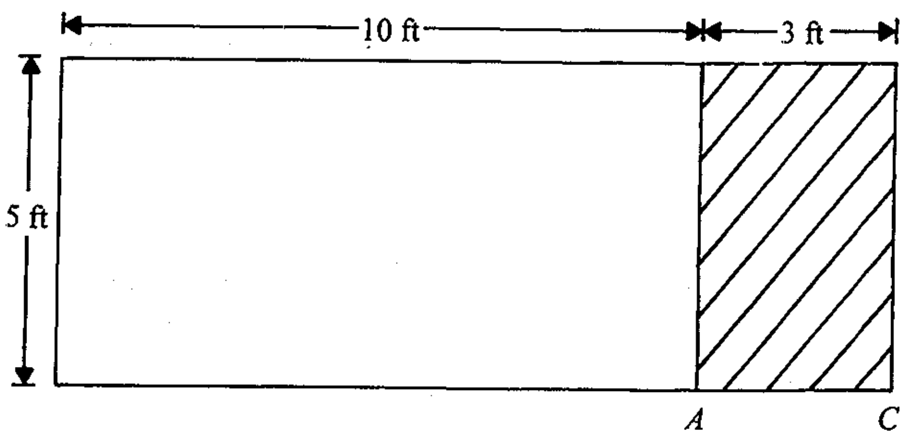
For rectangle 3: $m = \frac{3}{5} = 0.6; \quad n = \frac{4}{5} = 0.8; \quad I_4 = 0.1247$

For rectangle 4: $m = \frac{2}{5} = 0.4; \quad n = \frac{4}{5} = 0.8; \quad I_4 = 0.0931$

$$\Delta\sigma_z = q[I_{4(1)} + I_{4(2)} + I_{4(3)} + I_{4(4)}] = (1800)(0.1431 + 0.1063 + 0.1247 + 0.0931)$$

$$= \mathbf{841\ lb/ft^2}$$

c. Refer to the figure.



$$\Delta\sigma_z = \left\langle \begin{array}{l}\text{stress at } C \text{ due to rectangular area 13 ft} \times 5 \text{ ft} \\ \quad - \text{ stress at } C \text{ due to rectangular area 3 ft} \times 5 \text{ ft}\end{array}\right.$$

For rectangular area 13 ft × 5 ft: $m = \frac{5}{5} = 1$; $n = \frac{13}{5} = 2.6$; $I_4 = 0.202$

For rectangular area 3 ft × 5 ft: $m = \frac{3}{5} = 0.6$; $n = \frac{5}{5} = 1$; $I_4 = 0.1361$

$$\Delta\sigma_z = q(0.202 - 0.1361) = (1800)(0.202 - 0.1351) = \mathbf{118.6\ lb / ft^2}$$

9.22 Equations (9.41), (9.42), and (9.43):

$$b = \frac{B}{2} = \frac{5}{2} = 2.5 \text{ ft}$$

$$m_1 = \frac{L}{B} = \frac{10}{5} = 2$$

$$n_1 = \frac{z}{b} = \frac{15}{2.5} = 6$$

From Table 9.10, $I_5 = 0.095$

$$\Delta\sigma_z = qI_5 = (1800)(0.095) = \mathbf{171\ kN / m^2}$$

CHAPTER 10

10.1 Equation (10.1): $S_e = \Delta\sigma B \frac{1-\mu_s^2}{E_s} I_\rho$

$B = 3$ ft; $L = 6$ ft; $m_1 = 6/3 = 2$

Table 10.1: For $m_1 = 2$, $I_\rho = 1.21$

$$S_e = (3000)(3)\frac{1-0.4^2}{(140\times 2000\ \text{lb}/\text{ft}^2)}(1.21) = 0.03267\ \text{ft} = \mathbf{0.39\ in.}$$

10.2 $\Delta\sigma = \frac{711}{3\times 3} = 79\ \text{kN}/\text{m}^2$; $I_\rho = 0.88$ (Table 10.1)

$$S_e = (79)(3)\frac{1-0.32^2}{16{,}000}(0.88) = 0.0117 = \mathbf{11.7\ mm}$$

10.3 Equation (10.5): $S_e = \Delta\sigma B_e I_G I_F I_E \frac{(1-\mu_s^2)}{E_o}$

$\Delta\sigma = 100\ \text{kN}/\text{m}^2$

$$B_e = \sqrt{\frac{4B^2}{\pi}} = \sqrt{\frac{(4)(3)^2}{\pi}} = 3.385\ \text{m}$$

$\mu_s = 0.3$; $E_o = 16{,}000\ \text{kN}/\text{m}^2$

$$\beta = \frac{E_o}{kB_e} = \frac{16{,}000}{(400)(3.385)} = 11.82$$

$$\frac{h}{B_e} = \frac{20}{3.385} = 5.91$$

From Figure 10.4, $I_G \approx 0.89$. From Equation (10.6):

$$I_F = \frac{\pi}{4} + \frac{1}{4.6 + 10\left(\frac{E_f}{E_o + \frac{B_e}{2}k}\right)\left(\frac{2t}{B_e}\right)^3}$$

$$= \frac{\pi}{4} + \frac{1}{4.5 + 10\left[\frac{15 \times 10^6}{16{,}000 + \left(\frac{3.385}{2}\right)(400)}\right]\left[\frac{(2)(0.25)}{3.385}\right]^3} = 0.815$$

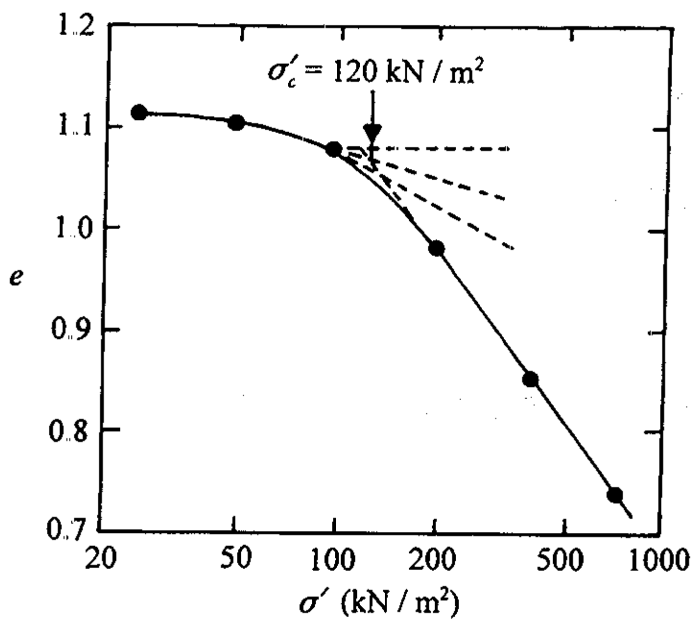
From Equation (10.7):

$$I_E = 1 - \frac{1}{3.5\exp(1.22\mu_s - 0.4)\left(\frac{B_e}{D_f} + 1.6\right)}$$

$$= 1 - \frac{1}{3.5\exp[(1.22)(0.3) - 0.4]\left(\frac{3.385}{1.5} + 1.6\right)} = 0.923$$

$$S_e = (100)(3.385)(0.89)(0.815)(0.923)\left(\frac{1 - 0.3^2}{16{,}000}\right) = 0.01289 \text{ m} \approx \mathbf{13\ mm}$$

10.4 a. The plot is shown.



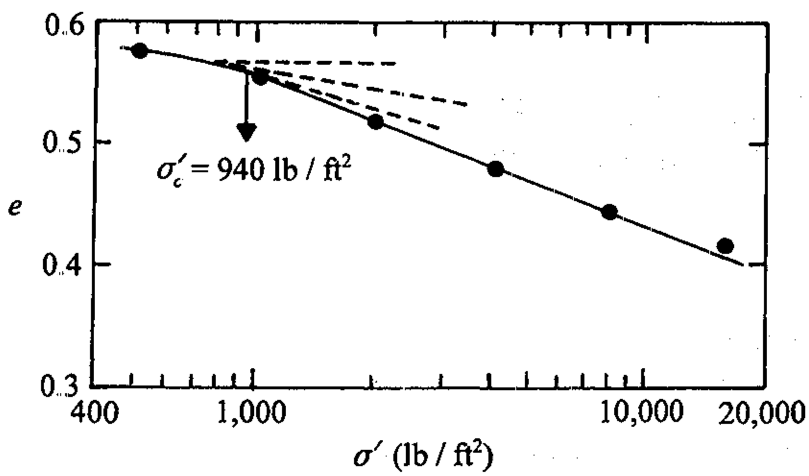
b. $\sigma'_c = \mathbf{120\ kN/m^2}$

c. $C_c = \dfrac{e_1 - e_2}{\log\left(\dfrac{\sigma'_2}{\sigma'_1}\right)} = \dfrac{0.985 - 0.85}{\log\left(\dfrac{400}{200}\right)} = \mathbf{0.448}$

10.5 a. Height of solids: $H_s = \dfrac{W_s}{AG_s\gamma_w} = \dfrac{95.2\ \text{g}}{(4.91)(2.54)^2(2.68)(1)} = 1.12\ \text{cm} = 0.441\ \text{in.}$

σ' (lb / ft²)	H (in.)	H_s (in.)	$H_v = H - H_s$ (in.)	$e = \dfrac{H_v}{H_s}$
500	0.6947	0.441	0.2537	0.575
1,000	0.6850	0.441	0.244	0.553
2,000	0.6705	0.441	0.2295	0.52
4,000	0.6520	0.441	0.211	0.478
8,000	0.6358	0.441	0.1948	0.442
16,000	0.6252	0.441	0.1842	0.418

The e-log σ' graph is plotted.



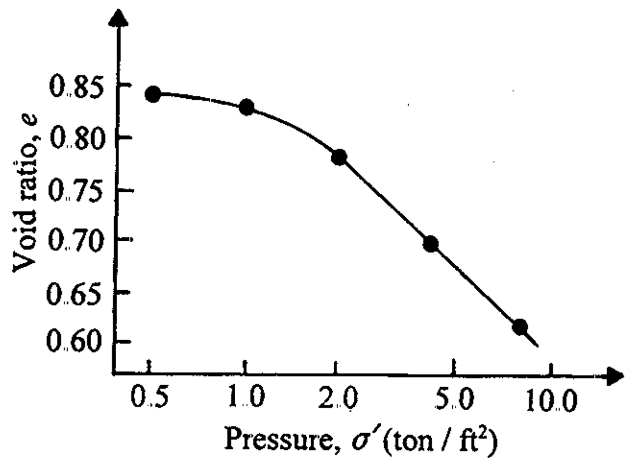
b. From the graph, $\sigma'_c = \mathbf{940\ lb/ft^2}$

c. $C_c = \dfrac{e_1 - e_2}{\log\left(\dfrac{\sigma'_2}{\sigma'_1}\right)} = \dfrac{0.52 - 0.478}{\log\left(\dfrac{4000}{2000}\right)} = \mathbf{0.133}$

10.6 $H_s = \frac{W_s}{AG_s\gamma_w} = \frac{117 \text{ g}}{\frac{\pi}{4}(2.5\times 2.54)^2(2.72)(1)} = 1.356 \text{ cm} = 0.539 \text{ in.}$

Pressure, σ' (ton / ft^2)	Final height of specimen, H (in.)	$H_v = H - H_s$ (in.)	$e = \frac{H_v}{H_s}$
0	1.000	0.461	0.855
0.5	0.9917	0.4527	0.840
1.0	0.9844	0.4454	0.826
2.0	0.9562	0.4172	0.774
4.0	0.9141	0.3751	0.696
8.0	0.8686	0.3296	0.612

The e-log σ' graph is shown.



10.7 a. $S_c = \frac{C_c H}{1+e_o}\log\left(\frac{\sigma'_o + \Delta\sigma'}{\sigma'_o}\right)$

$C_c = 0.009(LL - 10) = 0.009(50 - 10) = 0.36$

$\sigma'_o = \gamma_{d(\text{sand})} H_1 + [\gamma_{\text{sat(sand)}} - 62.4] H_2 + [\gamma_{\text{sat(clay)}} - 62.4]\frac{H_3}{2}$

$= (110)(8) + (115 - 62.4)(15) + (120 - 62.4)\left(\frac{17}{2}\right) = 2158.6 \text{ lb / ft}^2$

$S_c = \frac{(0.36)(17\times 12)}{1+0.9}\log\left(\frac{2158.6+1000}{2158.6}\right) = \mathbf{6.39 \text{ in.}}$

b. $S_c = \frac{C_s H}{1+e_o}\log\left(\frac{\sigma'_c}{\sigma'_o}\right) + \frac{C_c H}{1+e_o}\log\left(\frac{\sigma'_o + \Delta\sigma'}{\sigma'_c}\right)$

$$= \frac{(17)(12)}{1+0.9}\left[\frac{0.36}{6}\log\left(\frac{2600}{2158.6}\right) + 0.36\log\left(\frac{3158.6}{2600}\right)\right] = \mathbf{3.79\ in.}$$

10.8 $\gamma_{d(\text{sand})} = \frac{G_s \gamma_w}{1+e} = \frac{(2.68)(9.81)}{1+0.6} = 16.43\ \text{kN/m}^3$

$$\gamma_{\text{sat(sand)}} = \frac{(G_s + e)\gamma_w}{1+e} = \frac{(2.68+0.6)(9.81)}{1+0.6} = 20.11\ \text{kN/m}^3$$

$$\gamma_{\text{sat(clay)}} = \frac{(G_s + e)\gamma_w}{1+e} = \frac{(2.75+1.2)(9.81)}{1+1.2} = 17.6\ \text{kN/m}^3$$

$$\sigma'_o = (16.43)(2) + (20.11 - 9.81)(1.5) + (17.6 - 9.81)\frac{2.5}{2} = 58.06\ \text{kN/m}^2$$

$$C_c = 0.009(LL - 10) = 0.009(45 - 10) = 0.315$$

$$S_c = \frac{(0.315)(2.5 \times 1000)}{1+1.2}\log\left(\frac{58.06+140}{58.06}\right) = \mathbf{190.8\ mm}$$

10.9 $\gamma_{s(\text{sand})} = \frac{G_s \gamma_w}{1+e} = \frac{(2.67)(9.81)}{1+0.58} = 16.58\ \text{kN/m}^3$

$$\gamma'_{(\text{sand})} = \frac{(G_s - 1)\gamma_w}{1+e} = \frac{(2.67-1)(9.81)}{1.58} = 10.37\ \text{kN/m}^3$$

$$\gamma'_{(\text{clay})} = \frac{(G_s - 1)\gamma_w}{1+e} = \frac{(2.72-1)(9.81)}{1+1.1} = 8.03\ \text{kN/m}^3$$

$$\sigma'_o = (1.5)(16.58) + (1.5)(10.37) + \left(\frac{2}{2}\right)(8.03) = 48.46\ \text{kN/m}^2$$

$$C_c = 0.009(LL - 10) = 0.009(45 - 10) = 0.315$$

$$S_c = \frac{C_s H}{1+e_o}\log\left(\frac{\sigma'_c}{\sigma'_o}\right) + \frac{C_c H}{1+e_o}\log\left(\frac{\sigma'_o + \Delta\sigma'}{\sigma'_c}\right)$$

$$= \frac{\left(\frac{0.315}{5}\right)(2)}{2.1}\log\left(\frac{160}{48.46}\right) + \frac{(0.315)(2)}{2.1}\log\left(\frac{48.46+140}{160}\right) = 0.0524 \text{ m} = \mathbf{52.4\ mm}$$

10.10 $C_c = \dfrac{e_1 - e_2}{\log\left(\dfrac{\sigma'_2}{\sigma'_1}\right)} = \dfrac{1.2 - 0.95}{\log\left(\dfrac{220}{110}\right)} = 0.83$

$$C_c = \frac{e_1 - e_3}{\log\left(\frac{\sigma'_3}{\sigma'_1}\right)};\quad e_3 = e_1 - C_c \log\left(\frac{\sigma'_3}{\sigma'_1}\right) = 1.2 - 0.83\log\left(\frac{350}{110}\right) = \mathbf{0.78}$$

10.11 $C_c = \dfrac{1.1 - 0.9}{\log\left(\dfrac{3}{1}\right)} = 0.419$

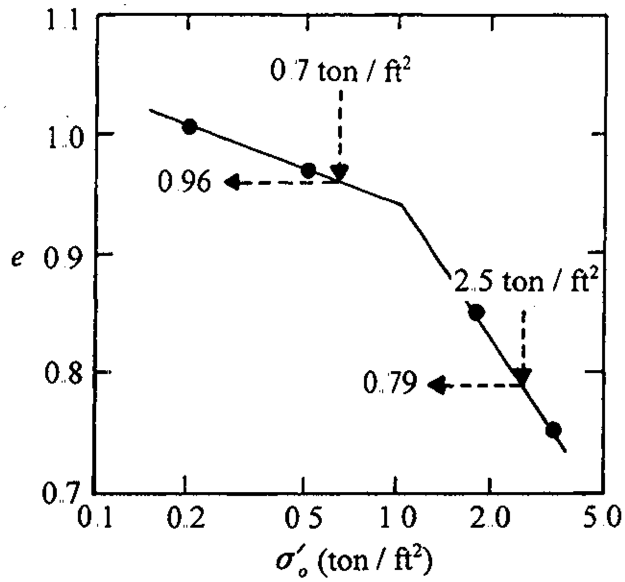
$$e_3 = 1.1 - 0.419\log\left(\frac{3.5}{1}\right) = \mathbf{0.872}$$

10.12 $T_v = \dfrac{c_v t}{H_{\text{dr}}^2};\quad U = 50\%;\quad T_v = 0.197$

$$0.197 = \frac{(0.002 \text{ cm}^2/s)t}{\left(\frac{2.5 \times 100}{2} \text{ cm}\right)}$$

$t =$ **17.8 days**

10.13 The e-log σ' plot is shown.



$\sigma'_o = 0.7$ tsf; $e_1 = 0.96$;

$\sigma'_o + \Delta\sigma' = 2.5$ tsf; $e = 0.79$.

$\Delta e = 0.96 - 0.79 = 0.17$

$$S_c = \frac{H\Delta e}{1+e_o}$$

$$= \frac{(7.5 \times 12)(0.17)}{1+0.96}$$

$$= \mathbf{7.8\ in.}$$

10.14 a. $m_v = \dfrac{a_v}{1+e_{av}} = \dfrac{\dfrac{\Delta e}{\Delta\sigma'}}{1+e_{av}}$

$\Delta e = e_1 - e_2 = 1.82 - 1.54 = 0.28$

$\Delta\sigma' = \sigma'_2 - \sigma'_1 = 400 - 200 = 200\ \text{kN/m}^2$

$$e_{av} = \frac{1.82+1.54}{2} = 1.68$$

$$m_v = \frac{\left(\dfrac{0.28}{200}\right)}{1+1.68} = \mathbf{0.000522\ m^2/kN}$$

b. $c_v = \dfrac{k}{m_v \gamma_w} = 0.003\ \text{cm}^2/\text{sec}$

$$= \frac{k}{(0.000522 \times 100^2\ \text{cm}^2/\text{kN})\left(\dfrac{9.81}{100^3}\right)\text{kN/cm}^3}$$

$$\mathbf{k = 1.53 \times 10^{-7}\ cm/sec}$$

10.15 $t_{50} = \dfrac{c_v t_L}{H^2_{L(\mathrm{dr})}} = \dfrac{c_v t_F}{H^2_{F(\mathrm{dr})}}$

$$t_F = \frac{H^2_{F(\mathrm{dr})} t_L}{H^2_{L(\mathrm{dr})}} = \frac{(10 \times 12 \text{ in.})^2 (140 \text{ sec})}{(0.5 \text{ in.})^2} = 8{,}064{,}000 \text{ sec} = \mathbf{93.3\ days}$$

10.16 Equation (10.58): $\dfrac{c_v t}{H^2_{(\mathrm{dr})}} = T_v \propto U^2$

$$\frac{t_1}{t_2} = \frac{U_1^2}{U_2^2}; \quad \frac{93.3}{t_2} = \frac{50^2}{30^2}$$

$t_2 =$ **33.6 days**

10.17 a. $m_v = \dfrac{a_v}{1+e_{av}} = \dfrac{\left(\dfrac{\Delta e}{\Delta\sigma'}\right)}{1+e_{av}} = \dfrac{\left(\dfrac{0.81-0.7}{120-50}\right)}{1+\left(\dfrac{0.81+0.7}{2}\right)} = 0.000895 \text{ m}^2/\text{kN}$

$$c_v = \frac{k}{m_v \gamma_w} = \frac{3.1 \times 10^{-7} \text{ m/s}}{(0.000895)(9.81 \text{ kN/m}^3)} = 353.1 \times 10^{-7} \text{ m}^2/\text{sec}$$

$$t_{50} = \frac{T_v H^2_{dr}}{c_v} = \frac{(0.197)\left(\dfrac{4}{2}\text{ m}^2\right)^2}{353.1 \times 10^{-7} \text{ m}^2/\text{sec}} = 0.00223 \times 10^7 \text{ sec} = \mathbf{6.2\ hrs}$$

b. $S_c = \dfrac{\Delta e H}{1+e_o} = \dfrac{(0.81-0.7)(4)}{1+0.81} = 0.243 \text{ m}$

S_c at 50% = (0.5)(0.243) = 0.1215 m = **121.5 mm**

10.18 $m_v = \dfrac{a_v}{1+e_{av}} = \dfrac{\left(\dfrac{\Delta e}{\Delta\sigma'}\right)}{1+e_{av}} = \dfrac{\left(\dfrac{0.81-0.73}{200-100}\right)}{1+\left(\dfrac{0.81+0.73}{2}\right)} = 0.4519 \times 10^{-3} \text{ m}^2/\text{kN}$

$$c_v = \frac{T_v H_{dr}^2}{t_{50}} = \frac{(0.197)\left(\frac{0.025}{2}\right)^2}{3.4} = 0.9 \times 10^{-5} \text{ m}^2 / \text{min}$$

$$k = c_v m_v \gamma_w = (0.4519 \times 10^{-3} \text{ m}^2 / \text{kN})(0.9 \times 10^{-5} \text{ m}^2 / \text{min})(9.81 \text{ kN} / \text{m}^3)$$

$$= \mathbf{3.99 \times 10^{-8} \text{ m / min}}$$

10.19 $T_{50} = \frac{c_v t_L}{H_{L(\text{dr})}^2} = \frac{c_v t_F}{H_{F(\text{dr})}^2}$

$$\frac{t_L}{H_{L(\text{dr})}^2} = \frac{t_F}{H_{F(\text{dr})}^2}; \quad \frac{150 \text{ sec}}{\left(\frac{0.025}{2}\text{m}\right)} = \frac{t_F}{(3 \text{ m})^2}$$

$t_F = 8{,}640{,}000$ sec = **100 days**

10.20 a. $m_v = \frac{a_v}{1+e_{av}} = \frac{\left(\frac{\Delta e}{\Delta \sigma'}\right)}{1+e_{av}}$

$\Delta e = 1.21 - 0.96 = 0.25$

$\Delta \sigma' = 4 - 2 = 2$ ton / ft^2

$$e_{av} = \frac{1.21+0.96}{2} = 1.085$$

So

$$m_v = \frac{\left(\frac{0.25}{2}\right)}{1+1.085} = 0.06 \text{ ft}^2 / \text{ton}$$

$$c_v = \frac{k}{m_v \gamma_w} = \frac{1.8 \times 10^{-4}}{(0.06 \text{ ft}^2 / \text{ton})\left(\frac{62.4}{2000} \text{ ton} / \text{ft}^2\right)} = 0.0962 \text{ ft}^2 / \text{day}$$

$$t_{50} = \frac{T_v H_{dr}^2}{c_v} = \frac{(0.286)(9)^2}{0.0962} = \mathbf{240.8 \text{ days}}$$

b. $C_c = \dfrac{e_1 - e_2}{\log\left(\dfrac{\sigma_2'}{\sigma_1'}\right)} = \dfrac{121 - 0.96}{\log\left(\dfrac{4}{2}\right)} = 0.83$

$$S_c = \frac{C_c H}{1+e_o}\log\left(\frac{\sigma_o' + \Delta\sigma'}{\sigma_o'}\right) = \frac{(0.83)(9)}{1+1.21}\log\left(\frac{4}{2}\right) = 1.018 \text{ ft}$$

S_c at 60% = (0.6)(1.018) = 0.611 ft ≈ **7.33 in.**

10.21 a. $m_v = \dfrac{\left(\dfrac{\Delta e}{\Delta\sigma'}\right)}{1+e_{av}} = \dfrac{\left(\dfrac{1.2-0.95}{220-110}\right)}{1+\dfrac{1.2+0.95}{2}} = \mathbf{10.95\times 10^{-4}\ m^2/kN}$

b. $c_v = \dfrac{k}{m_v \gamma_w}$

$$0.0036 \text{ cm}^2/\text{sec} = \frac{k}{[(10.95\times10^{-4})(100)^2 \text{ cm}^2/\text{kN}]\left(\dfrac{9.81}{100^2} \text{ kN/cm}^3\right)}$$

$k = \mathbf{3.87 \times 10^{-7}\ cm/sec}$

10.22 a. $t_{90} = \dfrac{c_v t_{90}}{H_{dr}^2}$; $0.848 = \dfrac{c_v(120\times 24\times 60\times 60)}{\left(\dfrac{15}{2}\times 12\times 2.54\right)^2}$

$c_v = \mathbf{4.27 \times 10^{-3}\ cm^2/sec}$

b. $\dfrac{t_{lab}}{H_{dr(lab)}^2} = \dfrac{t_{field}}{H_{dr(field)}^2}$; $\dfrac{t_{lab}}{\left(\dfrac{15\times 2.54}{2}\right)^2} = \dfrac{120\times 24\times 60\times 60}{\left(\dfrac{15}{2}\times 12\times 2.54\right)^2}$

$t_{lab} = \mathbf{720\ sec}$

10.23 a. $U(\%) = \left(\frac{30}{80}\right)(100) = \mathbf{37.5\%}$

b. $T_v = \frac{c_v t}{H_{dr}^2}$; $U = 50\%$; $T_v = 0.197$

$$0.197 = \frac{0.003t}{(400 \text{ cm})^2}$$

$t_{50} = 10{,}506{,}667 \text{ sec} = \mathbf{121.6 \text{ days}}$

c. $T_v = 0.197 = \frac{0.003t}{\left(\frac{400}{2}\right)^2}$

$t_{50} = 2{,}626{,}667 \text{ sec} = \mathbf{30.4 \text{ days}}$

10.24 Equation (10.66): $\Delta\sigma'_{av} = \frac{\Delta\sigma'_t + 4\Delta\sigma'_m + \Delta\sigma'_b}{6}$

Equation (9.39): $\Delta\sigma' = qI_5$

$m_1 = \frac{L}{B} = \frac{3}{1} = 3$; $b = \frac{B}{2} = 0.5 \text{ m}$; $n_1 = \frac{z}{b}$

m_1	z (m)	b	n_1	q (kN / m²)	I_5 Table 9.10	$\Delta\sigma' = qI_5$ (kN / m²)
3	1	0.5	2	$\frac{100}{3 \times 1} = 33.3$	0.525	$17.48 = \Delta\sigma'_t$
3	2	0.5	4	33.3	0.241	$8.03 = \Delta\sigma'_m$
3	3	0.5	6	33.3	0.13	$4.33 = \Delta\sigma'_b$

$$\Delta\sigma'_{av} = \frac{17.48 + (4 \times 8.03) + 4.33}{6} = 8.99 \text{ kN/m}^2$$

$$\gamma_{sat(clay)} = \frac{G_s\gamma_w + wG_s\gamma_w}{1 + wG_s} = \frac{(2.7)(9.81)(1+0.35)}{1+(0.35)(2.7)} = 18.38 \text{ kN/m}^3$$

$\sigma'_o = (1 \times 14.5) + (1)(17.8 - 9.81) + (1)(18.38 - 9.81) = 31.06 \text{ kN/m}^2$

$C_c = 0.009(LL - 10) = 0.009(38 - 10) = 0.252$

$$S_c = \frac{(0.252)(2)}{1+(0.35\times 2.7)}\log\left(\frac{31.06+8.99}{31.06}\right) = 0.0286 = \mathbf{28.6\ mm}$$

10.25 $\frac{L}{B} = m_1 = \frac{1.5}{1.5} = 1$

m_1	z (m)	$b = \frac{B}{2}$ (m)	$n_1 = \frac{z}{B}$	q (kN / m²)	I_5 Table 9.10	$\Delta\sigma' = qI_5$ (kN / m²)
1	1	0.75	1.33	33.3	≈0.56	18.65
1	2	0.75	2.67	33.3	≈0.285	9.49
1	3	0.75	4	33.3	≈0.108	3.60

$$\Delta\sigma'_{av} = \frac{18.65+(4\times 9.49)+3.6}{6} = 10.04\ \text{kN / m}^2$$

$$S_c = \frac{(0.252)(2)}{1+0.945}\log\left(\frac{31.06+10.04}{31.06}\right) = 0.0315\ \text{m} = \mathbf{31.5\ mm}$$

CHAPTER 11

11.1 a. Normal stress, $\sigma' = 192$ kN / m²; shear stress, $\tau_f = 120$ kN / m²

$$\phi' = \tan^{-1}\left(\frac{\tau_f}{\sigma'}\right) = \tan^{-1}\left(\frac{120}{192}\right) = \mathbf{32°}$$

b. $\tau_f = \sigma' \tan\phi' = 200\tan 32 = 124.97$ kN / m²

$$\text{Shear force, } S = (\tau_f)\left(\frac{50 \times 50}{1000 \times 1000}\right) = (124.97)(0.05)^2 = 0.312 \text{ kN} = \mathbf{312\ N}$$

11.2 Shear force, $S = (2 \times 2 \text{ in.}^2)(\sigma' \tan\phi') = (4)(15)(\tan 41) = \mathbf{52.16\ lb}$

11.3 Area of specimen $= \left(\frac{\pi}{4}\right)(0.05)^2 = 0.0019634 \text{ m}^2 = A$

Test No.	Normal force, N (N)	$\sigma' = \frac{N}{A}$ (kN / m²)	Shear force, S (N)	$\tau_f = \frac{S}{A}$ (kN / m²)	$\phi' = \tan^{-1}\left(\frac{\tau_f}{\sigma'}\right)$
1	250	127.3	139	70.8	29.08
2	400	203.7	222	113.1	29.04
3	500	254.7	279	142.1	29.16
4	550	280.1	308	156.9	20.26

A graph of τ_f versus σ' will yield $\phi' \approx$ **29.1°**.

11.4 Area, $A = 0.0019634$ m²

Test No.	Normal force, N (N)	$\sigma' = \frac{N}{A}$ (kN / m²)	Shear force, S (N)	$\tau_f = \frac{S}{A}$ (kN / m²)	$\phi' = \tan^{-1}\left(\frac{\tau_f}{\sigma'}\right)$
1	200	101.9	82	41.8	22.3
2	300	152.8	120	61.1	21.8
3	400	203.7	160	81.5	21.8
4	550	280.1	220	112.1	21.8

A graph of τ_f versus σ' will yield $\phi' \approx$ **21.9°**.

11.5 Equation (11.8). With $c' = 0$

$$\sigma_1' = \sigma_3' \tan^2\left(45 + \frac{\phi'}{2}\right) = 105\tan^2\left(45 + \frac{36}{2}\right) = 404.4 \text{ kN/m}^2$$

$$\Delta\sigma_{d(f)} = 404.4 - 105 = \mathbf{299.4 \text{ kN/m}^2}$$

11.6 a. Equation (11.4):

$$\theta = 45 + \frac{\phi'}{2} = 45 + \frac{36}{2} = \mathbf{63°}$$

b. From Equations (9.8) and (9.9):

$$\sigma' = \frac{\sigma_1' + \sigma_3'}{2} + \frac{\sigma_1' - \sigma_3'}{2}\cos 2\theta = \frac{404.4 + 105}{2} + \frac{404.4 - 105}{2}\cos(2 \times 25)$$

$$= 350.8 \text{ kN/m}^2$$

$$\tau = \frac{\sigma_1' - \sigma_3'}{2}\sin 2\theta = \frac{404.4 - 105}{2}\sin(2 \times 25) = 114.68 \text{ kN/m}^2$$

For failure, $\tau_f = \sigma' \tan\phi' = 350.8\tan 36 = 254.9 \text{ kN/m}^2$

Since the developed shear stress τ is 114.68 kN/m², which is less than 254.9 kN/m², **the specimen did not fail.**

11.7 $\phi' = 25 + 0.18D_r = 25 + (0.18)(60) = 35.8°$

$$\sigma_1' = \sigma_3' \tan^2\left(45 + \frac{\phi'}{2}\right) = 18\tan^2\left(45 + \frac{35.8}{2}\right) = \mathbf{68.7 \text{ lb/in.}^2}$$

11.8 $\sigma_1' = \sigma_3' + \Delta\sigma_{d(f)} = 140 + 264 = 404 \text{ kN/m}^2$

$$\sigma_1' = \sigma_3' \tan^2\left(45 + \frac{\phi'}{2}\right)$$

$$\phi' = 2\left[\tan^{-1}\left(\frac{\sigma_1'}{\sigma_3'}\right)^{0.5} - 45\right] = 2\left[\tan^{-1}\left(\frac{404}{140}\right)^{0.5} - 45\right] = \mathbf{29.03°}$$

11.9 $\sigma_1' = \sigma_3' + \Delta\sigma_{d(f)} = \sigma_3' \tan^2\left(45 + \frac{\phi'}{2}\right)$

$$\sigma_3' = \frac{\Delta\sigma_{d(f)}}{\tan^2\left(45 + \frac{\phi'}{2}\right) - 1} = \frac{23}{\tan^2\left(45 + \frac{26}{2}\right) - 1} = \mathbf{14.73\ lb/in.^2}$$

11.10 $\sigma_3' = \dfrac{\Delta\sigma_{d(f)}}{\tan^2\left(45 + \frac{\phi'}{2}\right) - 1} = \dfrac{180}{\tan^2\left(45 + \frac{25}{2}\right) - 1} = \mathbf{122.96\ kN/m^2}$

11.11 a. $\sigma_1' = \sigma_3' \tan^2\left(45 + \frac{\phi'}{2}\right)$; $(300 + 350) = 300 \tan^2\left(45 + \frac{\phi'}{2}\right)$

$\phi' = \mathbf{21.6°}$

b. $\theta = 45 + \frac{\phi'}{2} = 45 + \frac{21.6}{2} = \mathbf{55.8°}$

c. From Equations (9.8) and (9.9):

$$\sigma' = \frac{\sigma_1' + \sigma_3'}{2} + \frac{\sigma_1' - \sigma_3'}{2}\cos 2\theta = \frac{650 + 300}{2} + \frac{650 - 300}{2}\cos(2 \times 55.8)$$

$$= \mathbf{410.6\ kN/m^2}$$

$$\tau = \frac{\sigma_1' - \sigma_3'}{2}\cos 2\theta = \frac{650 - 300}{2}\cos(2 \times 55.8) = \mathbf{162.7\ kN/m^2}$$

11.12 $\sigma_1' = \sigma_3' \tan^2\left(45 + \frac{\phi'}{2}\right) + 2c' \tan\left(45 + \frac{\phi'}{2}\right)$

Specimen I: $(15 + 31.4) = 46.4 = 15 \tan^2\left(45 + \frac{\phi'}{2}\right) + 2c' \tan\left(45 + \frac{\phi'}{2}\right)$ (a)

Specimen II: $(25 + 47) = 72 = 25 \tan^2\left(45 + \frac{\phi'}{2}\right) + 2c' \tan\left(45 + \frac{\phi'}{2}\right)$ (b)

Equation (b) minus Equation (a):

$72 - 46.4 = 10 \tan^2\left(45 + \frac{\phi'}{2}\right)$; $\phi' = \mathbf{26°}$

From Equation (b):

$$c' = \frac{72 - 25\tan^2\left(45 + \frac{26}{2}\right)}{2\tan\left(45 + \frac{26}{2}\right)} = \mathbf{2.49\ lb / in.^2}$$

11.13 $\sigma_1' = 36\tan^2\left(45 + \frac{26}{2}\right) + (2)(2.49)\tan\left(45 + \frac{26}{2}\right) = \mathbf{100.2\ lb / in.^2}$

11.14 $c' = 0$

$$\sigma_1' = \sigma_3' + \Delta\sigma_{d(f)} = \sigma_3' \tan^2\left(45 + \frac{\phi'}{2}\right)$$

$$\sigma_3' = \frac{\Delta\sigma_{d(f)}}{\tan^2\left(45 + \frac{\phi'}{2}\right) - 1} = \frac{1.9}{\tan^2\left(45 + \frac{38}{2}\right) - 1} = \mathbf{0.59\ ton / ft^2}$$

11.15 $\sigma_1 = \sigma_3 \tan^2\left(45 + \frac{\phi}{2}\right);\quad \phi = 2\left[\tan^{-1}\left(\frac{12 + 9.14}{12}\right)^{0.5} - 45\right] = \mathbf{16°}$

$$\sigma_1' = \sigma_3' \tan^2\left(45 + \frac{\phi'}{2}\right);\quad \phi' = 2\left[\tan^{-1}\left(\frac{12 + 9.14 - 6.83}{12 - 6.83}\right)^{0.5} - 45\right] = \mathbf{28°}$$

11.16 $\phi = 2\left[\tan^{-1}\left(\frac{140 + 125}{140}\right)^{0.5} - 45\right] = \mathbf{18°}$

$$\phi' = 2\left[\tan^{-1}\left(\frac{140 + 125 - 75}{140 - 75}\right)^{0.5} - 45\right] = \mathbf{29.4°}$$

11.17 a. $\sigma_1 = \sigma_3 \tan^2\left(45 + \frac{\phi}{2}\right)$

$$\phi = 2\left[\tan^{-1}\left(\frac{105 + 97}{105}\right)^{0.5} - 45\right] = \mathbf{18.4°}$$

b. $\sigma_1' = \sigma_3' \tan^2\left(45 + \frac{\phi'}{2}\right)$

$$\frac{105 + 97 - \Delta u_{d(f)}}{105 - \Delta u_{d(f)}} = \tan^2\left(45 + \frac{28}{2}\right)$$

$$\Delta u_{d(f)} = \mathbf{50.2\ kN/m^2}$$

11.18 $\sigma_1' = \sigma_3' \tan^2\left(45 + \frac{\phi'}{2}\right) = 105 \tan^2\left(45 + \frac{28}{2}\right) = 290.8\ \text{kN/m}^2$

$$\Delta\sigma_{d(f)} = 290.8 - 105 = \mathbf{185.8\ kN/m^2}$$

11.19 $\sigma_1 = \sigma_3 \tan^2\left(45 + \frac{\phi}{2}\right) = 15 \tan^2\left(45 + \frac{22}{2}\right) = 32.97\ \text{lb/in.}^2$

$$\Delta\sigma_{d(f)} = 32.97 - 15 = \mathbf{17.97\ lb/in.^2}$$

$$\sigma_1' = \sigma_3' \tan^2\left(45 + \frac{\phi'}{2}\right)$$

$$\frac{32.97 - \Delta\sigma_{d(f)}}{15 - \Delta\sigma_{d(f)}} = \tan^2\left(45 + \frac{32}{2}\right)$$

$$\Delta u_{d(f)} = \mathbf{7.01\ lb/in.^2}$$

11.20 $q_u = \sigma_1 - \sigma_3 = 2800 - 1500 = \mathbf{1300\ lb/ft^2}$

11.21 $\sigma_1' = \sigma_3' \tan^2\left(45 + \frac{\phi'}{2}\right)$

$$\frac{100 - \Delta\sigma_{d(f)}}{0 - \Delta\sigma_{d(f)}} = \tan^2\left(45 + \frac{25}{2}\right)$$

$$\Delta u_{d(f)} = \mathbf{-68.5\ kN/m^2}$$

11.22 $\dfrac{140-\Delta\sigma_{d(f)}}{0-\Delta\sigma_{d(f)}} = \tan^2\left(45+\dfrac{20}{2}\right)$

$$\Delta u_{d(f)} = \mathbf{-134.6\ kN/m^2}$$

11.23 a.

Test No.	$\dfrac{\sigma_1'+\sigma_3'}{2}=p'$ (lb / in.^{2})	$\dfrac{\sigma_1'-\sigma_3'}{2}=q'$ (lb / in.^{2})
1	50	23
2	30	18

$q' = m + p'\tan\alpha$

$23 = m + 50\tan\alpha$ (a)

$18 = m + 30\tan\alpha$ (b)

$m = \mathbf{10.5\ lb/in.^2}$; $\alpha = \mathbf{14°}$

b. $\phi' = \sin^{-1}(\tan\alpha) = \sin^{-1}(\tan 14) = \mathbf{14.44°}$

$$c' = \frac{m}{\cos\alpha} = \frac{10.5}{\cos(14)} = \mathbf{10.82\ lb/in.^2}$$

11.24 $\dfrac{c_{u(\mathrm{VST})}}{\sigma_o'} = 0.11 + 0.0037\,PI$

$\sigma' = (3)(17) + (3)(19.5 - 9.81) = 80.07\ \mathrm{kN/m^2}$

$c_{u(\mathrm{VST})} = [0.11 + (0.0037)(18)](80.07) = \mathbf{14.14\ kN/m^2}$

CHAPTER 12

12.1 to 12.4 $K_o = (1 - \sin \phi')(\text{OCR})^{\sin\phi'}$

Problem	ϕ' (deg)	K_o	$P_o = ½ K_o \gamma H^2$	$\bar{z} = \frac{H}{3}$
12.1	35	0.634	(½)(0.634)(18.1)(5)² = **143.44 kN / m**	**1.67 m**
12.2	30	0.5	(½)(0.5)(90)(16.5)² = **6125.6 lb / ft**	**5.5 ft**
12.3	38	0.675	(½)(0.675)(17)(5)² = **143.44 kN / m**	**1.67 m**
12.4	40	0.463	(½)(0.463)(115)(18)² = **8625.7 lb / ft**	**6 ft**

12.5 to 12.8 $K_a = \tan^2\left(45 - \frac{\phi'}{2}\right)$

Problem	ϕ' (deg)	K_a	$\sigma'_{a(z=H)} = K_a \gamma H$	$P_a = ½ K_a \gamma H^2$	$\bar{z} = \frac{H}{3}$
12.5	32	0.307	(0.307)(110)(10) = **337.7 lb / ft²**	(½)(0.307)(110)(10)² = **1688.5 lb / ft**	**3.33 ft**
12.6	28	0.361	(0.361)(98)(12) = **424.5 lb / ft²**	(½)(0.361)(98)(12)² = **2547 lb / ft**	**4 ft**
12.7	36	0.26	(0.26)(17.6)(3) = **13.73 kN / m²**	(½)(0.26)(17.6)(3)² = **20.59 kN / m**	**1 m**
12.8	40	0.217	(0.217)(18.2)(6) = **23.7 kN / m²**	(½)(0.217)(18.2)(6)² = **71.09 kN / m**	**2 m**

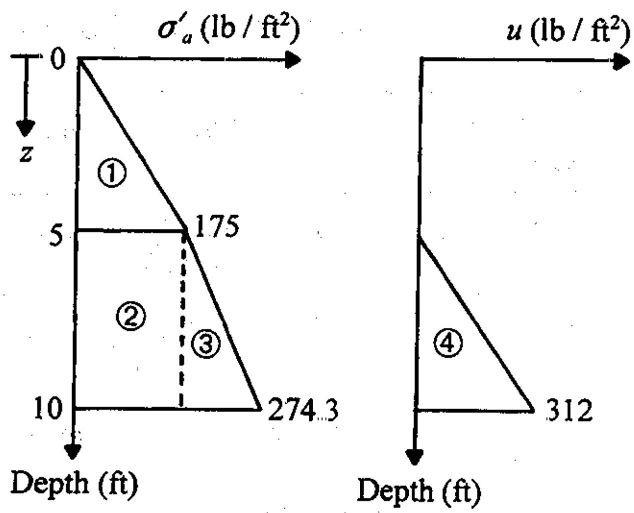
Note: 1. Pressure distribution is similar to that shown in Figure 12.13a; that is, $\sigma'_a = 0$ at $z = 0$ and $\sigma'_a = K_a \gamma H$ at $z = H$.
2. $\bar{z}$ is the distance measured from the bottom of the wall.

12.9 to 12.12 $K_p = \tan^2\left(45 + \frac{\phi'}{2}\right)$

Problem	ϕ' (deg)	K_p	$\sigma'_{p(z=H)} = K_p \gamma H$	$P_p = ½ K_p \gamma H^2$	$\bar{z} = \frac{H}{3}$
12.9	34	3.537	(3.537)(110)(10) = **3890.7 lb / ft²**	(½)(3.537)(110)(10)² = **19,454 lb / ft**	**3.33 ft**
12.10	36	3.852	(3.852)(105)(12) = **4853.5 lb / ft²**	(½)(3.852)(105)(12)² = **29,212 lb / ft**	**4 ft**
12.11	31	3.124	(3.124)(14.4)(5) = **224.9 kN / m²**	(½)(3.124)(14.4)(5)² = **562.3 kN / m**	**1.67 m**
12.12	28	2.77	(2.77)(13.5)(4) = **149.6 kN / m²**	(½)(2.77)(13.5)(4)² = **299.2 kN / m**	**1.33 m**

Note: 1. $\sigma'_{p(z=0)} = 0$; triangular pressure distribution
2. $\bar{z}$ is the distance measured from the bottom of the wall

12.13 $K_a = \tan^2\left(45 - \frac{\phi'}{2}\right) = \tan^2\left(45 - \frac{30}{2}\right) = \frac{1}{3}$. Refer to the figure.



$z = 0$ ft: $\sigma'_a = \sigma'_o K_a = 0$; $u = 0$

$z = 5$ ft: $\sigma'_a = (105)(5)(⅓) = 175$ lb / ft²; $u = 0$

$z = 10$ ft: $\sigma'_a = [(105)(5) + (122 - 62.4)(5)](⅓) = 274.3$ lb / ft²

$u = (62.4)(5) = 312$ lb / ft²

Area No.	Area
1	(½)(5)(175) = 437.5
2	(175)(5) = 875
3	(½)(5)(274.3 - 175) = 248.3
4	(½)(5)(312) = 780

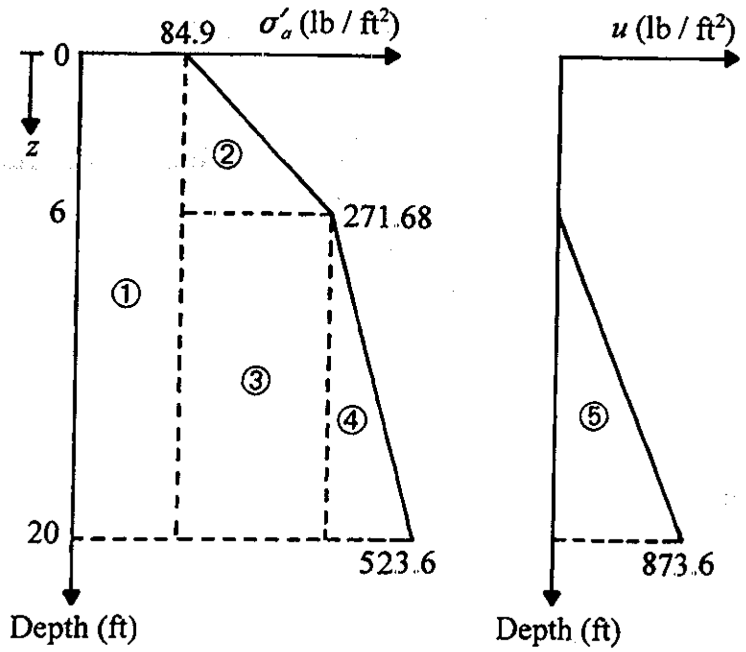
$P_a = \sum$**2,340.8 lb / ft**

Resultant: Taking the moment about the bottom of the wall,

$$\bar{z} = \frac{\left[(437.5)\left(5+\frac{5}{3}\right)+(875)\left(\frac{5}{2}\right)+(248.3)\left(\frac{5}{3}\right)+(780)\left(\frac{5}{3}\right)\right]}{2340.8}$$

$$= \frac{2916.7+2187.5+413.8+1300}{2340.8} = \mathbf{2.91\ ft}$$

12.14 $K_a = \tan^2\left(45-\frac{34}{2}\right) = 0.283$. Refer to the figure.



$z = 0$ ft: $\sigma'_a = \sigma'_o K_a = (300)(0.283) = 84.9\ \text{lb/ft}^2;\quad u = 0$

$z = 6$ ft: $\sigma'_a = [300 + (6)(110)](0.283) = 271.68\ \text{lb/ft}^2;\quad u = 0$

$z = 20$ ft: $\sigma'_a = [300 + (6)(110) + (126 - 62.4)(14)](0.283) = 523.66\ \text{lb}/\text{ft}^2$

$u = (62.4)(14) = 873.6\ \text{lb}/\text{ft}^2$

Area No.	Area
1	(84.9)(20) = 1,698
2	(½)(6)(271.68 − 84.9) = 560.34
3	(14)(271.68 − 84.9) = 2,614.92
4	(½)(14)(523.6 − 271.68) = 1,763.44
5	(½)(14)(873.6) = 6,115.2

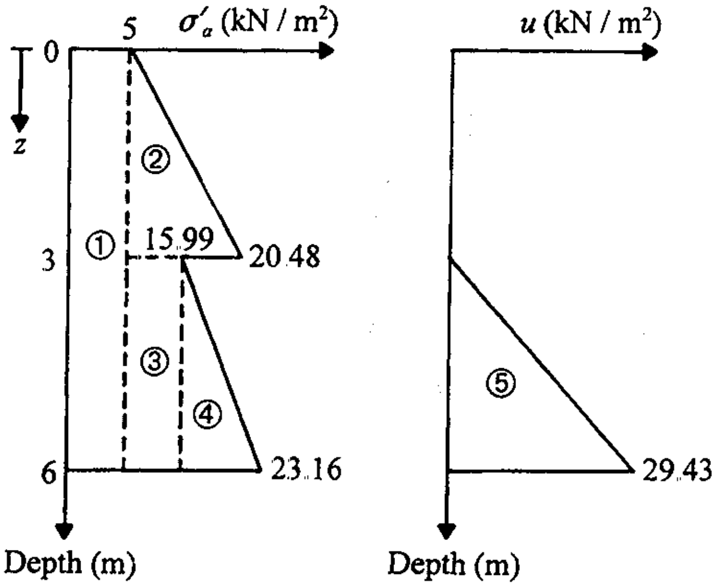
$P_a = \sum$ **12,751.9 lb / ft**

Location of resultant: Taking the moment about the bottom of the wall,

$$\bar{z} = \frac{\left[\begin{array}{l}(1{,}698)\left(\frac{20}{2}\right) + (560.34)\left(14 + \frac{6}{3}\right) + (2{,}614.92)\left(\frac{14}{2}\right) \\ +(1{,}763.44)\left(\frac{14}{3}\right) + (6{,}115.2)\left(\frac{14}{3}\right)\end{array}\right]}{12{,}751.9}$$

$$= \frac{16{,}980 + 8{,}965.44 + 18{,}304.44 + 8{,}229.4 + 28{,}537.6}{12{,}751.9} = \mathbf{6.35\ ft}$$

12.15 $K_{a(1)} = \tan^2\left(45 - \frac{30}{2}\right) = 0.333$; $K_{a(2)} = \tan^2\left(45 - \frac{36}{2}\right) = 0.26$. Refer to the figure.



$z = 0$ m: $\sigma'_a = \sigma'_o K_{a(1)} = (15)(0.333) = 5 \text{ kN/m}^2$; $u = 0$

$z = 3$m: $\sigma'_a = \sigma'_o K_{a(1)} = [(15.5)(3) + 15](0.333) = 20.48 \text{ kN/m}^2$

$\sigma'_a = \sigma'_o K_{a(2)} = [(15.5)(3) + 15](0.26) = 15.99 \text{ kN/m}^2$

$u = 0$

$z = 6$ m: $\sigma'_a = \sigma'_o K_{a(2)} = [15 + (15.5)(3) + (19 - 9.81)(3)](0.26) = 23.16 \text{ kN/m}^2$

$u = (9.81)(3) = 29.43 \text{ kN/m}^2$

Area No.	Area
1	$(6)(5) = 30$
2	$(½)(3)(20.48 - 5) = 23.22$
3	$(3)(15.99 - 5) = 32.97$
4	$(½)(3)(23.16 - 15.99) = 10.76$
5	$(½)(3)(29.43) = 44.15$

$P_a = \sum$ **141.1 kN / m**

Location of resultant: Taking the moment about the bottom

$$\bar{z} = \frac{(30)\left(\frac{6}{2}\right) + (23.22)\left(3 + \frac{3}{3}\right) + (32.97)\left(\frac{3}{2}\right) + (10.76)\left(\frac{3}{3}\right) + (44.15)\left(\frac{3}{3}\right)}{141.1}$$

$$= \frac{90 + 92.88 + 49.46 + 10.76 + 44.15}{141.1} = \frac{287.25}{141.1} = \mathbf{2.04\ m}$$

12.16 a. Equation (12.23):

$$\sigma'_a = \frac{\gamma z \cos\alpha \sqrt{1 + \sin^2\phi' - 2\sin\phi' \cos\psi_a}}{\cos\alpha + \sqrt{\sin^2\phi' - \sin^2\alpha}}$$

$$\psi_a = \sin^{-1}\left(\frac{\sin\alpha}{\sin\phi'}\right) - \alpha + 2\theta = \sin^{-1}\left(\frac{\sin 10}{\sin 30}\right) - 10 + (2)(5) = 20.32°$$

$$\sigma'_a = \frac{(15)(4)(\cos 10)\sqrt{1 + \sin^2 30 - (2)(\sin 30)(\cos 20.32)}}{\cos 10 + \sqrt{\sin^2 30 - \sin^2 10}} = \mathbf{22.7\ kN/m^2}$$

Equation (12.25):

$$\beta = \tan^{-1}\left(\frac{\sin\phi' \sin\psi_a}{1-\sin\phi' \cos\psi_a}\right) = \tan^{-1}\left[\frac{(\sin 30)(\sin 20.32)}{1-(\sin 30)(\cos 20.32)}\right] = \mathbf{18.1°}$$

b. Equation (12.27):

$$K_{a(R)} = \frac{\cos(\alpha-\theta)\sqrt{1+\sin^2\phi' - 2\sin\phi' \cos\psi_a}}{\cos^2\theta\left(\cos\alpha + \sqrt{\sin^2\phi' - \sin^2\alpha}\right)}$$

$$= \frac{\cos(10-5)\sqrt{1+\sin^2 30 - (2)(\sin 30)(\cos 20.32)}}{\cos^2 10\left(\cos 10 + \sqrt{\sin^2 30 - \sin^2 10}\right)} = 0.394$$

$$P_a = \frac{1}{2}\gamma H^2 K_{a(R)} = \frac{1}{2}(15)(4)^2(0.394) = \mathbf{47.28\ kN/m}$$

Location and direction of resultant: – **At a distance of $H/3 = 4/3 = 1.33$ m above the bottom of the wall inclined at an angle $\beta = 18.1°$ to the normal drawn to the back face of the wall**

12.17 This is a Rankine case since $\delta' = 0$. $P_p = \frac{1}{2}\gamma H^2 K_{p(R)}$

Equation (12.33): $$K_{p(R)} = \frac{\cos(\alpha-\theta)\sqrt{1+\sin^2\phi' + 2\sin\phi' \cos\psi_p}}{\cos^2\theta\left(\cos\alpha - \sqrt{\sin^2\phi' - \sin^2\alpha}\right)}$$

$\alpha = 0$; $\theta = 10°$; $\phi' = 36°$

$$\psi_p = \sin^{-1}\left(\frac{\sin\alpha}{\sin\phi'}\right) + \alpha - 2\theta = \sin^{-1}\left(\frac{\sin 0}{\sin 36}\right) + 0 - (2)(10) = -20°$$

$$K_{p(R)} = \frac{\cos(0-10)\sqrt{1+\sin^2 36 + (2)(\sin 36)\cos(-20)}}{\cos^2(10)\left(\cos 0 - \sqrt{\sin^2 36 - \sin^2 0}\right)} = 3.855$$

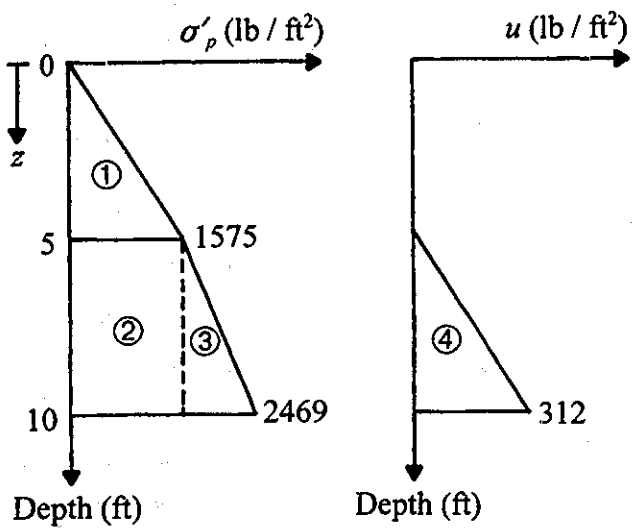
$$P_p = \frac{1}{2}(16.5)(3)^2(3.855) = \mathbf{286.2\ kN/m}$$

Equation (12.32):

$$\beta = \tan^{-1}\left(\frac{\sin\phi' \sin\psi_p}{1+\sin\phi' \cos\psi_p}\right) = \tan^{-1}\left\{\frac{\sin 36 \sin(-20)}{1+(\sin 36)[\cos(-20)]}\right\} = \mathbf{-7.34°}$$

P_p acts at a distance of $H/3 = 3/3 = 1$ m from the bottom of the wall inclined at an angle $\beta = -7.34°$ to the normal drawn to the back face of the wall.

12.18 $K_p = \tan^2\left(45+\frac{30}{2}\right) = 3$. Refer to the figure.



$z = 0$ ft: $\sigma'_p = 0;\ u = 0$

$z = 5$ ft: $\sigma'_p = \gamma_1 z K_p = (105)(5)(3) = 1575 \text{ lb/ft}^2;\ u = 0$

$z = 10$ ft: $\sigma'_p = [(105)(5) + (122 - 62.4)(5)](3) = 2469 \text{ lb/ft}^2$

$u = (62.4)(5) = 312 \text{ lb/ft}^2$

Area No.	Area
1	(½)(5)(1575) = 3,937.5
2	(5)(1575) = 7,875
3	(½)(5)(2469 − 1575) = 2,235
4	(½)(5)(312) = 780

$P_p = \sum$ **14,828 lb / ft**

Location of the resultant: Taking the moment about the bottom of the wall,

$$\bar{z} = \frac{(3937.5)\left(5+\frac{5}{3}\right)+(7875)\left(\frac{5}{2}\right)+(2235)\left(\frac{5}{3}\right)+(780)\left(\frac{5}{3}\right)}{14{,}828} = \mathbf{3.44\ ft}$$

12.19 a. $H = 4.5$ m; $c_u = 19.3$ kN / m²; $\gamma = 19.6$ kN / m³; $\phi = 0$

$$K_a = \tan^2\left(45-\frac{\phi}{2}\right) = 1; \quad \sigma_a = \gamma z - 2c_u$$

At the top ($z = 0$):

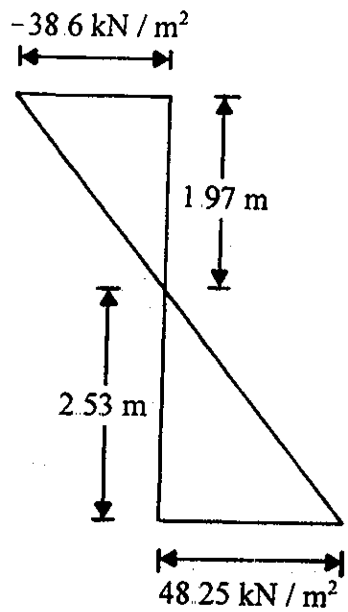
$$\sigma_a = -2c_u = (-2)(19.3) = -38.6 \text{ kN / m}^2$$

At the bottom ($z = 4.5$ m):

$$\sigma_a = (19.3)(4.5) - (2)(19.3)$$

$$= 86.85 - 38.6 = 48.25 \text{ kN / m}^2$$

The pressure diagram is shown.



b. Equation (12.49):

$$z_o = \frac{2c_u}{\gamma} = \frac{(2)(19.3)}{19.6} = \mathbf{1.97\ m}$$

c. Equation (12.51):

$$P_a = \frac{1}{2}\gamma H^2 - 2c_u H = \left(\frac{1}{2}\right)(19.6)(4.5)^2 - (2)(19.3)(4.5) = \mathbf{24.75\ kN / m}$$

d. Equation (12.53):

$$P_a = \frac{1}{2}\gamma H^2 - 2c_u H + \frac{2c_u^2}{\gamma} = \left(\frac{1}{2}\right)(19.6)(4.5)^2 - (2)(19.3)(4.5) + \frac{(2)(19.3)^2}{19.6}$$

$$= \mathbf{62.76\ kN / m}$$

Resultant measured from the bottom:

$$\frac{H - z_o}{3} = \frac{4.5 - 1.97}{3} = \mathbf{0.84\ m}$$

12.20 a. $\sigma_a = \sigma_o K_a - 2c_u\sqrt{K_a}$

$\sigma_o = \gamma z + q;\ \ K_a = 1$

At $z = 0$:

$\sigma_o = 8\ \text{kN/m}^2$

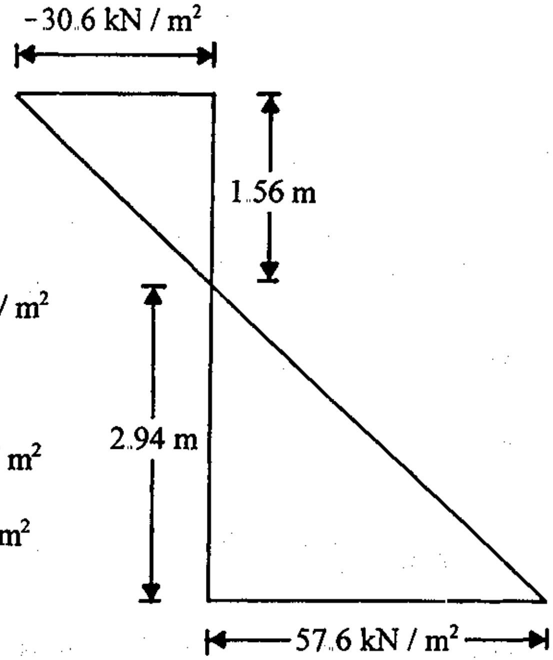
$\sigma_a = 8 - (2)(19.3) = -30.6\ \text{kN/m}^2$

At $z = 4.5$ m:

$\sigma_o = (19.6)(4.5) + 8 = 96.2\ \text{kN/m}^2$

$\sigma_a = \sigma_o - (2)(19.3) = 57.6\ \text{kN/m}^2$

The pressure diagram is shown.



b. $\sigma_a = 0.\ (\gamma z + q) - 2c_u = 0.$

$$z_o = \frac{2c_u - q}{\gamma} = \frac{38.6 - 8}{19.6} = \mathbf{1.56\ m}$$

c. Referring to the diagram in Part a:

$$P_a = \left(\frac{1}{2}\right)(2.94)(57.6) - \left(\frac{1}{2}\right)(30.6)(1.56) = \mathbf{60.8\ kN/m}$$

d. $P_a = \left(\frac{1}{2}\right)(2.94)(57.6) = \mathbf{84.67\ kN/m}$

Location of the resultant from the bottom of the wall $= \frac{2.94}{3} = \mathbf{0.98\ m}$

12.21 $K_a = \tan^2\left(45 - \frac{\phi'}{2}\right) = \tan^2\left(45 - \frac{16}{2}\right) = 0.568$; $\sqrt{K_a} = 0.754$. Equation (12.52):

$$P_a = \frac{1}{2}K_a\gamma H^2 - 2\sqrt{K_a}c'H + \frac{2c'^2}{\gamma}$$

$$= \frac{1}{2}(0.568)(19)(5)^2 - (2)(0.754)(26)(5) + \frac{(2)(26)^2}{19} = \mathbf{10.02\ kN/m}$$

12.22 Equation (12.63):

$$z_o = \frac{2c'}{\gamma}\sqrt{\frac{1+\sin\phi'}{1-\sin\phi'}} = \frac{(2)(88)}{110}\sqrt{\frac{1+\sin 25}{1-\sin 25}} = 2.51 \text{ ft}$$

At $z = 0$ ft: $\sigma'_a = 0$

At $z = 15$ ft: $\sigma'_a = \gamma z K'_{a(R)} \cos\alpha$

$$\frac{c'}{\gamma z} = \frac{88}{(110)(15)} = 0.053$$

For $\alpha = 10°$, $\phi' = 25°$, and $\frac{c'}{\gamma z} = 0.053$, the value of $K'_{a(R)} \approx 0.366$

$\sigma'_a = (110)(15)(0.366)(\cos 10) = 594.7 \text{ lb/ft}^2$

$$P_a = \frac{1}{2}(15 - 2.51)(594.7) = \mathbf{3714\ lb/ft}$$

12.23 Use Equations (12.68) and (12.69).

$\alpha = 0$; $\theta = 10°$; $\phi' = 36°$; $\gamma = 18 \text{ kN/m}^3$; $H = 5$ m

Part	δ' (deg)	K_a [Equation (12.69)]	$P_a = \frac{1}{2}K_a\gamma H^2$ [Equation (12.68)]
1	18	0.3118	70.15 kN / m
2	24	0.3137	70.58 kN / m

P_a is located at a vertical distance of 5/3 = 1.67 m above the bottom of the wall and is inclined at an angle δ' to the normal drawn to the back face of the wall.

12.24 a. $\phi' = 38°$; $\psi = 90 - \theta - \delta' = 90 - 5 - 20 = 65°$

Weight of wedge $ABC = \frac{1}{2}(11.6)(7.1)(\underbrace{128}_{\gamma}) = 5721 \text{ lb / ft} = 5.271 \text{ kip / ft}$

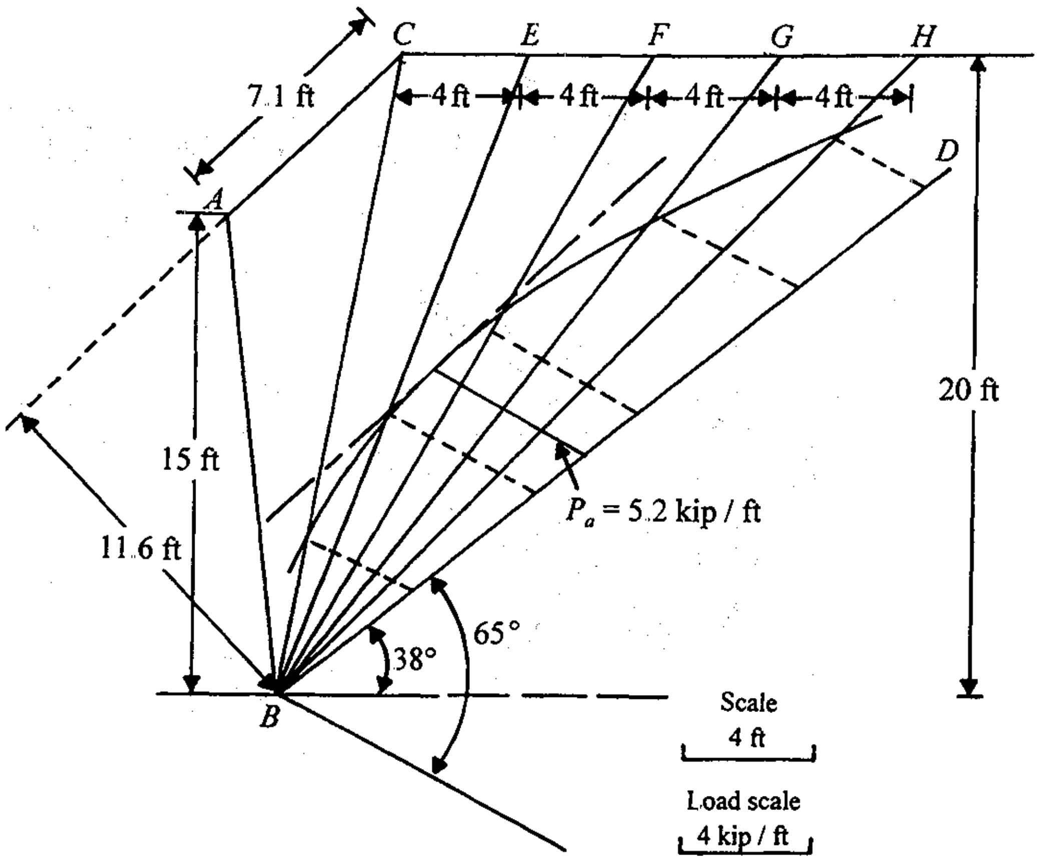
The weight of each of the wedges *CBE, EBF, FBG, GBH* =

$$\left(\frac{1}{2}\right)(20)(4)(128) = 5120 \text{ lb / ft} = 5.12 \text{ kip / ft}$$

Wedge	Weight (kip / ft)
ABC	5.271
ABE	5.271 + 5.12 = 10.391
ABF	10.391 + 5.12 = 15.511
ABG	15.511 + 5.12 = 20.631
ABH	20.631 + 5.12 = 25.751

The graphical construction is shown.

P_a = **5.2 kip / ft.**



b. $\phi' = 34°$; $\psi = 90 - 0 - 17 = 73°$

$$\text{Weight of wedge } ABC = \frac{1}{2}(16)(9)(116) = 8352 \text{ lb/ft} \approx 8.35 \text{ kip/ft}$$

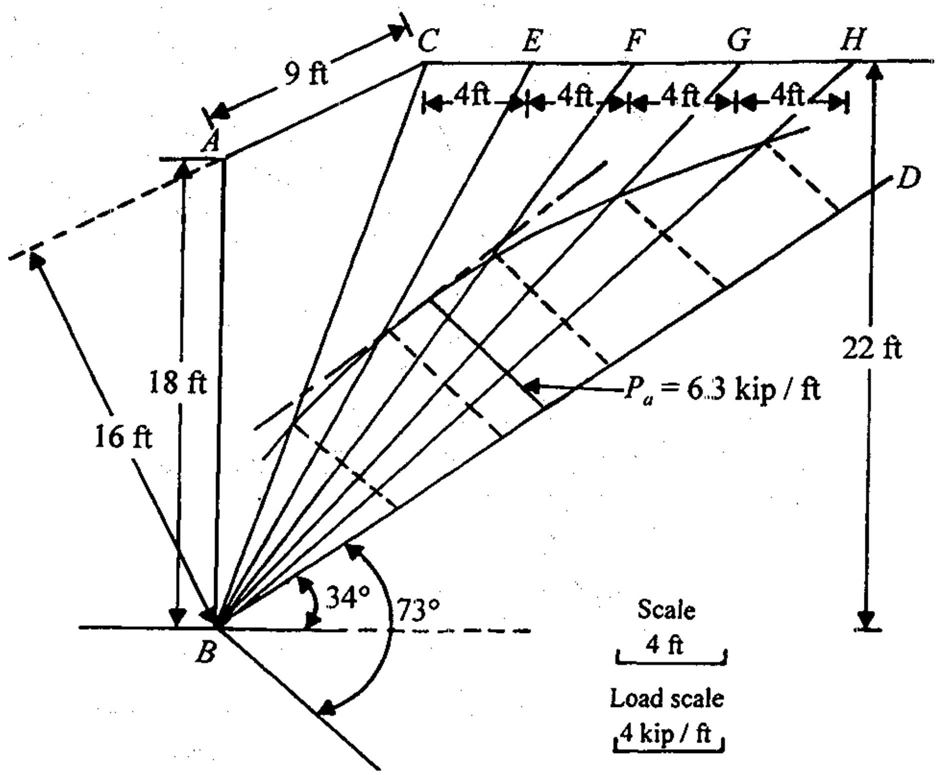
The weight of each of the wedges *CBE, EBF, FBG, GBH* =

$$\left(\frac{1}{2}\right)(4)(22)(116) = 5104 \text{ lb/ft} \approx 5.10 \text{ kip/ft}$$

Wedge	Weight (kip / ft)
ABC	8.35
ABE	8.35 + 5.10 = 13.45
ABF	13.45 + 5.10 = 18.55
ABG	18.55 + 5.10 = 23.65
ABH	23.65 + 5.10 = 28.75

The graphical construction is shown.

P_a = **6.3 kip / ft.**



c. $\gamma = \dfrac{(1680)(9.81)}{1000} = 16.48 \text{ kN/m}^3$; $\phi' = 30°$; $\psi = 90 - 10 - 30 = 50°$

Weight of wedge $ABC = \dfrac{1}{2}(5.25)(2.5)(16.48) = 108.15 \text{ kN/m}$

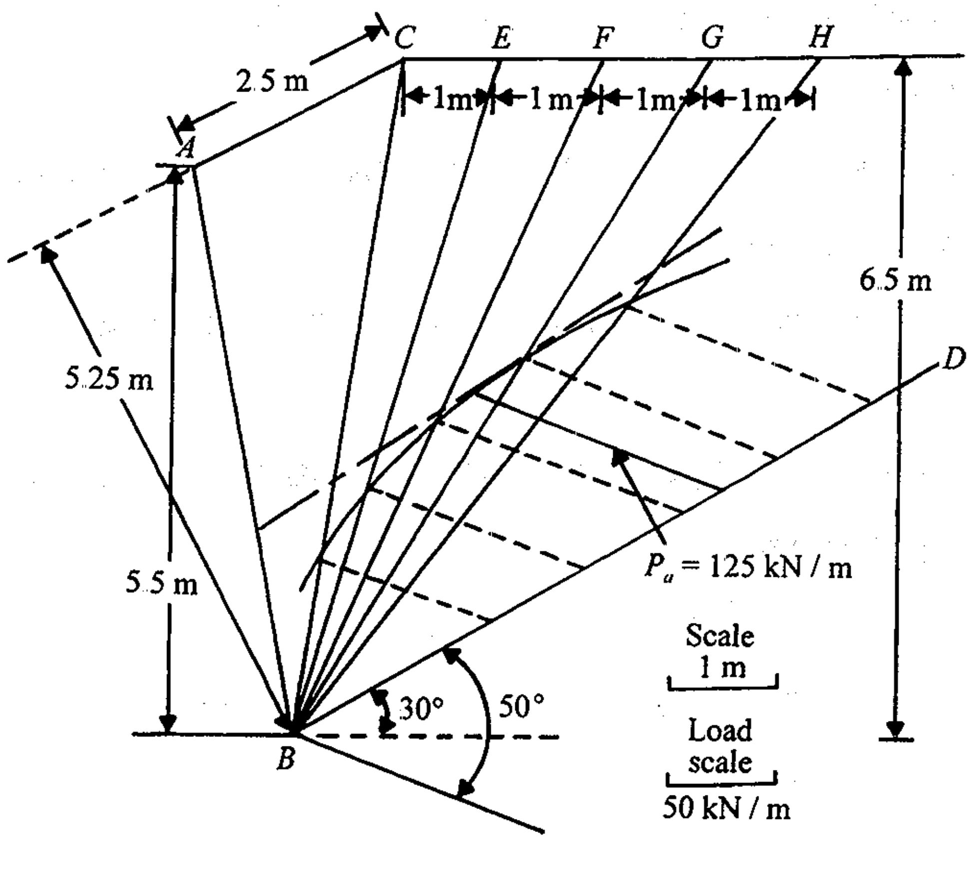
The weight of each of the wedges *CBE, EBF, FBG, GBH* =

$$\left(\frac{1}{2}\right)(1)(6.5)(16.48) = 53.46 \text{ kN/m}$$

Wedge	Weight (kN / m)
ABC	108.15
ABE	108.15 + 53.56 = 161.71
ABF	161.71 + 53.56 = 215.27
ABG	215.27 + 53.56 = 268.83
ABH	268.83 + 53.56 = 322.39

The graphical construction is shown.

P_a = **125 kN / m**.



12.25 Equation (12.74): $P_{ae} = \frac{1}{2}\gamma H^2(1-k_v)K_a''$

$k_v = 0;\ \theta = 0;\ \alpha = 0;\ \phi' = 35°;\ \frac{\delta}{\phi'} = \frac{2}{3};\ k_h = 0.3$. From Table 12.9, $K_a'' = 0.486$

$$P_{ae} = \frac{1}{2}(15)(6)^2(1-0)(0.486) = \mathbf{131.2\ kN/m}$$

For $\phi' = 35°$, $\frac{\delta'}{\phi'} = \frac{2}{3}$. From Table 12.6, $K_a = 0.2444$.

$$P_a = \frac{1}{2}\gamma H^2 K_a = \frac{1}{2}(15)(6)^2(0.2444) = 66\ \text{kN/m}$$

Equation (12.83):

$$\bar{z} = \frac{P_a\left(\frac{H}{3}\right) + \Delta P_{ae}(0.6H)}{P_{ae}} = \frac{(66)\left(\frac{6}{3}\right) + (131.2-66)(0.6\times 6)}{131.2} = \mathbf{2.8\ m}$$

12.26 Equation (12.84): $P_{ae} = \gamma(H - z_o)^2 N'_{a\gamma} - c'(H - z_o)^2 N'_{ac}$

Given: $z_o = 0;\ \theta = 10°;\ \phi' = 15°;\ k_h = 0.15$

$N'_{ac} = N_{ac} = 1.75$ (Figure 12.33); $N_{a\gamma} = 0.3$ (Figure 12.35); $\lambda = 1.3$ (Figure 12.36);

$N'_{a\gamma} = \lambda N_{a\gamma}$. So,

$$P_{ae} = (19)(6-0)^2(1.3\times 0.3) - (20)(6-0)(1.75) = \mathbf{56.76\ kN/m}$$

12.27 $z_o = 0;\ n = 0;\ \theta = 5°;\ \phi' = 20°;\ k_h = 0.25;\ N'_{ac} \approx 1.65;\ N_{a\gamma} \approx 0.25;\ \lambda \approx 1.65;\ N'_{a\gamma} = \lambda N_{a\gamma}$

Equation (12.84):

$$P_{ae} = \gamma(H - z_o)^2 N'_{a\gamma} - c'(H - z_o)^2 N'_{ac}$$

$$= (100)(10-0)^2(1.65\times 0.25) - (200)(10-0)(1.65)$$

$$= 4125 - 3300 = \mathbf{825\ lb/ft}$$

Chapter 13

13.1 Equation (13.10): $P_p = \frac{1}{2}\gamma H_1^2 K_p$

$H_1 = \frac{H}{\cos\theta} = \frac{3}{\cos 20} = 3.19$ m; $\gamma = 15.5$ kN / m³.

From Figure 13.4, with $\theta = +20°$ and $\phi' = 35°$, the value of $K_{p(\delta'=\phi')} \approx 5.3$

$\frac{\delta'}{\phi'} = \frac{24.5}{35} = 0.7.$

From Table 13.1, $R = 0.836$. $K_p = (5.3)(0.836) = 4.431$

$$P_p = \frac{1}{2}(15.5)(3.19)^2(4.431) = \mathbf{349.4\ kN / m}$$

13.2 $\frac{\delta'}{\phi'} = \frac{2}{3}$. Equation (13.10): $P_p = \frac{1}{2}\gamma H_1^2 K_p$

$\theta = 0$; $H_1 = H = 15$ ft; $\phi' = 30°$; $\alpha = 0$. From Figure 13.4, $K_{p(\delta'=\phi')} \approx 6.2$

From Table 13.1, for $\phi' = 30°$ and $\frac{\delta'}{\phi'} = \frac{2}{3}$, the value of R is 0.85. So

$$P_p = \frac{1}{2}(100)(15)^2(6.2 \times 0.85) = \mathbf{59{,}288\ lb / ft}$$

13.3 Equation (13.14): $P_p = \frac{1}{2}\gamma H^2 K_p$

$\delta' = \frac{2}{3}\phi' = 20°$. From Table 13.3, for $\phi' = 30°$ and $\delta' = 20°$, $K_p = 4.4$

$$P_p = \frac{1}{2}(100)(15)^2(4.4) = \mathbf{49{,}500\ lb / ft}$$

13.4 $\frac{\alpha}{\phi'} = \frac{12}{3} = +0.4$. From Figure 13.5, for $\frac{\alpha}{\phi'} = +0.4$ and $\phi' = 30°$, $K_{p(\delta'=\phi')} \approx 9.8$.

From Table13.2, $R = 0.686$

$$P_p = \frac{1}{2}\gamma H^2 K_p = \frac{1}{2}(14.8)(2.5)^2(9.8 \times 0.686) = \mathbf{311\ kN/m}$$

13.5 Equation (13.15): $P_{pe} = \frac{1}{2}\gamma H^2 K_p''$

For $\phi' = 30°$, $\frac{\delta'}{\phi'} = \frac{15}{30} = 0.5, k_v = 0$, and $k_h = 0.3$, the value of $K_p'' \approx 3.7$ (Figure 13.9)

$$P_{pe} = \frac{1}{2}(16)(5)^2(3.7) = \mathbf{740\ kN/m}$$

13.6 $n_a = \frac{2\text{ m}}{5\text{ m}} = 0.4.$ $\phi' = 35°$; $\delta' = 20°$. Table 13.4: $\frac{P_a}{0.5\gamma H^2} = 0.248$

$$P_a = (0.248)(0.5)(16)(5)^2 = \mathbf{49.6\ kN/m}$$

13.7 $n_a = \frac{4.68\text{m}}{15.6\text{m}} = 0.3.$

$$\frac{c'}{\gamma H} = \frac{28}{(18)(15.6)} = 0.1$$

From Table 13.5, for $\phi' = 20°$; $\delta' = 15°$, $\frac{P_a}{0.5\gamma H^2} = 0.122$

$$P_a = (0.122)(0.5)(18)(15.6)^2 \approx \mathbf{267.2\ kN}$$

13.8 Refer to Figure 13.15.

$$\sigma_a = 0.65\gamma H \tan^2\left(45 - \frac{\phi'}{2}\right) = (0.65)(16)(9)\tan^2\left(45 - \frac{30}{2}\right) = 31.2\ \text{kN/m}^2$$

Refer to the diagram on the next page.

$$2A = (31.2)(3)(3/2)$$

$$A = 70.2\ \text{kN/m}$$

Hence,

$B_1 = (31.2)(3) - 70.2 = 23.4 \text{ kN/m}$

$B_2 = C_1 = \dfrac{(31.2)(2)}{2} = 31.2 \text{ kN/m}$

Again, taking the moment about C_2, we have

$2D = (31.2)(4)(4/2)$

$D = 124.8 \text{ kN/m}$

So, $C_2 = (31.2)(4) - 124.8 = 0$

The strut loads are as follow:

At level A:

$(A)(s) = (70.2)(2) = \mathbf{140.4\ kN}$

At level B:

$(B_1 + B_2)(s) = (23.4 + 31.2)(2) = \mathbf{109.2\ kN}$

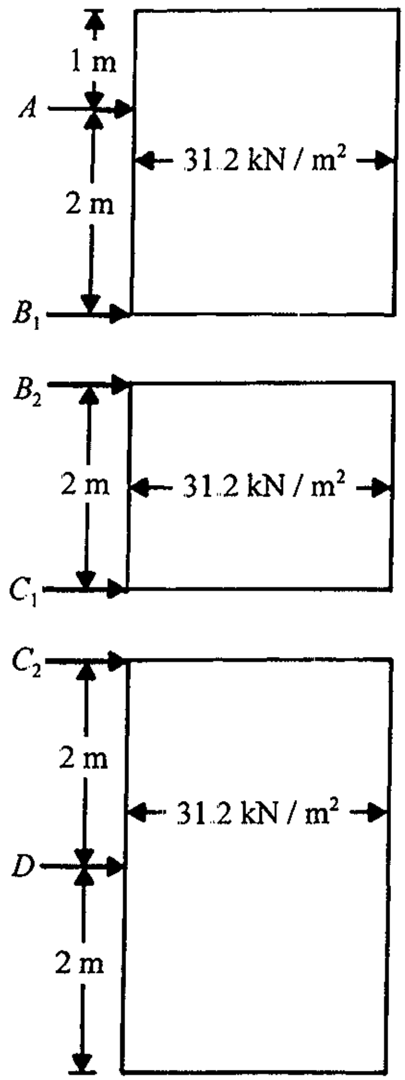
At level C:

$(C)(s) = (C_1 + C_2)(s)$

$= (31.2 + 0)(2) = \mathbf{62.4\ kN}$

At level D:

$(D)(s) = (124.8)(2) = \mathbf{249.6\ kN}$



CHAPTER 14

14.1 Equation (14.15):

$$F_s = \frac{c'}{\gamma H \cos^2\beta \tan\beta} + \frac{\tan\phi'}{\tan\beta}$$

$$2.5 = \frac{14}{(18)(H)(\cos^2 20)(\tan 20)} + \frac{\tan 25}{\tan 20}$$

$$2.5 = \frac{2.42}{H} + 1.28$$

$$H = \mathbf{1.98\ m}$$

14.2 Equation (14.16):

$$H_{cr} = \frac{c'}{\gamma}\frac{1}{\cos^2\beta(\tan\beta - \tan\phi')} = \left(\frac{250}{110}\right)\left[\frac{1}{\cos^2 20(\tan 20 - \tan 15)}\right] = \mathbf{26.8\ ft}$$

14.3 $\gamma_{sat} = \dfrac{(1850)(9.81)}{1000} = 18.15\ \text{kN/m}^3$

$$\gamma' = 18.15 - 9.81 = 8.34\ \text{kN/m}^3$$

Equation (14.18):

$$F_s = \frac{c'}{\gamma_{sat} H \cos^2\beta \tan\beta} + \frac{\gamma'}{\gamma_{sat}}\frac{\tan\phi'}{\tan\beta}$$

$$= \frac{25}{(18.15)(8)(\cos^2 15)(\tan 15)} + \frac{8.34}{18.15}\frac{\tan 20}{\tan 15} = \mathbf{1.31}$$

14.4 $\gamma_{sat} = \dfrac{(G_s + e)\gamma_w}{1+e} = \dfrac{(2.7 + 0.6)62.4}{1 + 0.6} = 128.7\ \text{lb/ft}^3$

$$\gamma' = 128.7 - 62.4 = 66.3\ \text{lb/ft}^3$$

$$F_s = \frac{c'}{\gamma_{\text{sat}} H \cos^2\beta \tan\beta} + \frac{\gamma'}{\gamma_{\text{sat}}} \frac{\tan\phi'}{\tan\beta}$$

$$= \frac{500}{(128.7)(20)(\cos^2 20)(\tan 20)} + \frac{66.3}{128.7} \frac{\tan 20}{\tan 20} = 0.604 + 0.515 \approx \mathbf{1.12}$$

14.5 Equation (14.42):

$$H_{\text{cr}} = \frac{4c'}{\gamma}\left[\frac{\sin\beta\cos\phi'}{1-\cos(\beta-\phi')}\right] = \frac{(4)(9.6)}{15.72}\left[\frac{\sin 60 \cos 10}{1-\cos(60-10)}\right] = \mathbf{5.83\ m}$$

14.6 $H_{\text{cr}} = \frac{4c'}{\gamma}\left[\frac{\sin\beta\cos\phi'}{1-\cos(\beta-\phi')}\right] = \frac{(25)(4)}{18}\left[\frac{(\sin 45)(\cos 20)}{1-\cos(45-20)}\right] = \mathbf{39.4\ m}$

14.7 $F_s = 2.5;\ c'_d = \frac{c'}{F_s} = \frac{25}{2.5} = 10\ \text{kN/m}^2;\ \phi'_d = \tan^{-1}\left(\frac{\tan 20}{2.5}\right) = 8.28°$

From Equation (14.40):

$$H = \frac{4c'_d}{\gamma}\left[\frac{\sin\beta\cos\phi'_d}{1-\cos(\beta-\phi'_d)}\right] = \frac{(4)(10)}{18}\left[\frac{(\sin 45)(\cos 8.28)}{1-\cos(45-8.28)}\right] = \mathbf{7.84\ m}$$

14.8 $H = \frac{4c'_d}{\gamma}\left[\frac{\sin\beta\cos\phi'}{1-\cos(\beta-\phi'_d)}\right];\quad \gamma = 115\ \text{lb/ft}^3$

$F_{s(\text{assumed})}$	$\phi'_d = \tan^{-1}\left(\frac{\tan 15}{F_s}\right)$ (deg)	$c'_d = \frac{c'}{F_s}$ (lb / ft²)	β (deg)	H (ft)
1.6	9.5	125	60	10.2
1.8	8.47	111	60	8.75
1.76	8.66	113.6	60	9.01

$F_s = \mathbf{1.76}$

14.9 $\rho = 1700\ \text{kg/m}^3$

$$\gamma = \frac{(1700)(9.81)}{1000} = 16.68 \text{ kN/m}^3$$

$$c' = 18 \text{ kN/m}^2; \quad \phi' = 20°$$

$$\beta = \tan^{-1}\left(\frac{1}{2}\right) = 26.57°$$

$$F_s = 2; \; c'_d = \frac{c'}{F_s} = \frac{18}{2} = 9 \text{ kN/m}^2$$

$$\phi'_d = \tan^{-1}\left(\frac{\tan\phi'}{F_s}\right) = \tan^{-1}\left(\frac{\tan 20}{2}\right) = 10.31°$$

$$H = \frac{4c'_d}{\gamma}\left[\frac{\sin\beta\cos\phi'_d}{1-\cos(\beta-\phi'_d)}\right] = \frac{(4)(9)}{16.68}\left[\frac{(\sin 26.57)(\cos 10.31)}{1-\cos(26.57-10.31)}\right] = \mathbf{23.74 \text{ m}}$$

14.10 $m = 0.185$ (from Figure 14.9). Equation (14.47):

$$H_{cr} = \frac{c_u}{\gamma m} = \frac{500}{(110)(0.185)} = \mathbf{24.56 \text{ ft}} \; \text{– **Toe failure**}$$

14.11 $m = 0.185$ for $\beta = 56°$ (Figure 14.9):

$$c_d = \frac{c_u}{F_s} = \frac{500}{2.5} = 200 \text{ lb/ft}^2$$

$$H = \frac{c_d}{\gamma m} = \frac{200}{(100)(0.185)} = \mathbf{9.83 \text{ ft}}$$

14.12 $\beta = \tan^{-1}\left[\frac{1}{\left(\frac{1}{2}\right)}\right] = 63.43°$. For $\beta = 63.43°$, $m = 0.196$ (Figure 14.9).

$$c_d = \frac{c_u}{F_s} = \frac{32.55}{2} = 16.275 \text{ kN/m}^2$$

$$H = \frac{c_d}{\gamma m} = \frac{16.275}{(18.9)(0.196)} = \mathbf{4.39 \text{ m}}$$

14.13 $H_{cr} = \frac{c_u}{\gamma m} = \frac{32.55}{(18.9)(0.196)} = \mathbf{8.78\ m}$

Since $\beta > 53°$, it is a **toe circle**

Refer to Figure 14.14 and Example Problem 14.5,

$$r = \frac{H_{cr}}{2\sin\alpha\sin\frac{\theta}{2}}$$

From Figure 14.10, $\alpha \approx 37°$; $\theta \approx 69°$. So

$$r = \frac{8.78}{(2\sin 37)\left(\sin\frac{69}{2}\right)} = \frac{8.78}{(2)(0.6)(0.566)} = \mathbf{12.93\ m}$$

14.14 a. $D = \frac{12}{8.5} = 1.41$; $\gamma_{sat} = 18.5\ \text{kN/m}^3$. For $\beta = 40°$, $D = 1.41$; $m = 0.175$

$$H_{cr} = \frac{c_u}{\gamma m}$$

$$c_u = (8.5)(18.5)(0.175) = \mathbf{27.5\ kN/m^2}$$

b. From Figure 14.9, **mid point circle**

c. From Figure 14.11, $n = 0.7$

Distance $= nH = (0.7)(8.5) = \mathbf{5.95\ m}$

14.15 Equation (14.56): $c_R = \frac{a_o H}{c_{u(z=0)}} = \frac{(3)(4)}{5} = 2.4$

Equation (14.55): $m = \frac{c_{u(z=0)}}{\gamma H F_s}$

Table 14.1, $m \approx 0.0478$

$$0.0478 = \frac{5}{(18.5)(4)(F_s)};\ F_s = \mathbf{1.41}$$

14.16 $F_s = \frac{c_u}{\gamma H} M$. $\beta = 30°$; $H = 12$ m; $c_u = 40$ kN / m^2

From Figure 14.16, for $k_h = 0.4$ and $D = 1$, $M \approx 4$

$$F_s = \frac{40}{(18)(12)}(4) = \mathbf{0.74}$$

14.17 $F_s = \frac{c_u}{\gamma H} M$. $\beta = 60°$; $c_u = 1000$ lb / ft^2; $\gamma = 115$ lb / ft^2; $H = 50$ ft; $k_h = 0.3$

From Figure 14.17, $M = 3.3$

$$F_s = \frac{1000}{(115)(50)}(3.3) = \mathbf{0.57}$$

14.18 a. $\beta = \tan^{-1}\left(\frac{1}{2}\right) = 26.57°$

$$\frac{F_s}{\tan\phi'} = \frac{1}{\tan 20} = 2.75$$

From Figure 14.22,

$$\frac{c'}{\gamma H_{cr} \tan\phi'} \approx 0.05$$

or

$$0.05 = \frac{700}{(110)(H_{cr})(\tan 20)} = \mathbf{349.7\ ft}$$

b. $\frac{F_s}{\tan\phi'} = \frac{1}{\tan 25} = 2.14$. $\beta = \tan^{-1}\left(\frac{1}{1.5}\right) = 33.7°$

Figure 14.22,

$$\frac{c'}{\gamma H_{cr} \tan\phi'} \approx 0.035; \quad \frac{750}{(110)(H_{cr})(\tan 25)} = 0.035$$

$H_{cr} = \mathbf{417.8\ ft}$

c. $\beta = \tan^{-1}\left(\frac{1}{3}\right) = 18.4°$

$$\frac{F_s}{\tan\phi'} = \frac{1}{\tan 20} = 3.73$$

Figure 14.22:

$$\frac{c'}{\gamma H_{cr}\tan\phi'} = \frac{30}{(15.8)(H_{cr})(\tan 15)} = 0.05$$

$H_{cr} \approx$ **142 m**

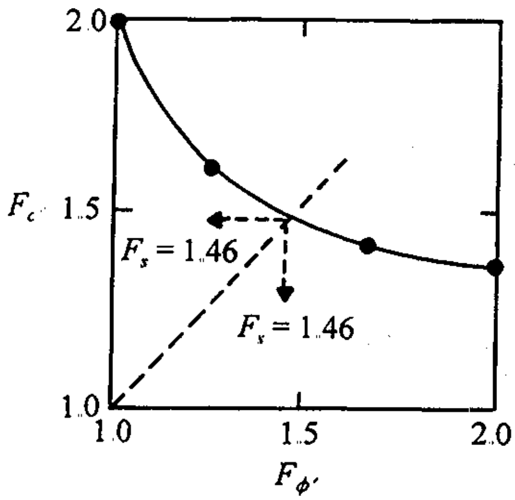
14.19 $\beta = \tan^{-1}\left(\frac{1}{2}\right) = 26.57°$; $\phi' = 10°$; $\gamma = 120 \text{ lb/ft}^3$; $H = 40$ ft; $c' = 600 \text{ lb/ft}^2$; $c'_d = m\gamma H$

ϕ'_d (deg)	$F_{\phi'} = \frac{\tan\phi'}{\tan\phi'_d}$	m	c'_d (lb/ft²)	$F_{c'} = \frac{c'}{c'_d}$
5	2.01	0.092	441.6	1.36
6	1.68	0.088	422.4	1.42
8	1.25	0.078	374.4	1.60
10	1	0.064	307.2	1.95

The plot of $F_{c'}$ versus $F_{\phi'}$ is shown.

From this

$F_{c'} = F_{\phi'} = F_s =$ **1.46**

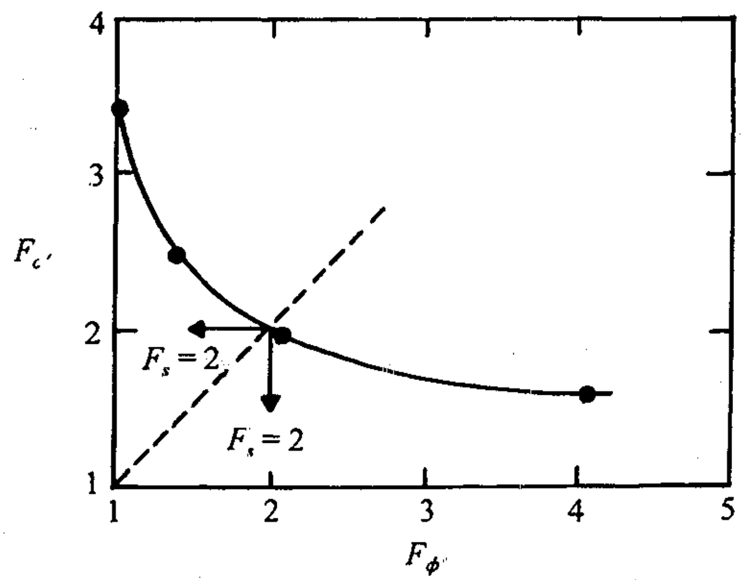


14.20 $\beta = 45°$; $\phi' = 20°$; $c' = 600\ \text{lb/ft}^2$; $\gamma = 115\ \text{lb/ft}^3$; $H = 25$ ft

ϕ'_d (deg)	$F_{\phi'} = \dfrac{\tan\phi'}{\tan\phi'_d}$	m	$c'_d = m\gamma H$ (lb / ft²)	$F_{c'} = \dfrac{c'}{c'_d}$
5	4.15	0.138	396.8	1.51
10	2.06	0.107	307.6	1.95
15	1.36	0.086	247.3	2.43
20	1	0.06	172.5	3.48

From the graph, given

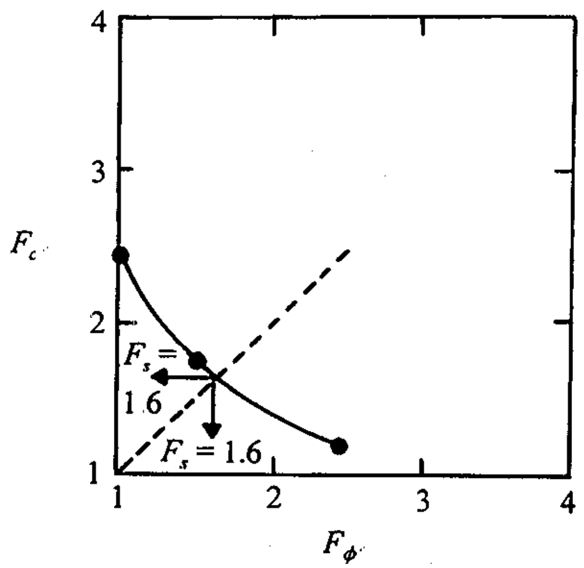
$F_{c'} = F_{\phi'} = F_s = \mathbf{2.0}$



14.21 $\beta = \tan^{-1}\left(\dfrac{1}{2.5}\right) = 21.8°$; $\phi' = 12°$; $\gamma = 17.5\ \text{kN/m}^3$; $H = 10$ m; $c' = 18\ \text{kN/m}^2$; $c'_d = m\gamma H$

ϕ'_d (deg)	$F_{\phi'} = \dfrac{\tan\phi'}{\tan\phi'_d}$	m	$c'_d = m\gamma H$ (kN / m²)	$F_{c'} = \dfrac{c'}{c'_d}$
5	2.43	0.088	15.4	1.17
8	1.51	0.06	10.5	1.71
12	1	0.042	7.35	2.45

From the graph on the next page, $F_{c'} = F_{\phi'} = F_s = \mathbf{1.6}$



Problem 14.21

14.22 $\beta = \tan^{-1}\left(\frac{1}{1}\right) = 45°$

$$\frac{c'}{\gamma H \tan\phi'} = \frac{18}{(17.1)(5)(\tan 15)} = 0.786. \quad \text{Figure 14.22,} \quad \frac{F_s}{\tan\phi'} \approx 6.9$$

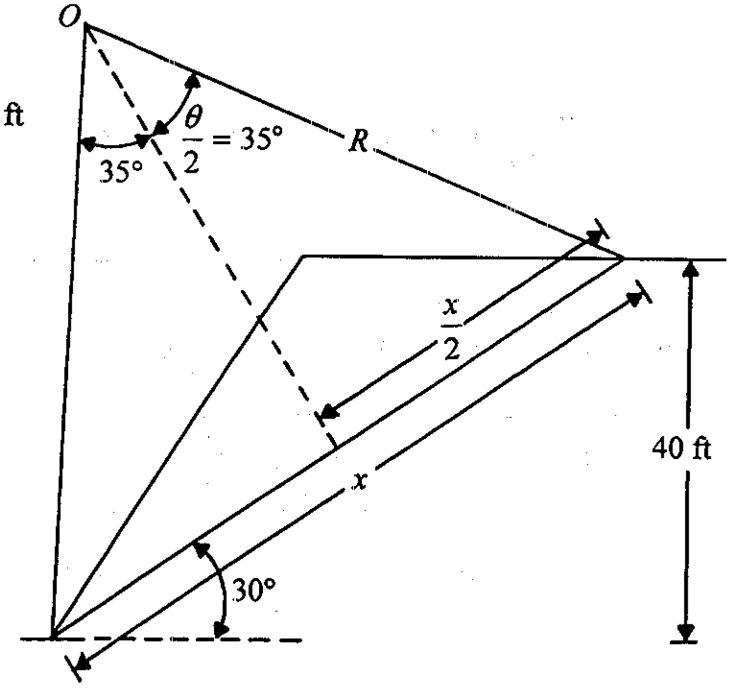
$$F_s = (6.9)(\tan 15) = \mathbf{1.85}$$

14.23 a. Refer to the figure.

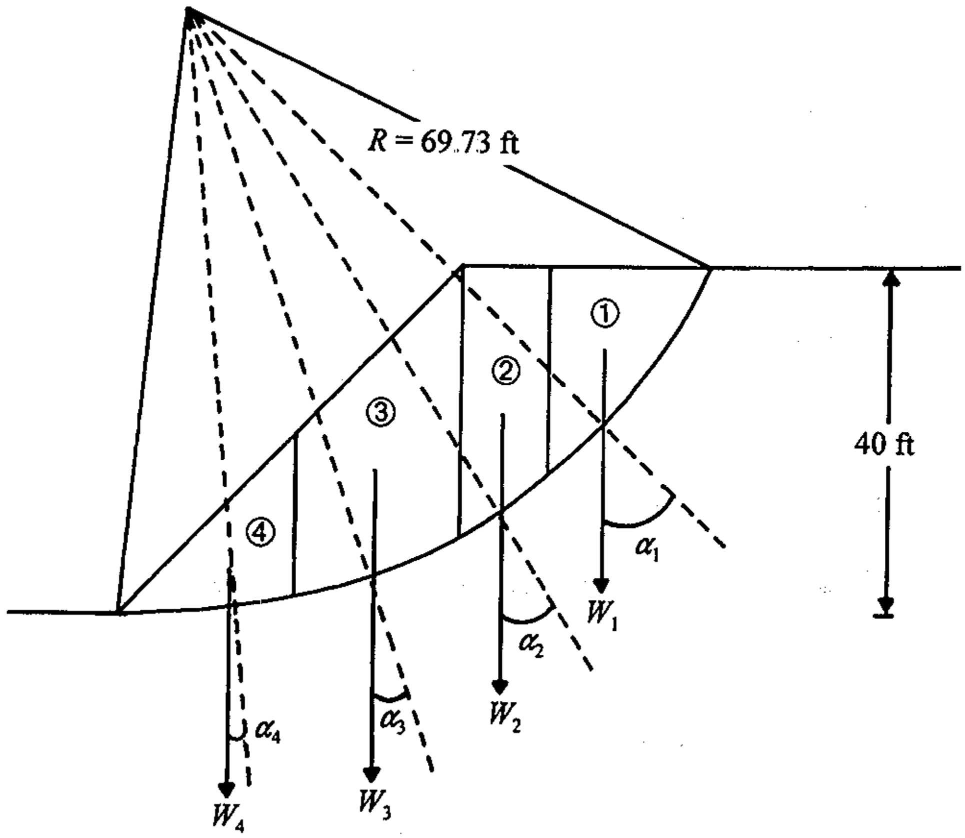
$$\frac{40}{x} = \sin 30°; \quad x = 80 \text{ ft}$$

$$\frac{40}{\text{radius, } R} = \sin 35°$$

$$R = \frac{40}{\sin 35} = 69.73 \text{ ft}$$



With radius $R = 69.73$ ft, the trial failure circle has been drawn.



The following table can now be prepared.

Slice No.	Area of slices, A (ft^2)	Weight of slice, $W_n = A \times \gamma$ (kip / ft)	α_n (deg)	$W_n \cos\alpha_n$ (kip / ft)	$W_n \sin\alpha_n$ (kip / ft)
1	$\frac{(26)(20)}{2} = 260$	29.9	47	20.39	21.86
2	$\frac{(10)(26+32)}{2} = 290$	33.35	32	28.28	17.67
3	$\frac{(20)(32+20)}{2} = 520$	59.8	20	56.19	20.45
4	$\frac{(20)(20)}{2} = 200$	23	5	22.91	2.0
				$\sum 127.77$	$\sum 61.98$

$$F_s = \frac{R\theta c' + (\Sigma W_n \cos\alpha_n)\tan\phi'}{\Sigma W_n \sin\alpha_n}$$

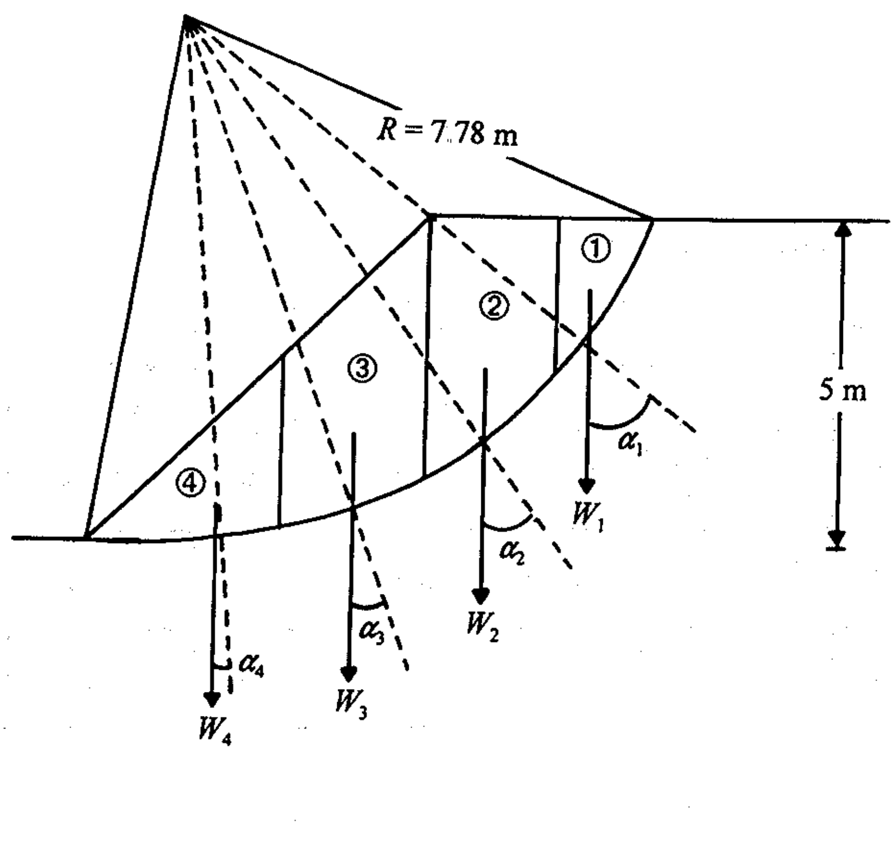
$$= \frac{(69.73)\left[\left(\frac{\pi}{180}\right)(70)\right](0.4) + (127.77)(\tan 20)}{61.98} = \mathbf{1.3}$$

(*Note*: Accuracy can be increased by increasing the number of slices.)

b. As in Part a, $\frac{H}{x} = \sin\alpha$; $x = \frac{H}{\sin\alpha} = \frac{5}{\sin 30} = 10$ m

$$\frac{\left(\frac{x}{2}\right)}{R} = \sin\left(\frac{\theta}{2}\right), \text{ or } \frac{5}{\sin 40} = R = 7.78 \text{ m}$$

With radius $R = 7.78$ m, the trial surface has been drawn.



The following table can now be prepared.

Slice No.	Area of slices, A (m²)	Weight of slice, $W_n = A \times \gamma$ (kN / m)	α_n (deg)	$W_n \cos\alpha_n$ (kN / m)	$W_n \sin\alpha_n$ (kN / m)
1	$\frac{(2.6)(1.5)}{2} = 1.95$	33.35	54	19.6	29.98
2	$\frac{(2)(2.6+4.2)}{2} = 6.8$	116.28	38	91.63	71.59
3	$\frac{(2)(4.2+2.8)}{2} = 7.0$	119.7	20	112.48	40.94
4	$\frac{(3)(2.8)}{2} = 4.2$	71.82	6	71.43	7.51
				$\sum 295.14$	$\sum 150.02$

$$F_s = \frac{R\theta c' + (\Sigma W_n \cos\alpha_n)\tan\phi'}{\Sigma W_n \sin\alpha_n}$$

$$= \frac{(7.78)\left[\left(\frac{\pi}{180}\right)(80)\right](18) + (295.14)(\tan 15)}{150.02} = \mathbf{1.83}$$

(*Note*: Accuracy will improve with smaller slices.)

14.24 $\phi' = 25°; \beta = 26.57°; r_u = 0.5; \frac{c'}{\gamma H} = \frac{115}{(115)(20)} = 0.05.$

Using Table 14.1, the following table can be prepared.

D	m'	n'	$F_s = m' - n'\, r_u$
1	1.624	1.338	0.955
1.25	1.822	1.595	1.025
1.5	2.143	1.903	1.19

$F_s \approx \mathbf{0.96}$

14.25 $\phi' = 20°; \beta = 18.43°; r_u = 0.5; \frac{c'}{\gamma H} = \frac{6}{(20)(6)} = 0.05$

Using Table 14.1, the following table can be prepared.

D	m'	n'	$F_s = m' - n' r_u$
1	1.840	1.387	1.15
1.25	1.834	1.493	1.09
1.5	2.011	1.705	1.16

$F_s \approx$ **1.09**

14.26 $r_u = 0.25; H = 25$ ft; $\beta = 30°; \phi' = 20°; c' = 100$ lb / ft^2; $\gamma = 115$ lb / ft^3

$$\lambda_{c'\phi'} = \frac{\gamma H \tan\phi'}{c'} = \frac{(115)(25)(\tan 20)}{100} = 10.46$$

From Figure 14.29(b), for toe circle: $N_s \approx 25, D \approx 1.05$

From Figure 14.30(b), $N_s \approx 25, D \approx 1$. So $N_s = 25$

$$F_s = \frac{N_s c'}{\gamma H} = \frac{(25)(100)}{(115)(25)} = \mathbf{0.87}$$

14.27 $\lambda_{c'\phi'} = \frac{\gamma H \tan\phi'}{c'} = \frac{(17.5)(15)(\tan 15)}{20} = 3.52$

$r_u = 0.5; \beta = 20°$

Figure 14.29(c): $N_s \approx 14, D \approx 1.25$

Figure 14.30(c): $N_s \approx 15, D \approx 1.25$.

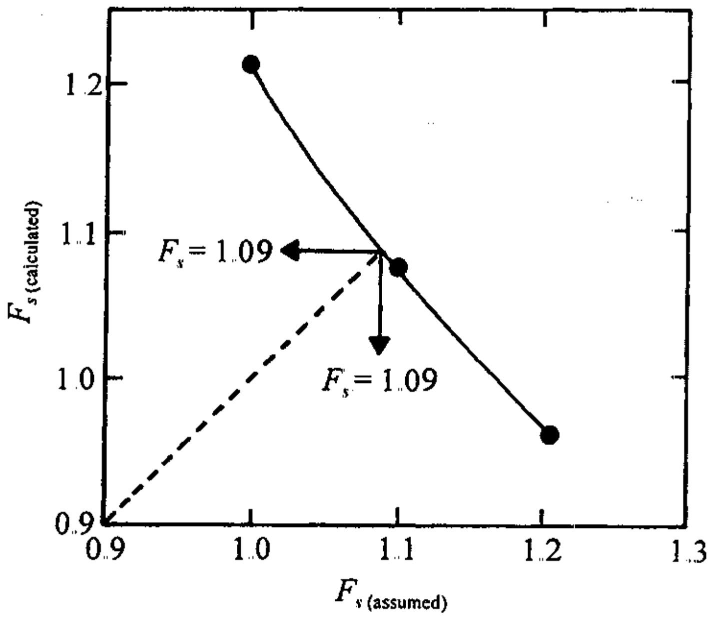
So $N_s \approx 25; D \approx 1.25$

$$F_s = \frac{N_s c'}{\gamma H} = \frac{(14.5)(20)}{(17.5)(15)} = \mathbf{1.1}$$

14.28 $\beta = 20°$; $\phi' = 15°$; $r_u = 0.5$; $\gamma = 17.5\ kN/m^3$; $c' = 20\ kN/m^2$; $H = 15$ m

$F_{s\,(assumed)}$	$\dfrac{c'}{\gamma H F_s}$	ϕ'_d (deg)	$F_{s(calculated)} = \dfrac{\tan\phi'}{\tan\phi'_d}$
1.2	0.0635	15.5	0.966
1.1	0.0693	14	1.075
1.0	0.0762	12.5	1.209
0.9	0.0847	11.5	1.317

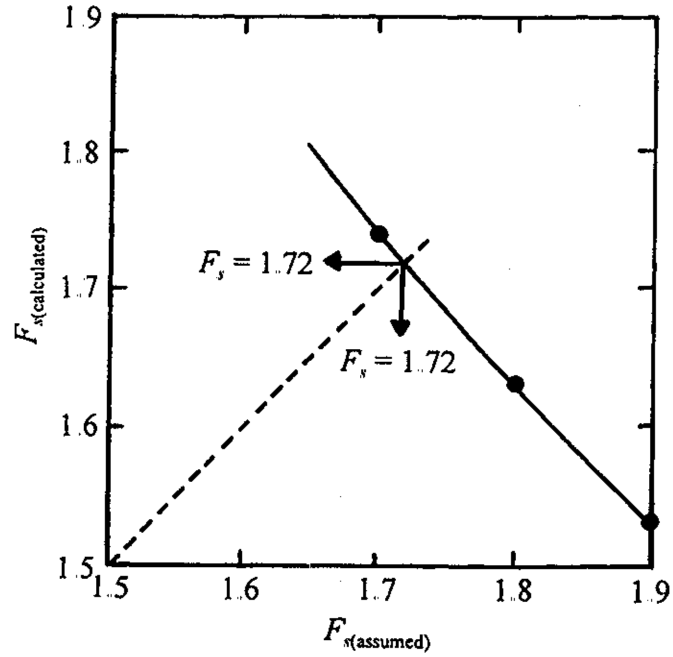
From the plot, $F_s = \mathbf{1.09}$



14.29 $\beta = \tan^{-1}\left(\frac{1}{3}\right) = 18.43°$; $\phi' = 25°$; $c' = 12\ kN/m^3$; $\gamma = 19\ kN/m^2$; $r_u = 0.25$; $H = 12.63$ m

$F_{s\,(assumed)}$	$\dfrac{c'}{\gamma H F_s}$	ϕ'_d (deg)	$F_{s(calculated)} = \dfrac{\tan\phi'}{\tan\phi'_d}$
1.7	0.0294	15	1.74
1.8	0.0278	16	1.63
1.9	0.0263	17	1.53

From the graph, $F_s \approx \mathbf{1.72}$



CHAPTER 15

15.1 Equation (15.11): $q_u = c'N_c + qN_q + \frac{1}{2}\gamma BN_\gamma$

$\phi' = 28°$; $N_c = 31.61$; $N_q = 17.81$; $N_\gamma = 13.7$ (Table 15.1)

$$q_{\text{all}} = \frac{q_u}{F_s} = \frac{1}{3}\left[(14)(31.61) + (0.7 \times 16.8)(17.81) + \frac{1}{2}(16.8)(0.8)(13.7)\right] = \mathbf{248\ kN/m^2}$$

15.2 $\phi' = 20°$. From Table 15.1, $N_c = 17.69$; $N_q = 7.44$; $N_\gamma = 3.64$

$$q_u = \frac{q_u}{F_s} = \frac{1}{3}\left[(14.2)(17.69) + (0.5 \times 18.2)(7.44) + \frac{1}{2}(18.2)(1.2)(3.64)\right] = \mathbf{119.6\ kN/m^2}$$

15.3 $\phi = 0$. From Table 15.1, $N_c = 5.7$; $N_q = 1$; $N_\gamma = 0$

$$q_{\text{all}} = \frac{q_u}{F_s} = \frac{1}{F_s}(c_u N_c + q) = \frac{1}{4}[(2600)(5.7) + (3 \times 110)] = \mathbf{3788\ lb/ft^2}$$

15.4 $\phi' = 20°$. From Table 15.2, $N_c = 11.85$; $N_q = 3.88$; $N_\gamma = 1.12$

Equation (15.16): $q'_u = \frac{2}{3}c'N'_c + qN'_q + \frac{1}{2}\gamma BN'_\gamma$

$$q_{\text{all}} = \frac{q'_u}{F_s} = \frac{1}{3}\left[\left(\frac{2}{3} \times 14.2\right)(11.85) + (0.5 \times 18.2)(3.88) + \frac{1}{2}(18.2)(1.2)(1.12)\right]$$

$$= \mathbf{53.2\ kN/m^2}$$

15.5 For continuous footing, Equation (15.39): $\lambda_{cs} = \lambda_{qs} = \lambda_{\gamma s} = 1$

Also, for vertical load: $\lambda_{ci} = \lambda_{qi} = \lambda_{\gamma i} = 1$

So, $q_u = c'\lambda_{cd}N_c + q\lambda_{qd}N_q + \frac{1}{2}\gamma B\lambda_{\gamma d}N_\gamma$

$\phi' = 28°$. From Tables 15.3 and 15.4, $N_c = 25.8$; $N_q = 14.72$; $N_\gamma = 11.19$. From Table 15.5

$$\lambda_{cd} = 1 + 0.2\left(\frac{D_f}{B}\right)\tan\left(45 + \frac{\phi'}{2}\right) = 1 + 0.2\left(\frac{0.7}{0.8}\right)\tan\left(45 + \frac{28}{2}\right) = 1.29$$

$$\lambda_{qd} = \lambda_{\gamma d} = 1 + 0.1\left(\frac{D_f}{B}\right)\tan\left(45 + \frac{\phi'}{2}\right) = 1 + 0.1\left(\frac{0.7}{0.8}\right)\tan\left(45 + \frac{28}{2}\right) = 1.146$$

$$q_{\text{all}} = \frac{q_u}{F_s} = \frac{1}{3}\begin{bmatrix}(14)(25.8)(1.29) + (0.7 \times 16.8)(14.72)(1.146) \\ +\frac{1}{2}(16.8)(0.8)(1.146)(11.9)\end{bmatrix} = \mathbf{252.1\ kN/m^2}$$

15.6 $\phi' = 20°$; $N_c = 14.83$; $N_q = 6.4$; $N_\gamma = 2.871$ (Tables 15.3 and 15.4)

$$\lambda_{cd} = 1 + 0.2\left(\frac{0.5}{1.2}\right)\tan\left(45 + \frac{20}{2}\right) = 1.119$$

$$\lambda_{qd} = \lambda_{\gamma d} = 1 + 0.1\left(\frac{0.5}{1.2}\right)\tan\left(45 + \frac{20}{2}\right) = 1.06$$

$$q_{\text{all}} = \frac{q_u}{F_s} = \frac{1}{3}\begin{bmatrix}(14.2)(14.83)(1.119) + (0.5 \times 18.2)(6.4)(1.06) \\ +\frac{1}{2}(18.2)(1.2)(2.871)(1.06)\end{bmatrix} = \mathbf{110.2\ kN/m^2}$$

15.7 $\phi = 0$; $N_c = 5.14$; $N_q = 1$; $N_\gamma = 0$ (Tables 15.3 and 15.4).

Shape and inclination factors are equal to 1.

$$q_{\text{all}} = \frac{q_u}{F_s} = \frac{1}{F_s}[c_u N_c \lambda_{cd} + q\lambda_{cd}]$$

Table 15.5: $\lambda_{cd} = 1 + 0.2\left(\frac{D_f}{B}\right) = 1 + 0.2\left(\frac{3}{3.5}\right) = 1.171$; $\lambda_{qd} = 1$

$$q_{\text{all}} = \frac{1}{4}[(2600)(5.14)(1.171) + (3 \times 110)(1)] = \mathbf{3995\ lb/ft^2}$$

15.8 Equation (15.12): $q_u = qN_q + 0.4\gamma' BN_\gamma$. $\phi' = 35°$; $N_q = 41.44$; $N_\gamma = 45.41$

$q = \gamma h + \gamma'(D_f - h) = (105 \times 2) + (118 - 62.4)(4 - 2) = 321.2$ lb / ft²

$$Q_{all} = \frac{q_u B^2}{F_s} = \frac{B^2}{F_s}(q N_q + 0.4\gamma' B N_\gamma)$$

$$Q_{all} = \frac{5^2}{3}[(321.2)(41.44) + (0.4)(118 - 62.4)(5)(45.41)]\frac{1}{1000} = \mathbf{153\ kip}$$

15.9 $\phi' = 25°$. From Table 15.1, $N_c = 25.13$; $N_q = 12.72$; $N_\gamma = 8.34$

$$\gamma = \frac{(1800)(9.81)}{1000} = 17.66 \text{ kN / m}^3$$

$$q_u = 1.3c' N_c + qN_q + 0.4\gamma_{av} BN_\gamma$$

$$q = \gamma D_f = (1.2)(17.66) = 21.19 \text{ kN / m}^2$$

$$\gamma_{av} = \frac{1}{B}[\gamma D + \gamma'(B - D)] - \text{[Equation (15.24)]}$$

$$D = h - D_f = 2 - 1.2 = 0.8 \text{ m}$$

$$\gamma_{sat} = \frac{(1980)(9.81)}{1000} = 19.42 \text{ kN / m}^3$$

$$\gamma_{av} = \frac{1}{1.8}[(17.66)(0.8) + (19.42 - 9.81)(1.8 - 0.8)] = 13.19 \text{ kN / m}^3$$

$$q_u = (1.3)(23.94)(25.13) + (21.19)(12.72) + (0.4)(13.19)(1.8)(8.34) = 1130.8 \text{ kN / m}^2$$

$$Q_{all} = \frac{(1130.8)(B^2)}{F_s} = \frac{(1130.8)(1.8)^2}{3} = \mathbf{1221\ kN}$$

15.10 $\phi' = 40°$. From Table 15.1, $N_q = 81.27$; $N_\gamma = 115.31$

$$q_{all} = \frac{q_u}{F_s} = \frac{1}{F_s}[qN_q + 0.4\gamma BN_\gamma] = \frac{1}{3}[(0.92 \times 18.1)(81.27) + (0.4)(18.1)(B)(115.31)]$$

$$= 451.1 + 278.3B \qquad \text{(a)}$$

$$q_{all} = \frac{670}{B^2} \qquad \text{(b)}$$

So, $\frac{670}{B^2} = 451.1 + 278.3B$

$B \approx$ **0.98 m**

15.11 $\phi = 35°$. From Table 15.1, $N_q = 41.44$; $N_\gamma = 45.41$

$$q_{all} = \frac{1}{3}[(2 \times 115)(41.44) + (0.4)(115)(B)(45.41)] = 3177 + 696.3B$$

$$q_{all} = \frac{92.5 \times 1000}{B^2} = 3177 + 696.3B$$

$B \approx$ **4 ft**

15.12 $\phi' = 35°$. From Tables 15.3 and 15.4, $N_q = 33.3$; $N_\gamma = 37.152$

$$q_u = qN_q \lambda_{qd}\lambda_{qs} + \frac{1}{2}\gamma B' N_\gamma \lambda_{\gamma d}\lambda_{\gamma s}$$

$q = 321.2 \text{ kN/m}^2$ (see Problem 15.8). Table 15.5:

$$\lambda_{qd} = \lambda_{\gamma d} = 1 + 0.1\left(\frac{D_f}{B}\right)\tan\left(45 + \frac{\phi'}{2}\right) = 1 + 0.1\left(\frac{4}{5}\right)\tan\left(45 + \frac{35}{2}\right) = 1.154$$

$$\lambda_{qs} = \lambda_{\gamma s} = 1 + 0.1\left(\frac{B}{L}\right)\tan^2\left(45 + \frac{\phi'}{2}\right) = 1 + 0.1\left(\frac{5}{5}\right)\tan^2\left(45 + \frac{35}{2}\right) = 1.369$$

$$q_u = (321.2)(33.3)(1.154)(1.369) + \frac{1}{2}(55.6)(5)(37.152)(1.154)(1.369) = 25{,}056 \text{ lb/ft}^2$$

$$Q_{all} = \frac{(26{,}056)(5)^2}{(3)(1000)} = \mathbf{208.8\ kip}$$

15.13 a. For vertical load, Equation (15.43):

$$q_u = q\lambda_{qs}\lambda_{qd}N_q + \frac{1}{2}\lambda_{\gamma s}\lambda_{\gamma d}\,\gamma B' N_\gamma$$

$c' = 0$; $\phi' = 30°$. Tables 15.3 and 15.4: $N_q = 18.4$; $N_\gamma = 15.668$

$B' = B - 2x = 4.5 - (2)(0.5) = 3.5$ ft; $L' = 4.5$ ft

Table 15.5:

$$\lambda_{qs} = \lambda_{\gamma s} = 1 + 0.1\left(\frac{B'}{L'}\right)\tan^2\left(45 + \frac{\phi'}{2}\right) = 1 + 0.1\left(\frac{3.5}{4.5}\right)\tan^2(45 + 15) = 1.233$$

$$\lambda_{qd} = \lambda_{\gamma d} = 1 + 0.1\left(\frac{D_f}{B'}\right)\tan\left(45 + \frac{\phi'}{2}\right) = 1 + 0.1\left(\frac{3.5}{3.5}\right)\tan(45 + 15) = 1.173$$

$$q_u = (105)(3.5)(1.233)(1.173)(18.4) + (0.5)(1.233)(1.173)(105)(3.5)(15.668)$$

$$= 13{,}944 \text{ lb / ft}^2$$

$$Q_{\text{all}} = \frac{q_u B'L'}{F_s} = \frac{(13{,}944)(3.5)(4.5)}{(4)(1000)} = \mathbf{54.9\ kip}$$

b. $B' = 6 - 2 \times 0.5 = 5.0$ ft; $L' = 6$ ft

$\phi' = 25°$. Tables 15.3 and 15.4: $N_c = 20.72$; $N_q = 10.66$; $N_\gamma = 6.765$

$$\lambda_{cs} = 1 + 0.2\left(\frac{B'}{L'}\right)\tan^2\left(45 + \frac{\phi'}{2}\right) = 1 + 0.2\left(\frac{5}{6}\right)\tan^2(45 + 12.5) = 1.411$$

$$\lambda_{qs} = \lambda_{\gamma s} = 1 + 0.1\left(\frac{B'}{L'}\right)\tan^2\left(45 + \frac{\phi'}{2}\right) = 1 + 0.1\left(\frac{5}{6}\right)\tan^2(57.5) = 1.205$$

$$\lambda_{cd} = 1 + 0.2\left(\frac{D_f}{B'}\right)\tan\left(45 + \frac{\phi'}{2}\right) = 1 + 0.2\left(\frac{4.5}{5}\right)\tan(57.5) = 1.283$$

$$\lambda_{qd} = \lambda_{\gamma d} = 1 + 0.1\left(\frac{D_f}{B'}\right)\tan\left(45 + \frac{\phi'}{2}\right) = 1 + 0.1\left(\frac{4.5}{5}\right)\tan(57.5) = 1.141$$

$$q_u = c'N_c\lambda_{cs}\lambda_{cd} + qN_q\lambda_{qs}\lambda_{qd} + \frac{1}{2}\gamma B'N_\gamma\lambda_{\gamma s}\lambda_{\gamma d}$$

So

$$q_u = (400)(20.72)(1.411)(1.283) + (120)(4.5)(10.66)(1.205)(1.141)$$

$$+ (0.5)(120)(5)(6.765)(1.205)(1.141) = 25{,}709 \text{ lb / ft}^2 = 25.71 \text{ kip / ft}^2$$

$$Q_{all} = \frac{(25.71)(5 \times 6)}{4} = \mathbf{192.8\ kip}$$

c. $q_u = q\lambda_{qs}\lambda_{qd}N_q + \frac{1}{2}\gamma B'\lambda_{\gamma s}\lambda_{\gamma d}N_\gamma$

$B' = 2.5 - (2 \times 0.2) = 2.1$ m; $L' = 2.5$ m

$$\gamma = \frac{(2000)(9.81)}{1000} = 19.62\ \text{kN/m}^3$$

$\phi' = 42°$. Tables 15.3 and 15.4: $N_q = 85.38$; $N_\gamma = 139.316$

$$\lambda_{qs} = \lambda_{\gamma s} = 1 + 0.1\left(\frac{B'}{L'}\right)\tan^2\left(45 + \frac{\phi'}{2}\right) = 1 + 0.1\left(\frac{2.1}{2.5}\right)\tan^2\left(45 + \frac{42}{2}\right) = 1.424$$

$$\lambda_{qd} = \lambda_{\gamma d} = 1 + 0.1\left(\frac{D_f}{B'}\right)\tan\left(45 + \frac{\phi'}{2}\right) = 1 + 0.1\left(\frac{1.5}{2.5}\right)\tan\left(45 + \frac{42}{2}\right) = 1.135$$

$$q_u = (19.62)(1.5)(85.38)(1.424)(1.135) + \frac{1}{2}(19.62)(2.1)(139.316)(1.424)(1.135)$$

$$= 8{,}700\ \text{kN/m}^2$$

$$Q_{all} = \frac{q_u B'L'}{F_s} = \frac{(8700)(2.1)(2.5)}{4} = \mathbf{11{,}419\ kN}$$

15.14 Equation (15.55):

$$q_{u(F)} = q_{u(P)}\left(\frac{B_F}{B_P}\right) = (3850)\left(\frac{6}{1}\right) = 23{,}100\ \text{lb/ft}^2$$

$$Q_{all} = \frac{Aq_{u(F)}}{4} = \left(\frac{23{,}100}{4}\right)(6)^2 = 207{,}900\ \text{lb} = \mathbf{207.9\ kip}$$

15.15 $q_{u(P)} = 248.9\ \text{kN/m}^2$. Equation 15.54: $q_{u(F)} = q_{u(P)}$; $q_{u(F)} = 248.9\ \text{kN/m}^2$

$$Q_{all} = \frac{Aq_{u(F)}}{F_s} = \frac{\left(\frac{\pi}{4}\right)(2)^2(248.9)}{3} = \mathbf{260.65\ kN}$$

CHAPTER 17

17.1 Equation (17.4):

$$\text{Area ratio, } A_r\,(\%) = \frac{D_o^2 - D_i^2}{D_i^2} \times 100 = \frac{(3.5)^2 - (3.375)^2}{(3.375)^2} \times 100 = \mathbf{7.54\%}$$

17.2 $$A_r = \frac{D_o^2 - D_i^2}{D_i^2} \times 100 = \frac{(3)^2 - (2.875)^2}{(2.875)^2} \times 100 = \mathbf{8.88\%}$$

17.3 $(N_1)_{60} = C_N N_{60} = \left(9.78\sqrt{\frac{1}{\sigma'_o}}\right)(N_{60})$. Given: $\gamma = 14.5\ \text{kN/m}^3$.

Now the following table can be prepared.

Depth, z (m)	$\sigma'_o = \gamma z$ (kN / m²)	C_N	N_{60}	$(N_1)_{60}$ *
1.5	21.75	2.1	6	≈**13**
3	43.5	1.48	8	≈**12**
4.5	65.25	1.21	10	≈**12**
6	87.0	1.05	12	≈**13**
7.5	108.75	0.938	15	≈**14**

* Rounded off

17.4 $$\phi' = \tan^{-1}\left[\frac{N_{60}}{12.2 + 20.3\left(\frac{\sigma'_o}{p_a}\right)}\right]; \quad p_a \approx 100\ \text{kN/m}^2$$

z (m)	$\sigma'_o = \gamma z$ (kN / m²)	N_{60}	ϕ' (deg)
1.5	21.75	6	35.27
3	43.5	8	35.75
4.5	65.25	10	36.05
6	87.0	12	36.26
7.5	108.75	15	37.05
	Average $\phi' \approx$ **36°**		

17.5 Equation (17.11):

$$D_r(\%) = \left[\frac{N_{60}\left(0.23+\frac{0.06}{D_{50}}\right)^{1.7}}{9}\left(\frac{98}{\sigma'_o}\right)\right]^{0.5}(100)$$

Given $\gamma = 15.5\ \text{kN/m}^3$. The following table can now be prepared.

Depth, z (m)	$\sigma'_o = \gamma z$ (kN / m²)	D_{50} (mm)	N_{60}	D_r
1.5	23.25	0.24	4	73.3 ≈ **73%**
3	46.5	0.24	7	68.6 ≈ **69%**
4.5	69.75	0.24	12	73.3 ≈ **73%**
6	93.0	0.24	14	68.6 ≈ **69%**
7.5	116.25	0.24	19	71.5 ≈ **72%**

17.6 $(N_1)_{60} = C_N N_{60} = \left(\frac{2}{1+\sigma'_o}\right)N_{60}$

Depth, z (ft)	σ'_o (ton / ft²)	N_{60}	C_N	$(N_1)_{60}$
5	$\frac{5\times 110}{2000} = 0.275$	6	1.57	9.42 ≈ **9**
10	$\frac{10\times 110}{2000} = 0.55$	8	1.29	10.32 ≈ **10**
15	$\frac{15\times 110}{2000} = 0.825$	9	1.1	9.9 ≈ **10**
20	$[(17.5\times 110)+2.5(120-62.4)]\frac{1}{2000} = 1.035$	9	0.983	8.845 ≈ **9**
25	$1.035+\frac{5(120-62.4)}{2000} = 1.179$	14	0.918	12.85 ≈ **13**
30	$1.179+\frac{5(120-62.4)}{2000} = 1.323$	12	0.861	10.332 ≈ **10**

17.7 a. Average value of $(N_1)_{60} \approx$ **13**

b. Equation (15.50):

$$q_{\text{all(net)}} = 11.98(N_1)_{60}\left(\frac{3.28B+1}{3.28B}\right)^2 F_d\left(\frac{S_e}{25}\right)$$

$$F_d = 1 + 0.33\left(\frac{D_f}{B}\right) = 1 + 0.33\left(\frac{1.5}{2}\right) = 1.248$$

$$q_{\text{all(net)}} = (11.98)(13)\left[\frac{(3.28)(2)+1}{(3.28)(2)}\right]^2 (1.248)\left(\frac{25}{25}\right) = \mathbf{258.1\ kN/m^2}$$

17.8 Equation (17.25): $\dfrac{\left(\dfrac{q_c}{p_a}\right)}{N_{60}} = 7.6429 D_{50}^{0.26}$. Use $p_a \approx 100\ \text{kN/m}^2$.

Depth, z (m)	N_{60}	D_{50} (mm)	q_c (kN / m²)
1.5	4	0.24	**2,109**
3	7	0.24	**3,692**
4.5	12	0.24	**6,328**
6	14	0.24	**7,383**
7.6	19	0.24	**10,020**

17.9 Equation (17.23): $c_u = \dfrac{q_c - \sigma_o}{N_k}$. $N_k \approx 18.3$

$$c_u = \frac{920-(8)(18)}{18.3} = \mathbf{42.4\ kN/m^2}$$

17.10 From Equations (17.20) and (17.21):

$$E_s = 2 \text{ to } 3q_c = 2 \text{ to } 3(205) = \mathbf{410\ to\ 615\ kN/m^2}$$

17.11 From Equation (17.29):

Recovery ratio, $R = (\frac{3}{4})(100) =$ **75%**