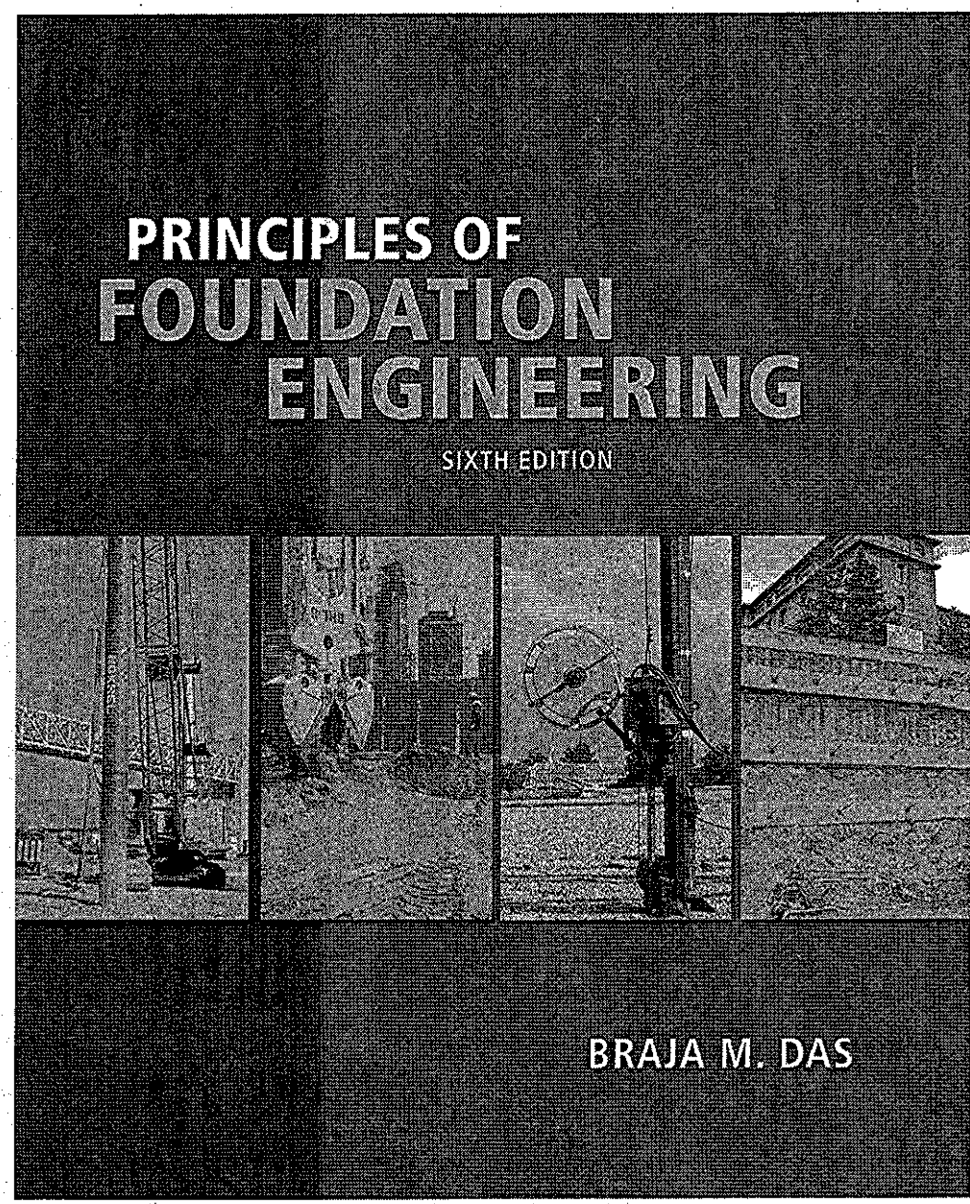
# INSTRUCTOR'S SOLUTIONS MANUAL

*to accompany*




THOMSON
ENGINEERING

ISBN 0-495-24454-6
9 780495 244547

THOMSON
ENGINEERING



For more information contact Nelson, 1120 Birchmount Road, Scarborough, Ontario M1K 5G4. Or you can visit our Internet site at www.nelson.com.

# Instructor's Solution Manual

To Accompany

## ***Principles of Foundation Engineering, 6e***

by

Braja M.Das

# Contents

# CHAPTER 1

1.1 d. $\gamma = \dfrac{(87.5)(9.81)}{(1000)(0.05)} = \mathbf{17.17\ kN/m^3}$

c. $\gamma = \dfrac{\gamma}{1+w} = \dfrac{17.17}{1+0.15} = \mathbf{14.93\ kN/m^3}$

a. Eq. (1.12): $\gamma_d = \dfrac{G_s \gamma_w}{1+e}$

$$14.93 = \frac{(2.68)(9.81)}{1+e}; \quad e = \mathbf{0.76}$$

b. Eq.(1.6): $n = \dfrac{e}{1+e} = \dfrac{0.76}{1+0.76} = \mathbf{0.43}$

e. From Figure 1.3b: $S = \dfrac{V_w}{V_v} = \dfrac{wG_s}{e} = \left[\dfrac{(0.15)(2.68)}{0.76}\right](100) = \mathbf{53\%}$

1.2 a. From Eqs. (1.11) and (1.12) it can be seen that

$$\gamma_d = \frac{\gamma}{1+w} = \frac{20.1}{1+0.22} = \mathbf{16.48\ kN/m^3}$$

b. $\gamma_d = 16.48\ \text{kN/m}^3 = \dfrac{G_s \gamma_w}{1+e} = \dfrac{G_s(9.81)}{1+e}$

Eq. (1.14): $e = wG_s = (0.22)(G_s)$. So

$$16.48 = \frac{9.81 G_s}{1+0.22}; \quad G_s = \mathbf{2.67}$$

1.3 a. Eq. (1.6): $n = \dfrac{e}{1+e} = \dfrac{0.81}{1+0.81} = \mathbf{0.45}$

b. Eqs. (1.7) and (1.14): $S = \dfrac{wG_s}{e} = \left[\dfrac{(0.21)(2.68)}{0.81}\right](100) = \mathbf{69.5\%}$

c. Eq. (1.11): $\gamma = \frac{G_s\gamma_w(1+w)}{1+e} = \frac{(2.68)(9.81)(1+0.21)}{1+0.81} = \mathbf{17.58\ kN/m^3}$

d. Eq. (1.12): $\gamma = \frac{G_s\gamma_w}{1+e} = \frac{(2.68)(9.81)}{1+0.81} = \mathbf{14.53\ kN/m^3}$

1.4 a. Eq. (1.11): $\gamma = \frac{G_s\gamma_w(1+w)}{1+e}$

$$122 = \frac{(2.68)(62.4)(1+0.147)}{1+e}; \quad e = \mathbf{0.57}$$

b. Eq. (1.6): $n = \frac{e}{1+e} = \frac{0.57}{1+0.57} = \mathbf{0.36}$

c. $S = \frac{wG_s}{e} = \left[\frac{(0.147)(2.68)}{0.57}\right](100) = \mathbf{69.1\%}$

d. From Eqs. (1.11) and (1.12): $\gamma_d = \frac{\gamma}{1+w} = \frac{122}{1+0.147} = \mathbf{106.4\ lb/ft^3}$

1.5 a. Eq. (1.15): $\gamma_{sat} = \frac{G_s\gamma_w + e\gamma_w}{1+e} = \frac{(62.4)(2.68+0.57)}{1+0.57} = \mathbf{129.2\ lb/ft^3}$

b. Water to be added = $\gamma_{sat} - \gamma = 129.2 - 122 = \mathbf{7.2\ lb/ft^3}$

c. $S = \frac{wG_s}{e}; w = \frac{Se}{G_s} = \frac{(0.8)(0.57)}{2.68} = 0.17$

$$\gamma = \frac{G_s\gamma_w(1+w)}{1+e} = \frac{(2.68)(62.4)(1+0.17)}{1+0.57} = \mathbf{124.6\ lb/ft^3}$$

1.6 From Eqs. (1.11) and (1.12): $\gamma_d = \frac{116.64}{1+0.08} = 108\ lb/ft^3$

Eq. (1.12): $\gamma_d = \frac{G_s\gamma_w}{1+e}; \; 108 = \frac{(2.65)(62.4)}{1+e}; \quad e = 0.53$

Eq. (1.19): $D_r = 0.82 = \frac{e_{max} - e}{e_{max} - e_{min}} = \frac{e_{max} - 0.53}{e_{nax} - 0.44}; \quad e_{max} = \mathbf{0.94}$

$$\gamma_{d(\min)} = \frac{G_s \gamma_w}{1+e_{\max}} = \frac{(2.65)(62.4)}{1+0.94} = \mathbf{85.2\ lb/ft^3}$$

1.7 Refer to Table 1.5 for classification.

*SOIL A*: **A-7-6(9)** (*Note*: PI is greater than LL – 30.)

$GI = (F_{200} - 35)[0.2 + 0.005(LL - 40)] + 0.01(F_{200} - 15)(PI - 10)$

$= (65 - 35)[0.2 + 0.005(42 - 40)] + 0.01(65 - 15)(16 - 10) = 9.3 = \mathbf{9}$

*SOIL B*: **A-6(5)**

$GI = (55 - 35)[0.2 + 0.005(38 - 40)] + 0.01(55 - 15)(13 - 10) = 5.4 \approx \mathbf{5}$

*SOIL C*: **A-3(0)**

*SOIL D*: **A-4(5)**

$GI = (64 - 35)[0.2 + 0.005(35 - 40)] + 0.01(64 - 15)(9 - 10) = 4.585 \approx \mathbf{5}$

*SOIL E*: **A-2-6(1)**

$GI = (F_{200} - 15)(PI - 10) = 0.01(33 - 15)(13 - 10) = 0.54 \approx \mathbf{1}$

*SOIL F*: **A-7-6(19)** (PI is greater that LL – 30.)

$GI = (76 - 35)[0.2 + 0.005(52 - 40)] + 0.01(76 - 15)(24 - 10) = 19.2 \approx \mathbf{19}$

1.8 *SOIL A*: Table 1.6: 65% passing No. 200 sieve. Fine grained soi..; LL = 42; PI = 16
Figure 1.5: **ML**
Figure 1.7: Plus No. 200 > 30%; Plus No. 4 = 0
% sand > % gravel – **sandy silt**

*SOIL B*: Table 1.6: 55% passing No. 200 sieve. Fine grained soil. LL = 38, PI = 13
Figure 1.5: Plots below A-line – **ML**
Figure 1.7: Plus No. 200 > 30%
% sand > % gravel – **sandy silt**

*SOIL C*: Table 1.6: 8% passing No. 200 sieve.
% sand > % gravel – sandy soil – **SP**
Figure 1.6: % gravel = 100 – 95 = 5% < 15% – **poorly graded sand**

*SOIL D*: Table 1.6: 65% passing No. 200 sieve. Fine grained soil. LL = 35, PI = 9
Figure 1.5 – **ML**
Plus No. 200 = 36% > 30%
% sand (31%) > % gravel (5%) – **sandy silt**

*SOIL E*: Table 1.6: 33% passing No. 200 sieve. 100% passing No. 4 sieve. Sandy soil.
LL = 38, PI = 13
Figure 1.5: Plots below A-line – **SM**
Figure 1.6: % gravel (0%) < 15% – **silty sand**

*SOIL F*: Table 1.6: 76% passing No. 200 sieve. LL = 52, PI = 24
Figure 1.5: **CH**
Figure 1.7: Plus No. 200 is 100 – 76 = 24%
% sand > % gravel – **fat clay with sand**

1.9 $$\gamma_d = \frac{G_s \gamma_w}{1+e}; \quad e = \frac{G_s \gamma_w}{\gamma_d} - 1 = \frac{(2.68)(62.4)}{117} - 1 = 0.43$$

Eq. (1.26):

$$\frac{k_1}{k_2} = \frac{\frac{e_1^3}{1+e_1}}{\frac{e_2^3}{1+e_2}}; \quad \frac{0.22}{k_2} = \frac{\frac{0.63^3}{1+0.63}}{\frac{0.43^3}{1+0.43}}$$

$k_2 = \mathbf{0.08\ cm/sec}$

1.10 From Eq. (1.26)

$$k_2 = \left(\frac{e_2^3}{1+e_2}\right)\left(\frac{1+e_1}{e_1^3}\right)k_1$$

$$0.115 = \left(\frac{e_2^3}{1+e_2}\right)\left(\frac{1+0.7}{0.7^3}\right)(0.25) = 1.239\left(\frac{e_2^3}{1+e_2}\right)$$

By trial and error, $e_2 = \mathbf{0.52}$

1.11 $$\frac{k_1}{k_2} = \frac{\frac{e_1^{5.1}}{1+e_1}}{\frac{e_2^{5.1}}{1+e_2}}; \quad \frac{5.4 \times 10^{-6}}{k_2} = \frac{\frac{(0.92)^{5.1}}{1+0.92}}{\frac{(0.72)^{5.1}}{1+0.72}} = 3.126$$

$k_2 = \mathbf{1.73 \times 10^{-6}\ cm / sec}$

1.12 $\gamma_{dry(sand)} = \frac{G_s \gamma_w}{1+e} = \frac{(2.66)(62.4)}{1+0.55} = 107.09 \text{ lb/ft}^3$

$$\gamma_{sat(sand)} = \frac{G_s \gamma_w + e\gamma_w}{1+e} = \frac{(62.4)(2.66+0.48)}{1+0.48} = 132.39 \text{ lb/ft}^3$$

$$\gamma_{sat(clay)} = \frac{G_s \gamma_w (1+w)}{1+wG_s} = \frac{(2.74)(62.4)(1+0.3478)}{1+(0.3478)(2.74)} = 117.99 \text{ lb/ft}^3$$

*At A*: $\sigma = 0$; $u = 0$; $\sigma' = 0$

*At B*: $\sigma = (107.09)(8) = \mathbf{856.72\ lb/ft^2}$; $u = \mathbf{0}$; $\sigma' = \mathbf{856.72\ lb/ft^2}$

*At C*: $\sigma = \sigma_B + (132.39)(4) = 856.72 + 529.56 = \mathbf{1386.28\ lb/ft^2}$
$u = (62.4)(4) = \mathbf{249.6\ lb/ft^2}$
$\sigma' = 1386.28 - 249.6 = \mathbf{1136.68\ lb/ft^2}$

*At D*: $\sigma = \sigma_C + (117.99)(15) = 1386.28 + 1769.85 = \mathbf{3156.13\ lb/ft^2}$
$u = (62.4)(19) = \mathbf{1185.6\ lb/ft^2}$
$\sigma' = \mathbf{1970.53\ lb/ft^2}$

1.13 In the top sand layer: $\gamma_{sat(sand)} = \frac{\gamma_w (G_s + e)}{1+e} = \frac{(62.4)(2.66+0.55)}{1+0.55} = 129.2 \text{ lb/ft}^3$

When the ground water table is 4 ft below the ground surface,

$$\sigma = (107.09)(4) + (129.2)(4) + (132.39)(4) + (117.99)(15) = 3244.57 \text{ lb/ft}^2$$
$$u = (62.4)(23) = 1435.2 \text{ lb/ft}^2$$
$$\sigma' = 3244.57 - 1435.2 = 1809.37 \text{ lb/ft}^2$$

Change in effective stress = 1809.37 − 1970.53 = $\mathbf{-161.2\ lb/ft^2}$

1.14 Equation (1.37): $i_{cr} = \frac{G_s - 1}{1+e}$

$$\left.\begin{array}{l} i_{cr} = \frac{2.65-1}{1+0.42} = \mathbf{1.16} \\ i_{cr} = \frac{2.65-1}{1+0.85} = \mathbf{0.89} \end{array}\right\} \text{Range}$$

1.15 Eq. (1.47): $S_c = \dfrac{C_c H_c}{1+e_o}\log\dfrac{\sigma'_o + \Delta\sigma'}{\sigma'_o}$

$$= \frac{[0.009(42-10)](3.7)}{1+0.82}\log\left(\frac{155}{110}\right) = 0.087 \text{ m} = \mathbf{87\ mm}$$

1.16 Eq. (1.51): $S = \dfrac{H_c}{1+e_o}\left[C_s\log\left(\dfrac{p_c}{p_o}\right) + C_c\log\left(\dfrac{p_c+\Delta p}{p_o}\right)\right]$

$C_c = 0.009(42-10) = 0.288$; $C_s = C_c/5 = 0.0576$

$$S_c = \frac{3.7}{1+0.82}\left[0.0576\log\left(\frac{128}{110}\right) + 0.288\log\left(\frac{155}{128}\right)\right] = 0.056 \text{ m} = \mathbf{56\ mm}$$

1.17 a. Eq. (1.38): $C_c = \dfrac{e_1 - e_2}{\log\left(\dfrac{\sigma'_2}{\sigma'_1}\right)} = \dfrac{0.91-0.792}{\log\left(\dfrac{42}{21}\right)} = 0.392$

From Eq.(1.47): $S_c = \dfrac{C_c H_c}{1+e_o}\log\dfrac{\sigma'_o + \Delta\sigma'}{\sigma'_o}$

Using the results of Problem 1.12

$\sigma'_o = (8)(107.09) + (4)(132.39 - 62.4) + (15/2)(117.99 - 62.4) = 1553.6 \text{ lb/ft}^2$

$e_o = wG_s = (0.3478)(2.74) = 0.953$

$$S_c = \frac{(0.392)(15\times 12)}{1+0.953}\log\left(\frac{1553.6+1000}{1553.6}\right) = \mathbf{7.8\ in.}$$

b. Eq. (1.55): $T_v = \dfrac{C_v t}{H^2}$. For $U = 50\%$, $T_v = 0.197$ (Figure 1.21)

$0.197 = \dfrac{1.45\times 10^{-4} t}{(15\times 12)^2}$; $t = 4402\times 10^4$ sec = **509.5 days**

1.18 a. Eq. (1.38): $C_c = \dfrac{e_2 - e_1}{\log\left(\dfrac{\sigma'_2}{\sigma'_1}\right)} = \dfrac{0.82-0.64}{\log\left(\dfrac{360}{120}\right)} = \mathbf{0.377}$

b. $C_c = \dfrac{e_2 - e_1}{\log\left(\dfrac{\sigma'_2}{\sigma'_1}\right)}$; $0.377 = \dfrac{0.82 - e_2}{\log\left(\dfrac{200}{120}\right)}$; $e_2 = \mathbf{0.736}$

1.19 Eq. (1.55): $T_v = \dfrac{C_v t}{H^2}$. For 60% consolidation, $T_v = 0.287$ (Figure 1.21)

Lab time: $t = 8\frac{1}{6}$ min $= \frac{49}{6}$ min

$$0.287 = \frac{C_v\left(\frac{49}{6}\right)}{(1.5)^2}; \quad C_v = 0.07907 \text{ in.}^2/\text{min}$$

Field: $U = 50\%$; $T_v = 0.197$

$$0.197 = \frac{(0.07907)t}{\left(\dfrac{10\times 12}{2}\right)^2}; \quad t = 8969.3 \text{ min} = \mathbf{6.23\ days}$$

1.20 $U = \frac{30}{60} = 0.5$

$$T_{v(1)} = \frac{C_{v(1)}t}{H_1^2} = \frac{(2)(t)}{\left(\dfrac{2\times 1000}{2}\right)^2} = 2\times 10^{-6}t$$

$$T_{v(2)} = \frac{C_{v(2)}t}{H_2^2} = \frac{(2)(t)}{\left(\dfrac{1\times 1000}{2}\right)^2} = 8\times 10^{-6}t$$

So, $T_{v(1)} = 0.25\ T_{v(2)}$. Now the following table can be prepared for trial and error procedure.

| $T_{v(1)}$ | $T_{v(2)}$ | $U_1$ (Fig. 1.21) | $U_2$ (Fig. 1.21) | $\dfrac{U_1H_1 + U_2H_2}{H_1 + H_2} = U$ |
|---|---|---|---|---|
| 0.05 | 0.2 | 0.26 | 0.51 | 0.34 |
| 0.1 | 0.4 | 0.36 | 0.7 | 0.473 |
| 0.125 | 0.5 | 0.4 | 0.76 | 0.52 |
| 0.1125 | 0.45 | 0.385 | 0.73 | 0.5 |

So, $T_{v(1)} = 0.1125 = 2 \times 10^{-6}t$; $t = 56{,}250$ min $=$ **39.06 days**

1.21 Eq. (1.66): $T_c = \frac{C_v t_c}{H^2}$. $T_c$ = 60 days = 60 × 24 × 60 × 60 s; $H = \frac{2}{2}$ m = 1000 mm

$$T_c = \frac{(8\times10^{-3})(60\times24\times60\times60)}{(1000)^2} = 0.0415$$

After 30 days: $T_v = \frac{C_v t}{H^2} = \frac{(8\times10^{-3})(30\times24\times60\times60)}{(1000)^2} = 0.0207$

From Figure 1.28, for $T_v$ = 0.0207 and $T_c$ = 0.0415, $U$ = 5%. So

$S_c$ = (0.05)(150) = **7.5 mm**

After 120 days: $T_v = \frac{(8\times10^{-3})(120\times24\times60\times60)}{(1000)^2} = 0.083$

From Figure 1.28, for $T_v$ = 0.083 and $T_c$ = 0.0415, $U$ = 27%. So

$S_c$ = (0.27)(150) = **40.5 mm**

1.22

| Area (in.$^2$) | Normal force, $N$ (lb) | $\sigma' = N/A$ (lb / in.$^2$) | Shear force, $S$ (lb) | $\tau = S/A$ (lb / in.$^2$) | $\phi'$ = tan-1($\tau/\sigma'$) |
|---|---|---|---|---|---|
| 4 | 50 | 12.5 | 43.5 | 10.88 | 41.06 |
| 4 | 110 | 27.5 | 95.5 | 23.88 | 40.97 |
| 4 | 150 | 37.5 | 132 | 33 | 41.35 |

When plotted, $\phi' \approx$ **41°**

1.23 $c'$ = 0. Eq. (1.69):

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

$$30 + 96 = 30\tan^2\left(45 + \frac{\phi'}{2}\right);\quad \phi' = 2\left[\tan^{-1}\left(\frac{126}{30}\right)^{1/2} - 45\right] \approx \mathbf{38°}$$

1.24 $\sigma_1' = \sigma_3' \tan^2\left(45 + \frac{\phi'}{2}\right)$

$$20 + 40 = 20\tan^2\left(45 + \frac{\phi'}{2}\right);\quad \phi' = \mathbf{30°}$$

1.25 $c'=0$. Eq. (1.69): $\sigma_1' = \sigma_3' \tan^2\left(45+\frac{\phi'}{2}\right) = 140\tan^2\left(45+\frac{28}{2}\right) = \mathbf{387.8\ kN/m^2}$

1.26 Eq. (1.69): $\sigma_1' = \sigma_3' \tan^2\left(45+\frac{\phi'}{2}\right) + 2c'\tan^2\left(45+\frac{\phi'}{2}\right)$

$368 = 140\tan^2(45+\phi'/2) + 2c'\tan(45+\phi'/2)$ (a)

$701 = 280\tan^2(45+\phi'/2) + 2c'\tan(45+\phi'/2)$ (b)

Solving Eqs. (a) and (b), $\phi' = $ **24°** and $c' = $ **12 kN/m²**

1.27 $\phi = \sin^{-1}\left(\frac{\sigma_1-\sigma_3}{\sigma_1+\sigma_3}\right) = \sin^{-1}\left(\frac{32-13}{32+13}\right) = \mathbf{25°}$

$\phi = \sin^{-1}\left(\frac{\sigma_1'-\sigma_3'}{\sigma_1'+\sigma_3'}\right)$

$\sigma_1' = 32-5.5 = 26.5\ \text{lb/in.}^2;\ \sigma_3' = 13-5.5 = 7.5\ \text{lb/in.}^2$

$\phi' = \sin^{-1}\left(\frac{26.5-7.5}{26.5+7.5}\right) = \mathbf{34°}$

Normally consolidated clay; $c_{cu} = \mathbf{0}$; $c' = \mathbf{0}$

1.28 $\sigma_1 = \sigma_3\tan^2\left(45+\frac{\phi}{2}\right)$. $\sigma_1 = 150\tan^2\left(45+\frac{20}{2}\right) = 305.9\ \text{kN/m}^2$

$\frac{\sigma_1'}{\sigma_3'} = \tan^2\left(45+\frac{\phi'}{2}\right)$; $\frac{305.9-u}{150-u} = \tan^2\left(45+\frac{28}{2}\right)$; $u = \mathbf{61.9\ kN/m^2}$

1.29 $\frac{c_u}{\sigma_o'} = 0.11+0.0037\text{PI}$; $\frac{c_u}{(8)(19.6-9.81)} = 0.11+(0.0037)(21) = \mathbf{14.7\ kN/m^2}$

# CHAPTER 2

2.1 a. Eq. (2.5): $A_R(\%) = \frac{D_o^2 - D_i^2}{D_i^2} \times 100 = \left[\frac{(2)^2 - (1.875)^2}{(1.875)^2}\right](100) = \mathbf{13.78\%}$

b. $A_R = \frac{10}{100} = \frac{(2)^2 - D_i^2}{D_i^2} = \mathbf{1.907 \text{ in.}}$

2.2

| Depth from ground surface (m) | $N_{60}$ | $c_u$ [a] (kN / m²) | $\sigma'_o$ (MN / m²) | OCR [b] |
|---|---|---|---|---|
| 4.0 | 6 | **105.4** | $\frac{1}{1000}[2(17) + 2(19 - 9.81)] = 0.0524$ | **5.06** |
| 5.5 | 9 | **141.1** | $0.0524 + \frac{1}{1000}(17 - 9.81)(1.5) = 0.0632$ | **5.88** |
| 7.0 | 8 | **129.6** | $0.0632 + \frac{1}{1000}(17 - 9.81)(1.5) = 0.074$ | **4.86** |
| 8.5 | 10 | **152.2** | $0.074 + \frac{1}{1000}(17 - 9.81)(1.5) = 0.0848$ | **5.16** |
| 10.0 | 11 | **163.0** | $0.0848 + \frac{1}{1000}(17 - 9.81)(1.5) = 0.0956$ | **5.08** |

[a] $c_u$ (kN / m²) $= 29N_{60}^{0.72}$; [b] $\text{OCR} = 0.193(N_{60}/\sigma'_o)^{0.689}$

2.3

| Depth (m) | $\sigma'_o$ (kN / m²) |
|---|---|
| 1.5 | $18.08 \times 1.5 = 27.12$ |
| 3 | $18.08 \times 3.0 = 54.24$ |
| 4.5 | $18.08 \times 4.5 = 81.36$ |
| 6 | $18.08 \times 5.5 + (19.34 - 9.81)(0.5) = 104.2$ |
| 7.5 | $18.08 \times 5.5 + (19.34 - 9.81)(2) = 118.5$ |
| 9 | $18.08 \times 5.5 + (19.34 - 9.81)(3.5) = 132.8$ |

Eq. (2.14): $C_N = \left[\frac{1}{(\sigma'_o/p_a)}\right]^{0.5}$. Now the following table can be prepared.

| Depth (m) | $N_{60}$ | $\sigma'_o$ (kN/m$^2$) | $C_N$ | $(N_1)_{60}$ [a] |
|---|---|---|---|---|
| 1.5 | 5 | 27.12 | 1.92 | **10** |
| 3 | 7 | 54.24 | 1.36 | **10** |
| 4.5 | 9 | 81.36 | 1.11 | **10** |
| 6 | 8 | 104.2 | 0.98 | **8** |
| 7.5 | 12 | 118.5 | 0.92 | **11** |
| 9 | 11 | 132.8 | 0.87 | **10** |

[a] rounded to nearest whole number

2.4

| Depth (m) | $N_{60}$ | $\sigma'_o$ (kN / m$^2$) | $\phi'$ (deg) [Eq. (2.24) | $\phi'$ (deg) [Eq. (2.25)] |
|---|---|---|---|---|
| 1.5 | 5 | 27.12 | 28.59 | 33.04 |
| 3.0 | 7 | 54.24 | 29.17 | 33.63 |
| 4.5 | 9 | 81.36 | 29.76 | 33.98 |
| 6.0 | 8 | 104.2 | 29.47 | 31.61 |
| 7.5 | 12 | 118.5 | 30.62 | 34.48 |
| 9.0 | 11 | 132.8 | 30.33 | 33.0 |
| | | | Av. 29.66° ≈ **30°** | Av. 33.29° ≈ **33°** |

2.5

| Depth (m) | $\sigma'_o$ (kN / m$^2$) | $N_{60}$ | $D_{50}$ (mm) | $p_a$ (kN / m$^2$) | $D_R$ (%) [Eq. (2.19)] |
|---|---|---|---|---|---|
| 1.5 | $1.5 \times 18 = 27$ | 6 | 0.6 | 100 | **61.2** |
| 3.0 | $3 \times 18 = 54$ | 8 | 0.6 | 100 | **50** |
| 4.5 | $4.5 \times 18 = 81$ | 9 | 0.6 | 100 | **43.3** |
| 6.0 | $6 \times 18 = 108$ | 8 | 0.6 | 100 | **35.4** |
| 7.5 | $108 + 1.5(20.2 - 9.81) = 123.6$ | 13 | 0.6 | 100 | **42.1** |
| 9.0 | $123.6 + 1.5(20.2 - 9.81) = 139.2$ | 14 | 0.6 | 100 | **41.2** |

2.6

| Depth (ft) | $\gamma$ (lb / ft$^3$) | $\sigma'_o$ (lb / in.$^2$) | $p_a$ (lb / in.$^2$) | $N_{60}$ | $\phi'$ (deg)[a] [Eq. (2.25)] |
|---|---|---|---|---|---|
| 10 | 106 | 7.36 | 14.7 | 7 | 34 |
| 15 | 106 | 11.04 | 14.7 | 9 | 34 |
| 20 | 106 | 14.72 | 14.7 | 11 | 35 |
| 25 | 118 | 18.82 | 14.7 | 16 | 37 |
| 30 | 118 | 22.92 | 14.7 | 18 | 36 |
| 35 | 118 | 27.02 | 14.7 | 20 | 36 |
| 40 | 118 | 31.12 | 14.7 | 22 | 36 |

[a] rounded to nearest whole number

Average $\phi' = \frac{1}{7}(34 + 34 + 35 + 37 + 36 + 36 + 36) = 35.4° \approx$ **35°**

2.7 Eq. (2.18b): $D_r\,(\%) = 12.2 + 0.75\left[222N_{60} + 2311 - 711\text{OCR} - 779\left(\frac{\sigma'_o}{p_a}\right) - 50C_u^2\right]^{0.5}$

At 10 ft: $D_r = 12.2 + 0.75\begin{bmatrix}(222)(9) + 2311 - 711(3.0) \\ -779\left(\frac{1150}{2000}\right) - (50)(3.2)^2\end{bmatrix}^{0.5} = 38.35\%$

At 15 ft: $D_r = 12.2 + 0.75\begin{bmatrix}(222)(11) + 2311 - 711(3.0) \\ -779\left(\frac{1725}{2000}\right) - (50)(3.2)^2\end{bmatrix}^{0.5} = 40.6\%$

At 20 ft: $D_r = 12.2 + 0.75\begin{bmatrix}(222)(12) + 2311 - 711(3.0) \\ -779\left(\frac{2030}{2000}\right) - (50)(3.2)^2\end{bmatrix}^{0.5} = 41.63\%$

Average $D_r = (1/3)(38.35 + 40.6 + 41.63) \approx$ **40%**

2.8 Eq. (2.29): $c_u = \frac{T}{K}$

Eq. (2.31): $K = 366 \times 10^{-8} D^3 = 366 \times 10^{-8}(6.35)^3 = 93.7 \times 10^{-5}$

$c_{u(\text{VST})} = \frac{0.072}{93.7 \times 10^{-5}} = 76.84 \text{ kN/m}^2$

$$c_{u\,(\text{corrected})} = \lambda c_{u\,(\text{VST})} = [1.7 - 0.54\log(\text{PI})](76.84)$$

$$= [1.7 - 0.54\log(51 - 18)](76.84) = \mathbf{67.62\ kN / m^2}$$

2.9 a. From Eq. (2.33), $K = 0.0021D^3 = 0.0021(2)^3 = 0.0168$

$$c_{u(\text{VST})} = \frac{T}{K} = \frac{12.4}{0.0168} = \mathbf{738.1\ lb / ft^2}$$

b. $c_{u\,(\text{corrected})} = [1.7 - 0.54\log(\text{PI})](738.1)$

$$= [1.7 - 0.54\log(64 - 29)](738.1) = \mathbf{639.3\ lb / ft^2}$$

2.10 $\text{OCR} = \beta \dfrac{c_{u(\text{field})}}{\sigma'_o}$; $\beta = 22(\text{PI})^{-0.48} = 22(51 - 18)^{-0.48} = 4.11$

$$\sigma'_o = (2)(17) + (2)(19 - 9.81) + (3)(17 - 9.81) = 73.95\ \text{kN / m}^2$$

$$c_{u\,(\text{VST})} = 76.84\ \text{kN/m}^2$$

$$\text{OCR} = (4.11)\left(\frac{76.84}{73.95}\right) = \mathbf{4.27}$$

2.11 $\gamma = 15.5\ \text{kN / m}^3$; $\underbrace{\sigma'_o}_{(\text{MN/m}^2)} = \left(\underbrace{\gamma}_{(\text{kN/m}^3)} \times \underbrace{\text{depth}}_{\text{m}}\right)\dfrac{1}{1000}$

| Depth | $\sigma'_o$ (MN / m²) | $q_c$ (MN / m²) | $\phi'$[a] (deg) |
|---|---|---|---|
| 1.5 | 0.0233 | 2.06 | 40 |
| 3.0 | 0.0465 | 4.23 | 40.2 |
| 4.5 | 0.0698 | 6.01 | 39.9 |
| 6.0 | 0.093 | 8.18 | 40 |
| 7.5 | 0.1163 | 9.97 | 39.9 |
| 9.0 | 0.1395 | 12.42 | 40.1 |
| [a]Eq. (2.47) | | Av. $\phi'$ = **40°** | |

2.12

| Depth (m) | $\sigma'_o$ (kN / m²) | $p_a$ (kN / m²) | $q_c$ (kN / m²) | $D_R$ (%) [Eq. (2.45)] |
|---|---|---|---|---|
| 1.5 | 23.3 | 100 | 2060 | **42.9** |
| 3.0 | 46.5 | 100 | 4230 | **53.9** |
| 4.5 | 69.8 | 100 | 6010 | **58.3** |
| 6.0 | 93 | 100 | 8180 | **63.1** |
| 7.5 | 116.3 | 100 | 9970 | **65.7** |
| 9.0 | 139.5 | 100 | 12420 | **69.5** |

2.13 a. $\sigma_o = (5)(116) + (124)(12) = 2068 \text{ lb / ft}^2$. Eq. (2.51):

$$c_u = \frac{q_c - \sigma_o}{N_k} = \frac{(90 \times 144) - 2068}{15} \approx \mathbf{726 \text{ lb / ft}^2}$$

b. $\sigma'_o = (5)(116) + (124 - 62.4)(12) = 1319.2 \text{ lb / ft}^2$. Eq. (2.55):

$$\text{OCR} = 0.37\left(\frac{q_c - \sigma_o}{\sigma'_o}\right)^{1.01} = (0.37)\left[\frac{(90 \times 144) - 2068}{1319.2}\right]^{1.01} = \mathbf{3.12}$$

2.14 Eq. (2.56):

$$E_p = 2(1 + \mu_s)(V_o + v_m)\left(\frac{\Delta p}{\Delta v}\right) = (2)(1 + 0.5)\left(535 + \frac{45 + 180}{2}\right)\left(\frac{326.5 - 42.4}{180 - 46}\right)$$

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

2.15 a. $K_D = \frac{p_o - u_o}{\sigma'_o} = \frac{280 - (9.81)(8 - 3)}{95} = 2.43$. Eq. (2.63):

$$K_o = (K_D/1.5)^{0.47} - 0.6 = (2.43/1.5)^{0.47} - 0.6 = \mathbf{0.65}$$

b. Eq. (2.64): $\text{OCR} = (0.5K_D)^{1.56} = (0.5 \times 2.43)^{1.56} = \mathbf{1.36}$

c. $E = (1 - \mu^2)E_D = (1 - 0.35^2)(34.7)(350 - 280) = \mathbf{2131 \text{ kN/m}^2}$

2.16 $K_D = \frac{p_o - u_o}{\sigma'_o} = \frac{260-(3)(9.81)}{(2)(15)+(3)(19-9.81)} = 4.01$. Eq. (2.69a):

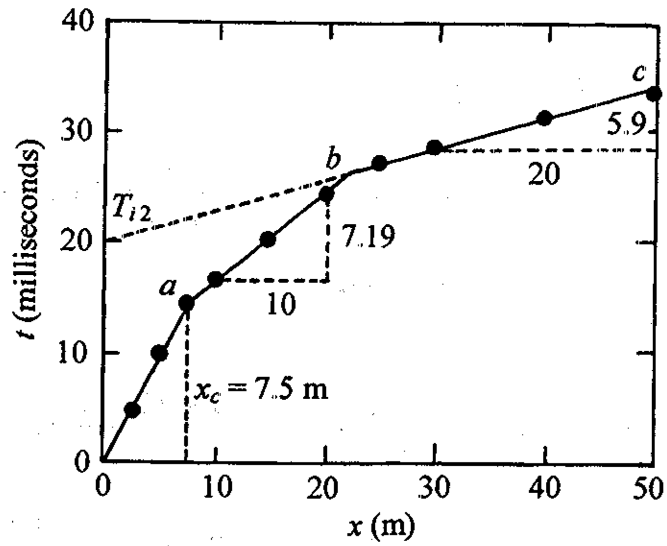
$$\phi' = 31 + \frac{K_D}{0.236 + 0.066K_D} = 31 + \frac{4.01}{0.236+(0.066)(4.01)} = \mathbf{39°}$$

2.17 Eq (2.70): Recovery ratio = 3.2ft/5 ft = **64%**

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

$$1900 = \sqrt{\frac{E_s}{(18/9.81)} \times \frac{0.68}{(0.36)(1.32)}}; \quad E_x = \mathbf{3125\ kN/m^2}$$

2.19 A time-distance plot is shown.




Slope of $0a = \frac{1}{v_1} = \frac{15.24\times10^{-3}}{7.5}$

$v_1 = \frac{7.5\times10^{-3}}{15.24} =$ **492 m / sec** (top layer)

$v_2 = \frac{10\times10^3}{7.19} \approx$ **1390 m / sec**

$v_3 = \frac{20\times10^3}{5.19} \approx$ **3390 m / sec**

$x_c = 7.5$m

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

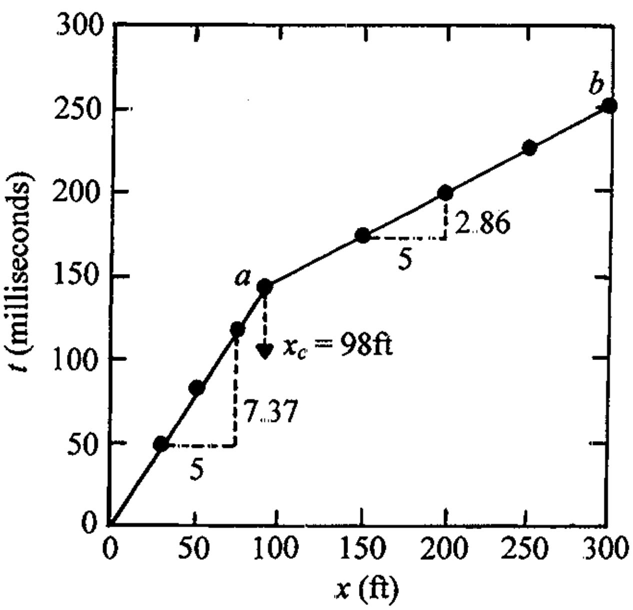
Eq. (2.74): $Z_2 = \frac{1}{2}\left[T_{i2} - \frac{2Z_1\sqrt{v_3^2 - v_1^2}}{(v_3)(v_1)}\right]\left[\frac{v_3 v_2}{\sqrt{v_3^2 - v_2^2}}\right]$; $T_{i2} \approx 20 \times 10^{-3}$ sec

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

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

So, $Z_2 = (½)(0.02 - 0.0105)(1524) = \mathbf{7.24\ m}$

2.20 A time-distance plot is shown.




Slope of $Oa = \frac{1}{v_1} = \frac{7.37 \times 10^{-3}}{5}$

$v_1 = \mathbf{678.4\ ft / sec}$

Slope of $ab = \frac{1}{v_2} = \frac{2.86 \times 10^{-3}}{5}$

$v_2 = \mathbf{1748.25\ ft / sec}$

$$Z_1 = \frac{1}{2}\sqrt{\frac{v_2 - v_1}{v_2 + v_1}}x_c$$

$$= \frac{1}{2}\sqrt{\frac{1748.25 - 678.4}{1748.25 + 678.4}} \times 98 = \mathbf{32.87\ ft}$$

# CHAPTER 3

3.1 a. Eq. (3.3) and Table 3.1: $q_{\text{all}} = \dfrac{q_u}{\text{FS}} = \dfrac{1}{\text{FS}}\left(c'N_c + qN_q + \dfrac{1}{2}\gamma BN_\gamma\right)$

For $\phi' = 28°, N_c = 31.61, N_q = 17.81, N_\gamma = 13.7$

$$q_{\text{all}} = \frac{1}{4}\left[(400)(31.61) + (110)(3)(17.81) + \frac{1}{2}(110)(3)(13.7)\right] = \mathbf{5195\ lb/ft^2}$$

b. $q_{\text{all}} = \dfrac{q_u}{\text{FS}} = \dfrac{1}{\text{FS}}\left(c'N_c + qN_q + \dfrac{1}{2}\gamma BN_\gamma\right)$

For $\phi' = 35°$, from Table 3.1, $N_c = 57.75, N_q = 41.44, N_\gamma = 45.41$

$$q_{\text{all}} = \frac{1}{4}\left[0 + (1.2 \times 17.8)(41.44) + \frac{1}{2}(17.8)(1.5)(45.41)\right] = \mathbf{372.8\ kN/m^2}$$

c. Table 3.1: $\phi' = 30°, N_q = 22.46, N_\gamma = 19.13$

Eq. (3.7), with $c' = 0$

$$q_{\text{all}} = \frac{q_u}{\text{FS}} = \frac{1}{\text{FS}}(qN_q + 0.4\gamma BN_\gamma)$$

$$= \frac{1}{4}[(2 \times 16.5)(22.46) + (0.4)(16.5)(3)(19.13)] = \mathbf{280\ kN/m^2}$$

3.2 Eq. (3.7); $c' = 0$

$$q_{\text{all}} = \frac{q_u}{\text{FS}} = \frac{1}{\text{FS}}(qN_q + 0.4\gamma BN_\gamma)$$

$$q_{\text{all}} = \frac{Q_{\text{all}}}{B^2} = \frac{1805}{B^2}$$

From Table 3.1, for $\phi' = 34°, N_q = 36.5, N_\gamma = 38.04$

$$\frac{1805}{B^2} = \frac{1}{3}[(15)(15.9)(36.5) + (0.4)(15.9)(B)(38.04)]$$

By trial and error, $B$ = **2 m**

3.3 a. In Eq. (3.25), all inclination factors are unity. Also, since it is a strip foundation, $B/L$ = 0. So all shape factors are equal to unity. Therefore

$$q_u = c'N_cF_{cd} + qN_qN_{qd} + ½\gamma BN_\gamma F_{\gamma d}$$

Table 3.3: $\phi' = 28°$, $N_c = 25.8$, $N_q = 14.72$, $N_\gamma = 16.72$

Eq. (3.30): $F_{cd} = 1 + 0.4(D_f/B) = 1 + 0.4(3/3) = 1.4$

Eq. (3.31): $F_{qd} = 1 + 2\tan\phi'(1 - \sin\phi')^2(D_f/B) = 1 + (0.299)(3/3) = 1.299$

Eq. (3.32): $F_{\gamma d} = 1$

$$q_u = (400)(25.8)(1.4) + (3)(110)(14.72)(1.299) + ½(110)(3)(16.72)(1)$$

$$= 14{,}448 + 6310 + 2758.8 \approx 23{,}517 \text{ lb / ft}^2$$

$q_{all} = q_u/4 \approx$ **5879 lb / ft²**

b. $F_{ci} = F_{qi} = F_{\gamma i} = 1$; $F_{cs} = F_{qs} = F_{\gamma s} = 1$; $F_{\gamma d} = 1$; $c' = 0$

$$q_{all} = \frac{q_u}{\text{FS}} = \frac{1}{\text{FS}}(qN_q + \frac{1}{2}\gamma BN_\gamma)$$

Table 3.3: $N_q = 33.3$; $N_\gamma = 48.03$

$F_{qd} = 1 + 2\tan\phi'(1-\sin\phi')^2(D_f/B) = 1 + 0.25(1.2/1.5) = 1.2$

$q_{all}$ = ¼[(1.2)(17.8)(33.3)(1.2) + ½(17.8)(1.5)(48.03)] = **373.7 kN / m²**

c. $q_u = qN_qF_{qd}F_{qs} + ½\gamma BN_\gamma F_{\gamma d}F_{\gamma s}$

$\phi' = 30°$. From Table 3.3, $N_q = 18.4$; $N_\gamma = 22.4$

Eqs. (3.29) and (3.32): $F_{\gamma s} = 0.6$; $F_{\gamma d} = 1$

Eq. (3.28): $F_{qs} = 1 + \tan\phi' = 1.577$

Eq. (3.31): $F_{qd} = 1 + 2\tan\phi'(1-\sin\phi')^2(D_f/B) = 1 + 0.29(2/3) = 2.294$

$q_{all} = ¼[(2)(16.5)(18.4)(1.193)(1.577) + ½(16.5)(3)(22.4)(0.6)(1) =$ **368.8 kN / m²**

3.4 $$Q_{all} = \left(\frac{1}{FS}\right)B^2\left[c'N_cF_{cs}F_{cd}F_{ci} + qN_qF_{qs}F_{qd}F_{qi} + ½\gamma BN_\gamma N_{\gamma s}N_{\gamma d}N_{\gamma i}\right]$$

$\phi' = 25°$; Table 3.3: $N_c = 20.72$, $N_q = 10.66$, $N_\gamma = 10.88$

$$F_{cs} = 1 + \frac{B}{L}\frac{N_q}{N_c} = 1 + \left(\frac{5.5}{5.5}\right)\left(\frac{10.66}{20.72}\right) = 1.514$$

$$F_{qs} = 1 + \frac{B}{L}\tan\phi' = 1 + \left(\frac{5.5}{5.5}\right)\tan 25 = 1.466$$

$$F_{\gamma s} = 1 - 0.4\frac{B}{L} = 1 - 0.4(1) = 0.6$$

$$F_{cd} = 1 + 0.4\left(\frac{D_f}{B}\right) = 1 + 0.4\left(\frac{4}{5.5}\right) = 1.29$$

$$F_{qd} = 1 + 2\tan\phi'(1-\sin\phi')^2\frac{D_f}{B} = 1 + 0.311\left(\frac{4}{5.5}\right) = 1.226$$

$$F_{\gamma d} = 1$$

$$F_{ci} = F_{qi} = \left(1 - \frac{15}{90}\right)^2 = 0.694$$

$$F_{\gamma i} = \left(1 - \frac{\beta}{\phi'}\right)^2 = \left(1 - \frac{15}{25}\right)^2 = 0.16$$

$$q_{all} = \left(\frac{1}{4}\right)\left(\frac{5.5^2}{1000}\right)\begin{bmatrix}(350)(20.72)(1.514)(1.29)(0.694)\\ +(107\times 4)(10.66)(1.466)(1.226)(0.694)\\ +(0.5)(107)(5.5)(10.88)(0.6)(1)(0.16)\end{bmatrix} = \textbf{119.7 kip}$$

3.5 $$Q_{all} = \left(\frac{1}{FS}\right)B\times L\left[c'N_cF_{cs}F_{cd}F_{ci} + qN_qF_{qs}F_{qd}F_{qi} + ½\gamma BN_\gamma N_{\gamma s}N_{\gamma d}N_{\gamma i} - q'\right]$$

$q' = (1)(16.8) + (1)(19.4 - 9.81) = 26.39$ kN / m²

$\phi' = 25°$. Table 3.3: $N_c = 20.72$; $N_q = 10.66$; $N_\gamma = 10.88$

$$F_{cs} = 1 + \left(\frac{2}{3}\right)\left(\frac{10.66}{20.72}\right) = 1.343$$

$$F_{qs} = 1 + \left(\frac{2}{3}\right)\tan 25 = 1.31$$

$$F_{\gamma s} = 1 - 0.4\left(\frac{2}{3}\right) = 0.73$$

$$F_{cd} = 1 + 0.4\left(\frac{2}{2}\right) = 1.4$$

$$F_{qd} = 1 + 0.311\left(\frac{2}{2}\right) = 1.311$$

$$F_{\gamma s} = 1$$

$$Q_{all} = \left(\frac{1}{4}\right)(2 \times 3)\begin{bmatrix}(50)(20.72)(1.343)(1.4) + (26.39)(10.66)(1.31)(1.311) \\ +(0.5)(19.4 - 9.81)(2)(10.88)(0.73)(1) - 26.39\end{bmatrix} = \mathbf{3721\ kN}$$

3.6 $Q_{all} = 150{,}000$ lb = 150 kip; $Q_u = (\text{FS})(Q_{all}) = (3)(150) = 450$ kip

Also, $q = \gamma D_f = (0.115)(3) = 0.345\ \text{kip / ft}^2$

$$q_u = \frac{450}{B^2} \qquad \text{(a)}$$

For $\phi' = 40°$, Table 3.3 gives $N_q = 64.20$, $N_\gamma = 109.41$

$F_{qs} = 1 + (B/L)\tan\phi' = 1 + (B/B)\tan 40° = 1.839$; $F_{qd} = 1 + 0.214(3/B)$

$F_{\gamma s} = 1 - 0.4(B/B) = 0.6$; $F_{\gamma d} = 1$

$$q_u = (0.345)(64.20)(1.839)\left(1 + \frac{0.642}{B}\right) + \frac{1}{2}(0.115)(B)(109.41)(0.6)(1)$$

$$= 40.73 + \frac{26.15}{B} + 3.77B \qquad \text{(b)}$$

Combining Eqs. (a) and (b)

$$\frac{450}{B^2} = 40.73 + \frac{26.15}{B} + 3.77B$$

By trial and error, Eq. (c) gives $B \approx$ **2.75 ft**

3.7 a.

| Depth (ft) | $\sigma'_o$ (lb / in.$^2$) | $p_a$ (lb / in.$^2$) | $N_{60}$ | $\phi'$ (deg) [Eq. (2.25)] |
|---|---|---|---|---|
| 5 | 3.82 | 14.7 | 11 | 40.5 |
| 10 | 7.64 | 14.7 | 14 | 40.3 |
| 15 | 11.46 | 14.7 | 16 | 39.6 |
| 20 | 15.28 | 14.7 | 21 | 40.5 |
| 25 | 19.1 | 14.7 | 24 | 40.4 |

Av. $\phi' = 40.26° \approx$ **40°**

b. $q_u = BL(qN_q F_{qs} F_{qd} + \frac{1}{2}\gamma B N_\gamma F_{\gamma s} F_{\gamma d})$

$\phi' = 40°$. Table 3.3: $N_q = 64.2$; $N_\gamma = 109.41$

$F_{qs} = 1 + (8/8)\tan 40 = 1.84$

$F_{qd} = 1 + 2\tan 40(1 - \sin 40)^2(5/8) = 1.134$

$F_{\gamma s} = 1 - 0.4(8/8) = 0.6$

$F_{\gamma d} = 1$

$$Q_u = \frac{(8 \times 8)}{1000}\left[(5 \times 110)(64.2)(1.84)(1.134) + \frac{1}{2}(110)(8)(109.41)(0.6)(1)\right]$$

= **6563.9 kip**

3.8 From Eq. (3.44)

$$I_r = \frac{E_s}{2(1+\mu_s)(c' + q'\tan\phi')}$$

$$q' = \gamma\left(D_f + \frac{B}{2}\right) = (17)\left(1 + \frac{1}{2}\right) = 25.5 \text{ kN / m}^2$$

$$I_r = \frac{1400}{2(1+0.35)(72 + 25.5\tan 20)} = 6.38$$

From Eq. (3.45)

$$I_{r(cr)} = \frac{1}{2}\left\{\exp\left[\left(3.3 - 0.45\frac{B}{L}\right)\cot\left(45 - \frac{\phi'}{2}\right)\right]\right\}$$

$$= \frac{1}{2}\left\{\exp\left[\left(3.3 - 0.45\frac{1}{2}\right)\cot\left(45 - \frac{20}{2}\right)\right]\right\} = 40.36$$

Since $I_{r(cr)} > I_r$, use Eqs. (3.46) and (3.48).

$$F_{\gamma c} = F_{qc} = \exp\left\{\left(-4.4 + 0.6\frac{B}{L}\right)\tan\phi' + \left[\frac{3.07\sin\phi'\log(2I_r)}{1+\sin\phi'}\right]\right\}$$

$$= \exp\left\{\left(-4.4 + 0.6\frac{1}{2}\right)\tan 20 + \left[\frac{3.07\sin 20\log(2\times 6.38)}{1+\sin 20}\right]\right\} = 0.534$$

$$F_{cc} = F_{qc} = \frac{1 - F_{qc}}{N_q \tan\phi'}$$

For $\phi' = 20°$, $N_q = 6.4$ (Table 3.3).

$$F_{cc} = 0.534 - \frac{1 - 0.534}{6.4\tan 20} = 0.334$$

Now, from Eq. (3.43)

$$q_u = c'N_cF_{cs}F_{cd}F_{cc} + q\,N_qF_{qs}F_{qd}F_{qc} + \tfrac{1}{2}\gamma B\,N_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma c}$$

From Table 3.3, for $\phi' = 20°$, $N_c = 14.83$, $N_q = 6.4$, $N_\gamma = 5.39$. From Section 3.6

$F_{cs} = 1 + (N_q/N_c)(B/L) = 1 + (6.4/14.83)(½) = 1.216$

$F_{qs} = 1 + (B/L)\tan\phi' = 1 + (½)\tan 20 = 1.182$

$F_{\gamma s} = 1 - 0.4(B/L) = 1 - 0.4(½) = 0.8$

$F_{cd} = 1 + 0.4(D_f/B) = 1 + 0.4(1/1) = 1.4$

$F_{qd} = 1 + 2\tan\phi'(1 - \sin\phi')^2(D_f/B) = 1 + 2\tan 20(1 - \sin 20)^2(1/1) = 1.315$

$F_{\gamma d} = 1$

Thus

$$q_u = (72)(14.83)(1.216)(1.4)(0.334) + (1 \times 17)(6.4)(1.182)(1.315)(0.534)$$

$$+ (½)(17)(1.0)(5.39)(0.8)(1)(0.534) = \mathbf{717\ kN / m^2}$$

3.9 $B' = B - 2e = 1.5 - 2(0.15) = 1.2$ m; $L = 1.5$ m

$q_u = q N_q F_{qs} F_{qd} + ½\gamma B' N_\gamma F_{\gamma s} F_{\gamma d}$

Table 3.3: $\phi' = 36°$; $N_q = 37.75$; $N_\gamma = 56.31$

$F_{qs} = 1 + (B'/L)\tan\phi' = 1 + (1.2/1.5)\tan 36 = 1.58$

$F_{qd} = 1 + 2\tan\phi'(1 - \sin\phi')^2 (D_f/B) = 1 + 2\tan 36(1 - \sin 36)^2(1/1.5) = 1.165$

$F_{\gamma s} = 1 - 0.4(B/L) = 1 - 0.4(1.2/1.5) = 0.68$

$F_{\gamma d} = 1$

$q_u = (1 \times 17)(37.75)(1.58)(1.165) + (½)(17)(1.2)(56.31)(0.68)(1)$

$= 1571.9$ kN / m²

$$Q_{all} = \frac{q_u B'L}{FS} = \frac{(1571.9)(1.2)(1.5)}{4} = \mathbf{707.3\ kN}$$

3.10 $B' = 8 - (2)(0.65) = 6.7$ ft; $L = 8$ ft

$q'_u = c'N_c F_{cs} F_{cd} + q'N_q F_{qs} F_{qd} + ½\gamma' B' N_\gamma F_{\gamma s} F_{\gamma d}$

Table 3.3: $\phi' = 26°$; $N_c = 22.25$; $N_q = 11.85$; $N_\gamma = 12.54$

Section 3.6:

$F_{cs} = 1 + (N_q/N_c)(B'/L) = 1 + (11.85/22.25)(6.7/8) = 1.446$

$F_{qs} = 1 + (B'/L)\tan\phi' = 1 + (6.7/8)\tan 26 = 1.408$

$F_{\gamma s} = 1 - 0.4(B'/L) = 1 - 0.4\,(6.7/8) = 0.665$

$F_{cd} = 1 + 0.4(D_f/B) = 1 + 0.4(6.5/8) = 1.325$

$F_{qd} = 1 + 2\tan 26(1 - \sin 26)^2(6.5/8) = 1.25$

$F_{\gamma d} = 1$

$$q'_u = (500)(22.25)(1.446)(1.325) + [(3)(110) + (3.5)(122 - 62.4)] \times$$

$$(11.85)(1.408)(1.25) + \tfrac{1}{2}(122 - 62.4)(6.7)(12.54)(0.665)(1)$$

$$= 34{,}213 \text{ lb / ft}^2$$

$$Q_u = q_u B'L = [(34{,}213)(6.7)(8)]\frac{1}{1000} = \mathbf{1833.8\ kip}$$

3.11 $B = 5$ ft; $L = 6$ ft; $e = B/2 - 2 = 2.5 - 2 = 0.5$ ft. Eq. (3.74):

$$Q_{ult} = BL\left[c'N_{c(e)}F_{cs(e)} + qN_{q(e)}F_{qs(e)} + \frac{1}{2}\gamma' BN_{\gamma(e)}F_{\gamma s(e)}\right]$$

$$F_{cs(e)} = 1.2 - 0.025\frac{L}{B} = 1.2 - (0.25)\left(\frac{6}{5}\right) = 1.17$$

$$F_{\gamma s(e)} = 1 + \left(\frac{2e}{B} - 0.68\right)\frac{B}{L} + \left[0.43 - \left(\frac{3}{2}\right)\left(\frac{e}{B}\right)\right]\left(\frac{B}{L}\right)^2$$

$$= 1 + \left(\frac{2 \times 0.5}{5} - 0.68\right)\left(\frac{5}{6}\right) + \left[0.43 - \left(\frac{3}{2}\right)\left(\frac{0.5}{5}\right)\right]\left(\frac{5}{6}\right)^2 = 0.794$$

$$F_{qs(e)} = 1$$

$$q = (2)(105) + (2)(118 - 62.4) = 321.2 \text{ lb / ft}^2$$

For $e/B = 0$ and $\phi' = 25°$, from Figures 3.20, 3.21, and 3.22: $N_{c(e)} = 16.8$, $N_{q(e)} = 12$, $N_{\gamma(e)} = 6.5$

$$Q_{ult} = (5)(6)[(400)(16.8)(1.17) + (321.2)(12)(1) + (\tfrac{1}{2})(118 - 62.4)(5)(6.5)(0.794)]$$

$$= 373{,}026 \text{ lb} \approx \mathbf{373\ kip}$$

3.12 $e = 70/450 = 0.156$; $c' = 0$. Eq. (3.74):

$$Q_{ult} = B^2\left[qN_{q(e)}F_{qs(e)} + \frac{1}{2}\gamma' BN_{\gamma(e)}F_{\gamma s(e)}\right]$$

$\phi' = 30°$; $e/B = 0.156/B$

$$Q_{ult} = (450)(\text{FS}) = (450)(6) = 2700 \text{ kN}$$

$F_{qs(e)} = 1; B = L$

$$F_{\gamma s(e)} = 1+\left(\frac{2\times 0.156}{B}-0.68\right)(1)+\left[0.43-(1.5)\left(\frac{0.156}{B}\right)\right](1)^2$$

$$= 1+\left(\frac{0.312}{B}-0.68\right)+\left(0.43-\frac{0.234}{B}\right)$$

$$= 0.75+\frac{0.312}{B}-\frac{0.234}{B}$$

Hence

$$2700 = B^2\left\{(1.2\times 16)[N_{q(e)}](1)+\frac{1}{2}(19-9.81)(B)[N_{\gamma(e)}]\left(0.75-\frac{0.312}{B}-\frac{0.234}{B}\right)\right\}$$

$$2700 = B^2\left[19.2N_{q(e)}+(4.595)(B)N_{\gamma(e)}\left(0.75-\frac{0.312}{B}-\frac{0.234}{B}\right)\right] \qquad \text{(a)}$$

TRIAL AND ERROR: Let $B = 2$ m; $e/B = 0.156/2 = 0.078$; $\phi' = 30°$

From Figures 3.21 and 3.22, $N_{q(e)} \approx 20$; $N_{\gamma(e)} \approx 14$

Right-hand side of Eq. (a):

$$(2)^2\left[(19.2)(20)+(4.595)(2)(14)\left(0.75-\frac{0.312}{2}-\frac{0.234}{2}\right)\right] = 1781.4\text{ kN} < 2700\text{ kN}$$

Let $B = 2.5$ m; $e/B = 0.156/2.5 = 0.0624$; $\phi' = 30°$

From Figures 3.21 and 3.22, $N_{q(e)} \approx 21$; $N_{\gamma(e)} \approx 16$

Right-hand side of Eq. (a):

$$(2.5)^2 = \left[(19.2)(20)+(4.595)(2.5)(16)\left(0.75-\frac{0.312}{2}-\frac{0.234}{2}\right)\right] = 3130\text{ kN} < 2700\text{ kN}$$

Let $B = 2.25$ m; $e/B = 0.156/2.25 = 0.0693$; $\phi' = 30°$

From Figures 3.21 and 3.22, $N_{q(e)} \approx 20.5$; $N_{\gamma(e)} \approx 15$

Right-hand side of Eq. (a):

$$(2.25)^2 = \left[(19.2)(20.5) + (4.595)(2.25)(15)\left(0.75 - \frac{0.312}{2} - \frac{0.234}{2}\right)\right] = 2391 \text{ kN} < 2700 \text{ kN}$$

So, $B \approx$ **2.4 m**

3.13 $e_B/B = 0.4/4 = 0.1$; $e_L/L = 1.2/6 = 0.2$. So Case II, Figure 3.16 applies.

From Figure 3.16, $L_1/L = 0.865$ and $L_2/L = 0.22$

$L_1 = (0.865)(6) = 5.19$ ft; $L_2 = (0.22)(6) = 1.32$ ft

Eq. (3.64): $A' = ½(L_1 + L_2)B = ½(5.19 + 1.32)(4) = 13.02 \text{ ft}^2$

Eq. (3.65): $B' = A'/L_1 = 13.02/5.19 = 2.51$ ft

Eq. (3.66): $L' = 5.19$ ft

$q'_u = qN_q F_{qs} F_{qd} + ½\gamma' B' N_\gamma F_{\gamma s} F_{\gamma d}$

Table 3.3: $\phi' = 35°$; $N_q = 33.3$; $N_\gamma = 48.03$

$F_{qs} = 1 + (B'/L')\tan\phi' = 1 + (2.51/5.19)\tan 35 = 1.339$

$F_{\gamma s} = 1 - 0.4(B'/L') = 1 - 0.4\ (2.51/5.19) = 0.806$

$F_{qd} = 1 + 2\tan 35(1 - \sin 35)^2(3/4) = 1.191$

$F_{\gamma d} = 1$

$q'_u = (115 \times 3)(33.3)(1.339)(1.191) + ½(115)(2.51)(48.03)(0.806)(1) = 23{,}908 \text{ lb/ft}^2$

$$Q_{\text{all}} = \frac{q_u B'L'}{\text{FS}} = \frac{(23{,}908)(2.51)(5.19)}{(4)(1000)} = \mathbf{77.86\ kip}$$

3.14 $e_B/B = 1.5/4 = 0.375$; $e_L/L = 0.06/6 = 0.01$. So Case III, Figure 3.17 applies.

From Figure 3.17, $B_1/B = 0.3$ and $B_2/B = 0.25$

$B_1 = (0.3)(4) = 1.2$ ft; $B_2 = (0.25)(4) = 1$ ft

Eq. (3.67): $A' = ½(B_1 + B_2)L = ½(1.2 + 1)(6) = 6.6 \text{ ft}^2$

Eq. (3.68): $B' = A'/L = 6.6/6 = 1.1$ ft

Eq. (3.66): $L' = L = 6$ ft

$F_{qs} = 1 + (B'/L')\tan\phi' = 1 + (1.1/6)\tan 35 = 1.128$

$F_{\gamma s} = 1 - 0.4(B'/L') = 1 - 0.4\ (1.1/6) = 0.927$

$F_{qd} = 1 + 2\tan 35(1 - \sin 35)^2(3/4) = 1.191$

$F_{\gamma d} = 1$

$q'_u = (115 \times 3)(33.3)(1.128)(1.191) + ½(115)(1.1)(48.03)(0.927)(1) = 18{,}250\ \text{lb}/\text{ft}^2$

$$Q_{all} = \frac{q_u B'L'}{\text{FS}} = \frac{(18{,}250)(1.1)(6)}{(4)(1000)} = \mathbf{30.1\ kip}$$

# CHAPTER 4

4.1 Eq. (4.3): $q_u = qN_q^* F_{qs}^* + \frac{1}{2}\gamma BN_\gamma^* F_{\gamma s}^*$

$\frac{H}{B} = \frac{1.5}{2.5} = 0.6$

$\phi' = 40°$. Figures 4.4 and 4.5: $N_q^* \approx 380$; $N_\gamma^* \approx 200$

Eqs. (4.4) and (4.5) and Figure 4.6:

$$F_{qs}^* = 1 - m_1\left(\frac{B}{L}\right) = 1 - 0.46\left(\frac{1.5}{2.5}\right) = 0.724$$

$$F_{\gamma s}^* = 1 - m_2\left(\frac{B}{L}\right) = 1 - 0.52\left(\frac{1.5}{2.5}\right) = 0.688$$

$$Q_{all} = \frac{q_u BL}{FS} = \frac{(1.5 \times 2.5)}{3}\left[(1.2 \times 17)(380)(0.724) + \frac{1}{2}(17)(1.5)(200)(0.688)\right] \approx \mathbf{9209\ kN}$$

4.2 $\frac{H}{B} = \frac{0.6}{1.5} = 0.4$

$\phi' = 35°$. $N_q^* \approx 300$; $N_\gamma^* \approx 100$

Eqs. (4.4) and (4.5) and Figure 4.6:

$$F_{qs}^* = 1 - m_1\left(\frac{B}{L}\right) = 1 - 0.55\left(\frac{1.5}{1.5}\right) = 0.45$$

$$F_{\gamma s}^* = 1 - m_2\left(\frac{B}{L}\right) = 1 - 0.58\left(\frac{1.5}{1.5}\right) = 0.42$$

$$Q_{all} = \frac{q_u BL}{FS} = \frac{(1.5 \times 1.5)}{3}\left[(15 \times 1)(300)(0.45) + \frac{1}{2}(15)(1.5)(100)(0.42)\right] = \mathbf{1873\ kN}$$

4.3 Eq. (4.8) and Table 4.1: $\frac{B}{H} = \frac{1.4}{0.7} = 2$

$$q_u = c_u N_c^* + q$$

$$N_c^* = 5.24$$

$$q_u = (105)(5.24) + (18)(1) = \mathbf{568.2\ kN/m^2}$$

4.4 Eq. (4.26): $q_u = \left(1 + 0.2\frac{B}{L}\right)c_2 N_c + \left(1 + \frac{B}{L}\right)\left(\frac{2c_a H}{B}\right) + \gamma_1 D_f$

$$\frac{B}{L} = 0; \quad \frac{c_2}{c_1} = \frac{585}{1000} = 0.585$$

From Figure 4.9 and Eq. (4.28):

$$\frac{c_a}{c_1} \approx 0.975; \quad c_a = (0.975)(1000) = 975\ \text{lb/ft}^2$$

$$q_u = (585)(5.14) + \frac{(2)(975)(1.65)}{3} + (121)(1.65) = 4279\ \text{lb/ft}^2$$

CHECK — Eq. (4.27):

$$q_u = q_t = \left(1 + 0.2\frac{B}{L}\right)c_1 N_c + \gamma_1 D_f = (1000)(5.14) + (121)(1.65) = 5339.7\ \text{lb/ft}^2$$

So, $q_u = 4279\ \text{lb/ft}^2$

$$q_{all} = \frac{q_u}{FS} = \frac{4279}{3} \approx \mathbf{1426\ lb/ft^2}$$

4.5 $\frac{B}{L} = \frac{0.92}{1.22} = 0.754; \quad \frac{c_2}{c_1} = \frac{43.2}{71.9} = 0.6$

From Figure 4.9: $\frac{c_a}{c_1} \approx 0.975; \quad c_a = (0.975)(71.9) = 70.1\ \text{kN/m}^2$

Eq. (4.26):

$$q_u = \left(1+0.2\frac{B}{L}\right)c_2 N_c + \left(1+\frac{B}{L}\right)\left(\frac{2c_a H}{B}\right) + \gamma_1 D_f$$

$$= [1+(0.2)(0.754)](43.2)(5.14) + (1+0.754)\left[\frac{(2)(70.1)(0.76)}{0.92}\right] + (17.29)(0.92)$$

$$= 255.53 + 203.15 + 15.91 = 474.6 \text{ kN/m}^2$$

CHECK — Eq. (4.27):

$$q_u = q_t = \left(1+0.2\frac{B}{L}\right)c_1 N_c + \gamma_1 D_f = [1+(0.2)(0.754)](71.9)(5.14) + (17.29)(0.92)$$

$$= 441.2 \text{ kN/m}^2$$

$$Q_u = (441.2)(0.92)(1.22) = \mathbf{495.2\ kN}$$

4.6 a. Eq. (4.21) [with $B/L = 0$]: $q_u = 5.14c_2 + \gamma_1 H^2 \left(1+\frac{2D_f}{H}\right)\frac{K_s \tan\phi_1'}{B} + \gamma_1 D_f$

Eq. (4.22): $\frac{q_2}{q_1} = \frac{5.14c_2}{0.5\gamma_1 B N_{\gamma(1)}}$

For $\phi' = 40°$, $N_{\gamma(1)} = 109.41$; $N_{q(1)} = 64.2$ (Table 3.3)

$$\frac{q_2}{q_1} = \frac{(5.14)(30)}{(0.5)(18)(2)(109.41)} = 0.078$$

From Figure 4.8, for $\phi_1' = 40°$ and $\frac{q_2}{q_1} = 0.078$, $K_s \approx 2.5$

$$q_u = (5.14)(30) + (18)(1.5)^2\left(1+\frac{2\times 1.2}{1.5}\right)\frac{2.5\tan 40}{2} + (18)(1.2) = 286.3 \text{ kN/m}^2$$

CHECK —

$$q_u = \gamma_1 D_f N_{q(1)} F_{qs(1)} + \frac{1}{2}\gamma_1 B N_{\gamma(1)} F_{\gamma s(1)} = (18)(1.2)(64.2)(1) + \frac{1}{2}(18)(2)(109.41)(1)$$

$$= 3356 \text{ kN/m}^2$$

So, $q_u = \mathbf{286.3\ kN/m^2}$

b. Minimum value of $H/B$ will be when, from Eq. (4.21) (*Note*: $B/L = 0$)

$$5.14c_2 + \gamma_1 H^2\left(1+\frac{2D_f}{H}\right)\frac{K_s \tan\phi_1'}{B} + \gamma_1 D_f = \underbrace{\gamma_1 D_f N_{q(1)} + \frac{1}{2}\gamma_1 B N_{\gamma(1)}}_{3356\ \text{kN/m}^2}$$

or

$$(5.14)(30) + (18)H^2\left(1+\frac{2\times 1.2}{H}\right)\frac{2.5\tan 40}{2} + (18)(1.2) = 3356\ \text{kN/m}^2$$

$$175.8 + 18.88H^2\left(1+\frac{2.4}{H}\right) = 3356\ \text{kN/m}^2$$

By trial and error, $H \approx \mathbf{11.9\ m}$

4.7 Eq. (4.23):

$$q_u = \left[\gamma_1 (D_f + H) N_{q(2)} F_{qs(2)} + \frac{1}{2}\gamma_2 B N_{\gamma(2)} F_{\gamma s(2)}\right]$$

$$+\gamma_1 H^2\left(1+\frac{B}{L}\right)\left(1+\frac{2D_f}{H}\right)\frac{K_s \tan\phi_1'}{B} - \gamma_1 H$$

$\phi' = 30°$. Table 3.3: $N_{q(2)} = 18.4$; $N_{\gamma(2)} = 22.4$

Eqs. (3.28) and (3.29):

$$F_{qs(2)} = 1 + \frac{B}{L}\tan\phi_2' = 1 + \frac{1.5}{1.5}\tan 30 = 1.577$$

$$F_{\gamma s(2)} = 1 - 0.4\frac{B}{L} = 1 - 0.4\left(\frac{1.5}{1.5}\right) = 0.6$$

Eq. (4.25): $\dfrac{q_2}{q_1} = \dfrac{\gamma_2 N_{\gamma(2)}}{\gamma_1 N_{\gamma(1)}}$

$\phi_1' = 40°$. $N_{\gamma(1)} = 109.41$ (Table 3.3)

$$\frac{q_2}{q_1} = \frac{(16)(18.4)}{(18)(109.41)} = 0.149$$

Figure 4.8: $\phi_1' = 40°$; $\frac{q_2}{q_1} = 0.149$; $K_s \approx 3$

$$q_u = [(18)(1+0.8)(18.4)(1.577) + (0.5)(16)(1.5)(22.4)(0.6)]$$

$$+(18)(0.8)^2\left(1+\frac{1.5}{1.5}\right)\left[1+\frac{(2)(1)}{0.8}\right]\frac{3\tan 40}{1.5} - (18)(0.8)$$

$$= (940.1 + 161.28) + 135.35 - 14.4 = 1222.3 \text{ kN/m}^2$$

CHECK — Eq. (4.24): $q_t = \gamma_1 D_f N_{q(1)} F_{qs(1)} + \frac{1}{2}\gamma_1 B N_{\gamma(1)} F_{\gamma s(1)}$

$\phi_1' = 40°$. Table 3.3: $N_{q(1)} = 64.2$; $N_{\gamma(1)} = 109.41$

$$F_{qs(1)} = 1 + \frac{B}{L}\tan\varphi_2' = 1 + \frac{1.5}{1.5}\tan 40 = 1.839$$

$$F_{\gamma s(1)} = 1 - 0.4\frac{B}{L} = 1 - 0.4\left(\frac{1.5}{1.5}\right) = 0.6$$

$$q_t = (18)(1)(64.2)(1.839) + \frac{1}{2}(18)(1.5)(109.41)(0.6) = 2125.2 + 886.2 = 3011.4 \text{ kN/m}^2$$

So, $q_u = 1222.3 \text{ kN/m}^2$

$q_{u\,(\text{net})} = 1222.3 - (1 \times 18) \approx 1204 \text{ kN/m}^2$

$$Q_{\text{all(net)}} = \frac{q_{u(\text{net})} B^2}{\text{FS}} = \frac{(1204)(1.5)^2}{4} = \mathbf{677.25\ kN}$$

4.8 Eq. (4.30): $q_u = qN_q\zeta_q + \frac{1}{2}\gamma B N_\gamma \zeta_\gamma$

$\phi' = 35°$. Table 3.1: $N_q = 41.44$; $N_\gamma = 45.41$

$$\frac{x}{B} = \frac{6}{3} = 2$$

For $\phi' = 35°$, from Figure 4.11, $\zeta_q = 1.31$; $\zeta_\gamma = 2.0$

$q_u = (3 \times 110)(41.44)(1.31) + (½)(110)(3)(45.41)(2) = 32{,}899.8 \text{ lb/ft}^2$

$q_{\text{net}} = q_u - \gamma D_f = 32{,}899.8 - (3 \times 110) = 32{,}569.8 \text{ lb/ft}^2$

Net allowable bearing capacity $= \frac{32{,}569.8}{4} \approx$ **8142 lb / ft²**

4.9 a. $B = 4$ ft; $H = 1.5$ ft. Since $B < H$, $N_s = 0$; $\frac{D_f}{B} = \frac{4}{4} = 1.0$

Eq. (4.33): $q_u = cN_{cq}$

Figure 4.15: $\frac{b}{B} = \frac{6}{4} = 1.5$; $\beta = 50°$; $N_{cq} \approx 6.6$

$$q_{all} = \frac{cN_{cq}}{FS} = \frac{(1500)(6.6)}{3} = \mathbf{3300\ lb / ft^2}$$

b.

| $b$ (ft) | $B$ (ft) | $b/B$ | $N_{cq}$[a] | $q_u = cN_{cq}$ (lb / ft²) |
|---|---|---|---|---|
| 0 | 4 | 0 | 4.9 | **7,350** |
| 4 | 4 | 1 | 5.7 | **8,550** |
| 8 | 4 | 2 | 6.6 | **9,900** |
| 12 | 4 | 3 | 7 | **10,500** |
| 16 | 4 | 4 | 7 | **10,500** |
| 20 | 4 | 5 | 7 | **10,500** |

[a]Figure 4.15. *Note*: $D_f/B = 1$

4.10 Eq. (4.32): $q_u = \frac{1}{2}\gamma BN_{\gamma q}$

$\frac{D_f}{B} = \frac{4}{4} = 1$; $\frac{b}{B} = \frac{6}{4} = 1.5$. From Figure 4.11 for $\frac{D_f}{B} = 1$ and $\frac{b}{B} = 1.5$, $\phi' = 40°$ and $\beta = 30°$, the value of $N_{\gamma q} \approx 135$

$$q_{all} = \frac{0.5\gamma BN_{\gamma q}}{FS} = \frac{(0.5)(110)(4)(135)}{4} = \mathbf{7425\ lb / ft^2}$$

4.11 $\frac{D_f}{B} = \frac{5}{4} = 1.25$. $\phi' = 35°$. Table 3.2: $(D_f/B)_{cr} \approx 5$; $m = 0.25$; $K_u = 0.936$.

So it is a shallow foundation.

Eq. (4.38):

$$F_q = 1+2\left[1+m\left(\frac{D_f}{B}\right)\right]\left(\frac{D_f}{B}\right)K_u \tan\phi'$$

$$= 1+2[1+(0.25)(1.25)](1.25)(0.936)\tan 35 = 3.15$$

$Q_u = F_q A \gamma D_f = (3.15)(4 \times 4)(112)(5) = 28{,}224$ lb ≈ **28.2 kip**

4.12 $\frac{D_f}{B} = \frac{2}{1.2} = 1.67$

$$\left(\frac{D_f}{B}\right)_{\text{cr-square}} = 0.107c_u + 2.6 = (0.107)(74) + 2.5 = 10.4 > 7$$

$$\text{So} \left(\frac{D_f}{B}\right)_{\text{sq}} = 7$$

$$\left(\frac{D_f}{B}\right)_{\text{cr-rectangular}} = \left(\frac{D_f}{B}\right)_{\text{cr-square}}\left[0.73+0.27\left(\frac{L}{B}\right)\right] = 7\left[0.73+0.27\left(\frac{2.4}{1.2}\right)\right] < 1.55\left(\frac{D_f}{B}\right)_{\text{cr-square}}$$

$$\left(\frac{D_f}{B}\right)_{\text{cr}} = 8.89$$

Hence, this is a shallow foundation.

Eq. (4.44): $$\alpha' = \frac{\frac{D_f}{B}}{\left(\frac{D_f}{B}\right)_{\text{cr}}} = \frac{1.67}{8.89} = 0.188$$

Eq. (4.46): $$F^*_{c\text{-rectangular}} = 7.56 + 1.44\left(\frac{B}{L}\right) = 7.56 + 1.44\left(\frac{1.2}{2.4}\right) = 8.28$$

From Figure 4.22, with $\alpha = 0.188$, the value of $\beta = 0.275$

Eq. (4.48):

$Q_u = A(\beta' F^*_c c_u + \gamma D_f) = (1.2 \times 2.4)[(0.275)(8.28)(74) + (18)(2)]$ ≈ **589 kN**

# CHAPTER 5

5.1 Eq. (5.3): $\Delta\sigma = q_o \left\{1 - \frac{1}{\left[1+\left(\frac{B}{2z}\right)^2\right]^{3/2}}\right\}$

$B = 9.5$ ft; $q_o = 3000$ lb / ft$^2$; $z = 7.5$ ft

$$\Delta\sigma = 3000\left\{1 - \frac{1}{\left[1+\left(\frac{9.5}{2\times 7.5}\right)^2\right]^{3/2}}\right\} = \mathbf{1191\ lb / ft^2}$$

5.2 Eq. (5.7): $m = B/z$; Eq. (5.8): $n = L/z$. Refer to areas in Figure 5.4.

**Area 1:** $m = 1.2/8 = 0.15$
$n = 3/8 = 0.375$
$I_1 \approx 0.025$ (Table 5.2)

**Area 2:** $m = 3/8 = 0.375$
$n = 3/8 = 0.375$
$I_2 \approx 0.06$

**Area 3:** $m = 0.15$
$n = 6/8 = 0.75$
$I_3 \approx 0.037$

**Area 5:** $m = 0.375$
$n = 0.75$
$I_4 \approx 0.08$

$$\Delta\sigma = q_o(I_1 + I_2 + I_3 + I_4) = (110)(0.202) \approx \mathbf{22.2\ kN / m^2}$$

5.3 Refer to Figure 5.4.

| Area | $z$ (ft) | $B$ (ft) | $L$ (ft) | $m = B/z$ | $n = L/z$ | $I$ (Table 5.2) |
|---|---|---|---|---|---|---|
| 1 | 20 | 5 | 7 | 0.25 | 0.35 | 0.036 |
| 2 | 20 | 10 | 7 | 0.5 | 0.35 | 0.064 |
| 3 | 20 | 5 | 12 | 0.25 | 0.6 | 0.053 |
| 4 | 20 | 10 | 12 | 0.5 | 0.6 | 0.0947 |
| | | | | | | $\sum$ 0.2477 |

$\Delta\sigma = (2500)(0.2477) \approx$ **619 lb / ft²**

5.4 $L = L_1 + L_2 = 3 + 6 = 9$ m

$B = B_1 + B_2 = 1.2 + 3 = 4.2$ m

| $z$ (m) | $m_1 = L/B$ | $n_1 = z/(B/2)$ | $I_c$ (Table 5.3) | $\Delta\sigma = I_c q_o$ (kN / m²) |
|---|---|---|---|---|
| 0 | 2.14 | 0 | 1 | **110** |
| 1 | 2.14 | 0.476 | 0.95 | **104.5** |
| 2 | 2.14 | 0.952 | 0.85 | **93.5** |
| 3 | 2.14 | 1.43 | 0.65 | **71.5** |
| 4 | 2.14 | 1.91 | 0.49 | **53.9** |
| 5 | 2.14 | 2.38 | 0.41 | **45.1** |

5.5 $L = 7 + 12 = 19$ ft; $B = 10 + 5 = 15$ ft

| $z$ (ft) | $m_1 = L/B$ | $n_1 = z/(B/2)$ | $I_c$ (Table 5.3) | $\Delta\sigma = I_c q_o$ (lb / ft²) |
|---|---|---|---|---|
| 0 | 1.27 | 0 | 1 | **2500** |
| 5 | 1.27 | 0.67 | 0.85 | **2125** |
| 10 | 1.27 | 1.33 | 0.55 | **1375** |
| 15 | 1.27 | 2 | 0.35 | **875** |
| 20 | 1.27 | 2.67 | 0.24 | **600** |

5.6 The plan of the foundation can be divided into 4 areas, each measuring 2.5 ft × 2.5 ft.

$H_1 = 3$ ft; $H_2 = 13$ ft; $B = 2.5$ ft; $L = 2.5$ ft

$$m_2 = \frac{B}{H_1} = \frac{2.5}{3} = 0.833; \quad n_2 = \frac{L}{H_1} = \frac{2.5}{3} = 0.833$$

Figure 5.7: $I_{a(H_1)} = 0.212$

$$m_2 = \frac{B}{H_2} = \frac{2.5}{3} = 0.833; \quad n_2 = \frac{L}{H_2} = \frac{2.5}{13} = 0.192$$

Figure 5.7: $I_{a(H_2)} = 0.13$

$$\Delta\sigma_{av(H_1/H_2)} = \left[\frac{H_2 I_{a(H_2)} - H_1 I_{a(H_1)}}{H_2 - H_1}\right] = (q_o)(4)$$

$$= \left[\frac{(13)(0.13) - (3)(0.212)}{13-3}\right]\left(\frac{50 \times 2000}{5 \times 5}\right)(4) = \mathbf{1686\ lb/ft^2}$$

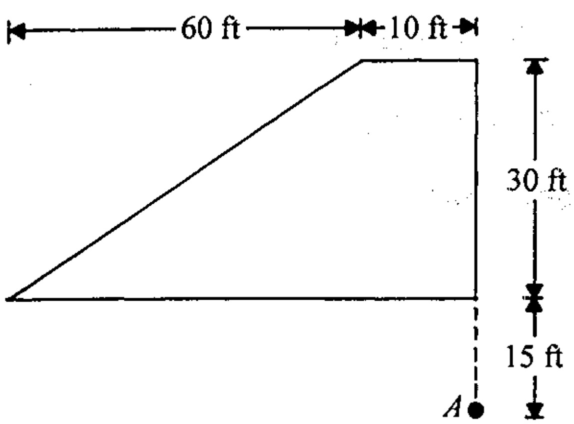
5.7 $\Delta\sigma_t = \frac{50 \times 2000}{(5+3)^2} = 1562.5\ \text{lb/ft}^2$

$$\Delta\sigma_m = \frac{50 \times 2000}{(5+8)^2} = 591.7\ \text{lb/ft}^2$$

$$\Delta\sigma_b = \frac{50 \times 2000}{(5+13)^2} = 308.6\ \text{lb/ft}^2$$

$$\Delta\sigma_{av} = \frac{1}{6}\,[1562.5 + (4)(591.7) + 308.6] = \mathbf{706.3\ lb/ft^2}$$

5.8 **Point A:**




$B_1/z = 10/15 = 0.67$

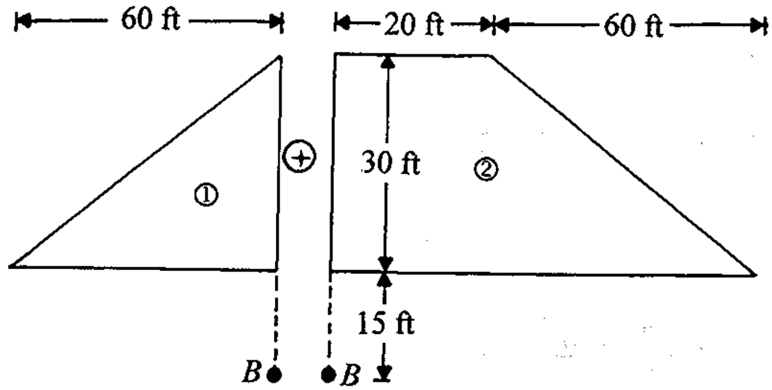
$B_2/z = 60/15 = 4$

Figure 5.11: $I' \approx 0.475$

$\Delta\sigma = (2)(30 \times 115)(0.475)$

$\approx \mathbf{3278\ lb/ft^2}$

**Point B:**

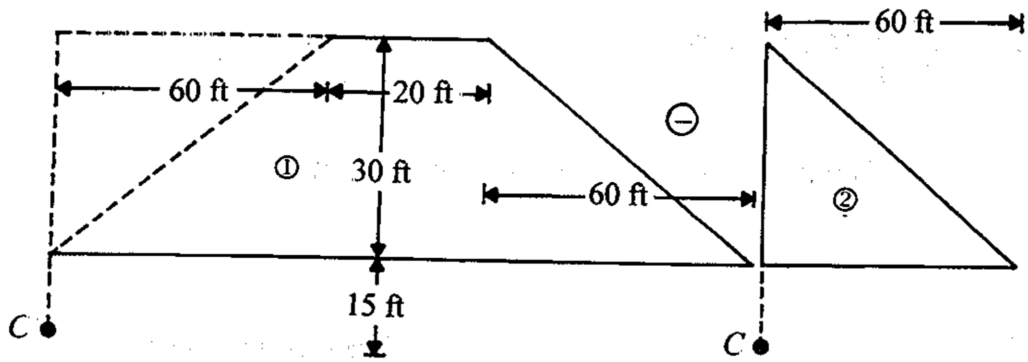



For ①: $B_1/z = 0/15 = 0$; $B_2/z = 60/15 = 4$; $I' = 0.415$

For ②: $B_1/z = 20/15 = 1.33$; $B_2/z = 60/15 = 4$; $I' \approx 0.49$

$$\Delta\sigma = (30 \times 115)(0.415 + 0.49) \approx \mathbf{3122\ lb/ft^2}$$

**Point C:**




For ①: $B_1/z = 80/15 = 5.33$; $B_2/z = 60/15 = 4$; $I' = 0.5$

For ②: $B_1/z = 0/15 = 0$; $B_2/z = 60/15 = 4$; $I' \approx 0.415$

$$\Delta\sigma = (30 \times 115)(0.5 - 0.415) \approx \mathbf{293\ lb/ft^2}$$

5.9 Eq. (5.25): $S_e = q_o(\alpha B')\dfrac{1-\mu_s^2}{E_s} I_s I_f$

$$B' = \frac{B}{2} = \frac{3}{2} = 1.5 \text{ m}$$

$q_o = 180 \text{ kN/m}^2; \mu_s = 0.3; \alpha = 4$

$$m' = \frac{L}{B} = \frac{4.6}{3} = 1.53$$

$$n' = \frac{H}{\left(\frac{B}{2}\right)} = \frac{\infty}{\left(\frac{B}{2}\right)} = \infty$$

Eq. (5.26) and Tables 5.4 and 5.5:

$$I_s = F_1 + \frac{1-2\mu_s}{1-\mu_s}F_2 = 0.669 + \frac{1-2\mu_s}{1-\mu_s}(0) = 0.669$$

$$\frac{D_f}{B} = \frac{2}{3} = 0.67; \ \frac{L}{B} = 1.53$$

Figure 5.15b: $I_f = 0.725$

$$S_e = (180)(4 \times 1.5)\left(\frac{1-0.3^2}{8500}\right)(0.669)(0.725) = 0.056 \text{ m} = \mathbf{56 \text{ mm}}$$

5.10 $m' = \frac{L}{B} = \frac{4.6}{3} = 1.53$

$$n' = \frac{H}{\left(\frac{B}{2}\right)} = \frac{4}{\left(\frac{3}{2}\right)} = 2$$

Tables 5.4 and 5.5: $F_1 = 0.292; F_2 = 0.085$

$$I_s = F_1 + \frac{1-2\mu_s}{1-\mu_s}F_2 = 0.292 + \frac{1-(2)(0.3)}{1-0.3}(0.085) = 0.34$$

$$\frac{D_f}{B} = \frac{5}{3} = 1.67$$

Figure 5.15b: $I_f = 0.62$

$$S_e = q_o(\alpha B')\frac{1-\mu_s^2}{1-\mu_s}I_s I_f = (180)(4\times 1.5)\left(\frac{1-0.3^2}{8500}\right)(0.34)(0.62)$$

$= 0.024 \text{ m} = \mathbf{24.4\ mm}$

5.11 Eqs. (5.25) and (5.33): $S_e = 0.93q_o(\alpha B')\frac{1-\mu_s^2}{E_s}I_s I_f$

$$B' = \frac{6.25}{2} = 3.125 \text{ ft}$$

$$m' = \frac{L}{B} = \frac{10}{6.25} = 1.6$$

$$n' = \frac{H}{\left(\frac{B}{2}\right)} = \frac{32}{\left(\frac{6.25}{2}\right)} = 10.24$$

Tables 5.4 and 5.5: $F_1 = 0.597$; $F_2 = 0.025$

$$I_s = F_1 + \frac{1-2\mu_s}{1-\mu_s}F_2 = 0.597 + \frac{1-(2)(0.3)}{1-0.3}(0.025) = 0.611$$

$$D_f = 2.5 \text{ ft};\quad \frac{D_f}{B} = \frac{2.5}{6.25} = 0.4$$

Figure 5.15b: $I_f = 0.83$

$$S_e = (0.93)(3000)\left(4\times\frac{6.25}{2}\right)\frac{1-0.3^2}{3200\times 144}(0.611)(0.83) = 0.0349 \text{ ft} = \mathbf{0.419\ in.}$$

5.12 Eqs. (5.25) and (5.33): $S_e = 0.93q_o(\alpha B')\frac{1-\mu_s^2}{E_s}I_s I_f$

$$B' = \frac{2.1}{2} = 1.06 \text{ m}$$

$$m' = \frac{2.1}{2.1} = 1$$

$$n' = \frac{12}{\left(\frac{2.1}{2}\right)} = 12.43$$

Tables 5.4 and 5.5: $F_1 \approx 0.52$; $F_2 \approx 0.01$

$$I_s = F_1 + \frac{1-2\mu_s}{1-\mu_s}F_2 = 0.52 + \frac{1-(2)(0.4)}{1-0.4}(0.01) = 0.523$$

$$\mu_s = 0.4; \quad \frac{D_f}{B} = \frac{1.5}{2.1} = 0.71; \quad \frac{L}{B} = 1$$

Figure 5.15c: $I_f \approx 0.74$

$$S_e = (0.93)(230)(4 \times 1.05)\frac{1-0.4^2}{16{,}000}(0.523)(0.74) = 0.0183 \text{ m} = \mathbf{18.3 \text{ mm}}$$

5.13 $S_e = A_1 A_2 \dfrac{q_o B}{E_s}$

$D_f/B = 1.2/1.5 = 0.8$; $H/B = 3/1.5 = 2$; $L/B = 3/1.5 = 2$

From Figure 5.17, $A_1 \approx 0.69$; $A_2 \approx 0.95$

$$S_e = (0.69)(0.95)\frac{(150)(1.5)}{600} = 0.245 \text{ m} = \mathbf{246 \text{ mm}}$$

5.14 From Eq. (5.36) the equivalent diameter is

$$B_e = \sqrt{\frac{4BL}{\pi}} = \sqrt{\frac{(4)(8)(2.5)}{\pi}} = 5.05 \text{ ft}$$

$$q_o = 3000 \text{ lb/ft}^2$$

$$\beta = \frac{E_o}{kB_e} = \frac{1250}{(30)(5.05)} = 8.25$$

$$\frac{H}{B_e} = \frac{8}{5.05} = 1.58$$

From Figure 5.19, for $\beta = 8.25$ and $H/B_e = 1.58$, the value of $I_G \approx 0.72$

Eq. (5.40):

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

$$= \frac{\pi}{4} + \frac{1}{4.6 + 10\left[\dfrac{2 \times 10^6}{1250 + \left(\dfrac{5.05}{2}\right)(30)}\right]\left[\dfrac{(2)(1)}{5.05}\right]^3} = 0.786$$

Eq. (5.41):

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

$$= 1 - \frac{1}{3.5\exp[(1.22)(0.4) - 0.4]\left(\dfrac{5.05}{2.5} + 1.6\right)} = 0.928$$

Eq. (5.39):

$$S_e = \frac{q_o B_e I_G I_F I_E}{E_o}(1 - \mu_s^2) = \frac{(3000)(5.05)(0.72)(0.786)(0.928)}{(1250 \times 144)}(1 - 0.4^2)$$

$= 0.037$ ft $\approx$ **0.446 in.**

5.15 Eq. (5.39): $S_e = \dfrac{q_o B_e I_G I_F I_E}{E_o}(1 - \mu_s^2)$

$q_o = 150\ \text{kN/m}^2$

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

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

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

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

From Figure 5.19, $I_G \approx 0.89$. From Eq. (5.40):

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

$$= \frac{\pi}{4} + \frac{1}{4.6 + 10\left[\dfrac{15 \times 10^6}{16,000 + \left(\dfrac{3.385}{2}\right)(400)}\right]\left[\dfrac{(2)(0.25)}{3.385}\right]^3} = 0.815$$

From Eq. (5.41):

$$I_E = 1 - \frac{1}{3.5\exp(1.22\mu_s - 0.4)\left(\dfrac{B_e}{D_f} + 1.6\right)} = 1 - \frac{1}{3.5\exp[(1.22)(0.3) - 0.4]\left(\dfrac{3.385}{1.5} + 1.6\right)}$$

$$= 0.923$$

$$S_e = (150)(3.385)(0.89)(0.815)(0.923)\left(\frac{1 - 0.3^2}{16,000}\right) = 0.0193 \text{ m} = \mathbf{19.3\ mm}$$

5.16 Refer to Figure 5.22. Assume $I_z$ plots approximately the same as square foundation.

$I_z = 0.1$ at $z = 0$; $I_z = 0.5$ at $z = 3.125$ ft; $I_z = 0$ at $z = 12.5$ ft

| Depth (ft) | $\Delta z$ (in.) | $E_s$ (lb / in.$^2$) | $I_z$ | $\frac{I_z}{E_s}(\Delta z)$ |
|---|---|---|---|---|
| 0–3.125 | 37.5 | 3200 | 0.3 | 0.00352 |
| 3.125–12.5 | 112.5 | 3200 | 0.25 | 0.00879 |
| | | | | **$\sum$0.01231** |

$q = \gamma D_f = (115)(2.5) = 287.5 \text{ lb / ft}^2 = 1.997 \text{ lb / in.}^2$

$$q_o = \bar{q} - q = \frac{3000}{144} = 20.83 \text{ lb / in.}^2$$

$$C_1 = 1 - 0.5\left(\frac{q}{\bar{q} - q}\right) = 1 - 0.5\left(\frac{1.997}{20.83}\right) = 0.952;\ C_2 = 1 + 0.2\log\left(\frac{5 \text{ years}}{0.1}\right) = 1.34$$

$S_e = (0.952)(1.34)(20.83)(0.01231) = \mathbf{0.327\ in.}$

5.17 Refer to Figure 5.22. $I_z = 0.1$ at $z = 0$; $I_z = 0.5$ at $z = 1.05$ m; $I_z = 0$ at $z = 4.2$ m

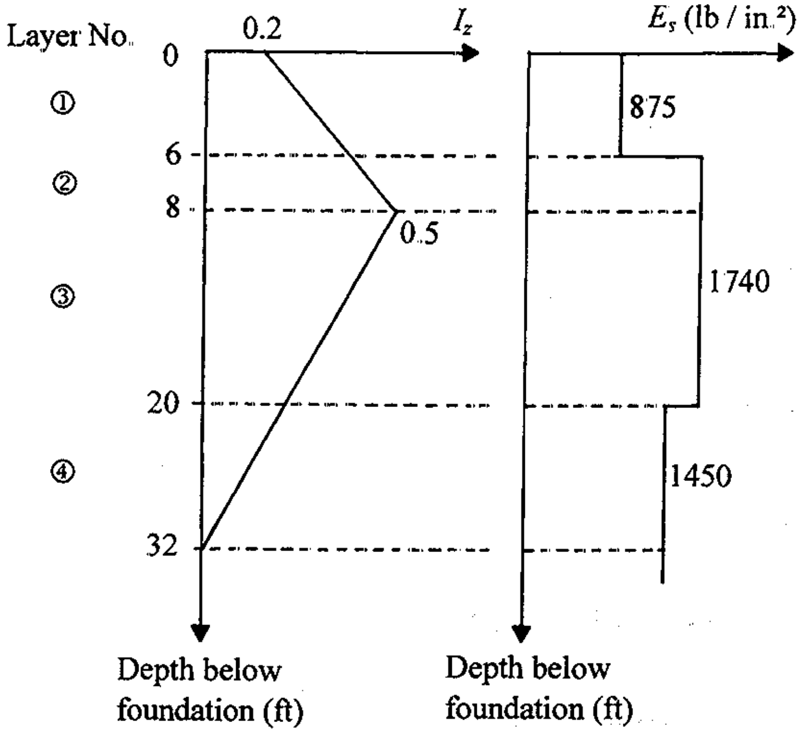
| Depth (m) | $\Delta z$ (m) | $E_s$ (kN / m$^2$) | $I_z$ | $\frac{I_z}{E_s}(\Delta z)$ |
|---|---|---|---|---|
| 0–1.05 | 1.05 | 16,000 | 0.3 | $0.196 \times 10^{-4}$ |
| 1.05–4.2 | 3.15 | 16,000 | 0.25 | $0.492 \times 10^{-4}$ |
| | | | | **$\sum 0.688 \times 10^{-4}$** |

$q = \gamma D_f = (18.1)(1.5) = 27.15 \text{ kN / m}^2$ ; $q_o = 230 \text{ kN / m}^2$

$$C_1 = 1 - 0.5\left(\frac{27.15}{230}\right) = 0.941;\quad C_2 = 1 + 0.2\log\left(\frac{5}{0.1}\right) = 1.4$$

$S_e = (0.941)(1.4)(230)(0.688 \times 10^{-4}) = 208.5 \times 10^{-4} \text{ m} = \mathbf{20.85\ mm}$

5.18 See the figure below for strain influence factor diagram.




| Depth (ft) | $\Delta z$ (in.) | $E_s$ (lb / in.²) | $I_z$ | $\frac{I_z}{E_s}(\Delta z)$ |
|---|---|---|---|---|
| 0–6 | 72 | 875 | 0.313 | 0.0258 |
| 6–8 | 24 | 1740 | 0.463 | 0.0064 |
| 8–20 | 144 | 1740 | 0.375 | 0.0301 |
| 20–32 | 144 | 1450 | 0.125 | 0.0124 |
| | | | | $\sum$0.0756 |

$q = \gamma D_f = (115)(5) = 575 \text{ lb / in.}^2$

$$C_1 = 1 - 0.5\left(\frac{q}{\overline{q} - q}\right) = 1 - 0.5\left(\frac{575}{4000 - 575}\right) = 0.916; \quad C_2 = 1 + 0.2\log\left(\frac{10}{0.1}\right) = 1.4$$

$$S_e = C_1 C_2 (\overline{q} - q)\sum\frac{I_z}{E_s}\Delta z = (0.916)(1.4)(\frac{4000 - 575}{144})(0.0756) = \mathbf{2.31\ in.}$$

5.19

| Depth (ft) | $N_{60}$ |
|---|---|
| 5 | 10 |
| 10 | 12 |
| 15 | 9 |
| 20 | 14 |
| 25 | 16 |

Average $N_{60} \approx 12$

From Eq. (5.46b):

$$\text{Allowable } q_{net} = \frac{N_{60}}{4}\left(\frac{B+1}{B}\right)^2 F_d S_e$$

$B = 5$ ft; $S_e = 1$ in.

$F_d = 1 + 0.33(D_f/B) = 1 + (0.33)(3/5) = 1.198$

$$q_{net} = \frac{12}{4}\left(\frac{5+1}{5}\right)^2 (1.198)(1) \approx \mathbf{5.18\ kip/ft^2}$$

5.20 Eq. (5.56):

$$\frac{z'}{B_R} = 1.4\left(\frac{B}{B_R}\right)^{0.75}$$

$$z' = (1.4)(0.3)\left(\frac{1}{0.3}\right)^{0.75} = 1.04$$

Eq. (5.57): $$\frac{S_e}{B_R} = \alpha_1\alpha_2\alpha_3\left[\frac{1.25\left(\frac{L}{B}\right)}{0.25+\frac{L}{B}}\right]^2\left(\frac{B}{B_R}\right)^{0.7}\left(\frac{q'}{p_a}\right)$$

Normally consolidated sand:

$\alpha_1 = 0.14$

$$\alpha_2 = \frac{1.71}{(\bar{N}_{60})^{1.4}} = \frac{1.71}{(8)^{1.4}} = 0.093$$

$$\alpha_3 = \frac{z''}{z'}\left(2-\frac{z''}{z'}\right) \le 1; \quad \alpha_3 = 1$$

$q' = 153\ \text{kN}/\text{m}^2$

$$\frac{S_e}{0.3} = (0.14)(0.093)(1)\left[\frac{(1.25)\left(\frac{2}{1}\right)}{0.25+\left(\frac{2}{1}\right)}\right]^2 \left(\frac{1}{0.3}\right)^{0.7}\left(\frac{153}{100}\right)$$

$S_e \approx 0.0171\ \text{m} = \mathbf{17.1\ mm}$

5.21

| Depth (m) | $q_c$ ($\text{MN}/\text{m}^2$) | $\sigma'_o$ ($\text{MN}/\text{m}^2$) | $\phi'$(deg) [Eq. (2.47)] |
|---|---|---|---|
| 2 | 2.1 | 0.033 | 38.1 |
| 4 | 4.2 | 0.066 | 38.1 |
| 6 | 5.2 | 0.099 | 37.0 |
| 8 | 7.3 | 0.132 | 37.3 |
| 10 | 8.7 | 0.165 | 37.0 |
| 15 | 14 | 0.248 | 37.4 |
| | | Average $\phi' \approx 37°$ | |

From Figure 5.29, for $\phi' = 37°$, $N_q \approx 43$; $N_\gamma \approx 60$

$$\tan\theta = \frac{k_h}{1-k_v} = \frac{0.2}{1-0} = 0.2$$

From Figure 5.30, for $\tan\theta = 0.2$ and $\phi' = 37°$, $\frac{N_{\gamma E}}{N_\gamma} = 0.34$; $\frac{N_{qE}}{N_q} = 0.54$

$N_{\gamma E} = (0.34)(60) = 20.4$; $N_{qE} = (0.54)(43) = 23.22$

Eq. (5.68):

$$q_{uE} = qN_{qE} + \frac{1}{2}\gamma BN_{\gamma E} = (16.5\times 1)(23.22) + \frac{1}{2}(16.5)(1.5)(20.4) = \mathbf{635.6\ kN/m^2}$$

5.22 $\frac{D_f}{B} = \frac{1}{1.5} = 0.67$. For $\phi' = 37°$, FS = 4. Using Figure 5.31 and interpolating, $k_h^* \approx 0.33$.

From Table 5.11, for $k_h^* \approx 0.33$ and $\phi' = 37°$, the value of $\tan\alpha_{AE} \approx 0.95$

From Eq. (5.69):

$$S_{Eq} = 0.174\left|\frac{k_h^*}{A}\right|^{-4} \tan\alpha_{AE}\left(\frac{V^2}{Ag}\right) = 0.174\left|\frac{0.33}{0.30}\right|^{-4}(0.95)\left(\frac{0.35^2}{0.3\times 9.81}\right)$$

$$= 0.0047 \text{ m} = \mathbf{4.7\ mm}$$

5.23 $\sigma_o' = (4.5)(100) + (3)(122 - 62.4) + \frac{10}{2}(120 - 62.4)$

$$= 450 + 178.8 + 288 = 916.8 \text{ lb/ft}^2$$

$$\sigma_o' + \Delta\sigma_{av}' = 916.8 + 1686 = 2602.8 \text{ lb/ft}^2$$

$$S_{e(p)} = \frac{C_s H_c}{1+e_o}\log\frac{\sigma_c'}{\sigma_o'} + \frac{C_c H_c}{1+e_o}\log\frac{\sigma_o' + \Delta\sigma_{av}'}{\sigma_c'}$$

$$= \frac{(0.06)(10\times 12)}{1+0.7}\log\left(\frac{2000}{916.8}\right) + \frac{(0.25)(10\times 12)}{1+0.7}\log\left(\frac{2602.8}{2000}\right) = \mathbf{3.45\ in.}$$

5.24 From Problems 5.23 and 5.7

$$\sigma_o' = 916.8 \text{ lb/ft}^2$$

$$\sigma_o' + \Delta\sigma' = 916.8 + 706.3 = 1623.1 \text{ lb/ft}^2$$

$$S_{e(p)} = \frac{C_s H_c}{1+e_o}\log\frac{\sigma_o' + \Delta\sigma'}{\sigma_o'} = \frac{(0.06)(10)}{1.7}\log\frac{1623.1}{916.8} = 0.0875 \text{ ft} = \mathbf{1.05\ in.}$$

# CHAPTER 6

6.1 a. Eq. (6.10):

$$q_{u(net)} = 5.14c_u\left[1+\left(\frac{0.195B}{L}\right)\right]\left[1+0.4\left(\frac{D_f}{B}\right)\right]$$

$$= (5.14)(120)\left[1+\frac{(0.195)(8)}{18}\right]\left[1+0.4\left(\frac{3}{8}\right)\right] = \mathbf{771\ kN/m^2}$$

b. $$q_{u(net)} = 5.14c_u\left[1+\left(\frac{0.195B}{L}\right)\right]\left[1+0.4\left(\frac{D_f}{B}\right)\right]$$

$$= (5.14)(2500)\left[1+\frac{(0.195)(20)}{30}\right]\left[1+0.4\left(\frac{6.2}{20}\right)\right] = \mathbf{16{,}321\ lb/ft^2}$$

6.2

| Depth (m) | $N_{60}$ |
|---|---|
| 1.5 | 9 |
| 3.0 | 12 |
| 4.5 | 11 |
| 6.0 | 7 |
| 7.5 | 13 |
| 9.0 | 11 |
| 10.5 | 13 |

Average $N_{60} = 10.86 \approx 11$

Eq. (6.12): $$q_{all(net)} = \frac{N_{60}}{0.08}\left(1+\frac{0.33D_f}{B}\right)\left(\frac{S_e}{25}\right) \le 16.63N_{60}\left(\frac{S_e}{25}\right)$$

$$= \frac{N_{60}}{0.08}\left[1+\frac{(0.33)(1.5)}{5}\right]\left(\frac{S_e}{25}\right) = 13.74N_{60}\left(\frac{S_e}{25}\right)$$

$$q_{\text{all(net)}} = (13.74)(11)\left(\frac{50}{25}\right) = \mathbf{302.3\ kN/m^2}$$

6.3 $$q_{\text{all(net)}} = 13.74 N_{60}\left(\frac{30}{25}\right) = (13.74)(11)\left(\frac{30}{25}\right) = \mathbf{181.4\ kN/m^2}$$

6.4 a. $B = 20$ m; $c_u = 30$ kN / m²; $L = 20$ m; $\gamma = 18.5$ kN / m³

Eq. (6.20): $$D_f = \frac{Q}{A\gamma} = \frac{48 \times 1000\ \text{kN}}{(20 \times 20)(18.5)} = \mathbf{6.49\ m}$$

b. Eq. (6.22):

$$\text{FS} = \frac{5.14 c_u \left(1 + \frac{0.195B}{L}\right)\left(1 + \frac{0.4D_f}{B}\right)}{\frac{Q}{A} - \gamma D_f}$$

$$2 = \frac{(5.14)(30)\left(1 + \frac{(0.195)(20)}{20}\right)\left(1 + \frac{0.4D_f}{20}\right)}{\left(\frac{48 \times 10^3}{20 \times 20}\right) - 18.5D_f}$$

$240 - 37D_f = 184.27 + 3.69D_f$; $D_f = \mathbf{1.37\ m}$

6.5 Eq. (6.22): $$\text{FS} = \frac{5.14 c_u \left(1 + \frac{0.195B}{L}\right)\left(1 + \frac{0.4D_f}{B}\right)}{\frac{Q}{A} - \gamma D_f}$$

FS = 2; $c_u = 20$ kN / m²; $B = L = 20$ m; $Q = 48 \times 10^3$ kN; $\gamma = 18.5$ kN / m³

$$2 = \frac{(5.14)(20)\left(1 + \frac{0.195 \times 20}{20}\right)\left(1 + \frac{0.4D_f}{20}\right)}{\frac{48 \times 10^3}{20 \times 20} - 18.5D_f}$$

$240 - 37D_f = 122.85 - 2.48D_f$; $D_f = \mathbf{3.39\ m}$

6.6 $B = 10$ m; $L = 12$ m; $Q = 30{,}000$ kN

Eq. (5.70): $\Delta\sigma'_{av} = \frac{1}{6}(\Delta\sigma'_t + \Delta\sigma'_m + \Delta\sigma'_b)$

Eq. (5.12): $m_1 = L/B = 12/10 = 1.2$

| $z$ (m) | $n_1 = \frac{z}{\left(\frac{B}{2}\right)}$ | $m_1$ | $I_c$ (Table 5.3) | $\Delta\sigma' = q_o I_c$ (kN / m²) |
|---|---|---|---|---|
| 4 | 0.8 | 1.2 | ≈ 0.81 | $0.81\left(\frac{30 \times 1000}{10 \times 12}\right) = 202.5$ |
| 6.6 | 1.32 | 1.2 | ≈ 0.64 | $0.64\left(\frac{30 \times 1000}{10 \times 12}\right) = 160$ |
| 9.2 | 1.84 | 1.2 | ≈ 0.45 | $0.45\left(\frac{30 \times 1000}{10 \times 12}\right) = 112.5$ |

$$\Delta\sigma'_{av} = \frac{1}{6}(202.5 + 4 \times 160 + 112.5) = 159.2 \text{ kN / m}^2$$

$$S_c = \frac{C_c H_c}{1 + e_o} \log \frac{\sigma'_o + \Delta\sigma'_{av}}{\sigma'_o}$$

$$\sigma'_o = (16)(4.2) + 2(18 - 9.81) + 2.6(17.5 - 9.81) = 103.58 \text{ kN / m}^2$$

$\sigma'_c = 105$ kN / m². So $\sigma'_o \approx \sigma'_c$ (normally consolidated).

$$S_c = \frac{(0.38)(5.2)}{1 + 0.88} \log \frac{103.58 + 159.2}{103.58} = \mathbf{0.425 \text{ m}}$$

6.7 We will need to use Table 5.2.

At the top of the clay layer: $m = B/z = 10/4 = 2.5$

$n = L/z = 12/4 = 3$

$\Delta\sigma'_t = 0.242 q_o$

At the middle of the clay layer: $m = 10/6.6 = 1.515$

$n = 12/6.6 = 1.818$

$\Delta\sigma'_m = 0.22q_o$

At the bottom of the clay layer: $m = 10/9.2 = 1.09$

$n = 12/9.2 = 1.30$

$\Delta\sigma'_b = 0.189q_o$

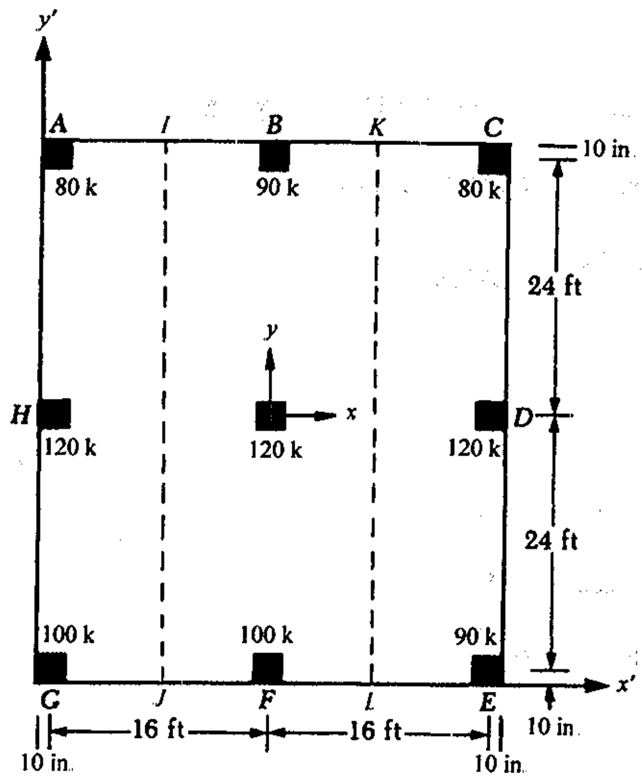
$$\Delta\sigma'_{av} = \frac{1}{6}(\Delta\sigma'_t + 4\Delta\sigma'_m + \Delta\sigma'_b)$$

$$= \frac{1}{6}\left(\frac{30{,}000}{10 \times 12}\right)[0.242 + (4)(0.22) + 0.180] = 54.63 \text{ kN/m}^2$$

$$S_c = \frac{C_c H_c}{1+e_o}\log\frac{\sigma'_o + \Delta\sigma'_{av}}{\sigma'_o} = \frac{(0.38)(5.2)}{1+0.88}\log\frac{103.58 + 54.63}{103.58} = \mathbf{0.193\ m}$$

6.8 The plan of the mat foundation is shown.

Area of the mat = (32'20")(48'20") = 1672.11 ft$^2$



$$I_x = \frac{1}{12}BL^3 = \frac{1}{12}(32'\,20")(48'\,20")^3 = 343{,}727\ \text{ft}^4$$

$$I_y = \frac{1}{12}LB^3 = \frac{1}{12}(48'\,20")(32'\,20")^3 = 157{,}937\ \text{ft}^4$$

$Q = (2)(40) + (3)(60) + (2)(45) + (2)(50) = 450\ \text{ton} = 900\ \text{kip}$

$$x' = \frac{1}{900}\left[(32'\,20")(80+120+90) + (16'\,10")(100+120+90) + (10")(100+120+80)\right]$$

$$= 16.655\ \text{ft}$$

$$e_x = x' - \frac{B}{2} = 16.655 - \frac{32'\,20"}{2} = \text{-}0.178\ \text{ft}$$

$M_y = (900)(0.178) = 160.2\ \text{kip - ft}$

$$y' = \frac{1}{900}\left[(48'\,20")(80+90+80) + (24'\,20")(120+120+120) + (20")(100+100+90)\right]$$

$$= 24.6\ \text{ft}$$

$$e_x = 24.6 - \frac{48'\,20"}{2} = \text{-}0.233\ \text{ft}$$

$M_x = (900)(0.233) = 209.7\ \text{kip - ft}$

Eq. (6.24): $$q = \frac{Q}{A} \pm \frac{M_y x}{I_y} \pm \frac{M_x y}{I_x} = \frac{900}{1672.11} \pm \frac{160.2x}{157{,}937} \pm \frac{209.7y}{343{,}727}$$

$$= 0.5328 \pm 0.0010143x \pm 0.00061y$$

**At *A*:** $q = 0.5382 + (0.0010143)(16.83) - (0.00061)(24.83) =$ **0.54 kip / ft²**

**At *B*:** $q = 0.5382 + (0.0010143)(0) - (0.00061)(24.83) =$ **0.523 kip / ft²**

**At *C*:** $q = 0.5382 - (0.0010143)(16.83) - (0.00061)(24.83) =$ **0.506 kip / ft²**

**At *D*:** $q = 0.5382 - (0.0010143)(16.83) + 0 =$ **0.521 kip / ft²**

**At *E*:** $q = 0.5382 - (0.0010143)(16.83) + (0.00061)(24.83) =$ **0.536 kip / ft²**

**At *F*:** $q = 0.5382 + 0 + (0.00061)(24.83) =$ **0.553 kip / ft²**

**At *G*:** $q = 0.5382 + (0.0010143)(16.83) + (0.00061)(24.83) =$ **0.570 kip / ft²**

**At *H*:** $q = 0.5382 + (0.0010143)(16.83) + 0 =$ **0.555 kip / ft²**

6.9 Eq. (6.24): $q = \frac{Q}{A} \pm \frac{M_y x}{I_y} \pm \frac{M_x y}{I_x}$

$A = (16.5)(21.5) = 354.75 \text{ m}^2$

$$I_x = \frac{1}{12} BL^3 = \frac{1}{12}(16.5)(21.5)^3 = 13{,}665 \text{ m}^4$$

$$I_y = \frac{1}{12} LB^3 = \frac{1}{12}(21.5)(16.5)^3 = 8{,}050 \text{ m}^4$$

$Q = 350 + (2)(400) + 450 + (2)(500) + (2)(1200) + (4)(1500) = 11{,}000 \text{ kN}$

$$M_y = Qe_x; \quad e_x = x' - \frac{B}{2}$$

$$x' = \frac{Q_1 x_1' + Q_2 x_2' + Q_3 x_3' + \ldots}{Q}$$

$$= \frac{1}{11{,}000}\begin{bmatrix}(8.25)(500+1500+1500+500) \\ +(16.25)(350+1200+1200+450) \\ +(0.25)(400+1500+1500+400)\end{bmatrix} = 7.814 \text{ m}$$

$$e_x = x' - \frac{B}{2} = 7.814 - 8.25 = -0.435 \text{ m} \approx -0.44 \text{ m}$$

Hence, the resultant line of action is located to the left of the center of the mat. So

$M_y = (11{,}000)(0.44) = 4840$ kN - m. Similarly

$$M_x = Qe_y; \quad e_y = y' - \frac{L}{2}$$

$$y' = \frac{Q_1 y_1' + Q_2 y_2' + Q_3 y_3' + \ldots}{Q}$$

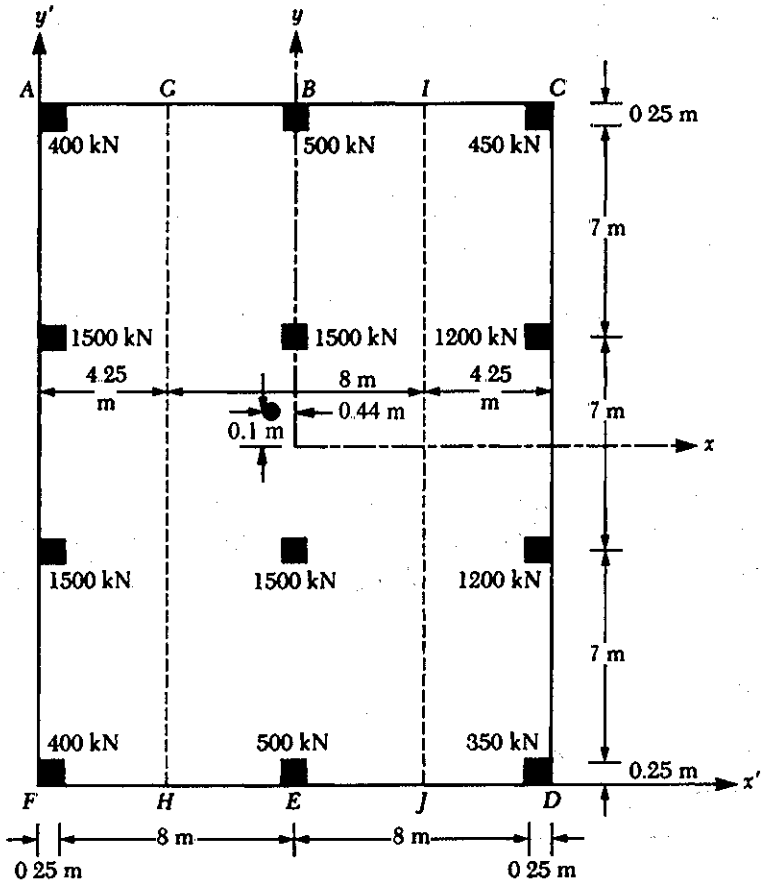
$$= \frac{1}{11{,}000}\begin{bmatrix}(0.25)(400+500+350)+(7.25)(1500+1500+1200) \\ +(14.25)(1500+1500+1200)+(21.25)(400+500+450)\end{bmatrix} = 10.85 \text{ m}$$

$$e_y = y' - \frac{L}{2} = 10.85 - 10.75 = 0.1 \text{ m}$$

The location of the line of action of the resultant column loads is shown on the following page.

$M_x = (11{,}000)(0.1) = 1100$ kN - m. So

$$q = \frac{11{,}000}{354.75} \pm \frac{4840x}{8050} \pm \frac{1100y}{13{,}665} = 31.0 \pm 0.6x \pm 0.08y \text{ (kN / m}^2\text{)}$$




**At *A*:** $q = 31.0 + (0.6)(8.25) + (0.08)(10.75) = \mathbf{36.81\ kN / m^2}$

**At *B*:** $q = 31.0 + (0.6)(0) + (0.08)(10.75) = \mathbf{31.86\ kN / m^2}$

**At *C*:** $q = 31.0 - (0.6)(8.25) + (0.08)(10.75) = \mathbf{26.91\ kN / m^2}$

**At *D*:** $q = 31.0 - (0.6)(8.25) - (0.08)(10.75) = \mathbf{25.19\ kN / m^2}$

**At *E*:** $q = 31.0 + (0.6)(0) - (0.08)(10.75) = \mathbf{30.14\ kN / m^2}$

**At *F*:** $q = 31.0 + (0.6)(8.25) - (0.08)(10.75) = \mathbf{35.09\ kN / m^2}$

6.10 **Determination of Shear and Moment Diagrams for Strips:**

**Strip *AGHF*:**

$$\text{Average soil pressure} = q_{av} = q_{(\text{at } A)} + q_{(\text{at } F)} = \frac{36.81 + 35.09}{2} = 35.95 \text{ kN / m}^2$$

$$\text{Total soil reaction} = q_{av} B_1 L = (35.95)(4.25)(21.50) = 3285 \text{ kN}$$

$$\text{Average load} = \frac{\text{load soil reaction} + \text{column loads}}{2} = \frac{3285 + 3800}{2} = 3542.5 \text{ kN}$$

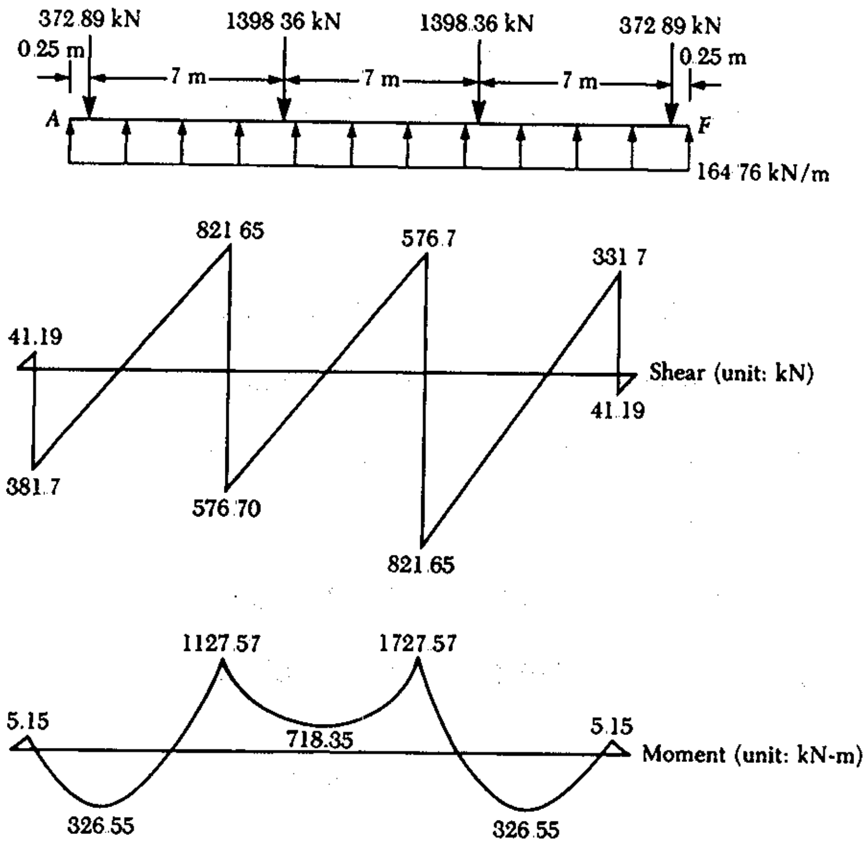
So, modified average soil pressure,

$$q_{av(\text{modified})} = q_{av}\left(\frac{3542.5}{3285}\right) = (35.95)\left(\frac{3542.5}{3285}\right) = 38.768 \text{ kN / m}^2$$

The column loads can be modified in a similar manner by multiplying factor

$$F = \frac{3542.5}{3800} = 0.9322$$

Figure (a) shows the loading on the strip and corresponding shear and moment diagrams. Note that the column loads shown in this figure have been multiplied by $F = 0.9322$. Also the load per unit length of the beam is equal to $B_1\, q_{av(\text{modified})} = (4.25)(38.768) = 164.76$ kN / m.




(a) Strip AGHF

**Strip *GIJH*:** In a similar manner

$$q_{av} = \frac{q_{(at\,B)} + q_{(at\,E)}}{2} = \frac{31.86 + 30.14}{2} = 31.0 \text{ kN / m}^2$$

Total soil reaction = (31)(8)(21.5) = 5332 kN

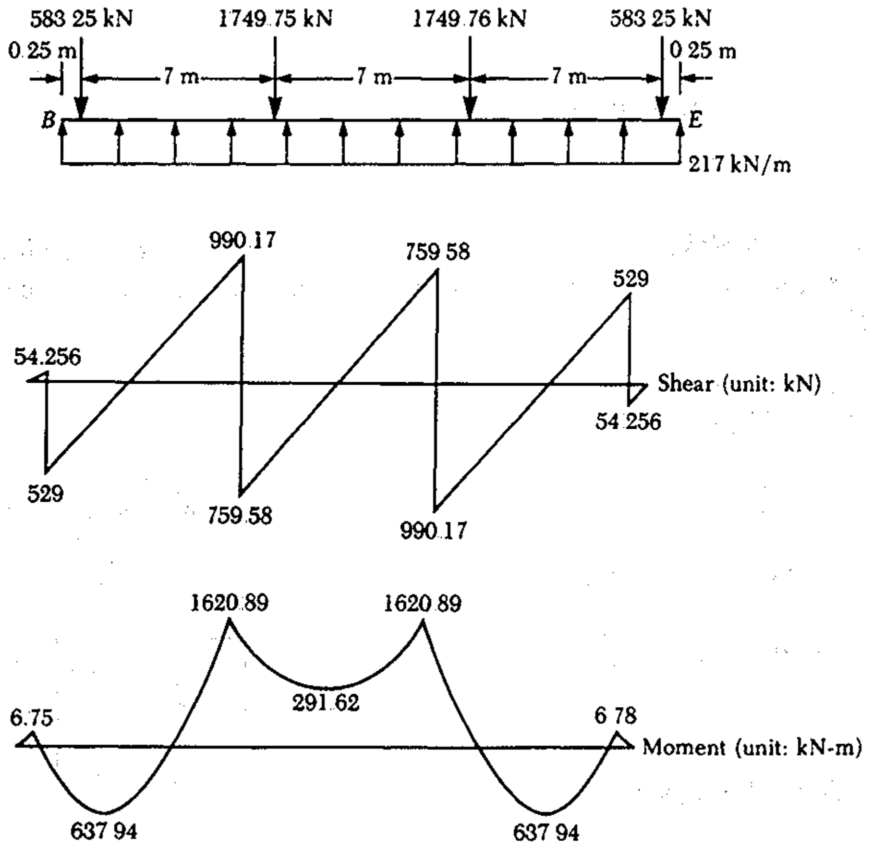
Total column load = 4000 kN

$$\text{Average load} = \frac{5332 + 4000}{2} = 4666 \text{ kN}$$

$$q_{av(modified)} = (31.0)\left(\frac{4666}{5332}\right) = 27.12 \text{ kN / m}^2$$

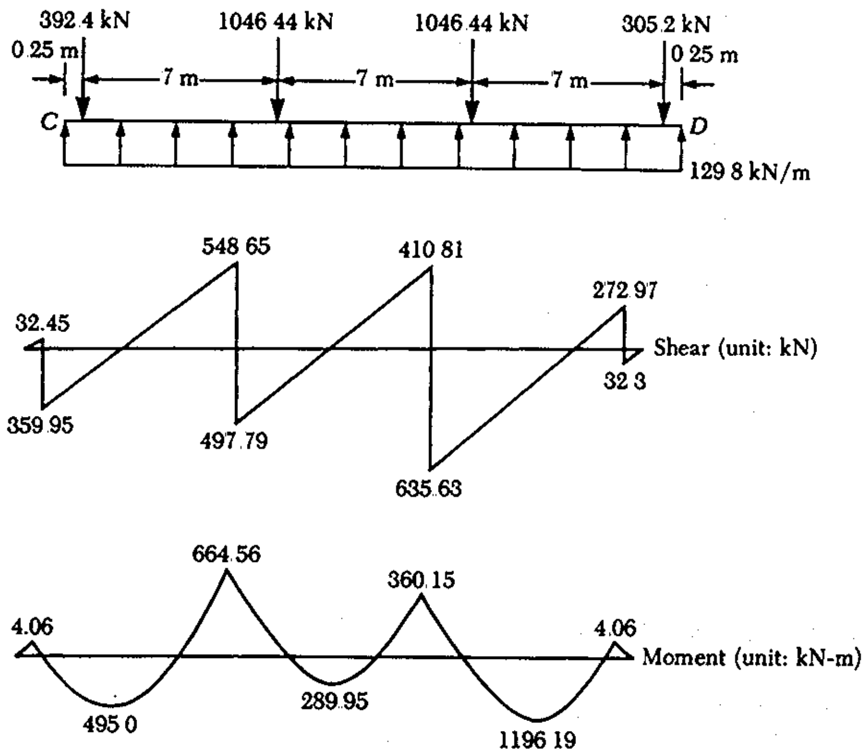
$$F = \frac{4666}{4000} = 1.1665$$

The load, shear, and moment diagrams are shown in Figure (b).




(b) Strip GIJH

**Strip *ICDJ*:** Figure (c) shows the load, shear, and moment diagrams for this strip.




(c) Strip ICDJ

**Determination of the Thickness of the Mat:** For this problem, the critical section for diagonal tension shear will be at the column carrying 1500 kN of load at the edge of the mat [Figure (d)]. So

$$b_o = \left(0.5 + \frac{d}{2}\right) + \left(0.5 + \frac{d}{2}\right) + (0.5 + d) = 1.5 + 2d$$

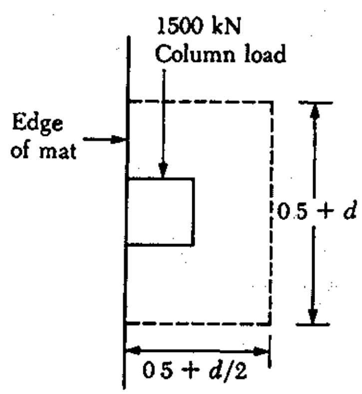
$$U = (b_o d)\left[(\phi)(0.34)\sqrt{f_c'}\right]$$

$$U = (1.7)(1500) = 2550 \text{ kN} = 2.55 \text{ MN}$$

$$2.55 = (1.5 + 2d)(d)\left[(0.85)(0.34)\sqrt{20.7}\right]$$

or

$$(1.5 + 2d)(d) = 1.94; \quad d = 0.68 \text{ m}$$




(d)

Assuming a minimum cover of 76 mm over the steel reinforcement and also assuming that the steel bars to be used are 25 mm in diameter, the total thickness of the slab is

$$h = 0.68 + 0.076 + 0.025 = 0.781 \text{ m} \approx \mathbf{0.8\ m}$$

The thickness of this mat will satisfy the wide beam shear condition across the three strips under consideration.

**Determination of Reinforcement:** From the moment diagram shown in Figures (a), (b), and (c), it can be seen that the maximum positive moment is located in strip *AGHF*, and its magnitude is

$$M' = \frac{1727.57}{B_1} = \frac{1727.57}{4.25} = 406.5 \text{ kN - m / m}$$

Similarly, the maximum negative moment is located in strip *ICDJ* and its magnitude is

$$M' = \frac{1196.19}{B_1} = \frac{1196.19}{4.25} = 281.5 \text{ kN - m / m}$$

From Eq. (6.35): $M_u = (M')(\text{load factor}) = \phi A_s f_y\left(d - \frac{a}{2}\right)$

For the positive moment, $M_u = (406.5)(1.7) = (\phi)(A_s)(413.7 \times 1000)\left(0.68 - \frac{a}{2}\right)$

$\phi = 0.9$. Also, from Eq. (6.36):

$$a = \frac{A_s f_y}{0.85 f_c' b} = \frac{(A_s)(413.7)}{(0.85)(20.7)(1)} = 23.51 A_s; \text{ or } A_s = 0.0425a.$$

$$691.05 = (0.9)(0.0425a)(413{,}700)\left(0.68 - \frac{0.0425a}{2}\right); \text{ or } a \approx 0.0645$$

So, $A_s = (0.0425)(0.0645) = 0.00274 \text{ m}^2/\text{m} = 2740 \text{ mm}^2/\text{m}$

**Use 25-mm diameter bars at 175 mm center-to-center**

$$\left[A_s \text{ provided} = (491)\left(\frac{1000}{175}\right) = 2805.7 \text{ mm}^2/\text{m}\right]$$

Similarly, for negative reinforcement

$$M_u = (281.5)(1.7) = (\phi)(A_s)(413.7 \times 1000)\left(0.68 - \frac{a}{2}\right)$$

$\phi = 0.9$. $A_s = 0.0425a$. So

$$478.55 = (0.9)(0.0425a)(413.7 \times 1000)\left(0.68 - \frac{0.0425a}{2}\right); \text{ or } a \approx 0.045$$

So, $A_s = (0.045)(0.0425) = 0.001913 \text{ m}^2/\text{m} = 1913 \text{ mm}^2/\text{m}$

**Use 25-mm diameter bars at 175 mm center-to-center**

[$A_s$ provided = 1924 mm$^2$]

Because negative moment occurs at midbay of strip *ICDJ*, reinforcement should be provided. This moment is

$$M' = \frac{289.95}{4.25} = 68.22 \text{ kN - m/m}$$

Hence,

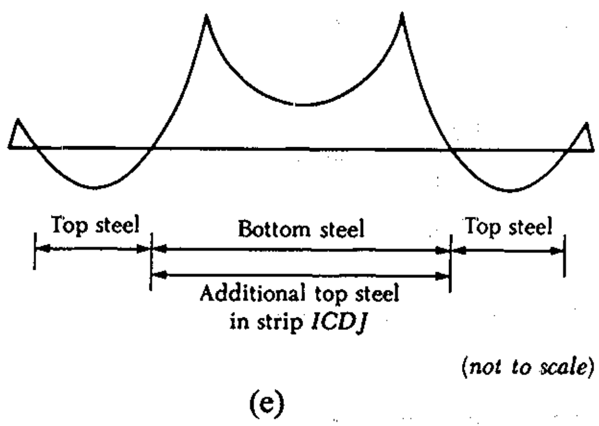
$$M_u = (68.22)(1.7) = (0.9)(0.0425a)(413.7 \times 1000)\left(0.68 - \frac{0.0425a}{2}\right); \text{ or } a \approx 0.0108$$

$A_s = (0.0108)(0.0425) = 0.000459 \text{ m}^2/\text{m} = 459 \text{ mm}^2/\text{m}$

Provide **16-mm diameter bars at 400 mm center-to-center**

[$A_s$ provided = 502 mm$^2$].

For general arrangement of the reinforcement see Figure (e).




(e)

6.11 Eq. (6.45): $k = k_1\left(\frac{B+1}{2B}\right)^2 = 55\left(\frac{25+1}{50}\right)^2 =$ **14.9 lb/in.$^3$**

6.12 $B = 30$ ft; $L = 70$ ft. Eq. (6.48): $k = \dfrac{k_{(B\times B)}\left(1+0.5\dfrac{B}{L}\right)}{1.5}$

From Problem 6.11, $k_{(B\times B)} = 14.9\ \text{lb/in.}^3$

$$k = \frac{(14.9)\left[1+0.5\left(\frac{30}{70}\right)\right]}{1.5} = \mathbf{12.1\ lb/in.^3}$$

6.13 From Eq. (6.48):

$$\frac{k_{(1\times 0.7)}}{k_{(5\times 3.5)}} = \frac{k_{(B\times B)}\left[1+0.5\left(\frac{0.7}{1}\right)\right]}{k_{(B\times B)}\left[1+0.5\left(\frac{3.5}{5}\right)\right]} = \frac{1.35}{1.35} = 1$$

$$k_{(5\times 3.5)} = \frac{k_{(1\times 0.7)}}{1} = \frac{18}{1} = \mathbf{18\ kN/m^3}$$

# CHAPTER 7

7.1 $K_o = (1 - \sin\phi')(\text{OCR})^{\sin\phi'} = (1 - \sin 30)(2)^{\sin 30} = 0.707$

At $z = 0$ ft: $\sigma'_h = 0$

At $z = 12$ ft: $\sigma'_h = K_o \sigma'_o = (0.707)(108 \times 12) = 916.27 \text{ lb/ft}^2$; $u = 0$

So from Eq. (7.5):

$$P_o = \left(\frac{1}{2}\right)(916.27)(12) = \mathbf{5497.5\ lb/ft}$$

$$\bar{z} = \frac{H}{3} = \mathbf{4\ ft}$$

7.2 $K_o = (1 - \sin 35)(1.5)^{\sin 35} = 0.538$. Eq. (7.5):

$$P_o = P_1 + P_2 = qK_oH + \frac{1}{2}\gamma H^2 K_o$$

$$= (20)(0.538)(3.5) + \frac{1}{2}(18.2)(3.5)^2(0.538) = 37.66 + 59.97$$

$$= \mathbf{97.63\ kN/m}$$

$$\bar{z} = \frac{P_1\left(\frac{H}{2}\right) + P_2\left(\frac{H}{3}\right)}{P_o} = \frac{(37.66)(1.75) + (59.97)(1.167)}{97.63} = \mathbf{1.39\ m}$$

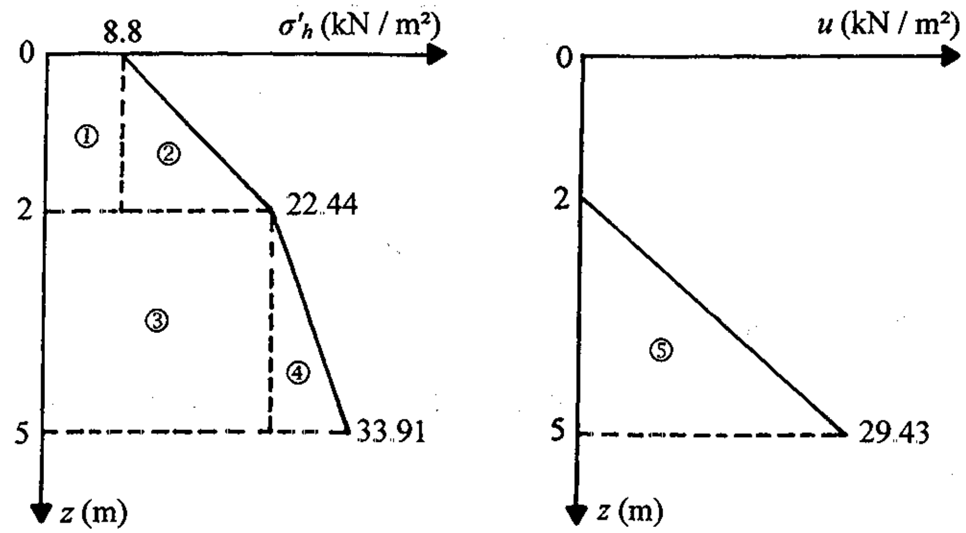
7.3 $K_o = 1 - \sin 34 = 0.44$

At $z = 0$ m: $\sigma'_h = K_o \sigma'_o = (0.44)(20) = 8.8 \text{ kN/m}^2$

At $z = 2$ m: $\sigma'_h = (0.44)[20 + (2)(15.5)] = 22.44 \text{ kN/m}^2$; $u = 0$

At $z = 5$ m: $\sigma'_h = (0.44)[20 + (2)(15.5) + (3)(18.5 - 9.81)] = 33.91 \text{ kN/m}^2$

$u = (3)(9.81) = 29.43 \text{ kN/m}^2$




$$P_o = A_1 + A_2 + A_3 + A_4 + A_5 = 17.6 + 13.64 + 67.32 + 17.21 + 44.15$$

$$= \mathbf{159.92\ kN / m}$$

$$\bar{z} = \frac{(17.6)(4) + (13.64)(3.67) + (67.32)(1.5) + (17.21)(1) + (44.15)(1)}{159.92} = \mathbf{1.77\ m}$$

7.4 a. $K_a = \tan^2\left(45 - \frac{\phi}{2}\right)$; $K_a = 1$; $\phi = 0$

The pressure distribution diagram is similar to that shown in Figure 7.5c.

At $z = 0$ ft: $\sigma_a = -2c\sqrt{K_a} = -(2)(500)(1) = \mathbf{-1000\ lb / ft^2}$

At $z = 18$ ft: $\sigma_a = \gamma z K_a - 2c\sqrt{K_a} = (120)(18)(1) - 1000 = \mathbf{1160\ lb / ft^2}$

b. Eq. (7.9): $z_c = \dfrac{2c}{\gamma\sqrt{K_a}} = \dfrac{(2)(500)}{(120)(1)} = \mathbf{8.33\ ft}$

c. Before crack: Eq. (7.10):

$$P_a = \frac{1}{2}\gamma H^2 K_a - 2cH\sqrt{K_a} = \left(\frac{1}{2}\right)(120)(18)^2(1) - (2)(500)(18)(1)$$

$$= \mathbf{1440\ lb / ft}$$

After crack: Eq. (7.12):

$$P_a = \frac{1}{2}\left[H - \frac{2c}{\gamma\sqrt{K_a}}\right]\left(\gamma H K_a - 2c\sqrt{K_a}\right)$$

$$= \frac{1}{2}(18 - 8.33)[(18)(120)(1) - (2)(500)(1)] = \mathbf{5608\ lb/ft}$$

7.5 Eq. (7.12):

$$P_a = \frac{1}{2}\left[H - \frac{2c'}{\gamma\sqrt{K_a}}\right]\left(\gamma H K_a - 2c'\sqrt{K_a}\right)$$

$$K_a = \tan^2\left(45 - \frac{\phi'}{2}\right) = \tan^2\left(45 - \frac{26}{2}\right) = 0.39; \quad \sqrt{K_a} = 0.625$$

$$P_a = \frac{1}{2}\left[6.3 - \frac{(2)(15)}{(17.9)(0.625)}\right][(17.9)(6.3)(0.39) - (2)(15)(0.625)]$$

$$= \frac{1}{2}(3.618)(43.98 - 18.75) = \mathbf{45.64\ kN/m}$$

7.6 $K_a = \tan^2\left(45 - \frac{34}{2}\right) = 0.283$

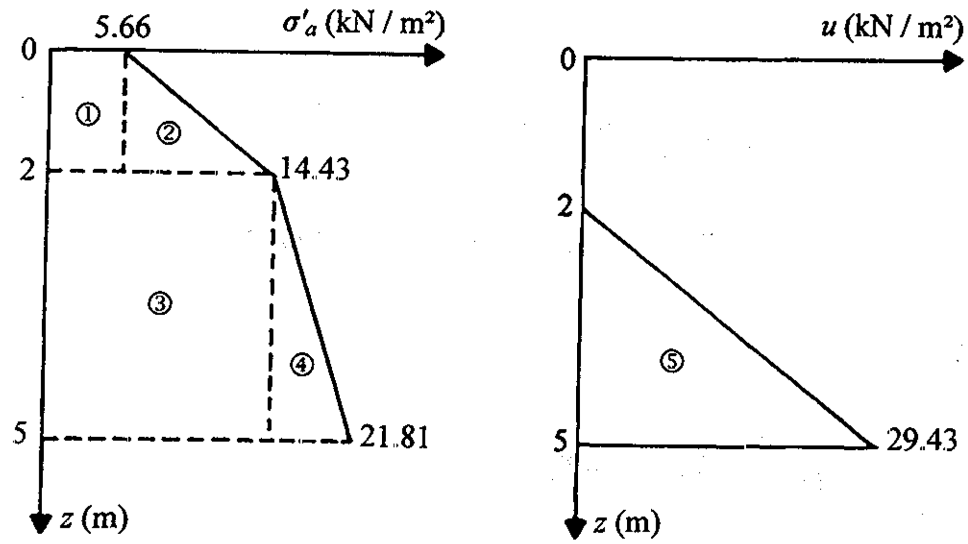
At $z = 0$ m: $\sigma_a = K_a \sigma'_o = (0.283)(20) = 5.66\ \text{kN/m}^2;\ u = 0$

At $z = 2$ m: $\sigma_a = (0.283)[20 + (2)(15.5)] = 14.43\ \text{kN/m}^2;\ u = 0$

At $z = 5$ m: $\sigma_a = (0.283)[20 + (2)(15.5) + 3(18.5 - 9.81)] = 21.81\ \text{kN/m}^2$

$u = (3)(9.81) = 29.43\ \text{kN/m}^2$

The pressure diagram is shown on the next page.




$$P_a = A_1 + A_2 + A_3 + A_4 + A_5$$

$$= 11.32 + \frac{1}{2}(2)(14.43 - 5.66) + (14.43)(3) + \frac{1}{2}(3)(21.81 - 14.43)$$

$$+ \frac{1}{2}(3)(29.43) = 11.32 + 8.77 + 43.29 + 11.07 + 44.15 = \mathbf{118.6\ kN/m}$$

$$\bar{z} = \frac{(11.32)(4) + (8.77)(3.67) + (43.29)(1.5) + (11.07)(1) + (44.15)(1)}{118.6} = \mathbf{1.67\ m}$$

7.7 $\phi_1' = 34°;\quad K_{a(1)} = \tan^2\left(45 - \frac{\phi_1'}{2}\right) = \tan^2\left(45 - \frac{34}{2}\right) = 0.283$

$\phi_2' = 25°;\quad K_{a(2)} = \tan^2\left(45 - \frac{\phi_2'}{2}\right) = \tan^2(45 - 12.5) = 0.406;\quad \sqrt{K_{a(2)}} = 0.637$

At $z = 0$ ft: $\sigma_a' = 0$

At $z = 8.2$ ft (top layer): $\sigma_a' = \gamma_1 z K_{a(1)} = (107)(8.2)(0.283) = 248.3\ \text{lb/ft}^2$

At $z = 8.2$ ft (bottom layer): $\sigma_a' = \gamma_1 z K_{a(2)} - 2c_2'\sqrt{K_{a(2)}}$

$$= (107)(8.2)(0.406) - (2)(209)(0.637)$$

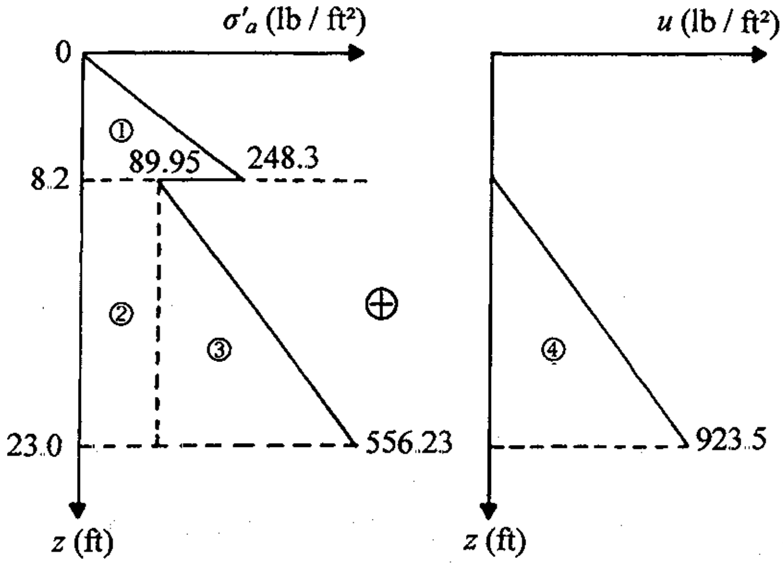
$$= 356.22 - 266.27 = 89.95\ \text{lb/ft}^2$$

At $z = 23$ ft: $\sigma_a' = [(107)(8.2) + (140 - 62.4)(14.8)](0.406) - (2)(209)(0.637)$

$$= 822.5 - 266.27 = 556.23\ \text{lb/ft}^2$$

$$u = (62.4)(14.8) = 923.5 \text{ lb / ft}^2$$

The pressure diagram follows:




$P_a$ = Area of pressure diagram 1 + 2 + 3 + 4

= 1018 + 1331 + 3450 + 6834 = 12,633 lb / ft = **12.6 kip / ft**

7.8 a. $\phi' = 32°$; $\alpha = 5°$; $K_a \approx 0.311$ (Table 7.1). $\sigma'_a = \gamma z K_a$.

At $z$ = 2 m: $\sigma'_a = (2)(18.2)(0.311) = $ **11.32 kN / m²**

At $z$ = 4 m: $\sigma'_a =$ **22.62 kN / m²**

At $z$ = 6 m: $\sigma'_a =$ **33.96 kN / m²**

At $z$ = 7.5 m: $\sigma'_a =$ **42.45 kN / m²**

b. $P_a = \frac{1}{2}\gamma H^2 K_a = \frac{1}{2}(18.2)(7.5)^2(0.311) =$ **159.2 kN / m**

7.9 Eq. (7.24): $z_c = \dfrac{2c'}{\gamma}\sqrt{\dfrac{1+\sin\phi'}{1-\sin\phi'}} = \dfrac{(2)(250)}{115}\sqrt{\dfrac{1+\sin 25}{1-\sin 25}} = 6.82 \text{ ft}$

At $z = 22$ ft: $z_c = \frac{c'}{\gamma z} = \frac{(250)}{(115)(22)} = 0.099 \approx 0.1$

For $\phi' = 25°$, $\alpha = 10°$. From Table 7.2, $K'_a = 0.296$. So

At $z = 22$ ft: $\sigma'_a = \gamma z K'_a \cos\alpha = (115)(22)(0.296)\cos 10 = 737.5 \text{ lb / ft}^2$

$$P_a = \frac{1}{2}(737.5)(22 - 6.82) = \mathbf{5598 \text{ lb / ft}}$$

7.10 a. Eq. (7.25): $P_a = \frac{1}{2} K_a \gamma H^2$. $\delta'/\phi' = 20/30 = 2/3$; $\alpha = 10°$; $\beta = 85°$; $\phi' = 30°$

Table 7.4: $K_a = 0.3857$

$$P_a = \frac{1}{2}(0.3857)(105)(12)^2 = \mathbf{2916 \text{ lb / ft}}$$

Acts at a distance of 4 ft from the bottom of the wall inclined at an angle of 20° to the normal drawn from the back face of the wall.

b. $\delta'/\phi' = 15/30 = 1/2$; $\alpha = 20°$; $\beta = 85°$. Table 7.5: $K_a = 0.4708$

$$P_a = \frac{1}{2}(0.4708)(105)(12)^2 = \mathbf{3559 \text{ lb / ft}}$$

Acts at a distance of 4 ft from the bottom of the wall inclined at an angle of 15° to the normal drawn to the back face of the wall.

7.11 Eq. (7.29): $P_{ae} = \frac{1}{2}\gamma H^2(1 - k_v)K_{ae}$

For $k_h = 0.2$, $\delta'/\phi' = 2/3$, $\phi' = 30°$, $\alpha = 10°$, and $\beta = 85°$, $K_a = 0.454$ [Eq. (7.30)]

$$P_{ae} = \frac{1}{2}(18.2)(5)^2(1 - 0)(0.454) = \mathbf{103.3 \text{ kN / m}}$$

Eq. (7.25): $P_a = \frac{1}{2} K_a \gamma H^2$.

For $\delta'/\phi' = 2/3$, $\phi' = 30°$, $\alpha = 10°$, $\beta = 85°$, $K_a = 0.3857$ (Table 7.4)

$$P_a = \frac{1}{2}(0.3857)(18.2)(5)^2 = 87.8 \text{ kN / m}$$

$$\Delta P_{ae} = 103.3 - 87.8 = 15.5 \text{ kN / m}$$

Eq. (7.33):

$$\bar{z} = \frac{0.6H(\Delta P_{ae}) + \left(\frac{H}{3}\right)P_a}{P_{ae}} = \frac{(0.6)(5)(15.5) + \left(\frac{5}{3}\right)(87.8)}{103.3} = \mathbf{1.87\ m}$$

7.12

| $\phi'$ (deg) | $\delta'/\phi'$ | $\gamma$ (kN / m³) | $n_a$ | $\frac{P_a}{0.5\gamma H^2}$ (Table 7.7) | $P_a$ (kN / m) |
|---|---|---|---|---|---|
| 35 | 0.5 | 17.5 | 0.3 | 0.231 | **129.36** |
| 35 | 0.5 | 17.5 | 0.4 | 0.249 | **139.44** |
| 35 | 0.5 | 17.5 | 0.5 | 0.269 | **150.64** |

7.13 For a frictionless wall, $\delta' = 0$; hence, $m = 1$ [Eq. (7.40)]. For rotation about the top, from Eq. (7.41)

$$\sigma'_a(z) = \gamma \tan^2\left(45 - \frac{\phi' z}{2H}\right)\left[z - \frac{\phi' z^2}{H\cos\left(\frac{\phi' z}{H}\right)}\right]$$

For rotation about the bottom, from Eq. (7.42)

$$\sigma'_a(z) = \gamma z \tan^2\left(\frac{\cos\phi'}{1+\sin\phi'}\right)^2$$

$$\sigma'_a(z)_{\text{translation}} = \frac{[\sigma'_a(z) - \text{top}] + [\sigma'_a(z) - \text{bottom}]}{2}$$

With $\gamma = 16$ kN / m³, $\phi' = 30°$, and $H = 6$ m, the following table can now be prepared.

| z (in.) | $\sigma'_a(z)$–top (kN / m²) | $\sigma'_a(z)$–bottom (kN / m²) | $\sigma'_a(z)_{\text{translation}}$ (kN / m²) |
|---|---|---|---|
| 1.5 | 16.01 | 8 | **12.01** |
| 3.0 | 20.59 | 16 | **18.30** |
| 4.5 | 18.50 | 24 | **21.23** |
| 6.0 | 12.64 | 32 | **22.32** |

7.14 a. $K_p = \tan^2\left(45 + \frac{\phi}{2}\right)$; $\phi = 0$; $K_p = 1$

At $z = 0$ ft: $\sigma_p = \sigma_o K_p + 2c\sqrt{K_p} = 0 + (2)(500)(1) = $ **1000 lb /ft²**

At $z = 18$ ft: $\sigma_p = (120)(18)(1) + (2)(500)(1) = 2160 + 1000 = $ **3160 lb / ft²**

The pressure diagram is similar to Figure 7.21.

b. Eq. (7.47):

$$P_p = \frac{1}{2}\gamma H^2 K_p + 2cH\sqrt{K_p} = \frac{1}{2}(120)(18)^2(1) + (2)(500)(18)(1)$$

$= 19{,}440 + 18{,}000 = $ **37,440 lb / ft²**

$$\bar{z} = \frac{\left(2cH\sqrt{K_p}\right)\left(\frac{H}{2}\right) + \left(\frac{1}{2}\gamma H^2 K_p\right)\left(\frac{H}{3}\right)}{P_p} = \frac{(18{,}000)(9) + (19{,}400)(6)}{37{,}440}$$

= **7.44 ft from bottom of wall**

7.15 $K_{p(1)} = \tan^2\left(45 + \frac{\phi_1'}{2}\right) = \tan^2(45 + 19) = 4.2$; $K_{p(2)} = \tan^2(45 + 12.5) = 2.463$;

$\sqrt{K_{p(2)}} = 1.57$

At $z = 0$: $\sigma_p' = 0$

At $z = 8$ ft (in first layer): $\sigma_p' = \gamma_1 z K_{p(1)} = (110)(8.0)(4.2) = 3696$ lb / ft²

$\approx 3.7$ kip / ft²

At $z = 8$ ft (in bottom layer): $\sigma_p' = \gamma_1 z K_{p(1)} + 2c_2' \sqrt{K_{p(1)}}$

$= (110)(8)(2.463) + (2)(209)(1.57)$

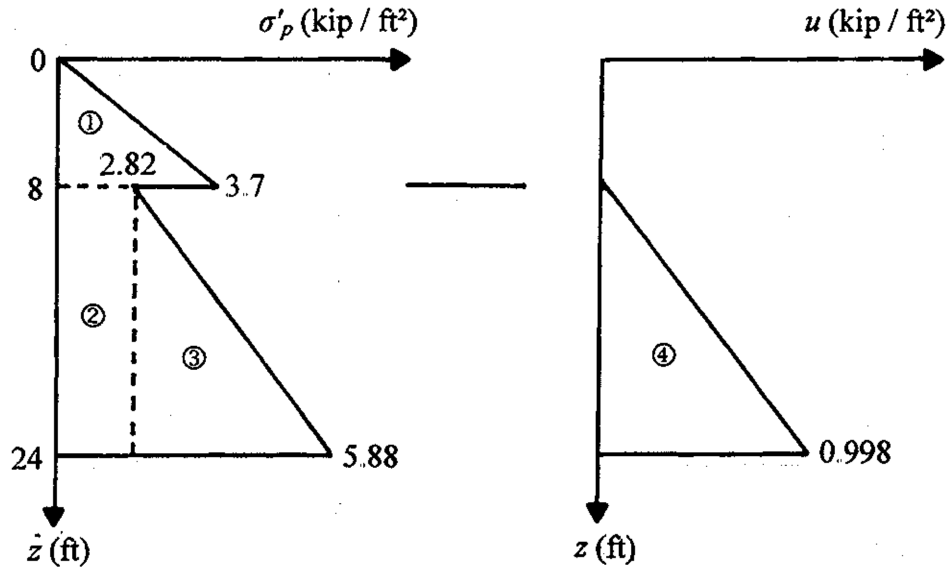
$= 2824$ lb / ft² $\approx 2.82$ kip / ft²

At $z = 24$ ft: $\sigma_p' = [(110)(8) + (140 - 62.4)(16)](2.463) + (2)(209)(1.57)$

$= 5882$ lb / ft² $\approx 5.88$ kip / ft²

$u = (16)(62.4) = 998.4$ lb / ft² $\approx 0.998$ kip / ft²

The pressure distribution diagram is shown below.




$P_p$ = Area of pressure diagrams 1 + 2 + 3 + 4 = 14.8 + 45.12 + 24.48 + 7.98

= **92.38 kip / ft**

7.16 $K_{p(1)} = \tan^2(45 + 14) = 2.77$; $\sqrt{K_{p(1)}} = 1.664$; $K_{p(2)} = 2.04$; $\sqrt{K_{p(2)}} = 1.428$

At $z = 0$ ft: $\sigma'_p = 2c'_1\sqrt{K_{p(1)}} = (2)(350)(1.664) = 1164.8 \text{ lb / ft}^2 \approx 1.165 \text{ kip / ft}^2$

At $z = 8.2$ ft (in top layer): $\sigma'_p = \gamma_1 z K_{p(1)} + 2c'_1\sqrt{K_{p(1)}}$

$= (107)(8.2)(2.77) + (2)(350)(1.664)$

$= 3595.2 \text{ lb / ft}^2 \approx 3.6 \text{ kip / ft}^2$

At $z = 8.2$ ft (in bottom layer): $\sigma'_p = (107)(8.2)(2.04) + (2)(100)(1.428)$

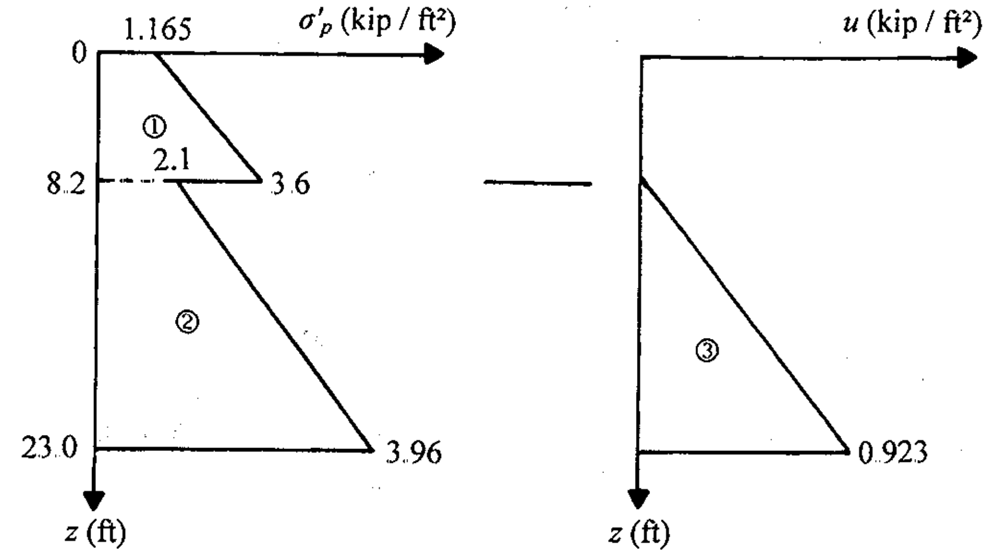
$= 2075.5 \text{ lb / ft}^2 \approx 2.1 \text{ kip / ft}^2$

At $z = 23$ ft: $\sigma'_p = [(107)(8.2) + (125 - 62.4)(14.8)](2.04) + (2)(100)(1.428)$

$= 3965.5 \text{ lb / ft}^2 \approx 3.96 \text{ kip / ft}^2$

$u = (62.4)(14.8) = 923.52 \text{ lb / ft}^2 \approx 0.923 \text{ kip / ft}^2$

The pressure diagram is shown.




$$P_p = A_1 + A_2 + A_3 = \frac{1}{2}(1.165 + 3.6)(8.2) + \frac{1}{2}(2.1 + 3.96)(14.8) + \frac{1}{2}(14.8)(0.923)$$

$$= \mathbf{71.21\ kip / ft}$$

7.17 $P_p = \frac{1}{2}\gamma H^2 K_p$

$\phi' = 35°$; $\delta' = 10°$; $\phi'/\delta' = 10/35 = 0.286$; $K_p = 4.84$ (Figure 7.26)

$$P_p = \frac{1}{2}\gamma H^2 K_p = \frac{1}{2}(16.5)(4)^2(4.84) = \mathbf{638.88\ kN / m}$$

7.18 Eq. (7.56): $P_{pe} = \left[\frac{1}{2}\gamma H^2 K_{p\gamma(e)}\right]\frac{1}{\cos\delta'}$

$\delta' = 20°$; $\phi' = 40°$; $\phi'/\delta' = 0.5$; $K_v = 0$; $K_h = 0.2$. From Figure 7.28, $K_{p\gamma(e)} = 8.73$

$$P_{pe} = \left[\left(\frac{1}{2}\right)(18)(4)^2(8.73)\right]\frac{1}{\cos 20} = \mathbf{1338\ kN / m}$$

# CHAPTER 8

8.1 Refer to the diagram.

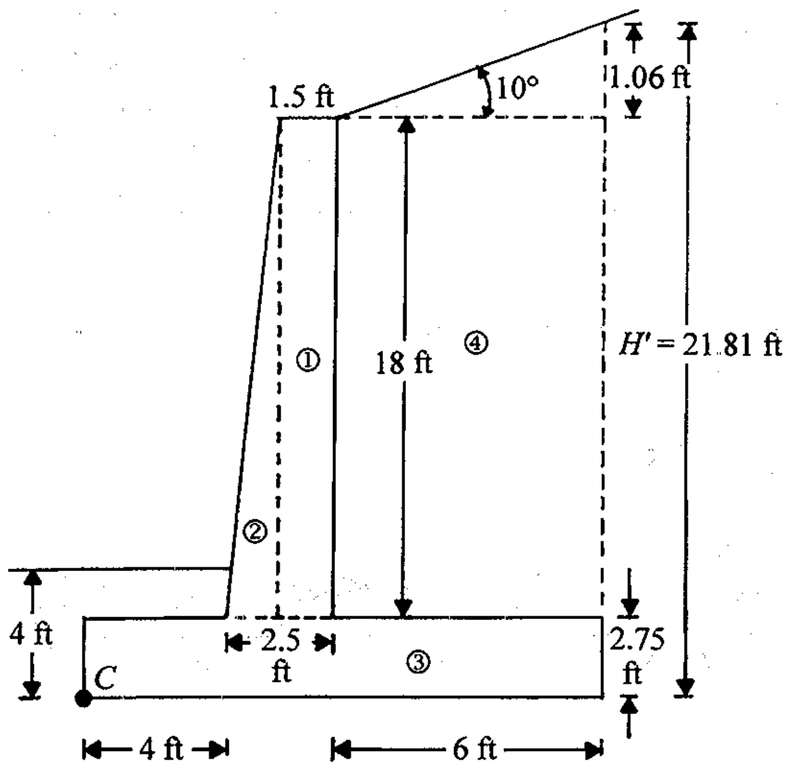



Table 7.1. $\phi_1' = 34°$; $\alpha = 10°$; $K_a = 0.294$

$$P_a = \frac{1}{2}(H')^2 \gamma_1 K_a = \frac{1}{2}\left(\frac{(21.81)^2(117)(0.294)}{1000}\right) = 8.18 \text{ kip/ft}$$

$$P_v = P_a \sin 10° = 1.42 \text{ kip/ft}$$

$$P_h = P_a \cos 10° = 8.06 \text{ kip/ft}$$

Refer to the table on the next page.

| Section | Weight (kip / ft) | Moment arm from $C$ (ft) | Moment about $C$ (kip-ft / ft) |
|---|---|---|---|
| 1 | $(1.5)(18)(\gamma_c) = 4.05$ | 5.75 | 23.29 |
| 2 | $\frac{1}{2}(1.0)(18)(\gamma_c) = 1.35$ | $4 + \frac{2}{3}(1) = 4.67$ | 6.3 |
| 3 | $(12.5)(2.75)(\gamma_c) = 5.156$ | 6.25 | 32.23 |
| 4 | $\frac{(18+19.06)}{2}(6)(0.117) = 13.01$ | $4 + 2.5 + \frac{6}{2} = 9.5$ | 123.6 |
| | $P_v = 1.42$ | 12.5 | 17.75 |
| | $\sum 24.986$ | | $\sum 203.17$ |

$$M_o = P_h \frac{H'}{3} = (8.06)\left(\frac{21.81}{3}\right) = 58.6 \text{ kip-ft / ft}$$

$$\text{FS}_{\text{overturning}} = \frac{203.17}{58.6} = \mathbf{3.47}$$

$$\text{FS}_{\text{sliding}} = \frac{\Sigma V \tan\left[\left(\frac{2}{3}\right)\phi_2'\right] + B\left(\frac{2}{3}\right)c_2'}{P_a \cos\alpha} = \frac{(24.986)\tan\left(\frac{2}{3}\times 18\right) + (12.5)\left(\frac{2}{3}\right)(0.8)}{8.06}$$

$$= \mathbf{1.49}$$

$$e = \frac{B}{2} - \frac{\Sigma M_R - \Sigma M_o}{\Sigma V} = 6.25 - \frac{203.17 - 58.6}{24.986} = 0.464 \text{ ft}$$

$$q_{\text{toe}} = \frac{\Sigma V}{B}\left(1 + \frac{6e}{B}\right) = \frac{24.986}{12.5}\left[1 + \frac{(6)(0.464)}{12.5}\right] = 2.44 \text{ kip / ft}$$

$$B' = 12.5 - (2)(0.464) = 11.572 \text{ ft}$$

$$q_u = c_2' N_c F_{cd} F_{ci} + qN_q F_{qd} F_{qi} + \frac{1}{2}\gamma_2 B' N_\gamma F_{\gamma d} F_{\gamma i}$$

From Table 3.3, for $\phi_2' = 18°$, $N_c = 13.1$; $N_q = 5.26$; $N_\gamma = 4.07$

$$F_{cd} = 1 + 0.4\left(\frac{4}{11.572}\right) = 1.138$$

$$F_{qi} = F_{ci} = \left(1 - \frac{\psi}{90}\right)^2$$

$$\psi = \tan^{-1}\left(\frac{P_a \cos\alpha}{\Sigma V}\right) = \tan^{-1}\left(\frac{8.06}{24.986}\right) = 17.88°$$

$$F_{qi} = F_{ci} = \left(1 - \frac{17.88}{90}\right)^2 = 0.642$$

$$q = (4)(0.110) = 0.44 \text{ kip / ft}^2$$

$$F_{qd} = 1 + 0.31\left(\frac{4}{11.572}\right) = 1.107$$

$$F_{\gamma i} = \left(1 - \frac{17.88}{18}\right)^2 = 0$$

$$q_u = (0.8)(13.1)(1.138)(0.642) + (0.44)(5.26)(1.107)(0.641) + 0 = 9.3 \text{ kip / ft}^2$$

$$\text{FS}_{(\text{bearing})} = \frac{q_u}{q_{\text{toe}}} = \frac{9.3}{2.44} = \mathbf{3.81}$$

8.2 Refer to the diagram.

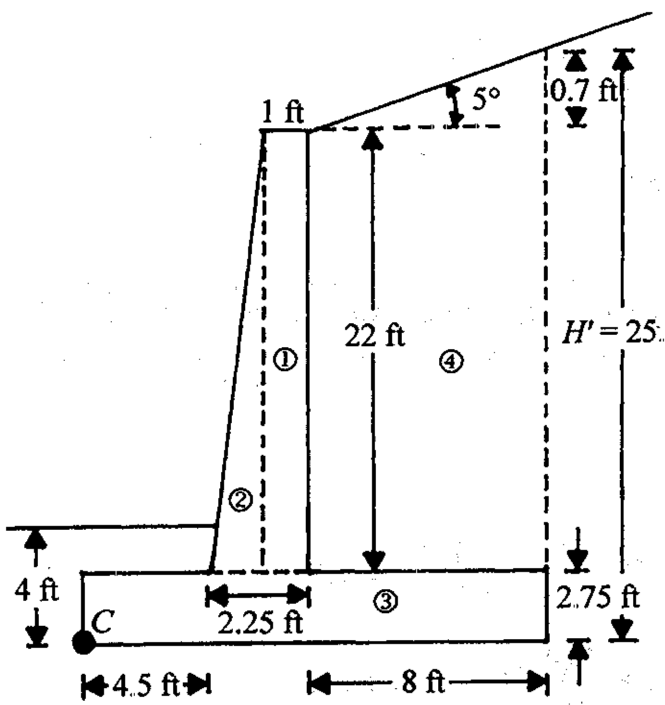


Table 7.1. $\phi_1' = 36°$; $\alpha = 5°$; $K_a = 0.262$

$$P_a = \frac{1}{2}(H')\gamma_1 K_a = \frac{1}{2}\left[\frac{(25.45)^2(110)(0.262)}{1000}\right] = 9.29 \text{ kip/ft}$$

$P_v = P_a \sin 5° = 0.813$ kip / ft

$P_h = P_a \cos 5° = 9.29$ kip / ft

Refer to the table. *Note:* $\gamma_c = 0.15$ kip/ft$^3$

| Section | Weight (kip / ft) | Moment arm from *C* (ft) | Moment about *C* (kip-ft / ft) |
|---|---|---|---|
| 1 | $(2)(22)(\gamma_c) = 3.3$ | 6.25 | 20.63 |
| 2 | $\frac{1}{2}(1.25)(22)(\gamma_c) = 2.063$ | $4.5 + \frac{2}{3}(1.25) = 5.33$ | 11 |
| 3 | $(14.75)(2.75)(\gamma_c) = 6.086$ | 7.375 | 44.87 |
| 4 | $\frac{22+22.7}{2}(8)(0.11) = 19.67$ | $4.5 + 2.25 + \frac{8}{2} = 10.75$ | 211.45 |
| | $P_v = 0.813$ | 14.75 | 11.99 |
| | $\Sigma 31.93$ | | $\Sigma 299.94$ |

$$M_o = P_h \frac{H'}{3} = (9.29)\left(\frac{25.45}{3}\right) = 78.81 \text{ kip-ft}$$

$$\text{FS}_{\text{overturning}} = \frac{299.94}{78.81} = \mathbf{3.81}$$

$$\text{FS}_{\text{(sliding)}} = \frac{\Sigma V \tan\left(\frac{2}{3}\right)\phi_2 + B\left(\frac{2}{3}\right)c_2}{P_a \cos\alpha} = \frac{(31.93)\tan\left(\frac{2}{3}\times 15\right) + (14.75)\left(\frac{2}{3}\right)(1.0)}{9.29}$$

$$= \mathbf{1.66}$$

$$e = \frac{B}{2} - \frac{\Sigma M_R - \Sigma M_o}{\Sigma V} = 7.375 - \frac{299.79 - 78.81}{31.93} = 0.45 \text{ ft}$$

$$q_{\text{toe}} = \frac{\Sigma V}{B}\left(1 + \frac{6e}{B}\right) = \frac{31.93}{14.75}\left[1 + \frac{(6)(0.45)}{14.75}\right] = 2.56 \text{ kip/ft}^2$$

$B' = B - 2e = 14.75 - (2)(0.45) = 13.85$ ft

$$q_u = c_2' N_c F_{cd} F_{ci} + q N_q F_{qd} F_{qi} + \frac{1}{2}\gamma_2 B' N_\gamma F_{\gamma d} F_{\gamma i}$$

For $\phi_2' = 15°$, $N_c = 10.98$; $N_q = 3.94$; $N_\gamma = 2.65$

$$F_{cd} = 1 + 0.4\left(\frac{4}{13.85}\right) = 1.115$$

$$\psi = \tan^{-1}\left(\frac{P_a \cos\alpha}{\sum V}\right) = \tan^{-1}\left(\frac{9.29}{31.93}\right) = 16.22°$$

$$F_{qi} = F_{ci} = \left(1 - \frac{\psi}{90}\right)^2 = \left(1 - \frac{16.22}{90}\right)^2 = 0.672$$

$$q = (4)(0.12) = 0.48 \text{ kip / ft}^2$$

$$F_{qd} = 1 + 0.294\left(\frac{4}{13.85}\right) = 1.085; \quad F_{\gamma i} = \left(1 - \frac{16.22}{15}\right)^2 \approx 0$$

$$q_u = (1.0)(10.98)(1.115)(0.672) + (0.48)(3.94)(1.085)(0.672) + 0 = 9.606 \text{ kip / ft}^2$$

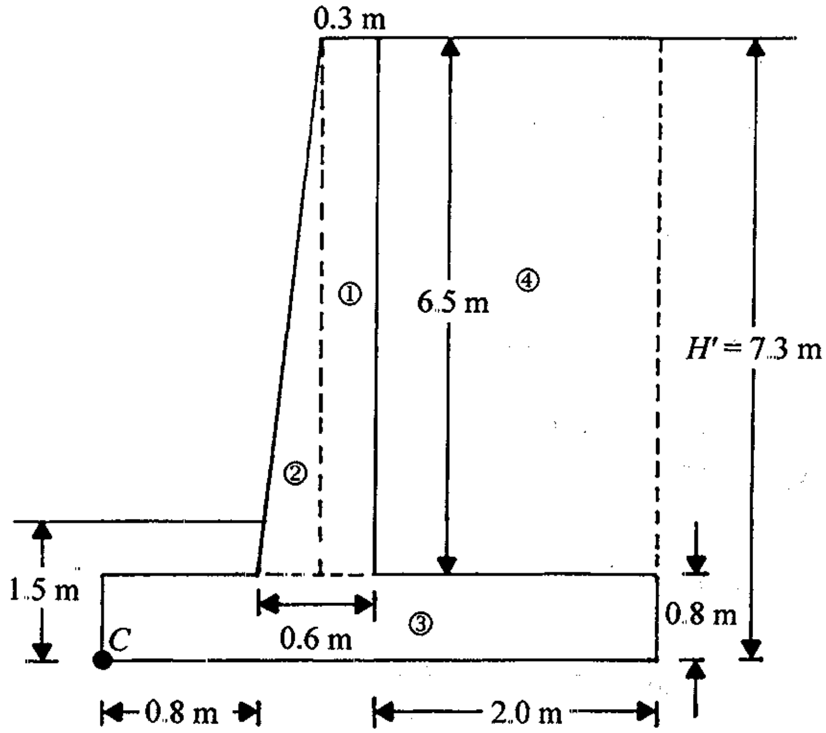
$$\text{FS}_{(\text{bearing})} = \frac{q_u}{q_{\text{toe}}} = \frac{9.606}{2.56} = \mathbf{3.75}$$

8.3 $K_a = 0.26$; $H' = 7.3$ m

$$P_a = \frac{1}{2}\gamma(H')^2 K_a = \frac{1}{2}(18.08)(7.3)^2(0.26) = 125.25 \text{ kN / m}$$

$P_h = 125.25$ kN / m; $P_v = 0$

| Section | Weight (kN / m) | Moment arm from *C* (m) | Moment about *C* (kN-m / m) |
|---|---|---|---|
| 1 | $(0.3)(6.5)(\gamma_c) = 45.98$ | $0.8 + 0.3 + 0.15 = 1.25$ | 57.48 |
| 2 | $½(0.3)(6.5)(\gamma_c) = 22.99$ | $0.8 + 0.2 = 1.0$ | 22.9 |
| 3 | $(3.4)(0.8)(\gamma_c) = 64.14$ | 1.7 | 109.04 |
| 4 | $(6.5)(2)(18.08) = 235.04$ | 2.4 | 564.1 |
| | $\sum 368.15$ | | $\sum 753.52$ |




$$M_o = (125.25)\left(\frac{7.3}{3}\right) = 304.78 \text{ kN-m}$$

$$\text{FS}_{(\text{overturning})} = \frac{753.52}{304.78} = \mathbf{2.47}$$

$$\text{FS}_{(\text{sliding})} = \frac{(368.15)\tan\left[\left(\frac{2}{3}\right)(15)\right] + (3.4)\left(\frac{2}{3}\right)(30)}{125.25} = \mathbf{1.06}$$

$$e = \frac{3.4}{2} - \frac{753.52 - 304.78}{368.15} = 0.481 \text{ m}$$

$$q_{\text{toe}} = \frac{368.15}{3.4}\left[1 + \frac{(6)(0.481)}{3.4}\right] = 200.19 \text{ kN/m}^2$$

$$B' = B - 2e = 3.4 - (2)(0.481) = 2.438 \text{ m}$$

$$q_u = c'_2 N_c F_{cd} F_{ci} + q N_q F_{qd} F_{qi} + \frac{1}{2}\gamma_2 B' N_\gamma F_{\gamma d} F_{\gamma i}$$

$$F_{cd} = 1 + 0.4\left(\frac{1.5}{2.438}\right) = 1.246; \quad F_{qd} = 1 + 0.294\left(\frac{1.5}{2.438}\right) = 1.181$$

$$\psi = \tan^{-1}\left(\frac{125.25}{368.15}\right) = 18.79°$$

$$F_{ci} = F_{qi} = \left(1 - \frac{18.79}{90}\right)^2 = 0.626; \quad F_{\gamma i} = \left(1 - \frac{18.79}{15}\right)^2 = 0.064$$

$$q_u = (30)(10.98)(1.246)(0.626) + (1.5)(19.65)(3.94)(1.181)(0.626)$$
$$+ \frac{1}{2}(19.65)(2.438)(2.65)(1)(0.064) = 346.85 \text{ kN / m}^2$$

$$\text{FS}_{(\text{bearing})} = \frac{346.11}{q_{\text{toe}}} = \frac{346.85}{200.19} = \mathbf{1.73}$$

8.4 Refer to the figure.

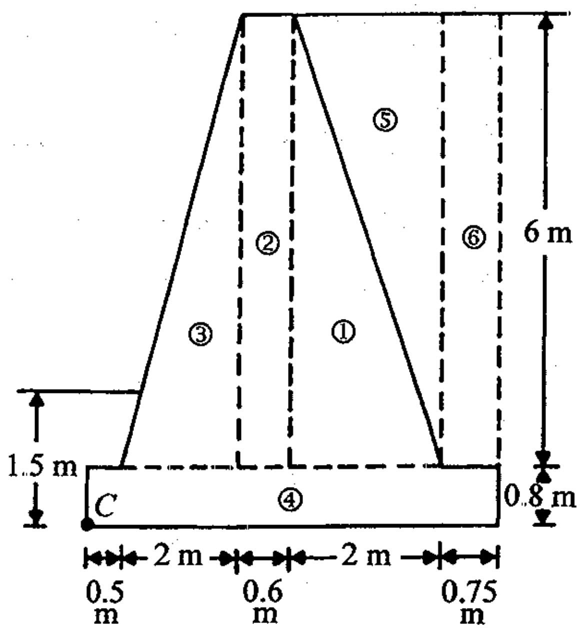
$\phi'_1 = 32°$; $H' = 6.8$ m

$$K_a = \tan^2\left(45 - \frac{32}{3}\right) = 0.307$$

$$P_a = P_h = \frac{1}{2}\gamma(H')^2 K_a$$

$$= \frac{1}{2}(16.5)(6.8)^2(0.307)$$

$$= 117.1 \text{ kN / m}$$




Refer to the table.

| Section | Weight (kN / m) | Moment arm from $C$ (m) | Moment about C (kN-m / m) |
|---|---|---|---|
| 1 | $\frac{1}{2}(2)(6)(\gamma_c) = 141.48$ | 3.77 | 533.38 |
| 2 | $(0.6)(6)(\gamma_c) = 84.89$ | 2.8 | 237.69 |
| 3 | 141.48 | 1.83 | 258.9 |
| 4 | $(5.85)(0.8)(\gamma_c) = 110.35$ | 2.925 | 322.8 |
| 5 | $\frac{1}{2}(2)(6)(16.5) = 99$ | 4.43 | 438.57 |
| 6 | $(0.75)(6)(16.5) = 74.25$ | 5.475 | 405.52 |
| | $\sum 651.45$ | | $\sum 2196.86$ |

$$M_O = \frac{H'P_a}{3} = \left(\frac{6.8}{3}\right)(117.1) = 265.4 \text{ kN-m/m}$$

$$\text{FS}_{\text{(overturning)}} = \frac{\sum M_R}{\sum M_O} = \frac{2196.86}{265.4} = \mathbf{8.28}$$

$$\text{FS}_{\text{(sliding)}} = \frac{\sum V \tan\left(\frac{2}{3}\phi_2'\right) + \left(\frac{2}{3}\right)c_2' B}{P_a} = \frac{(651.45)\tan(14.66) + \left(\frac{2}{3}\right)(40)(5.85)}{117.1}$$

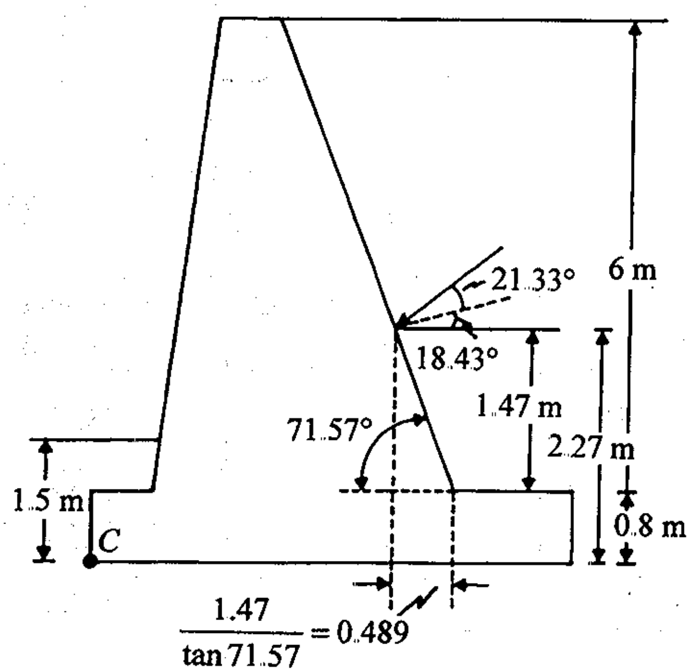
$$= \frac{170.42 + 156}{117.1} = \mathbf{2.79}$$

8.5 $\frac{\delta}{\phi_1'} = \frac{2}{3}$. From Table 7.4, for $\phi_1' = 32°$, $\alpha = 0$; $\beta = 71.57°$; $K_a = 0.45$; $\delta = 21.33°$

$$P_a = \frac{1}{2}(16.5)(6.8)^2(0.45) = 171.67 \text{ kN/m}$$

$$P_h = 171.67\cos(21.33 + 18.43) = 131.97 \text{ kN/m}$$

$$P_v = 171.67\sin(21.33 + 18.43) = 109.8 \text{ kN/m}$$




Refer to sections in the figure shown for Problem 8.4.

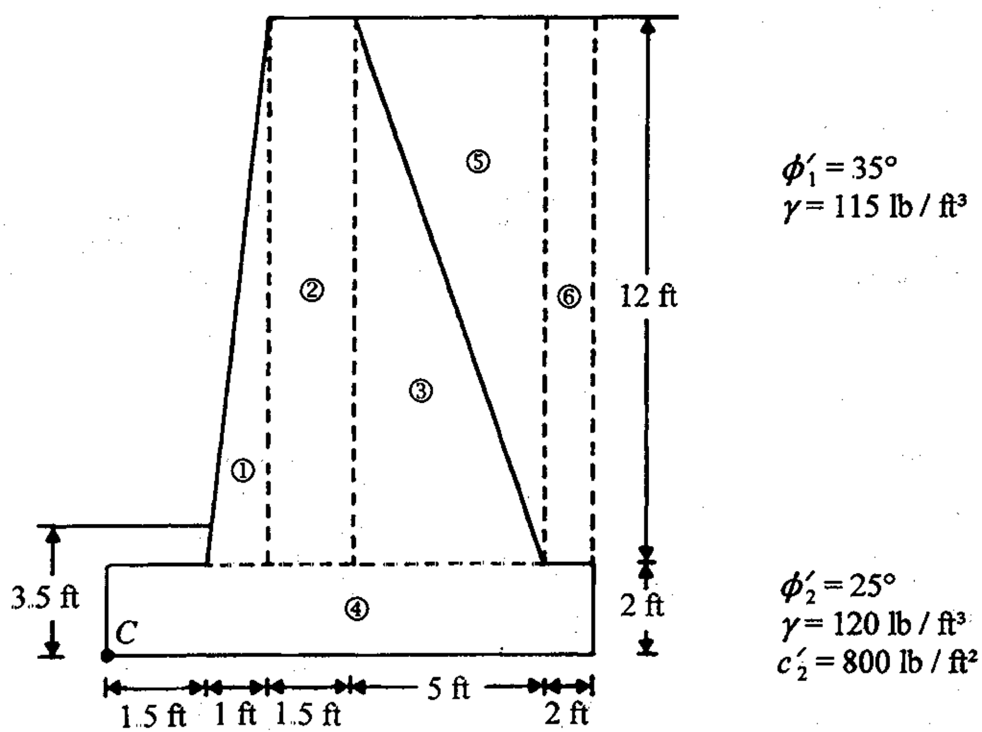
| Section | Weight (kN / m) | Moment arm from $C$ (m) | Moment about C (kN-m / m) |
|---|---|---|---|
| 1 | 141.48 | 3.77 | 533.38 |
| 2 | 84.89 | 2.8 | 237.69 |
| 3 | 141.48 | 1.83 | 258.9 |
| 4 | 110.35 | 2.925 | 322.8 |
| $P_v$ | 109.8 | 4.611 | 506.29 |
| | $\sum 588$ | | $\sum 1859.06$ |

$$M_O = P_h \frac{H'}{3} = (131.97)\left(\frac{6.8}{3}\right) = 299.13 \text{ kN - m / m}$$

$$\text{FS}_{(\text{overturning})} = \frac{1859.06}{299.13} = \mathbf{6.2}$$

$$\text{FS}_{(\text{sliding})} = \frac{\sum V \tan\left(\frac{2}{3}\phi_2'\right) + \left(\frac{2}{3}\right)c_2' B}{P_h} = \frac{(588)\tan(14.66) + \left(\frac{2}{3}\right)(40)(5.85)}{131.97} = \mathbf{2.35}$$

8.6 Refer to the figure.



$$K_a = \tan^2\left(45 - \frac{\phi'_1}{2}\right) = \tan^2\left(45 - \frac{35}{2}\right) = 0.27$$

$$P_a = \frac{1}{2}\gamma(H')^2 K_a = \frac{1}{2}(115)(14)^2(0.27) = 3042.9 \text{ lb/ft} \approx 3.043 \text{ kip/ft}$$

| Area | Weight (kip / ft) | Moment arm from $C$ (ft) | Moment about C (kip-ft / ft) |
|---|---|---|---|
| 1 | $\frac{1}{2}(1)(12)(\gamma_c) = 0.9$ | $1.5 + \frac{2}{3}(1) = 2.17$ | 1.953 |
| 2 | $(1.5)(12)(\gamma_c) = 2.7$ | $1.5 + 1 + 0.75 = 3.25$ | 8.775 |
| 3 | $\frac{1}{2}(5)(12)(\gamma_c) = 4.5$ | $1.5 + 1 + 1.5 + \frac{5}{3} = 5.67$ | 25.515 |
| 4 | $(11)(2)(\gamma_c) = 3.3$ | $\frac{11}{2} = 5.5$ | 18.15 |
| 5 | $\frac{1}{2}(5)(12)(0.115) = 3.45$ | $1.5 + 1 + 1.5 + \frac{2}{3}(5) = 7.33$ | 25.29 |
| 6 | $(2)(12)(0.115) = 2.76$ | $1.5 + 1 + 1.5 + 5 + 1 = 10.00$ | 27.6 |
| | $\sum 17.61$ | | $\sum 107.28 = M_R$ |

$$M_O = \frac{H'}{3} P_a = \left(\frac{14}{3}\right)(3.043) = 14.2 \text{ kip-ft}$$

$$\text{FS}_{(\text{overturning})} = \frac{107.28}{14.2} = \mathbf{7.55}$$

$$\text{FS}_{(\text{sliding})} = \frac{\Sigma V \tan\left(\frac{2}{3}\phi'_2\right)_2 + B\left(\frac{2}{3}\right)c'_2}{P_a \cos\alpha} = \frac{(17.61)\tan\left(\frac{2\times 25}{3}\right) + (11)\left(\frac{2}{3}\right)(0.8)}{3.043} = \mathbf{3.66}$$

8.7 $b' = 6$ ft; $a' = 5$ ft; $q = 2000$ lb / ft$^2$

| $z$ (ft) | $\sigma'_{o(1)} = \gamma z$ (lb / ft$^2$) | $\frac{z}{2b'}$ | $\sigma'_{o(2)}$ (lb / ft$^2$) | $\sigma'_o = \sigma'_{o(1)} + \sigma'_{o(2)}$ (lb / ft$^2$) |
|---|---|---|---|---|
| 5 | 525 | 0.416 | 1000[a] | **1525** |
| 10 | 1050 | 0.833 | 666.7[a] | **1716.7** |
| 15 | 1575 | 1.25 | 540.5[b] | **2115.5** |
| 20 | 2100 | 1.67 | 476.2[b] | **2576.2** |

[a]Eq. (8.25); [b]Eq. (8.26)

8.8 Eq. (8.29): $M = 1.4 - \dfrac{0.4b'}{0.14H} = 1.4 - \dfrac{(0.4)(6)}{(0.14)(20)} = 0.543$. So use $M = 1.0$.

Refer to Figure 8.24

$$\beta = \tan^{-1}\left(\frac{b'+a'}{z}\right) - \tan^{-1}\left(\frac{b'}{z}\right) = \tan^{-1}\left(\frac{11}{z}\right) - \tan^{-1}\left(\frac{6}{z}\right)$$

$$\alpha = \tan^{-1}\left(\frac{b'+a'}{z}\right) - \frac{\beta}{2} = \frac{1}{2}\left[\tan^{-1}\left(\frac{b'+a'}{z}\right) + \tan^{-1}\left(\frac{b'}{z}\right)\right] = \frac{1}{2}\left[\tan^{-1}\left(\frac{11}{z}\right) + \tan^{-1}\left(\frac{6}{z}\right)\right]$$

$K_a = \tan^2(45 - 15) = 1/3$; $\gamma_1 = 105$ lb / ft$^3$; $q = 2000$ lb / ft$^2$

| $z$ (ft) | $\sigma'_{a(1)} = K_a \gamma z$ (lb / ft$^2$) | $\alpha$ (deg) | $\beta$ (deg) | $\sigma'_{a(2)}$ [a] (lb / ft$^2$) | $\sigma'_a = \sigma'_{a(1)} + \sigma'_{a(2)}$ (lb / ft$^2$) |
|---|---|---|---|---|---|
| 5 | 175 | 57.87 | 15.36 | 487.7 | **662.7** |
| 10 | 350 | 39.35 | 16.77 | 193.1 | **543.1** |
| 15 | 525 | 29.03 | 14.45 | 155.3 | **680.3** |
| 20 | 700 | 22.76 | 12.11 | 81.2 | **781.2** |

[a] Eq. (8.28)

8.9 a. $K_a = \tan^2\left(45 - \dfrac{\phi'_1}{2}\right) = \tan^2\left(45 - \dfrac{34}{2}\right) = 0.2827$

Eq. (8.39): $t = \dfrac{(\gamma_1 H K_a S_V S_H)[\text{FS}_{(B)}]}{w f_y} = \dfrac{(119)(30)(0.2827)(3)(4)(3)}{(4.75)(38{,}000)} = \mathbf{0.201\ in.}$

b. Eq. (8.38). At $z = 0$,

$$L = H\tan\left(45 - \frac{\phi'_1}{2}\right) + \frac{\text{FS}_{(P)} S_V S_H (K_a \gamma z)}{(2w\tan\phi'_1)(\gamma z)}$$

$$= (30)\tan(45 - 17) + \frac{(3)(0.2827)(3)(4)}{(2)\left(\frac{4.75}{12}\right)(\tan 25)} = \mathbf{43.52\ ft}$$

8.10 a. Check for overturning: $P_a = \frac{1}{2}\gamma_1 H^2 K_a = \frac{1}{2}(119)(30^2)(0.2827) = 15{,}138.5$ lb / ft

$M_o = P_a z' = (15{,}138.5)\left(\frac{30}{3}\right) = 151{,}385 \text{ lb-ft} \approx 151.4 \text{ kip-ft/ft};$

$L = 43.52$ ft

Eq. (8.41): $M_r = (HL)(\gamma_1)\left(\frac{L}{2}\right) = H\gamma_1\left(\frac{L^2}{2}\right) = \frac{(30)(119)(43.52)^2}{2}$

$= 3{,}380{,}773 \text{ lb-ft} \approx 3381 \text{ kip-ft/ft}$

$$\text{FS}_{(\text{overturning})} = \frac{3381}{151.4} = \mathbf{22.33}$$

b. Check for sliding: Eq. (8.43):

$$\text{FS}_{(\text{sliding})} = \frac{\gamma_1 HL \tan\left(\frac{2}{3}\phi_1'\right)}{P_a} = \frac{(119)(30)(43.52)\tan\left[\left(\frac{2}{3}\right)(34)\right]}{15{,}138.5} = \mathbf{4.29}$$

b. Check for bearing capacity: $\phi_2' = 25°$. From Table 3.3, $N_c = 20.72$; $N_\gamma = 10.88$

$q_{ult} = c_2' N_c + \frac{1}{2}\gamma_2 L' N_\gamma$

$e = \frac{L}{2} - \frac{M_R - M_O}{\Sigma V} = \frac{43.52}{2} - \frac{3381 - 151.4}{(30)(43.52)(0.119)} = 0.97 \text{ ft}$

$L' = 43.52 - (2 \times 0.97) = 41.58$ ft

$q_u = (650)(20.72) + \frac{1}{2}(116)(41.58)(10.88) = 13{,}468 + 26{,}238.6 \approx 39{,}706.6 \text{ lb/ft}^2$

$\sigma'_{o(H)} = \gamma_1 H = (119)(30) = 3570 \text{ lb/ft}^2$

$$\text{FS}_{(\text{bearing capacity})} = \frac{39{,}706.6}{3570} = \mathbf{11.1}$$

8.11 a. $t = \frac{(\gamma_1 H K_a S_V S_H)[\text{FS}_{(B)}]}{w f_y} = \frac{(119)(24)(0.2827)(3)(4)(3)}{(4.75)(38{,}000)} = \mathbf{0.161 \text{ in.}}$

b. $L = H\tan\left(45 - \frac{\phi_1'}{2}\right) + \frac{\text{FS}_{(P)} S_V S_H (K_a \gamma z)}{(2w\tan\phi_1)(\gamma z)} = (24)\tan(45 - 17) + \frac{(3)(0.2827)(3)(4)}{(2)\left(\frac{4.75}{12}\right)(\tan 25)}$

$= \mathbf{40.33 \text{ ft}}$

8.12 $\phi'_2 = 30°$; $K_a = \tan^2(45 - 30/2) = 0.333$

Eq. (8.48): $$S_V = \frac{\sigma_G}{\gamma_1 z K_a \left[\mathrm{FS}_{(B)}\right]}$$

At $z = H = 6$ m: $$S_V = \frac{16}{(15.9)(6)(0.333)(1.5)} = \mathbf{0.336\ m}$$

$$L = \frac{H - z}{\tan\left(45 + \frac{\phi'_1}{2}\right)} + \frac{S_V K_a \left[\mathrm{FS}_{(B)}\right]}{2 \tan \phi'_F}$$

At $z = 0$ (maximum length): $$L = \frac{6}{\tan(45 + 15)} + \frac{(0.336)(0.333)(1.5)}{2 \tan\left(\frac{2}{3} \times 30\right)}$$

$$= 3.47 + 0.23 = \mathbf{3.7\ m}$$

Eq. (8.52): $$l_l = \frac{S_V K_a \left[\mathrm{FS}_{(P)}\right]}{4 \tan \phi'_F} = \frac{(0.336)(0.333)(1.5)}{4 \tan\left(\frac{2}{3} \times 30\right)} = 0.115 \text{ m -- Use } \mathbf{1\ m}$$

8.13 Check for overturning:

$$P_a = \frac{1}{2}(15.9)(6)^2(0.333) = 95.3 \text{ kN/m}$$

$$M_O = P_a \frac{6}{3} = 190.6 \text{ kN-m/m}$$

Use $L = 3.7$ for all depths.

$$M_R = \frac{H \gamma_1 L^2}{2} = \frac{(6)(15.9)(3.7)^2}{2} = 653 \text{ kN-m/m}$$

$$\mathrm{FS}_{(\text{overturning})} = \frac{653}{190.6} = \mathbf{3.43}$$

Check for sliding:

$$\mathrm{FS}_{(\text{sliding})} = \frac{\gamma_1 H L \tan\left(\frac{2}{3}\phi'_1\right)}{P_a} = \frac{(15.9)(6)(3.7)(\tan 20)}{95.3} = \mathbf{1.35}$$

Check for bearing capacity:

For $\phi_2' = 20°$, from Table 3.3, $N_c = 14.83$; $N_\gamma = 5.39$

$$e = \frac{L}{2} - \frac{M_R - M_O}{\Sigma V} = \frac{3.7}{2} - \frac{653 - 190.6}{(15.9)(6)(3.7)} = 0.54 \text{ m}$$

$$L' = L - 2e = 3.7 - (2)(0.54) = 2.62 \text{ m}$$

$$q_{\text{ult}} = c_2' N_c + \frac{1}{2}\gamma_2 L' N_\gamma = (55)(14.83) + \frac{1}{2}(16.8)(2.62)(5.39) = 934.3 \text{ kN/m}^2$$

$$\text{FS}_{(\text{bearing capacity})} = \frac{934.3}{(15.9)(6)} = \mathbf{9.79}$$

***Note:*** FS against sliding is below acceptable values, so increase $L$ to about 8 m.

# CHAPTER 9

9.1 a. Refer to Figure 9.7 in the text. $L_1 = 4$ m; $L_2 = 8$ m

$\gamma = 16.1 \text{ kN/m}^3$; $\gamma_{sat} = 18.2 \text{ kN/m}^3$; $\phi' = 32°$

$\gamma' = 18.2 - 9.81 = 8.39 \text{ kN/m}^3$

$$K_a = \tan^2\left(45 - \frac{32}{2}\right) = 0.307; \quad K_p = \tan^2\left(45 + \frac{32}{2}\right) = 3.255$$

$$\sigma_1' = \gamma L_1 K_a = (16.1)(4)(0.307) = 19.77 \text{ kN/m}^2$$

$$\sigma_2' = (\gamma L_1 + \gamma' L_2)K_a = [(16.1)(4) + (8.39)(8)](0.307) = 40.38 \text{ kN/m}^2$$

$$L_3 = \frac{40.38}{(8.39)(3.255 - 0.307)} = 1.63 \text{ m}$$

$$P = \frac{1}{2}(4)(19.77) + (8)(19.77) + \frac{1}{2}(8)(40.38 - 19.77)$$
$$+\frac{1}{2}(1.63)(40.38) = 39.54 + 158.16 + 82.44 + 32.91 = 313.05 \text{ kN/m}$$

$$P(\bar{z}) = (39.54)\left(9.63 + \frac{4}{3}\right) + (158.16)(5.63) + (82.44)\left(1.63 + \frac{8}{3}\right)$$
$$+\left(\frac{(2)(1.63)}{3}\right)(32.91)$$

$$\bar{z} = \frac{1713.91}{313.05} = 5.47 \text{ m}$$

$$\sigma_5' = (\gamma L_1 + \gamma' L_2)K_p + \gamma' L_3 (K_p - K_a)$$
$$= [(16.1)(4) + (8.39)(8)](3.255) + (8.39)(1.63)(2.948) = 468.4 \text{ kN/m}^2$$

$$A_1 = \frac{468.4}{(8.39)(2.948)} = 18.94$$

$$A_2 = \frac{(8)(313.05)}{(8.39)(2.948)} = 101.25$$

$$A_3 = \frac{(6)(313.05)[(2)(5.47)(8.39)(2.948)+468.4]}{(8.39)^2(2.948)^2} = 2268.94$$

$$A_4 = \frac{(313.05)[(6)(5.47)(468.4)+(4)(313.05)]}{(8.39)^2(2.948)^2} = 8507.44$$

$L_4^4 + 18.94L_4^3 - 101.25L_4^2 - 2268.94L_4 - 8507.44 = 0$; $L_4 = 11.68$ m

$D = L_3 + L_4 = 1.63 + 11.68 =$ **13.31 m**

b. Total length = 4 + 8 + (1.3)(13.31) = **29.3 m**

c. $z' = \sqrt{\frac{2P}{\gamma'(K_p - K_a)}} = \sqrt{\frac{(2)(313.05)}{(8.39)(2.948)}} = 5$ m

$$M_{\max} = P(\bar{z}+z') - \frac{1}{6}\gamma' z'^3 (K_p - K_a)$$

$$= (313.05)(5.47+5) - \frac{1}{6}(8.39)(5)^3(2.948) = \mathbf{2762\ kN\text{-}m/m}$$

9.2 a. Refer to Figure 9.7

$$K_a = \tan^2\left(45 - \frac{\phi'}{2}\right) = \tan^2(45-15) = \frac{1}{3} = 0.333; \quad K_p = \tan^2(45+15) = 3$$

$$\sigma_1' = \gamma L_1 K_a = (17.3)(3)\left(\frac{1}{3}\right) = 17.3 \text{ kN/m}^2$$

$$\sigma_2' = (\gamma L_1 + \gamma' L_2)K_a = [(17.3)(3) + (19.4-9.81)(6)]\frac{1}{3} = 36.48 \text{ kN/m}^2$$

$$L_3 = \frac{\sigma_2'}{\gamma'(K_p - K_a)} = \frac{36.48}{(19.4-9.81)(2.667)} = 1.426 \text{ m}$$

$P$ = Areas of 1 + 2 + 3 + 4 = 25.95 + 103.8 + 57.54 + 26.01 = 213.3 kN/m

$$\bar{z} = \frac{(25.95)(8.426)+(103.8)(4.426)+(57.54)(3.426)+(26.01)(0.95)}{213.3}$$

$$= \frac{218.65+459.4+197.13+24.71}{213.3} = 4.22 \text{ m}$$

Eq. (9.11): $\sigma'_5 = (\gamma L_1 + \gamma' L_2)K_p + \gamma' L_3(K_p - K_a)$

$$= (17.3 \times 3 + 9.59 \times 6)(3) + (9.59)(1.426)(2.667)$$

$$= 364.79 \text{ kN/m}^2$$

Eq. (9.17): $A_1 = \frac{364.79}{(9.59)(2.667)} = 14.26$

Eq. (9.18): $A_2 = \frac{(8)(213.3)}{(9.59)(2.667)} = 66.72$

Eq. (9.19): $A_3 = \frac{(6)(213.3)[(2)(4.22)(9.59)(2.667)+364.79]}{(9.59)^2(2.667)^2} = 1136$

Eq. (9.20): $A_4 = \frac{213.3[(6)(4.22)(364.79)+(4)(213.3)]}{(9.59)^2(2.667)^2} = 3290$

Eq. (9.16): $L_4^4 + 14.26L_4^3 - 66.72L_4^2 - 1136L_4 - 3290 = 0$; $L_4 = 9$ m

$D = L_3 + L_4 = 1.426 + 9 \approx$ **10.43 m**

b. Total length = 3 + 6 + (1.3)(10.43) = **22.56 m**

c. Eq. (9.21): $z' = \sqrt{\frac{2P}{\gamma'(K_p - K_a)}} = \sqrt{\frac{(2)(213.3)}{(2.667)(9.59)}} = 4.08$ m

Eq. (9.22):

$$M_{max} = (213.3)(4.22+4.08) - \left[\frac{1}{2}(9.59)(4.08)^2(2.667)\right]\left(\frac{4.08}{3}\right)$$

$$= 1770.39 - 289.58 = \mathbf{1480.9 \text{ kN-m/m}}$$

9.3 $K_a = \tan^2(45 - 17.5) = 0.271$; $K_p = (45 + 17.5) = 3.69$

Eq. (9.24): $\sigma_2' = \gamma L K_a = (108)(15)(0.271) = 439.02 \text{ lb/ft}^2$

Eq. (9.28): $L_3 = \dfrac{LK_a}{K_p - K_a} = \dfrac{(15)(0.271)}{3.69 - 0.271} = 1.189 \text{ ft}$

Eq. (9.29): $P = \frac{1}{2}\sigma_2' L + \frac{1}{2}\sigma_2' L_3 = \frac{1}{2}(439.02)(15) + \frac{1}{2}(439.02)(1.189)$

$= 3292.65 + 261 = 3553.65 \text{ lb/ft}$

Eq. (9.30): $\bar{z} = \dfrac{L(2K_a + K_p)}{3(K_p - K_a)} = \dfrac{15[(2)(0.271) + 3.69]}{3(3.69 - 0.271)} = 6.19 \text{ ft}$

Eq. (9.27): $\sigma_5' = \gamma L K_p + \gamma L_3 (K_p - K_a)$

$= (108)(15)(3.69) + (108)(1.189)(3.69 - 0.271)$

$= 5977.8 + 439 = 6416.8 \text{ lb/ft}^2$

Eqs. (9.32) to (9.35):

$$A_1' = \frac{\sigma_5'}{\gamma(K_p - K_a)} = \frac{6416.8}{(108)(3.69 - 0.271)} = 17.38$$

$$A_2' = \frac{8P}{\gamma(K_p - K_a)} = \frac{(8)(3553.65)}{(108)(3.69 - 0.271)} = 76.99$$

$$A_3' = \frac{6P[2\bar{z}\gamma(K_p - K_a) + \sigma_5']}{\gamma^2 (K_p - K_a)^2}$$

$$= \frac{(6)(3553.65)[(2)(6.19)(108)(3.69 - 0.271) + 6416.8]}{(369.25)^2} = 1718.34$$

$$A_4' = \frac{P(6\bar{z}\sigma_5' + 4P)}{\gamma^2 (K_p - K_a)^2} = \frac{(3553.65)[(6)(6.19)(6416.8) + (4)(3553.65)]}{(369.25)^2} = 6581.95$$

Eq. (9.31): $L_4^4 + 17.38L_4^3 - 76.99L_4^2 - 1718.34L_4 - 6581.95 = 0$; $L_4 \approx 10.7 \text{ ft}$

$D_{\text{theory}} = L_3 + L_4 = 1.189 + 10.7 \approx \mathbf{11.9 \text{ ft}}$

**Maximum Moment:** Similar to Eq. (9.21):

$$z' = \sqrt{\frac{2P}{(K_p - K_a)\gamma}} = \sqrt{\frac{(2)(3553.65)}{369.25}} = 4.39 \text{ ft}$$

$$M_{max} = P(\bar{z} + z') - \frac{1}{6}\gamma(z')^3(K_p - K_a)$$

$$= (3553.65)(6.19 + 4.39) - \frac{1}{6}(108)(4.39)^3(3.69 - 0.271)$$

$$= 37{,}597.6 - 5{,}206.7 = \mathbf{32{,}391 \text{ lb-ft / ft}}$$

9.4 $K_a = \tan^2\left(45 - \frac{\phi'}{2}\right) = 0.333; \quad K_p = 3$

$$\sigma'_2 = \gamma L K_a = (16.7)(3)(0.333) = 16.68 \text{ kN / m}^2$$

$$L_3 = \frac{LK_a}{K_p - K_a} = \frac{(3)(0.333)}{2.667} = 0.375 \text{ m}$$

$$P = \frac{1}{2}\sigma'_2 L + \frac{1}{2}\sigma'_2 L_3 = \frac{1}{2}(16.68)(3 + 0.375) = 28.15 \text{ kN / m}$$

$$\bar{z} = \frac{L(2K_a - K_p)}{3(K_p - K_a)} = \frac{(3)(0.666 + 3)}{(3)(2.667)} = 1.375 \text{ m}$$

$$\sigma'_5 = \gamma L K_p + \gamma L_3(K_p - K_a) = (16.7)(3)(3) + (16.7)(0.375)(2.667)$$

$$= 150.3 + 16.7 = 167 \text{ kN / m}^2$$

$$A'_1 = \frac{p_5}{\gamma(K_p - K_a)} = \frac{167}{(16.7)(2.667)} = 3.75$$

$$A'_2 = \frac{8P}{\gamma(K_p - K_a)} = \frac{(8)(28.15)}{(16.7)(2.667)} = 5.056$$

$$A'_3 = \frac{6P[2\bar{z}\gamma(K_p - K_a) + \sigma'_5]}{\gamma^2(K_p - K_a)^2} = \frac{(6)(28.15)[(2)(1.375)(16.7)(2.667) + 167]}{[(16.7)(2.667)]^2} = 24.65$$

$$A'_4 = \frac{P(6\bar{z}\sigma'_5 + 4P)}{\gamma^2(K_p - K_a)^2} = \frac{(28.15)[(6)(1.375)(167) + (4)(28.15)]}{[(16.7)(2.667)]^2} = 21.15$$

$$L_4^4 + 3.75L_4^3 - 5.056L_4^2 - 24.65L_4 - 21.15 = 0; L_4 \approx 2.8 \text{ m}$$

$$D_{theory} = L_3 + L_4 = 0.375 + 2.8 = 3.175 \text{ m} \approx \mathbf{3.18 \text{ m}}$$

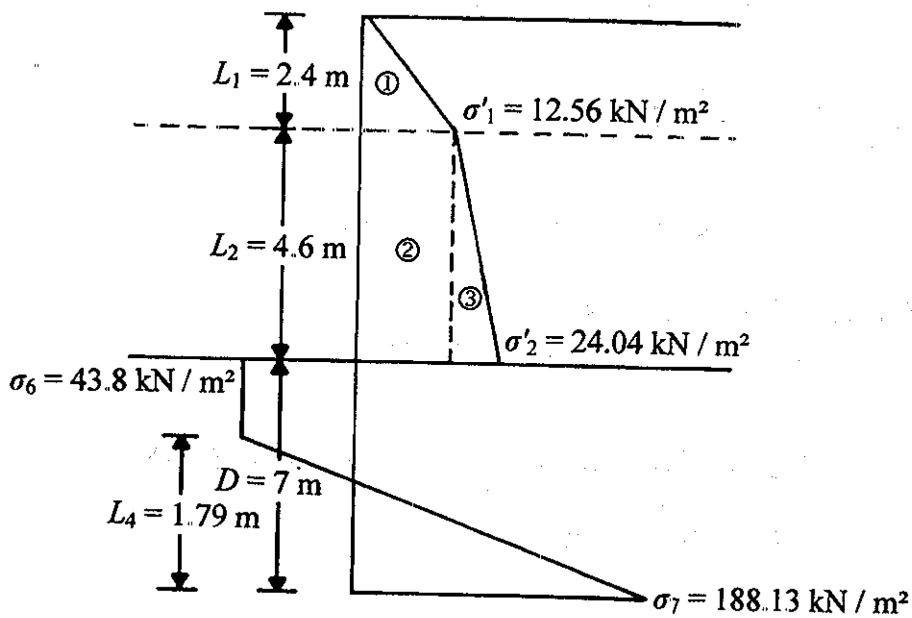
$$\bar{z} = \sqrt{\frac{2P}{(K_p - K_a)\gamma}} = \sqrt{\frac{(2)(28.15)}{(2.667)(16.7)}} = 1.12 \text{ m}$$

$$M_{max} = P(\bar{z} + z') - \frac{1}{6}\gamma(z')^3(K_p - K_a)$$

$$= (28.15)(1.375 + 1.12) - \frac{1}{6}(16.7)(1.12)^3(2.667)$$

$$= 70.23 - 10.43 = \mathbf{59.8\ kN\text{-}m / m}$$

9.5 a. Refer to the following figure:




$$K_a = \tan^2\left(45 - \frac{\phi'}{2}\right) = \tan^2(45 - 15) = \frac{1}{3}$$

$$K_a = \tan^2\left(45 + \frac{\phi'}{2}\right) = \tan^2(45 + 15) = 3$$

$$\sigma'_1 = \gamma L_1 K_a = (15.7)(2.4)\frac{1}{3} = 12.56 \text{ kN / m}^2$$

$$\sigma'_2 = (\gamma L_1 + \gamma' L_2) = [(15.7)(2.4) + (17.3 - 9.81)(4.6)]\frac{1}{3} = 24.04 \text{ kN / m}^2$$

$P_1$ = Areas of 1 + 2 + 3 = 15.07 + 57.78 + 26.4 = 99.25 kN / m

$$\bar{z}_1 = \frac{(15.07)(5.4) + (57.78)(2.3) + (26.4)\left(\frac{4.6}{3}\right)}{99.25} = 2.567 \text{ m}$$

Eq. (9.44): $D^2[4c-(\gamma L_1+\gamma' L_2)]-2DP_1-\dfrac{P_1(P_1+12c\bar{z}_1)}{(\gamma L_1+\gamma' L_2)+2c}=0$

$$D^2[(4)(29)-72.13]-2D(99.25)-\frac{99.25[99.25+(12)(29)(2.567)]}{72.13+(2)(29)}=0$$

$43.87D^2-198.5D-757=0$; $D=$ **7 m**

b. Length of sheet pile = 2.4 + 4.6 + 1.4(7) = **16.8 m**

c. Eq. (9.38): $\sigma_6=4c-(\gamma L_1+\gamma' L_2)$

$$=(4)(29)-[(15.7)(2.4)-(17.3-9.81)(4.6)]=43.87 \text{ kN/m}^2$$

Eq. (9.45): $z'=\dfrac{P_1}{\sigma_6}=\dfrac{99.25}{43.87}=2.26 \text{ m}$

$$M_{max}=P_1(z'+\bar{z}_1)-\frac{\sigma_6 z'^2}{2}=(99.25)(2.26+2.567)-\frac{(43.87)(2.26)^2}{2}$$

$= 479.08 - 112.04 =$ **367.04 kN - m / m of the wall**

9.6 a. $K_a=\tan^2(45-18)=0.26$

$\sigma'_1=\gamma L_1 K_a=(108)(5)(0.26)=140.4 \text{ lb/ft}^2$

$\sigma'_2=(\gamma L_1+\gamma' L_2)K_a=[(108)(5)+(60)(10)]0.26=296.4 \text{ lb/ft}^2$

$P_1=\frac{1}{2}(5)(140.4)+(140.4)(10)+\frac{1}{2}(10)(296.4-140.4)=351+1494+780$

$=2535 \text{ lb/ft}$

$$\bar{z}_1=\frac{(351)\left(10+\frac{5}{3}\right)+(1404)(5)+(780)\left(\frac{10}{3}\right)}{2535}=5.41 \text{ ft}$$

$$D^2[4c-(\gamma L_1+\gamma' L_2)]-2DP_1-\frac{P_1(P_1+12c\bar{z}_1)}{(\gamma L_1+\gamma' L_2)+2c}=0$$

$$D^2[3200-(108\times5+60\times10)]-2D(2535)-\frac{2535[2535+(12)(5.41)(800)]}{(108\times5+60\times10)+1600}=0$$

$$D^2 - 2.46D - 24.46 = 0; \quad D = \mathbf{6.4\ ft}$$

b. Length of sheet pile = 5 + 10 + 1.4(6.4) = 23.96 ft ≈ **24 ft**

c. $\sigma_6 = (\gamma L_1 + \gamma' L_2) = 3200 - (540 + 600) = 2060\ \text{lb/ft}^2$

$$z' = \frac{P_1}{\sigma_6} = \frac{2535}{2060} = 1.23\ \text{ft}$$

$$M_{max} = P_1(z' + \bar{z}_1) - \frac{\sigma_6 z'^2}{2} = 2535(1.23 + 5.41) - \frac{(2060)(1.23)^2}{2}$$

$$= \mathbf{15{,}274\ lb\text{-}ft/ft}$$

9.7 $K_a = \tan^2(45 - \phi'/2) = \tan^2(45 - 35/2) = 0.271$

Eq. (9.50): $P_1 = \frac{1}{2}\gamma L^2 K_a = \frac{1}{2}(16)(4)^2(0.271) = 34.69\ \text{kN/m}$

$\bar{z}_1 = L/3 = 4/3 = 1.33\ \text{m}$

Eq. (9.52): $D^2(4c - \gamma L) - 2DP_1 - \frac{P_1(P_1 + 12c\bar{z}_1)}{\gamma L + 2c} = 0$

$$D^2[(4 \times 45) - (16)(4)] - (2)(D)(34.69) - \frac{34.69[34.69 + (12)(45)(1.33)]}{(16)(4) + (2)(45)} = 0$$

$$116D^2 - 69.38D - 169.6 = 0$$

$D \approx \mathbf{1.6\ m}$

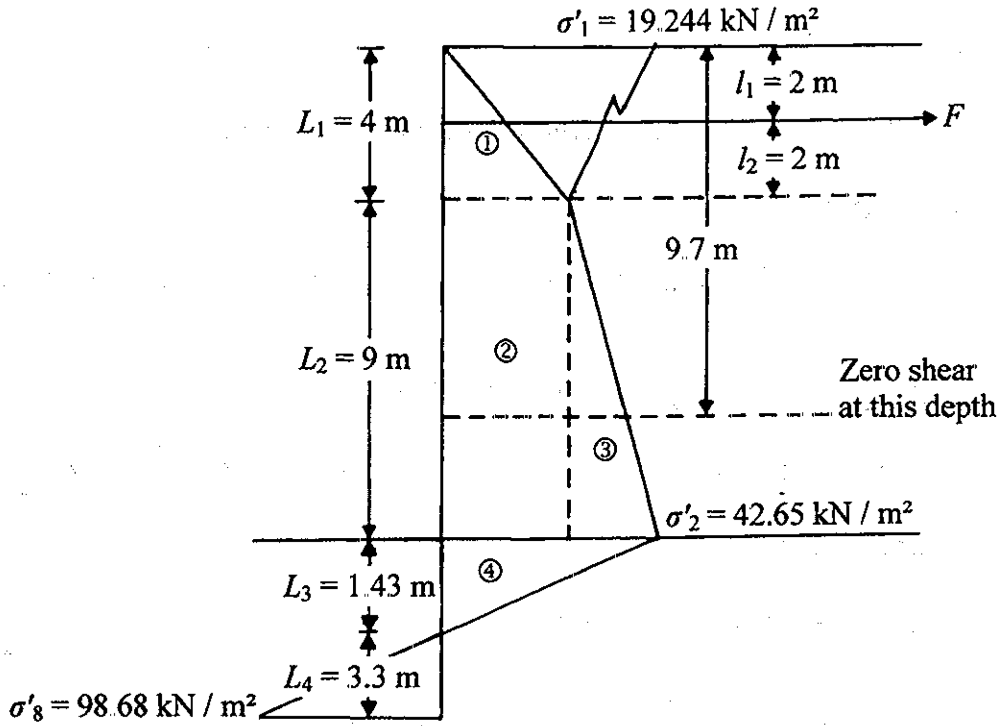
Eq. (9.54): $M_{max} = P_1(z' + \bar{z}_1) - \frac{\sigma_6 z'^2}{2}$

$\sigma_6 = 4c - \gamma L = (4 \times 45) - (16 \times 4) = 116\ \text{kN/m}^2$

Eq. (9.55): $z' = \frac{P_1}{\sigma_6} = \frac{34.69}{116} = 0.299\ \text{m} \approx 0.3\ \text{m}$

$$M_{max} = (34.69)(1.33 + 0.3) - \frac{(116)(0.3)^2}{2} = 56.54 - 5.22 = \mathbf{51.32\ kN\text{-}m/m}$$

9.8 a. Refer to the figure. $\phi' = 34°$.




$$K_a \tan^2\left(45 - \frac{\phi'}{2}\right) = 0.283; \quad K_p \tan^2\left(45 + \frac{\phi'}{2}\right) = 3.537$$

$$\sigma_1' = \gamma L_1 K_a = (17)(4)(0.283) = 19.244 \text{ kN / m}^2$$

$$\sigma_2' = (\gamma L_1 + \gamma' L_2)K_a = [(17)(4) + (19 - 9.81)(9)](0.283) = 42.65 \text{ kN / m}^2$$

$$L_3 = \frac{42.65}{\gamma'(K_p - K_a)} = \frac{42.65}{(9.19)(3.254)} \approx 1.43 \text{ m}$$

$$P = \text{Area of } 1 + 2 + 3 + 4 = 38.49 + 173.2 + 105.33 + 30.49 = 347.51 \text{ kN / m}$$

$$\bar{z} = \frac{1}{347.51}\left[(38.49)(11.76) + (173.2)(5.93) + (105.33)(4.43) + (30.49)(0.95)\right] = 5.68 \text{ m}$$

Eq. (9.58):

$$L_4^3 + 1.5L_4^2(l_2 + L_2 + L_3) - \frac{3P[(L_1 + L_2 + L_3) - (\bar{z} + l_1)]}{\gamma'(K_p - K_a)} = 0$$

$$L_4^3 + 1.5L_4^2(2 + 9 + 1.43) - \frac{(3)(347.51)[(4 + 9 + 1.43) - (5.68 + 2)]}{(9.19)(3.254)} = 0$$

$L_4^3 + 18.645\, L_4^2 - 235.32 = 0;\ L_4 \approx 3.3$ m

$D = 3.3 + L_3 = 3.3 + 1.43 = \mathbf{4.73}$

b. Eq. (9.56): $\sigma_8' = \gamma'(K_p - K_a)L_4 = (9.19)(3.254)(3.3) \approx 98.68$ kN / m$^2$

The pressure distribution diagram is shown in the figure.

c. Eq. (9.57):

$$F = P - \frac{1}{2}[\gamma'(K_p - K_a)L_4^2] = 347.51 - \frac{1}{2}[(9.19)(3.254)(3.3)^2] = \mathbf{184.68\ kN / m}$$

9.9 a. $D_{actual} = (1.3)(D_{theory}) = (1.3)(4.73) \approx 6.15$ m

For zero shear, use Eq. (9.60): $\frac{1}{2}\sigma_1' L_1 - F + \sigma_1'(z - L_1) + \frac{1}{2}K_a\,\gamma'(z - L_1)^2 = 0$

Let $z - L_1 = x$

$$\frac{1}{2}\sigma_1' L_1 - F + \sigma_1' x + \frac{1}{2}K_a\,\gamma' x^2 = 0$$

$$\frac{1}{2}(19.244)(4) - 184.68 + 19.244x + \frac{1}{2}(0.283)(9.19)x^2 = 0$$

$x^2 + 14.8x - 112.46 = 0;\ x \approx 5.7$ m

$z = x + L_1 = 5.7 + 4 = 9.7$ m

Taking the moment about the point of zero shear

$$M_{max} = -\frac{1}{2}\sigma_1' L_1\left(x + \frac{4}{3}\right) + F(x + 2) - \sigma_1'\left(\frac{x^2}{2}\right) - \frac{1}{2}K_a\gamma' x^2\left(\frac{x}{3}\right)$$

With $\sigma_1' = 19.244$ kN / m, $L_1 = 4$, $x = 5.7$, $F = 184.68$ kN / m

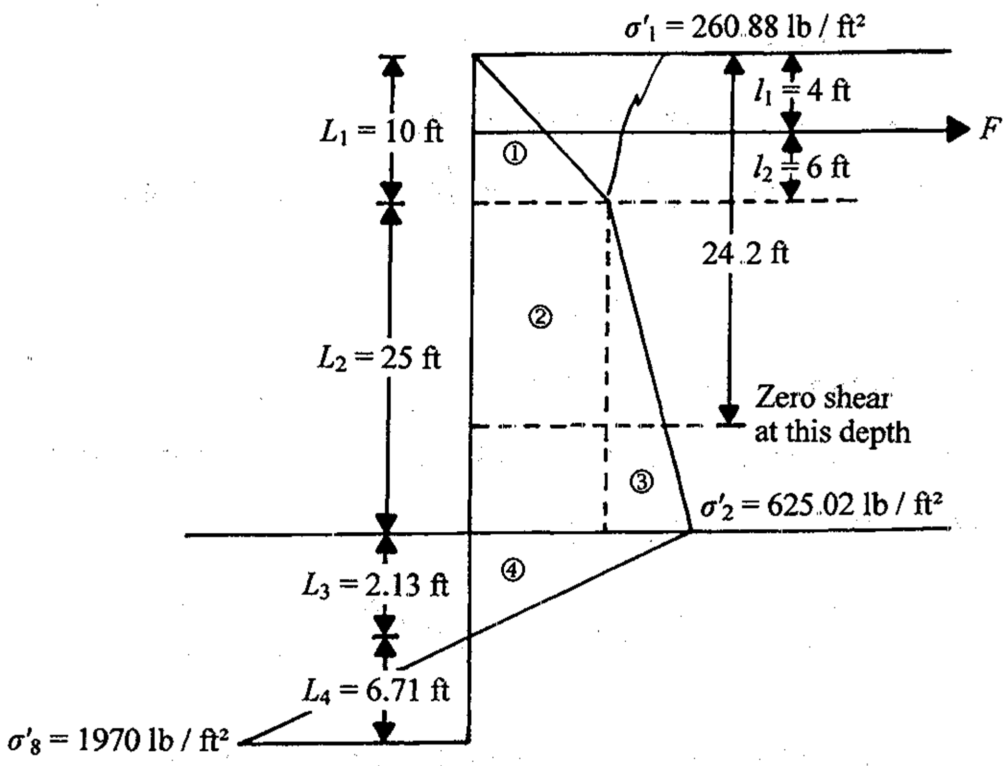
$M_{max} \approx$ **759 kN - m / m**

b. $H' = L_1 + L_2 + D_{actual} = 4 + 9 + 6.15 = 19.15$ m $\approx 20$ m

| Section | $I$ (m$^4$ / m) | $H'$ (m) | $\rho = \dfrac{10.91 \times 10^{-7} H'^4}{EI}$ | $\log \rho$ | $S$ (m$^3$ / m) | $M_d = S\sigma_{all}$ (kN / m - m) | $\dfrac{M_d}{M_{max}}$ |
|---|---|---|---|---|---|---|---|
| PZ-35 | $493.4\times10^{-6}$ | 20 | $16.85\times10^{-4}$ | −2.773 | $260.5\times10^{-5}$ | 547.05 | 0.721 |
| PZ-27 | $251.5\times10^{-6}$ | 20 | $33.05\times10^{-4}$ | −2.481 | $162.3\times10^{-5}$ | 340.83 | 0.449 |

If log$\rho$ and $M_d/M_{max}$ are plotted in Figure 9.22 with the curve for loose sand as the separating line, it can be seen that **PZ-35 will be sufficient**; however, PZ-27 is not suitable.

9.10. a. Refer to the figure. $\phi' = 40°$.




$$K_a = \tan^2\left(45 - \frac{\phi'}{2}\right) = 0.2174; \; K_p = \tan^2\left(45 + \frac{\phi'}{2}\right) = 4.599$$

$$\sigma'_1 = \gamma L_1 K_a = (120)(10)(0.2174) = 260.88 \text{ lb / ft}^2$$

$$\sigma'_2 = (\gamma L_1 + \gamma' L_2)K_a = [(120)(10) + (67)(25)](0.2174) = 625.02 \text{ lb / ft}^2$$

$$L_3 = \frac{625.02}{\gamma'(K_p - K_a)} = \frac{625.02}{(67)(4.3816)} = 2.13 \text{ ft}$$

$$P = \text{Areas of } 1 + 2 + 3 + 4 = A_1 + A_2 + A_3 + A_4$$

$$= 1304.4 + 6522 + 4551.75 + 665.65 = 13{,}043.8 \text{ lb / ft}$$

$$\bar{z} = \frac{(A_1)(30.46) + (A_2)(14.63) + (A_3)(10.46) + (A_4)(1.42)}{13{,}043.8} = 14.05 \text{ ft}$$

$$L_4^3 + 1.5L_4^2(l_2 + L_2 + L_3) - \frac{3P[(L_1 + L_2 + L_3) - (\bar{z} + l_1)]}{\gamma'(K_p - K_a)} = 0$$

$$L_4^3 + 49.7L_4^2 - 2543.3 = 0; \quad L_4 \approx 6.71 \text{ ft}$$

$$D = L_3 + L_4 = 2.13 + 6.71 = \mathbf{8.84\ ft}$$

b. $\sigma'_8 = \gamma'(K_p - K_a)L_4 = (67)(4.3816)(6.71) = 1970 \text{ lb / ft}^2$

The pressure diagram is shown in the figure.

c. $F = P - \frac{1}{2}\gamma'(K_p - K_a)L_4^2 = 13{,}043.8 - \frac{1}{2}(67)(4.3816)(6.71)^2 = \mathbf{6435\ lb\ /\ ft}$

9.11 $D_{actaul} = (1.3)(D_{theory}) = (1.3)(8.84) = 11.49 \text{ ft}$

For zero shear: $\frac{1}{2}\sigma'_1 L_1 - F + \sigma'_1(z - L_1) + \frac{1}{2}K_a\gamma'(z - L_1)^2 = 0$

Let $(z - L_1) = x$: $\frac{1}{2}(260.88)(10) - 6435 + (260.88)(x) + \frac{1}{2}(0.2174)(67)(x^2) = 0$

$x^2 + 35.82x - 704.5 = 0; x \approx 14.2 \text{ ft}$

$$M_{max} = -\frac{1}{2}\sigma'_1 L_1\left(x + \frac{10}{3}\right) + F(x + 6) - \sigma'_1\left(\frac{x^2}{2}\right) - \frac{1}{2}K_a\gamma' x\left(\frac{x^2}{3}\right)$$

With $\sigma'_{11} = 260.88 \text{ lb / ft}^2$, $L_1 = 10$ ft, $x = 14.20$ ft, $F = 6435$ lb / ft,

$M_{max} = 73{,}864 \text{ lb-ft / ft} = 8.86 \times 10^5 \text{ lb-in. / ft}$

| Section | $I$ (in.$^4$/ ft) | $H'$ (ft) | $\rho = \frac{H'^4}{EI}$ | $\log \rho$ | $S$ (in.$^3$/ ft) | $M_d = S\sigma_{all}$ (lb-in. / ft) | $\frac{M_d}{M_{max}}$ |
|---|---|---|---|---|---|---|---|
| *PZ–35* | 361.2 | 46.49 | 0.000445 | −3.35 | 48.5 | 1,212,500 | 1.37 |
| *PZ–27* | 184.2 | 46.49 | 0.000874 | −3.06 | 30.2 | 755,000 | 0.85 |
| $H' = L_1 + L_2 + D_{actual} = 10 + 25 + 11.49 = 46.49$ ft; $E = 29 \times 10^6$ lb / in.$^2$; $\sigma_{all} = 25$ kip / in.$^2$ | | | | | | | |

*PZ–27* falls above the plot for loose sand in Figure 9.22, so ***PZ–27* may be used**.

9.12 a. $\frac{l_1}{L_1 + L_2} = \frac{2}{4 + 8} = 0.167; \quad \phi' = 35°; \quad \frac{L_1}{L_1 + L_2} = \frac{4}{4 + 8} = 0.333$

From Figure 9.16, $GD = 0.18$; from Figure 9.19, $CDL_1 = 1.144$

Eq. (9.61): $D = (L_1 + L_2)(GD)(CDL_1) = (12)(0.18)(1.144) = \mathbf{2.47\ m}$

b. From Figure 9.17, $GF \approx 0.059$. From Figure 9.20, $CFL_1 = 1.071$

$$\gamma_a = \frac{\gamma L_1^2 + \gamma' L_2^2 + 2\gamma L_1 L_2}{(L_1 + L_2)^2} = \frac{(16)(4)^2 + (18.5 - 9.81)(8)^2 + (2)(16)(4)(8)}{12^2}$$

$$= 12.75\ \text{kN/m}^3$$

Eq. (9.62): $F = \gamma_a(L_1 + L_2)^2(GF)(CFL_1) = (12.75)(12)^2(0.059)(1.071) = \mathbf{116\ kN/m}$

c. From Figure 9.18, $GM = 0.018$. From Figure 9.21, $CML_1 = 1.026$

$$M_{max} = \gamma_a(L_1 + L_2)^3(GM)(CML_1) = (12.75)(12)^3(0.018)(1.026)$$

$$= \mathbf{406.9\ kN\text{-}m/m}$$

9.13 $\gamma' = \gamma_{sat} - \gamma_w = 19.5 - 9.81 = 9.69\ \text{kN/m}^3$

$$\gamma'_{av} = \frac{\gamma L_1 + \gamma' L_2}{L_1 + L_2} = \frac{(17.5)(3) + (9.69)(6)}{3 + 6} = 12.29\ \text{kN/m}^3$$

$$K_a = \tan^2\left(45 - \frac{\phi'}{2}\right) = \tan^2(45 - 17.5) = 0.271$$

$$\bar{\sigma}'_a = CK_a \gamma'_{av} L = (0.68)(0.271)(12.29)(9) = 20.38\ \text{kN/m}^2$$

$$\bar{\sigma}'_p = R\bar{\sigma}'_a = (0.6)(20.38) = 12.23\ \text{kN/m}^2$$

$$D^2 + 2DL\left(1 - \frac{l_1}{L}\right) - \frac{L^2}{R}\left[1 - 2\left(\frac{l_1}{L}\right)\right] = 0$$

$$D^2 + 2D(9)\left(1 - \frac{1.5}{9}\right) - \frac{9^2}{0.6}\left[1 - (2)\left(\frac{1.5}{9}\right)\right] = 0$$

$D^2 + 15D - 90 = 0$; $D \approx \mathbf{4.6\ m}$

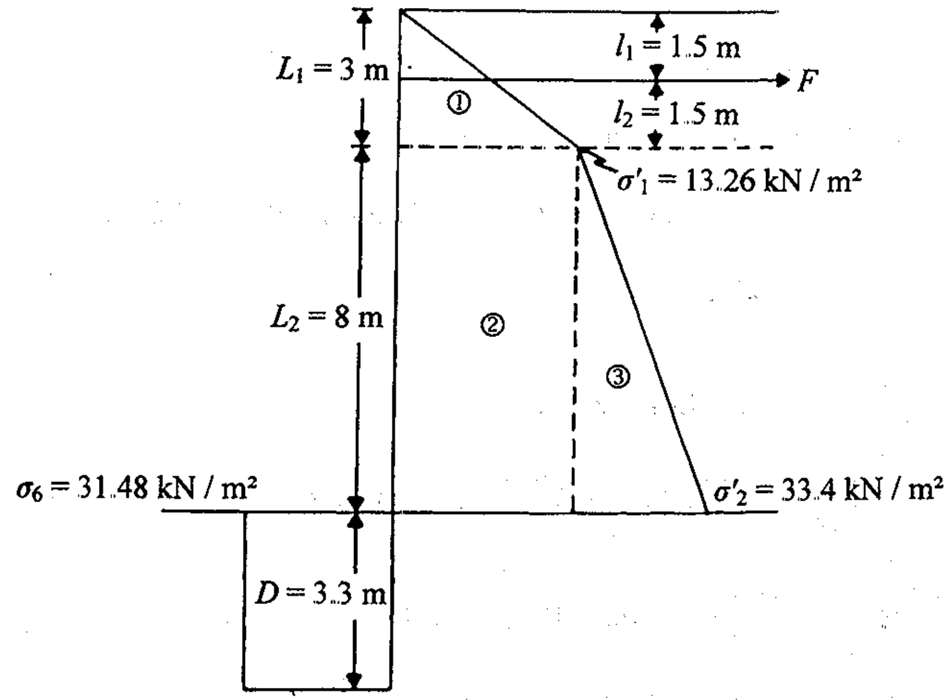
Check for $R$: $R = \dfrac{L(L - 2l_1)}{D(2L + D - 2l_1)} = \dfrac{9(9 - 3)}{4.6(18 + 4.6 - 3)} = 0.599$ -- O.K.

$F = \bar{\sigma}'_a(L - RD) = (20.38)[9 - (0.6)(4.6)] = \mathbf{127.17\ kN/m}$

$$M_{max} = 0.5\overline{p}_a L^2\left[\left(1-\frac{RD}{L}\right)^2 - \left(\frac{2l_1}{L}\right)\left(1-\frac{RD}{L}\right)\right]$$

$$= (0.5)(20.38)(9)^2\left[\left(1-\frac{0.6\times 4.6}{9}\right)^2 - \left(\frac{2\times 1.5}{9}\right)\left(1-\frac{0.6\times 4.6}{9}\right)\right] = \mathbf{206\ kN\text{-}m/m}$$

9.14 a. Refer to the figure.




$$K_a = \tan^2\left(45-\frac{\phi'}{2}\right) = 0.26;\quad K_p = \tan^2\left(45+\frac{\phi'}{2}\right) = 3.85;\quad K_p - K_a = 3.59$$

$$\sigma'_1 = \gamma L_1 K_a = (17)(3)(0.26) = 13.26\ \text{kN/m}^2$$

$$\sigma'_2 = (\gamma L_1 + \gamma' L_2) = [(17)(3) + (19.5 - 9.81)(8)](0.26) \approx 33.4\ \text{kN/m}^2$$

$$P_1 = \text{Areas of } 1 + 2 + 3 = 19.89 + 106.08 + 80.56 = 206.53\ \text{kN/m}$$

$$\bar{z}_1 = \frac{(19.89)(9) + (106.08)(4) + (80.56)(2.67)}{206.53} = \frac{179.01 + 424.32 + 215.1}{206.53} = 3.96\ \text{m}$$

Eq. (9.75): $\sigma_6 D^2 + 2\sigma_6 D(L_1 + L_2 - l_1) - 2P_1(L_1 + L_2 - l_1 - \bar{z}_1) = 0$

$\sigma_6 = 4c - (\gamma L_1 + \gamma' L_2) = (4)(40) - 128.52 = 31.48\ \text{kN/m}^2$

So, $31.48D^2 + (2)(31.48)(9.5)D - (2)(206.53)(3 + 8 - 1.5 - 3.96) = 0$

or

$$D^2 + 19D - 72.69 = 0;\ D \approx \mathbf{3.3\ m}$$

b. $P_1 - \sigma_6 D = F$

$$206.53 - (31.48)(3.3) = \mathbf{102.6\ kN/m}$$

9.15 a. $K_a = \tan^2\left(45 - \frac{40}{2}\right) = 0.2174$

$$\sigma_1' = \gamma L_1 K_a = (115)(8)(0.2174) = 200\ \text{lb/ft}^2$$

$$\sigma_2' = (\gamma L_1 + \gamma' L_2)K_a = [(115)(8) + (128 - 62.4)(20)](0.2174) = 485.24\ \text{lb/ft}^2$$

$$P_1 = \frac{1}{2}\sigma_1' L_1 + \sigma_1' L_2 + \frac{1}{2}(\sigma_2' - \sigma_1')L_2 = \frac{1}{2}(200)(8) + (200)(20) + \frac{1}{2}(485.24 - 200)(20)$$

$$= 800 + 4000 + 2852.4 = 7652.4\ \text{lb/ft}$$

Taking the moment about the dredge line (at $z = L_1 + L_2$)

$$P_1\bar{z}_1 = \left(\frac{1}{2}\sigma_1' L_1\right)\left(L_2 + \frac{L_1}{3}\right) + (_1' L_2)\left(\frac{L_2}{2}\right) + \left[\frac{1}{2}(\sigma_2' - \sigma_1')(L_2)\right]\left(\frac{L_2}{3}\right)$$

$$7652.4\bar{z}_1 = (800)\left(20 + \frac{8}{3}\right) + (4000)\left(\frac{20}{2}\right) + (2852.4)\left(\frac{20}{3}\right)$$

$$\bar{z}_1 = \frac{77{,}149.33}{7652.4} = 10.08\ \text{ft}$$

$$\sigma_6 = 4c - (\gamma L_1 + \gamma' L_2) = (4)(1500) - [(115)(8) + (128 - 62.4)(20)] = 3768\ \text{lb/ft}^2$$

Eq. (9.75): $\sigma_6 D^2 + 2\sigma_6 D(L_1 + L_2 - l_1) - 2P_1(L_1 + L_2 - l_1 - \bar{z}_1) = 0$

$$3768D^2 + (2)(3768)(D)(8 + 20 - 4) - (2)(7652.4)[8 + 20 - 4 - 10.08)] = 0$$

$$D^2 + 48D - 56.54 = 0;\quad D = \mathbf{1.15\ ft}$$

b. $F = P_1 - \sigma_6 D = 7652.4 - (3768)(1.15) = \mathbf{3319\ lb/ft}$

9.16 From Figure 9.33(a), for $\phi' = 30°$, the value of $K_a \approx 0.31$.

$$W = Ht\gamma_{\text{concrete}} = (5)\left(\frac{3}{12}\right)(150) = 187.5\ \text{lb/ft}$$

Eq. (9.79):

$$K_p \sin\delta' = \frac{W + \frac{1}{2}\gamma H^2 K_a \sin\phi'}{\frac{1}{2}\gamma H^2} = \frac{187.5 + \frac{1}{2}(110)(5)^2(0.31)(0.5)}{\frac{1}{2}(110)(5)^2} = 0.291$$

From Figure 9.33(b), $K_p\cos\delta' \approx 3.4$

Eq. (9.78):

$$P_u' = \frac{1}{2}\gamma H^2(K_p\cos\delta' - K_a\cos\phi') = \frac{1}{2}(110)(5)^2[3.4 - (0.31)(0.866)] = 4305.9 \text{ lb / ft}$$

Assume loose sand.

Eq. (9.85): $$P_{us}' = \left(\frac{C_{ov} + 1}{C_{ov} + \frac{H}{h}}\right)P_u' = \left(\frac{14+1}{14+\frac{5}{3}}\right)(4328.5) = 4144.3 \text{ lb / ft}$$

$$\frac{S' - B}{H + h} = \frac{7-4}{5+3} = 0.375.$$ Referring to Figure 9.35(b),

$$\frac{B_e - B}{H + h} \approx 0.19; B_e = (0.19)(8) + 4 = 5.52$$

$$P_u = P_{us}' B_e = (4122.7)(5.52) \approx 22{,}757 \text{ lb} = \mathbf{22.76\ kip}$$

9.17 Eq. (9.82):

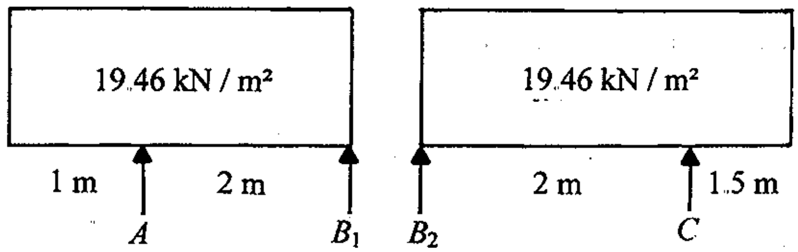
$$P_u = \frac{5.4}{\tan\phi'}\left(\frac{H^2}{Bh}\right)^{0.28}\gamma BhH = \frac{5.4}{\tan 32}\left(\frac{0.9^2}{0.3B}\right)^{0.28}(17)(B)(0.3)(0.9) = 52.39B^{0.72} \text{ kN}$$

| $B$ (m) | $P_u = 52.39B^{0.72}$ (kN) |
|---|---|
| 0.3 | **22** |
| 0.6 | **36.3** |
| 0.9 | **48.6** |

# CHAPTER 10

10.1 Eq. (10.1):

$$\sigma_a = 0.6\gamma HK_a = 0.65\gamma H\tan^2(45 - \phi'/2) = (0.65)(17)(6.6)\tan^2(45 - 35/2) = 19.46 \text{ kN / m}^2$$




$$\Sigma M_{B_1} = 0$$

$$A = \frac{(19.46)(3)\left(\frac{3}{2}\right)}{2} = 43.79 \text{ kN / m}$$

$$B_1 = (19.46)(3) - 43.79 = 14.59 \text{ kN / m}$$

$$\Sigma M_{B_2} = 0$$

$$C = \frac{(19.46)(3.5)\left(\frac{3.5}{2}\right)}{2} = 59.6 \text{ kN / m}$$

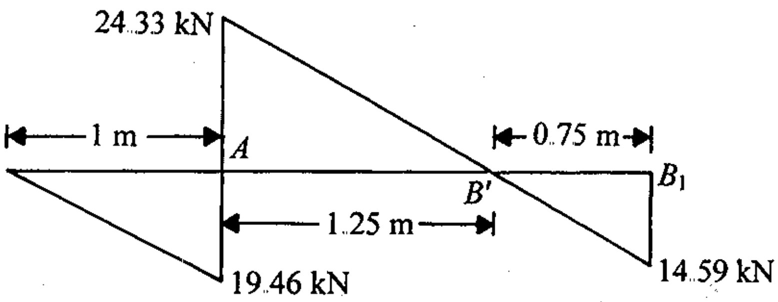
$$B_2 = (19.46)(3.5) - 59.6 = 8.51 \text{ kN / m}$$

Strut load at $A$ = (43.79)(spacing) = (43.79)(3) = **131.4 kN**

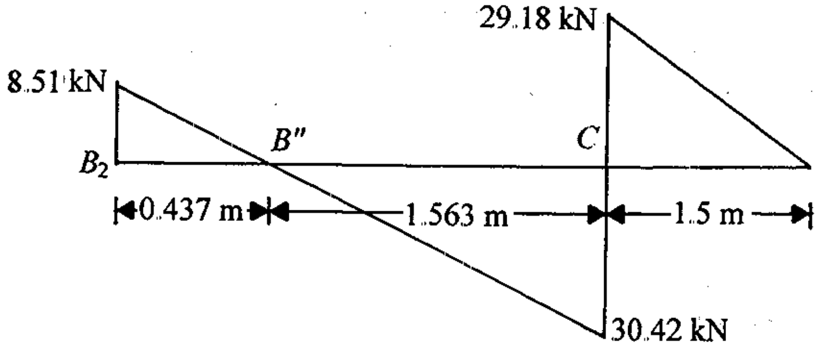
Strut load at $B = (B_1 + B_2)$(spacing) = (14.59 + 8.51)(3) = **69.3 kN**

Strut load at $C$ = (59.6)(3) = **178.8 kN**

10.2 a. For the sheet pile, refer to the shear force diagram on the next page.




$$M_A = \frac{1}{2}(1)(19.46) = 9.73 \text{ kN - m / m}; \; M_{B'} = \frac{1}{2}(0.75)(14.59) = 5.47 \text{ kN - m / m}$$




$$M_{B''} = \frac{1}{2}(0.437)(8.51) = 1.86 \text{ kN - m / m}; \; M_C = \frac{1}{2}(1.5)(29.18) \approx 21.9 \text{ kN - m /m}$$

$$S = \frac{21.9 \text{ kN - m / m}}{170 \times 10^3 \text{ kN / m}^2} = \mathbf{0.129 \times 10^{-3} \text{ m}^3 \text{ / m of wall}}$$

b. For wales, $M_{max} = \frac{Bs^2}{8}$

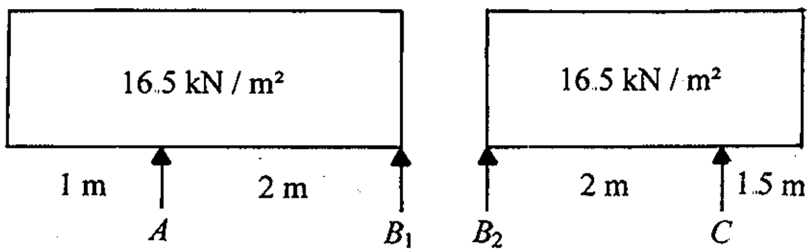
$$S = \frac{Bs^2}{8\sigma_{all}} = \frac{(69.3)(3^2)}{(8)(170 \times 10^3)} = \mathbf{0.459 \times 10^{-3} \text{ m}^3 \text{ / m}}$$

10.3 $K_a = \left(45 - \frac{40}{2}\right) = 0.217$

$\Sigma M_{B_1} = 0$

$$\sigma_a = 0.65\gamma H K_a = (0.65)(18)(6.5)(0.217) = 16.5 \text{ kN / m}^2$$

$$A = \frac{(16.5)(3)\left(\frac{3}{2}\right)}{2} = 37.13 \text{ kN / m}$$




$B_1 = (16.5)(3) - 37.13 = 12.37$ kN / m

$\sum M_{B_2=0}$

$$C = \frac{(16.5)(3.5)\left(3.5/2\right)}{2} = 50.53 \text{ kN / m}$$

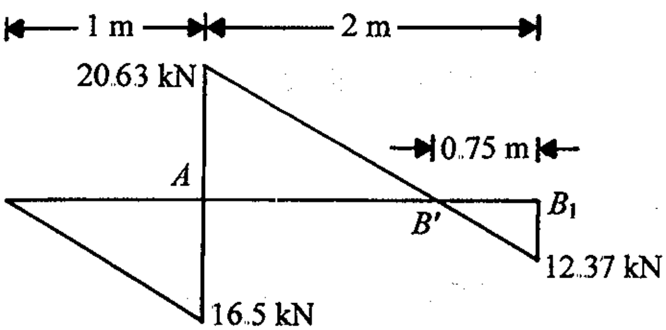
$B_2 = (16.5)(3.5) - 50.53 = 7.22$ kN / m

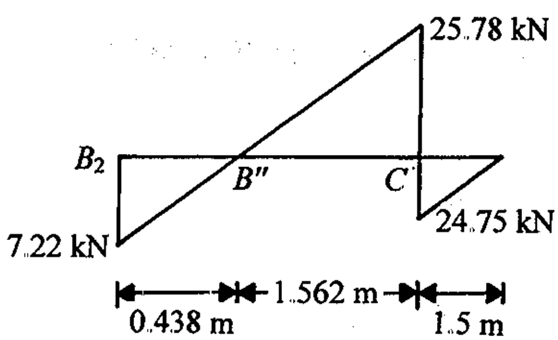
Strut load at $A = (37.13)(4) =$ **148.5 kN**

Strut load at $B = (12.37 + 7.22)(4) =$ **78.4 kN**

Strut load at $C = (50.53)(4) =$ **202 kN**

10.4 Refer to the pressure diagram in Problem 10.2. The shear force diagram is given.



It can be seen that $M_C$ will be maximum.

$$M_C = \frac{1}{2}(1.5)(24.75) = 18.56 \text{ kN - m}$$

$$S = \frac{18.56 \text{ kN - m}}{\sigma_{\text{all}}} = \frac{18.56}{170 \times 10^3} = \mathbf{0.109 \times 10^{-3}\ m^3 / m\ of\ wall}$$

10.5 a. $H = 8$ m, $H_s = 3$ m, $H_c = 5$ m

Eq. (10.5): $\gamma_{av} = \frac{1}{H}[\gamma_s H_s + (H - H_s)\gamma_c] = \frac{1}{8}[(17.5)(3) + (5)(18.2)] = \mathbf{17.94\ kN / m^3}$

Eq. (10.4): $c_{av} = \frac{1}{2H}\left[\gamma_s K_s H_s^2 \tan\phi'_s + (H - H_s)n' q_u\right]$

$$= \frac{1}{(2)(8)}\left[(17.5)(1)(3)^2(\tan 34) + (5)(0.75)(55)\right] = \mathbf{19.53\ kN / m^2}$$

b. $\frac{\gamma_{av} H}{c_{av}} = \frac{(17.94)(8)}{19.53} = 7.35$

The pressure diagram will be like Figure 10.6.

$$\sigma_a = \gamma_a H\left(1 - \frac{4c_{av}}{\gamma_a H}\right) = (17.94)(8)\left(1 - \frac{4}{7.35}\right) = 65.4 \text{ kN / m}^2$$

Also check $\sigma_a = 0.3\gamma_a H = (0.3)(17.94)(8) = 43.06$ kN/m$^2$

Use $\sigma_a = \mathbf{65.4\ kN / m^2}$

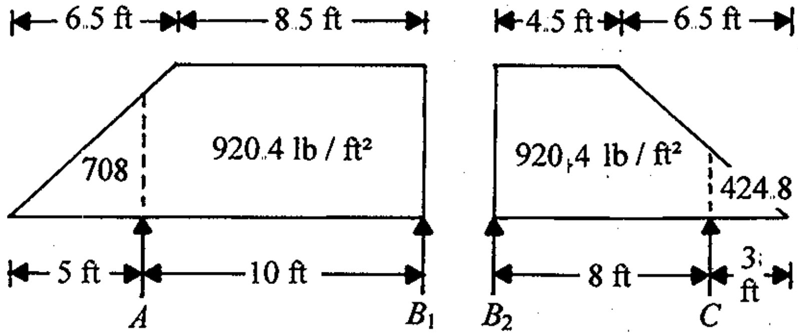
10.6 a. Eq. (10.6): $c_{av} = \frac{1}{25}[(5)(2125) + (10)(1565) + (10)(1670)] = \mathbf{1719\ lb / ft^2}$

Eq. (10.7): $\gamma_{av} = \frac{1}{25}[(5)(111) + (10)(107) + (10)(109)] = \mathbf{108.6\ lb / ft^3}$

b. $\frac{\gamma_{av} H}{c_{av}} = \frac{(108.6)(25)}{1719} = 1.58$. Use Figure 10.7.

$\sigma_a = 0.3\gamma_a H = (0.3)(108.6)(25) = \mathbf{814.5\ lb / ft^2}$

10.7 $\frac{\gamma H}{c} = \frac{(118)(26)}{800} = 3.84$. Use Figure 10.7.




$$\sigma_a = 0.3\gamma_a H = (0.3)(118)(26) = \mathbf{920.4\ lb / ft^2}$$

$$\Sigma M_{B_1} = 0$$

$$A = \frac{\left(\frac{920.4 \times 8.5^2}{2}\right) + \left(\frac{1}{2} \times 920.4 \times 6.5\right)\left(8.5 + \frac{6.5}{3}\right)}{10} = 6515.6 \text{ lb / ft}$$

$$B_1 = \left[(920.4)(8.5) + \frac{1}{2}(6.5)(920.4)\right] - 6515.6 = 4299.1 \text{ lb / ft}$$

$$\Sigma M_{B_2} = 0$$

$$C = \frac{\left(\frac{920.4 \times 4.5^2}{2}\right) + \left(\frac{1}{2} \times 920.4 \times 6.5\right)\left(4.5 + \frac{6.5}{3}\right)}{8} = 3657.63 \text{ lb / ft}$$

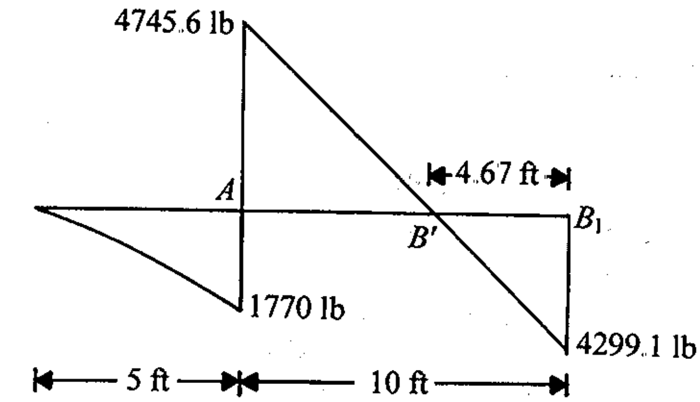
$$B_2 = \left[(920.4)(4.5) + \frac{1}{2}(6.5)(920.4)\right] - 3657.63 = 3475.47 \text{ lb / ft}$$

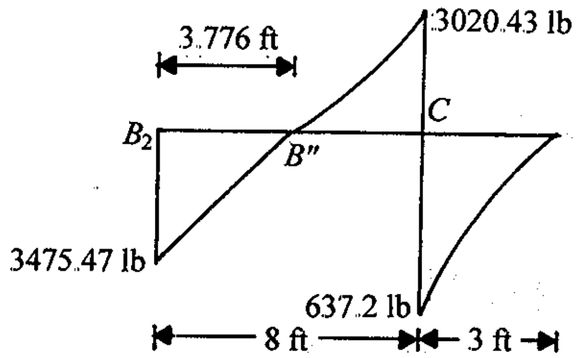
Strut load at $A = \left(\frac{6515.6}{1000}\right)(12) = \mathbf{78.19\ kip}$

Strut load at $B = (B_1 + B_2)(12) = \frac{(4299.1 + 3475.47)(12)}{1000} = \mathbf{93.29\ kip}$

Strut load at $C = (3.657)(12) = \mathbf{43.88\ kip}$

10.8 Refer to the load diagrams in Problem 10.7. The shear force diagrams are given on the next page.




It can be seen that $M_{max} = M_{B'} = \frac{1}{2}(4.67)(4299.1) \approx 10{,}038 \text{ lb-ft/ft}$

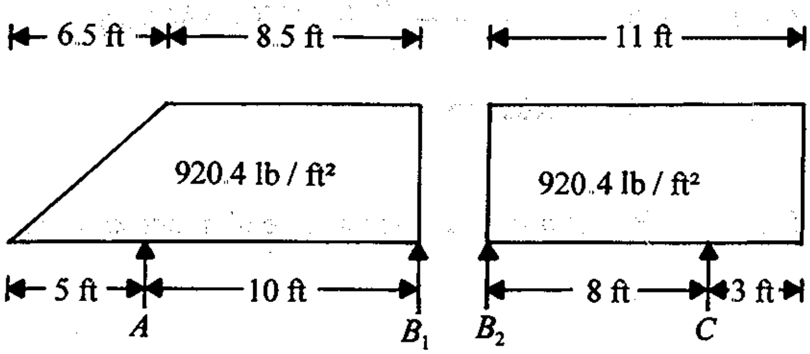
$$S = \frac{10{,}038 \text{ lb-ft}}{\sigma_{all}} = \frac{(10{,}038)(12)}{25{,}000 \text{ lb/in.}^2} = \mathbf{4.82\ in.^3/ft}$$

10.9 $\frac{\gamma H}{c} = \frac{(118)(26)}{600} = 5.11$. Use Figure 10.6.

$\sigma_a = 0.3\gamma H = 920.4 \text{ lb/ft}^2$, or

$$\sigma_a = \gamma H\left(1 - \frac{4c}{\gamma H}\right) = (26)(118)\left(1 - \frac{4}{5.11}\right) = 666.4 \text{ lb/ft}^2$$

So, use $\sigma_a = 920.4 \text{ lb/ft}^2$



Reactions at $A$ and $B_1$ will be similar to those in Problem 10.7; that is, $A = 6515.6$ lb / ft, and $B_1 = 4299.1$ lb / ft.

$$\sum M_{B_2} = 0$$

$$C = \frac{(920.4)(11)\left(\frac{11}{2}\right)}{8} = 6960.5 \text{ lb / ft}$$

$$B_2 = (920.4)(11) - 6960.5 = 3163.9 \text{ lb / ft}$$

$$\text{Strut load at } A = \left(\frac{6515.6}{1000}\right)(12) = \mathbf{78.19\ kip}$$

$$\text{Strut load at } B = \left(\frac{4299.1 + 3163.9}{1000}\right)(12) = \mathbf{89.56\ kip}$$

$$\text{Strut load at } C = \left(\frac{6960.5}{1000}\right)(12) = \mathbf{83.53\ kip}$$

10.10 Eq. (10.14): $\text{FS} = \dfrac{5.14c\left(1 + \dfrac{0.2B''}{L}\right) + \dfrac{cH}{B'}}{\gamma H + q}$

Given: $c = 800$ lb / ft²; $q = 0$; $\gamma = 118$ lb / ft³; $H = 26$ ft; and $L = 30$ ft

$B' = \dfrac{B}{\sqrt{2}} = \dfrac{20}{(2)^{0.5}} = 14.14$ ft. *Note:* $T > \dfrac{B}{\sqrt{2}}$. So $B'' = \sqrt{2}\,B$.

$$\text{FS} = \frac{(5.14)(800)\left[1 + \frac{(0.2)(20)}{30}\right] + \frac{(800)(26)}{14.14}}{(118)(26)} \approx \mathbf{2}$$

10.11 Eq. (10.13): $\text{FS} = \dfrac{cN_c\left(1 + \dfrac{0.2B'}{L}\right)}{\left(\gamma + \dfrac{q}{H} - \dfrac{c}{B'}\right)H}$

$$B' = \frac{B}{\sqrt{2}} = \frac{20}{\sqrt{2}} = 14.14 \text{ ft.}$$

$$FS = \frac{(600)(5.7)\left[1 + \frac{(0.2)(14.14)}{40}\right]}{\left(118 + 0 - \frac{600}{14.14}\right)26} = \mathbf{0.88}$$

# CHAPTER 11

11.1 a. Eq. (11.15): $Q_p = A_p q' N_q^*$

$A_p = (0.46)^2 = 0.2116 \text{ m}^2$

$q' = \gamma L = (18.6)(20) = 372 \text{ kN / m}^2$

$N_q^* = 55$ (Figure 11.12)

$Q_p = (0.2116)(372)(55) = \mathbf{4329 \text{ kN}}$

Check: Eq. (11.17):

$Q_p = A_p q_1 = 0.5 p_a A_p N_q^* \tan\phi' = (50)(0.2116)(55)(\tan 30) = 335.96 \text{ kN} \approx \mathbf{336 \text{ kN}}$

Use $Q_p = \mathbf{336 \text{ kN}}$

b. Eq. (11.20) (for $c' = 0$): $Q_p = A_p \overline{\sigma}'_o N^*_\sigma$

$I_{rr} = 75$; $\phi' = 30°$; $N^*_\sigma = 45$ (Table 11-5)

$$\overline{\sigma}' = \left(\frac{1 + 2K_o}{3}\right) q'$$

$q' = 372 \text{ kN / m}^2$; $K_o = 1 - \sin\phi' = 0.5$

$$\overline{\sigma}' = \left[\frac{1 + (2)(0.5)}{3}\right](372) = 248 \text{ kN / m}^2$$

$Q_p = (0.2116)(248)(45) = 2361.5 \text{ kN} \approx \mathbf{2362 \text{ kN}}$

c. Eq. (11.31) (for $c = 0$): $Q_p = A_p q' N_q^*$

$N_q^* = 18.4$ (Table 11.6)

$Q_p = (0.2116)(372)(18.4) = 1448.4 \text{ kN} \approx \mathbf{1448 \text{ kN}}$

11.2 Eq. (1137) $L' = 15D = (15)(0.46) = 6.9 \text{ m}$

At $z = 0$, $f = 0$.

At $z = 6.9$ m, $f = K\sigma'_o \delta' = (1.5)(18.6 \times 6.9)[\tan(0.6 \times 30)] = 62.55 \text{ kN / m}^2$

$$Q_{s\,(z=0 \text{ to } 6.9 \text{ m})} = (4 \times 0.46)(6.9)\left(\frac{62.55}{2}\right) = 397.1 \text{ kN}$$

$$Q_{s\,(z=6.9 \text{ to } 20 \text{ m})} = (4 \times 0.46)(13.1)(62.55) = 1507.7 \text{ kN}$$

$Q_s = 397.1 + 1507.7 \approx$ **1905 kN**

11.3 $\frac{L}{D} = \frac{20}{0.46} = 43.48$; $\phi' = 30°$. From Figure 11.15, $N_q^* = 23$.

Eq. (11.33): $Q_p = A_p q' N_q^* = (0.2116)(372)(23) = 1810.5$ kN

With $\frac{L}{D} = 43.48$, from Figure 11.19, $K \approx 0.2$ (extrapolation)

Eq. (11.41): $Q_s = K\overline{\sigma}'_o \tan(0.8\phi')pL$

$$= (0.2)\left(\frac{18.6 \times 20}{2}\right)\tan(24)(4 \times 0.46)(20) = 609.5 \text{ kN}$$

$$Q_{\text{all}} = \frac{1810.5 + 609.5}{4} = \textbf{605 kN}$$

11.4 a. Eq. (11.15): $Q_p = A_p q' N_q^*$

$\phi' = 35°$; $N_q^* \approx 125$ (Figure 11.12)

$$Q_p = \left(\frac{(12 \times 12)}{12 \times 12}\right)^2 (115 \times 80)(125) = 1{,}150{,}000 \text{ lb} = \textbf{1150 kip}$$

Check: Eq. (11.17):

$$Q_p = A_p q_l = (0.5 \times 2000)\left(\frac{12 \times 12}{12 \times 12}\right)^2 (125)(\tan 35) = 87{,}526 \text{ lb} \approx \textbf{87.5 kip}$$

Use **87.5 kip**

b. $I_{rr} = 75$; $\phi' = 35°$; $N_\sigma^* = 72$ (Table 1.5); $K_o = 1 - \sin 35 = 0.426$

$$\overline{\sigma}'_o = \left[\frac{1+(2\times 0.426)}{3}\right](115\times 80) = 5679.5\ \text{lb}/\text{ft}^2$$

$$Q_p = A_p\overline{\sigma}'_o N^*_\sigma = \left(\frac{12\times 12}{12\times 12}\right)^2 (5679.6)(72) = 408.924\ \text{lb} \approx \textbf{409 kip}$$

c. Eq. (11.31): $Q_p = A_p q' N^*_q$. $N^*_q \approx 34$

$$Q_p = \left(\frac{12\times 12}{12\times 12}\right)^2 (115\times 80)(34) = 312{,}800\ \text{lb} \approx \textbf{313 kip}$$

11.5 $L' = 15D = 15(12/12) = 15$ ft

At $z = 0$, $f = 0$

At $z = 15$ ft, $f = K\sigma'_o \tan\delta' = (1.35)(115\times 15)\tan(0.75\times 35) = 1148.4\ \text{lb}/\text{ft}^2$

$$Q_{s(0\text{ to }15\text{ ft})} = \left(4\times\frac{12}{12}\right)(15)\left(\frac{1148.4}{2}\right) = 34{,}452\ \text{lb}$$

$$Q_{s(15\text{ to }80\text{ ft})} = \left(4\times\frac{12}{12}\right)(65)(1148.4) = 298{,}584\ \text{lb}$$

$$Q_s = 34{,}452 + 298{,}584 = 333{,}036\ \text{lb} \approx \textbf{333 kip}$$

11.6 $\dfrac{L}{D} = \dfrac{80}{\left(\frac{12}{12}\right)} = 80$; $\phi' = 35°$; $N^*_q \approx 17$ (extrapolated from Figure 11.15)

$$Q_p = A_p q' N^*_q = \left(\frac{12\times 12}{12\times 12}\right)^2 (115\times 80)(17) = 156{,}400\ \text{lb}$$

$$Q_{p(\text{all})} = \frac{156.4\ \text{kip}}{4} = \textbf{39.1 kip}$$

11.7 Eq. (11.19): $Q_p = 9c_u A_p = (9)(0.381)^2(70) = 91.45$ kN

Eq. (11.50): $Q_s = \alpha c_u pL$

Average value of effective vertical pressure = $\overline{\sigma}'_o = (18.5)\left(\frac{20}{2}\right) = 185 \text{ kN/m}^2$

$$\frac{c_u}{\overline{\sigma}'_o} = \frac{70}{185} = 0.378$$

From Figure 11.23, $\alpha \approx 0.76$

$Q_s = (0.76)(4 \times 0.381)(70)(20) = 1621.5 \text{ kN}$

$$Q_{all} = \frac{91.45 + 1621.5}{3} \approx \mathbf{571\ kN}$$

11.10 $Q_s = pLf_{av}$

Eq. (11.47): $f_{av} = \lambda(\overline{\sigma}'_o + 2c_u)$

$$\overline{\sigma}'_o = \frac{(18.5)(20)}{2} = 185 \text{ kN/m}^2$$

$L = 20$ m. Table 11.7: $\lambda = 0.173$

$Q_s = (4 \times 0.381)(20)(0.173)[185 + (2)(70)] = 1714 \text{ kN}$

$$Q_{all} = \frac{91.45 + 1714}{3} \approx \mathbf{602\ kN}$$

11.9 Eq. (11.19): $Q_p = A_p c_u N_c^* = \dfrac{\left(\frac{15}{12}\right)^2 (1450)(9)}{1000} = 20.39 \text{ kip}$

$L = 60 \text{ ft} = 18.29$ in.; $\lambda = 0.184$

$$\overline{\sigma}'_o = \frac{(60 \times 122)}{2} = 3660 \text{ lb/ft}^2$$

$$Q_s = pL\lambda(\overline{\sigma}'_o + 2c_u) = \left(4 \times \frac{15}{12}\right)(60)(0.184)(3660 + 2 \times 1450) = 362{,}112 \text{ lb} \approx 362 \text{ kip}$$

$$Q_{all} = \frac{20.39 + 362}{3} = 127.46 \text{ kip} \approx \mathbf{128\ kip}$$

11.10 a. $Q_s = p[L_1 \alpha_1 c_{u(1)} + L_2 \alpha_2 c_{u(2)}]$. $p = 4 \times 16/12 = 5.33$ ft

$$z = 0 \text{ to } 20 \text{ ft:} \quad \overline{\sigma}'_o = \frac{118 \times 20}{2} = 1180 \text{ lb / ft}^2$$

$$\frac{c_{u(1)}}{\overline{\sigma}'_o} = \frac{700}{1180} = 0.59$$

Figure 11.23: $\alpha_1 \approx 0.6$

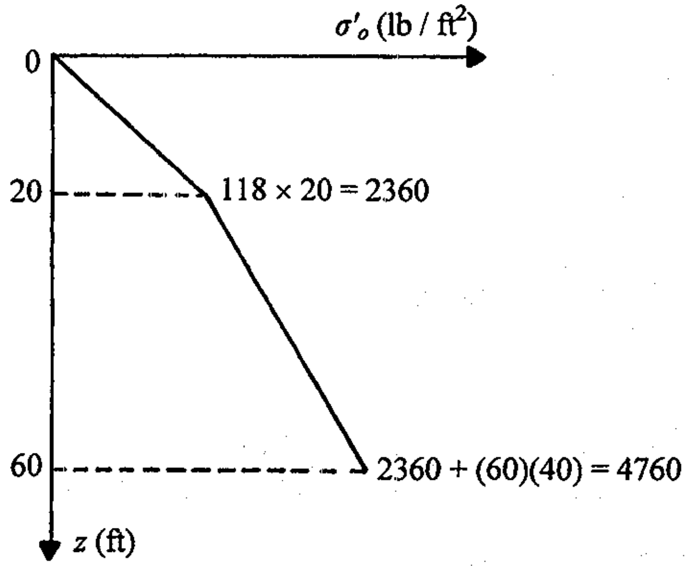
$$z = 0 \text{ to } 20 \text{ ft:} \quad \overline{\sigma}'_o = \frac{(118 \times 20) + 40(122.4 - 62.4)}{2} = 2380 \text{ lb / ft}^2$$

$$\frac{c_{u(2)}}{\overline{\sigma}'_o} = \frac{1500}{2380} = 0.63$$

Figure 11.23: $\alpha_2 \approx 0.59$

$$Q_s = 5.33[(20)(0.6)(700) + (40)(0.59)(1500)] = 233{,}454 \text{ lb} \approx \mathbf{233\ kip}$$

b. $$c_{u(\text{av})} = \frac{(700)(20) + (1500)(40)}{60} = 1233.3 \text{ lb / ft}^2$$




$$\overline{\sigma}'_{o(\text{av})} = \frac{\frac{1}{2}(20)(2360) + \frac{1}{2}(40)(2360 + 4760)}{60} = 2766.7 \text{ lb / ft}^2$$

Length of pile = 60 ft ≈ 18.3 m; $\lambda \approx 0.18$

$$Q_s = pL\lambda[\bar{\sigma}'_{0(\text{av})} + 2c_{u(\text{av})}]$$

$$= \frac{1}{1000}\left(4 \times \frac{16}{20}\right)(60)(0.18)[2766.7 + (2)(1233.3)] = 301.4 \text{ kip} \approx \mathbf{301 \text{ kip}}$$

c. $f_{\text{av}(1)} = (1 - \sin\phi'_R)\tan\phi'_R\bar{\sigma}'_{o(\text{av})}$

$$= (1 - \sin 20)(\tan 20)\left(\frac{1}{2} \times 118 \times 20\right) = 282.6 \text{ lb/ft}^2$$

$$f_{\text{av}(2)} = (1 - \sin 20)(\tan 20)\left(\frac{2360 + 4760}{2}\right) = 852.6 \text{ lb/ft}^2$$

$$Q_s = p[L_1 f_{\text{av}(1)} + L_2 f_{\text{av}(2)}] = \left(\frac{1}{1000}\right)\left(4 \times \frac{16}{12}\right)[(20)(282.6) + (40)(852.6)] = \mathbf{212 \text{ kip}}$$

11.11 Eq. (11.59): $q_{u(\text{design})} = \frac{q_{u(\text{lab})}}{5} = \frac{11{,}400}{5} = 2280 \text{ lb/in.}^2$

$$N_\phi = \tan^2\left(45 + \frac{\phi'}{2}\right) = \tan^2\left(45 + \frac{36}{2}\right) = 3.852$$

Eq. (11.61): $Q_{p(\text{all})} = \frac{q_{u(\text{design})}(N_\phi + 1)A_p}{\text{FS}}$

For HP 14 × 102, $A_p = 30 \text{ in.}^2$

$$Q_{p(\text{all})} = \frac{(2280)(3.852 + 1)(30)}{(3)(1000)} = \mathbf{110.6 \text{ kip}}$$

11.12 Eq. (11.63): $s_{e(1)} = \frac{(Q_{wp} + \xi Q_{ws})L}{A_p E_p} = \frac{[70 + (0.57)(110)](50)}{(16 \times 16 \text{ in.}^2)(3 \times 10^3 \text{ kip/in.}^2)}$

$$= 0.0086 \text{ ft} = 0.104 \text{ in.}$$

Eq. (11.64): $s_{e(2)} = \frac{q_{wp}D}{E_s}(1 - \mu_s^2)I_{wp}$

$$= \left[\left(\frac{70 \text{ kip}}{16 \times 16}\right)\left(\frac{16}{5 \text{ kip/in.}^2}\right)\right](1 - 0.38^2)(0.85) = 0.636 \text{ in.}$$

Eq. (11.66): $s_{e(3)} = \left(\frac{Q_{ws}}{pL}\right)\frac{D}{E_s}(1-\mu_s^2)I_{ws}$

$$I_{ws} = 2 + 0.35\sqrt{\frac{50}{\left(\frac{16}{12}\right)}} = 4.13$$

$$s_{e(3)} = \left[\frac{110}{(4\times 16)(50\times 12)}\right]\left(\frac{16}{5}\right)(1-0.38^2)(4.13) = 0.032 \text{ in.}$$

$s_e = 0.104 + 0.636 + 0.032 = \mathbf{0.772\ in.}$

11.13 Eq. (11.63): $s_{e(1)} = \frac{(Q_{wp} + \xi Q_{ws})L}{A_p E_p} = \frac{[98 + (0.6)(240)]12}{(0.305)^2(21\times 10^6)} = 0.00148 \text{ m} = 1.48 \text{ mm}$

Eq. (11.64): $s_{e(2)} = \frac{q_{wp}D}{E_s}(1-\mu_s^2)I_{wp}$

$$q_{wp} = \frac{Q_{wp}}{A_p} = \frac{98}{(0.305)^2} = 1053.4 \text{ kN/m}^2$$

So, $s_{e(2)} = \left[\frac{(1053.4)(0.305)}{30{,}000}\right](1-0.3^2)(0.85) = 0.0083 \text{ m} = 8.3 \text{ mm}$

Again, from Eq. (11.66)

$$s_{e(3)} = \left(\frac{Q_{ws}}{pL}\right)\frac{D}{E_s}(1-\mu_s^2)I_{ws}$$

$$I_{ws} = 2 + 0.35\sqrt{\frac{L}{D}} = 2 + 0.35\sqrt{\frac{12}{0.305}} = 4.2$$

So, $s_{e(3)} = \frac{240}{(4\times 0.305)(12)}\left(\frac{0.305}{30{,}000}\right)(1-0.3^2)(4.2) = 0.00064 \text{ m} = 0.64 \text{ mm}$

$s_e = 1.48 + 8.3 + 0.64 = \mathbf{10.42\ mm}$

11.14 $I = \frac{1}{12}bh^3 = \frac{1}{12}(0.305)^4 = 0.0007 \text{ m}^4$

$E_p = 21 \times 10^6$ kN / m²

Eq. (11.80): $T = \sqrt[5]{\dfrac{E_p I_p}{n_h}} = \sqrt[5]{\dfrac{(21 \times 10^6)(0.0007)}{9200}} = 1.098$ m

$\dfrac{L}{T} = \dfrac{30}{1.098} > 5$. So, long pile. $M_g = 0$. From Eq. (11.75)

$$x_z(z) = A_x \frac{Q_g T^3}{E_p I_p}; \quad Q_g = \frac{x_z(z) E_p I_p}{A_x T^3}$$

At $z = 0$, $x_z = 12$ mm $= 0.012$ m; $A_x = 2.435$ (Table 11.13)

$$Q_g = \frac{(0.012)(21 \times 10^6)(0.0007)}{(2.435)(1.098)^3} = 54.7 \text{ kN}$$

Check for moment capacity: $M_{z(\max)} = F_Y \dfrac{I_p}{\frac{d}{2}} = A_m Q_g T$

$$Q_g = \frac{2 F_Y I_p}{d A_m T}$$

From Table 11.13, the maximum value of $A_m$ is 0.772.

$$Q_g = \frac{(2)(21{,}000)(0.0007)}{(0.305)(0.772)(1.098)} = 113.7 \text{ kN}$$

Use $Q_p$ = **54.7 kN**

11.15 <u>Check for bending failure:</u>

$$M_y = F_Y \frac{I_p}{\frac{d}{2}} = (21{,}000)\left(\frac{0.0007}{\frac{0.305}{2}}\right) = 96.39 \text{ kN - m}$$

$$\frac{M_y}{D^4 \gamma K_p} = \frac{M_y}{D^4 \gamma \tan^2\left(45 + \frac{\phi'}{2}\right)} = \frac{96.39}{(0.305)^4 (16) \tan^2(45 + 15)} = 232$$

From Figure 11.34a, with $\dfrac{e}{D} = 0$, $\dfrac{Q_{u(g)}}{K_p D^3 \gamma} \approx 50$

$Q_{u(g)} = 50\tan^2(60)(0.305)^3(16) = 68$ kN

<u>Check for pile head deflection:</u>

Eq. (11.91): $\eta = \sqrt[5]{\dfrac{n_h}{E_p I_p}} = \sqrt[5]{\dfrac{9200}{(21\times10^6)(0.0007)}} = 0.91\ \text{m}^{-1}$

$\eta L = (0.91)(30) = 27.3$. From Figure 11.35a, for $\eta L = 27.3, \dfrac{e}{L} = 0$

$$\frac{x_{z(z=0)}(E_p I_p)^{\frac{3}{5}}(n_h)^{\frac{2}{5}}}{Q_g L} \approx 0.15$$

$$Q_g = \frac{x_{z(z=0)}(E_p I_p)^{\frac{3}{5}}(n_h)^{\frac{2}{5}}}{(0.15)L} = \frac{(0.012)[(21\times10^6)(0.0007)]^{\frac{3}{5}}(9200)^{\frac{2}{5}}}{(0.15)(30)} = 32.5\ \text{kN}$$

Use $Q_g$ = **32.5 kN**

11.16 Eq. (11.108): $Q_u = \dfrac{EH_E}{S+C}$

$H_E = 40$ kip - ft $= 40 \times 12$ kip - in.; $E = 0.85$

$$Q_u = \frac{(0.85)(40\times12)}{\frac{1}{10}+0.1} = 2040\ \text{kip}$$

$$Q_{\text{all}} = \frac{2040}{6} = \mathbf{340\ kip}$$

11.17 $Q_u = \dfrac{EW_R h}{S+C}\,\dfrac{W_R + n^2 W_p}{W_R + W_p}$

$W_p$ = weight of (pile + cap) $= \dfrac{90\times100}{1000} + 2.4 = 11.4$ kip

$$Q_u = \left[\frac{(0.85)(40\times12)}{\frac{1}{10}+0.1}\right]\left[\frac{12+(0.35)^2(11.4)}{12+11.4}\right] = 1167.9\ \text{kip}$$

$$Q_{all} = \frac{1167}{4} \approx \mathbf{292\ kip}$$

11.18 $$Q_u = \frac{EH_E}{S + \sqrt{\dfrac{EH_E L}{2A_p E_p}}};\quad \sqrt{\frac{EH_E L}{2A_p E_p}} = \sqrt{\frac{(0.85)(40\times 12)(90\times 12)}{(2)(29.4)(30\times 10^3)}} = 0.5$$

$$Q_u = \frac{(0.85)(36\times 12)}{0.1+0.5} = 680\ \text{kip}$$

$$Q_{all} = \frac{680}{3} \approx \mathbf{227\ kip}$$

11.19 Eq. (11.116): $$Q_n = \frac{p(1-\sin\phi'_{\text{fill}})\gamma'_f H_f^2 \tan\delta'}{2}$$

$$= \frac{(\pi\times 0.450)(1-\sin 25)(17.5)(4^2)\tan(0.5\times 25)}{2} = \mathbf{25.3\ kN}$$

11.20 $$Q_n = \frac{p(1-\sin\phi'_{\text{fill}})\gamma'_f H_f^2 \tan\delta'}{2}$$

$$= \frac{(\pi\times 0.450)(1-\sin 25)(19.8-9.81)(4^2)\tan(0.5\times 25)}{2} = \mathbf{14.5\ kN}$$

11.21 Eq. (11.117): $$L_1 = \frac{(L-H_f)}{L_1}\left(\frac{(L-H_f)}{2} + \frac{\gamma'_f H_f}{\gamma'}\right) - \frac{2\gamma'_f H_f}{\gamma'}$$

$$= \frac{(60-12)}{L_1}\left[\frac{(60-12)}{2} + \frac{(105)(12)}{(121-62.4)}\right] - \frac{2(105)(12)}{(121-62.4)}$$

$$L_1 = \frac{2184}{L_1} - 43;\quad L_1 \approx 30\ \text{ft}$$

Eq. (11.119): $Q_n = p(1-\sin\phi_{clay})\gamma'_f H_f \tan\delta L_1 + \dfrac{L_1^2 p(1-\sin\phi_{clay})\gamma' \tan\delta}{2}$

$$= \left(\pi \times \frac{18}{12}\right)(1-\sin 28)(105)(12)\tan(0.5\times 28)(30) +$$

$$\frac{(30^2)\left(\pi \times \frac{18}{12}\right)(1-\sin 28)(121-62.4)\tan(0.5\times 28)}{2}$$

$= 56{,}434$ lb $\approx$ **56.4 kip**

11.22 a. $\eta = \dfrac{2(n_1+n_2-2)d+4D}{pn_1n_2}$

$d = 0.92$ m; $D = 0.46$ m. So

$$\eta = \left[\frac{(2)(3+3-2)(0.92)+(4)(0.46)}{(\pi\times 0.46)(3)(3)}\right](100) = \mathbf{70.7\%}$$

b. $\eta = 1 - \dfrac{D}{\pi d n_1 n_2}\left[n_1(n_2-1)+n_2(n_1-1)+\sqrt{2}(n_1-1)(n_2-1)\right]$

$$= 1 - \frac{0.46}{(\pi)(0.92)(3)(3)}\left[(3)(2)+(3)(2)+\left(\sqrt{2}\right)(2)(2)\right] = 0.688 = \mathbf{68.8\%}$$

11.23 a. $d = 1.2$ m

$$\eta = \left[\frac{(2)(3+3-2)(1.2)+(4)(0.46)}{(\pi\times 0.46)(3)(3)}\right](100) = \mathbf{87.96\%}$$

b. $\eta = 1 - \dfrac{0.46}{(\pi)(1.2)(3)(3)}\left[(3)(2)+(3)(2)+\left(\sqrt{2}\right)(2)(2)\right] = 0.76 = \mathbf{76.06\%}$

11.24 <u>Piles acting individually:</u>

Eq. (11.123): $\Sigma Q_u = n_1 n_2 [9A_p c_{u(p)} + \alpha p c_u L]$

To obtain $\alpha$: $\bar{\sigma}'_o = \dfrac{(18)(18.5)}{2} = 166.5 \text{ kN/m}^2$

$$\frac{c_u}{\overline{\sigma}'_o} = \frac{95.8}{166.5} = 0.575 \text{ Figure 11.23: } \alpha \approx 0.6$$

$$\sum Q_u = (3)(3)\left[(9)\left(\frac{\pi}{4} \times 0.406^2\right)(95.8) + (0.6)(\pi \times 0.406)(95.8)(18.5)\right]$$

$$= (9)(111.62 + 1356.3) = 13{,}211 \text{ kN}$$

$$Q_{all} = \frac{Q_u}{FS} = \frac{13{,}211}{3} \approx 4404 \text{ kN}$$

Piles acting as a group:

Eq. (11.124): $\sum Q_u = L_g B_g c_{u(p)} N_c^* + 2\sum(L_g + B_g)c_u \Delta L$

$$L_g = B_g = (n-1)d + 2\left(\frac{D}{2}\right) = (2)(0.406) + \frac{(2)(0.7)}{2} = 1.512 \text{ m}$$

$\frac{L_g}{B_g} = 1;\ \frac{L}{B_g} = \frac{18.5}{1.512} = 12.24$. From Figure 11.44, $N_c^* = 9$. So

$$\sum Q_u = (1.512)(1.512)(95.8)(9) + (2)(1.512 + 1.512)(95.8)(18.5)$$

$$= 1971.1 + 10{,}718.9 = 12{,}690 \text{ kN}$$

$$Q_{all} = \frac{12{,}690}{3} = \mathbf{4230\ kN}$$

11.25 Piles acting individually:

Eq. (11.123): $\sum Q_u = n_1 n_2 [9A_p c_{u(p)} + \alpha p c_u L]$

To obtain $\alpha$:

$$\overline{\sigma}'_o = \frac{(45)(122.4 - 62.4)}{2} = 1350 \text{ lb/ft}^2$$

$$\frac{c_u}{\overline{\sigma}'_o} = \frac{860}{1350} = 0.637$$

Figure 11.23: $\alpha \approx 0.58$

$$Q_u = (3)(3)\left\{(9)\left[\frac{\pi}{4}\times\left(\frac{12}{12}\right)^2\right](860)+(0.58)\left(\pi\times\frac{12}{12}\right)(860)(45)\right\}$$

$$= (9)(6079+70{,}516)\text{ lb} \approx 689\text{ kip}$$

Piles acting as a group:

Eq. (11.124): $\sum Q_u = L_g B_g c_{u(p)} N_c^* + 2\sum(L_g + B_g)c_u \Delta L$

$$L_g = B_g = (n-1)d + 2\left(\frac{D}{2}\right) = (2)(2.5\text{ ft}) + 1\text{ ft} = 6\text{ ft}$$

$\frac{L_g}{B_g} = 1$; $\frac{L}{B_g} = \frac{45}{6} = 7.5$. From Figure 11.44, $N_c^* = 9$

$$\sum Q_u = \frac{(6)(6)(860)(9)+(2)(6+6)(860)(45)}{1000} = 1207.4\text{ kip}$$

$$Q_{all} = \frac{689}{3} = 229.7 \approx \mathbf{230\ kip}$$

11.26 Piles acting individually:

$$\sum Q_u = n_1 n_2 [9A_p c_{u(p)} + \alpha_1 p c_{u(1)} L_1 + \alpha_2 p c_{u(2)} L_2 + \alpha_3 p c_{u(3)} L_3]$$

| Depth (ft) | $c_u$ (lb / ft²) | $\overline{\sigma'_o}$ (lb / ft²) | $c_u/\overline{\sigma'_o}$ | $\alpha$ (Figure 11.23) |
|---|---|---|---|---|
| 0 – 15 | 550 | $\frac{15\times 115}{2} = 862.5$ | 0.64 | 0.58 |
| 15 – 35 | 875 | $\frac{(15\times 115)+(20\times 120)}{2} = 2062.5$ | 0.424 | 0.7 |
| 35 – 55 | 1200 | $\frac{\{[(15\times 115)+(20\times 12)] + (124\times 20)\}}{2} = 3302.5$ | 0.363 | 0.88 |

$$\sum Q_u = \frac{1}{1000}(3\times 4)\left[\begin{array}{l}(9)\left(\frac{14}{12}\right)^2(1200)+(0.58)\left(4\times\frac{14}{12}\right)(550)(15)\\ +(0.7)\left(4\times\frac{14}{12}\right)(875)(20)+(0.88)\left(4\times\frac{14}{12}\right)(1200)(20)\end{array}\right] = 2313\text{ kip}$$

Piles acting as a group:

Eq. (11.124): $\sum Q_u = L_g B_g c_{u(p)} N_c^* + 2\sum(L_g + B_g)c_u \Delta L$

$L_g = 120 + 14 = 134$ in. $= 11.17$ ft; $B_g = 80 + 14 = 94$ in. $= 7.83$ ft

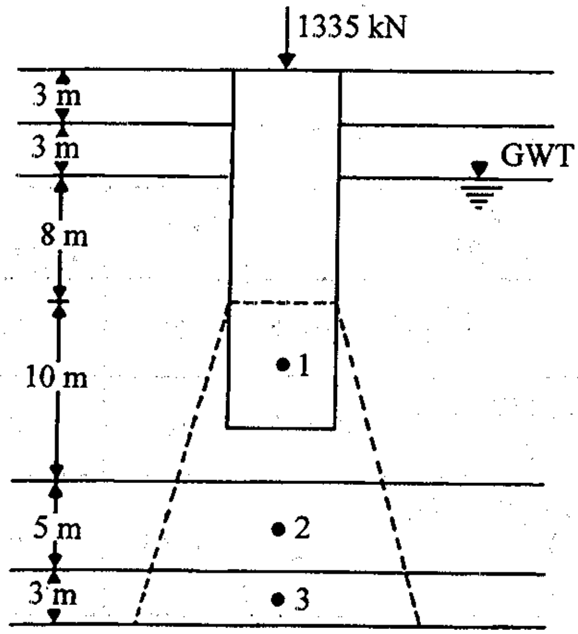
$$\frac{L_g}{B_g} = \frac{11.17}{7.83} = 1.43; \quad \frac{L}{B_g} = \frac{55}{7.83} = 7.02$$

From Figure 11.14, $N_c^* = 7{,}57$

$$\Sigma Q_u = \frac{1}{1000}\begin{Bmatrix}(11.17)(7.83)(1200)(8.57) + (2)(11.17 + 7.83) \\ \times[(550)(15) + (875)(20) + (1200)(20)]\end{Bmatrix} = \mathbf{2790\ kip}$$

$$Q_{\text{all}} = \frac{2313}{4} \approx \mathbf{578\ kip}$$

11.27 The pressure distribution diagram is shown.



| Layer | $\sigma'_o$ (kN / m²) | $\Delta\sigma'$ (kN / m²) | $\sigma'_o + \Delta\sigma'$ (kN / m²) |
|---|---|---|---|
| 1 | $(15.72)(3) + (18.55 - 9.81)(3) + (13)(19.18 - 9.81) = 47.16 + 26.22 + 121.81 = 195.19$ | $\frac{1335}{(2.75+5)^2} = 22.23$ | 217.42 |
| 2 | $195.19 + (5)(19.18 - 9.81) + (2.5)(18.08 - 9.81) = 262.72$ | $\frac{1335}{(2.75+12.5)^2} = 5.74$ | 268.46 |
| 3 | $262.72 + (2.5)(18.08 - 9.81) + (1.5)(19.5 - 9.81) = 297.93$ | $\frac{1335}{(2.75+16.5)^2} = 3.6$ | 301.53 |

$$\Delta s_{c(1)} = \frac{(0.8)(10)}{1+0.8}\log\left(\frac{217.42}{195.19}\right) = 0.208 \text{ m}$$

$$\Delta s_{c(2)} = \frac{(0.31)(5)}{1+1}\log\left(\frac{268.46}{262.72}\right) = 0.0073 \text{ m}$$

$$\Delta s_{c(3)} = \frac{(0.26)(3)}{1+0.7}\log\left(\frac{301.53}{297.93}\right) = \underline{0.0024 \text{ m}}$$

$$\sum \Delta s_c \approx \mathbf{217.7\ mm}$$

# CHAPTER 12

12.1 Eq. (12.20): $Q_{p(\text{net})} = A_p q'(\omega N_q^* - 1)$

$q' = L_1 \gamma_c + L_2 \gamma_s = (18)(100) + (10)(112) = 2920 \text{ lb/ft}^2$

$A_p = \frac{\pi}{4} D_b^2 = \frac{\pi}{4}(6)^2 = 28.27 \text{ ft}^2$

Eq. (12.21): $N_q^* = 0.21 e^{0.17\phi'} = 0.21 e^{(0.17)(38)} = 134.2$

$\frac{L}{D_b} = \frac{18+10}{6} = 4.67$. Assume approximately 5.

Figure 12.7: $\omega \approx 0.83$

$Q_{p(\text{net})} = (28.27)(2920)[(0.83 \times 134.2) - 1] = 9{,}112{,}187.7 \text{ lb} \approx 9112 \text{ kip}$

$Q_{\text{all(net)}} = \frac{Q_{p(\text{net})}}{\text{FS}} = \frac{9112}{3} \approx$ **3037 kip**

12.2 Eq. (12.16): $Q_{p(\text{net})} = A_p q'(N_q - 1) F_{qs} F_{qd} F_{qc}$

$\phi' = 35°$. Table 3.3: $N_q = 48.93$

$F_{qs} = 1 + \tan\phi' = 1 + \tan 38 = 1.78$

$$F_{qd} = 1 + 2\tan\phi'(1-\sin\phi')^2 \tan^{-1}\left(\frac{L}{D_b}\right) = 1 + 2\tan 38(1-\sin 38)^2 \tan^{-1}\left(\frac{28}{6}\right) = 1.314$$

Eq. (12.9): $$I_{rc} = 0.5\exp\left[2.85\cot\left(45 - \frac{\phi'}{2}\right)\right] = 0.5\exp\left[2.85\cot\left(45 - \frac{38}{2}\right)\right] = 172.47$$

Eq. (12.10): $$I_{rr} = \frac{I_r}{1 + I_r \Delta}$$

$$I_r = \frac{E_s}{2(1+\mu_s)q' \tan\varphi'}$$

$E_s = 400 p_a = (400)(2000) = 800{,}000 \text{ lb/ft}^2 = 800 \text{ kip/ft}^2$

Eq. (12.18): $\mu_s = 0.1 + 0.3\left(\frac{\phi' - 25}{20}\right) = 0.1 + 0.3\left(\frac{35-25}{20}\right) = 0.295$

$$I_r = \frac{800}{2(1+0.295)(2.92)(\tan 38)} = 135.4$$

Eq. (12.19): $\Delta = 0.005\left(1 - \frac{\phi' - 25}{20}\right)\left(\frac{q'}{p_a}\right) = 0.005\left(1 - \frac{38-25}{20}\right)\left(\frac{2.92}{2}\right) = 0.00256$

$$I_{rr} = \frac{135.4}{1 + (135.4 \times 0.00256)} = 100.55$$

So, $I_{rr} < I_{rc}$. Hence, $F_{qc} = 1$.

$$F_{qc} = \exp\left\{(-3.8\tan\phi') + \left[\frac{(3.07\sin\phi')(\log 2I_{rr})}{1+\sin\phi'}\right]\right\}$$

$$= \exp\left\{(-3.8\tan 38) + \left[\frac{(3.07\sin 38)(\log 2 \times 100.55)}{1+\sin 38}\right]\right\} = \exp\left(-2.969 + \frac{4.354}{1.616}\right) = 0.76$$

$Q_{p(\text{net})} = (28.27)(2.92)(48.93 - 1)(1.78)(1.314)(0.76) = 7033$ kip

$$Q_{\text{all(net)}} = \frac{7033}{4} \approx \mathbf{2344\ kip}$$

12.3 Eqs. (12.42) and (12.44):

$Q_s = \alpha^* c_u pL = (0.4)(720)(\pi \times 3.5)(18) = 57{,}000$ lb ≈ **57 kip**

12.4 $q' = (4)(17.8) + (2.5)(18.2) = 116.7\ \text{kN/m}^2$

$A_p = \frac{\pi}{4}(1.75)^2 = 2.405\ \text{m}^2$

$N_q^* = 0.21e^{0.17\phi'} = 0.21e^{(0.17)(32)} = 48.39$

$\frac{L}{D_b} = \frac{6.5}{1.75} = 3.71$. Assume 5

Fig. 12.7: $\omega = 0.79$

$Q_{p(\text{net})} = A_p q'(\omega N_q^* - 1) = (2.405)(116.7)[(0.79)(48.39 - 1] = 10{,}508$ kN

$$Q_{all(net)} = \frac{10{,}508}{4} \approx \mathbf{2627\ kN}$$

12.5 $\phi' = 32°$. Table 3.4: $N_q = 23.18$

$F_{qs} = 1 + \tan\phi' = 1 + \tan 32 = 1.625$

$$F_{qd} = 1 + 2\tan\phi'(1-\sin\phi')^2 \tan^{-1}\left(\frac{L}{D_b}\right) = 1 + 2\tan 32(1-\sin 32)^2 \tan^{-1}\left(\frac{6.5}{1.75}\right) = 1.361$$

Eq. (12.9): $I_{rc} = 0.5\exp\left[2.85\cot\left(45 - \frac{\phi'}{2}\right)\right] = 0.5\exp\left[2.85\cot\left(45 - \frac{32}{2}\right)\right] = 85.5$

Eq. (12.10): $I_{rr} = \frac{I_r}{1 + I_r\Delta}$

$$I_r = \frac{E_s}{2(1+\mu_s)q'\tan\phi'}$$

$E_s = 600p_a = (600)(100) = 60{,}000\ \text{kN/m}^2$

Eq. (12.18): $\mu_s = 0.1 + 0.3\left(\frac{\phi' - 25}{20}\right) = 0.1 + 0.3\left(\frac{32-25}{20}\right) = 0.205$

$$I_r = \frac{60{,}000}{2(1+0.205)(116.7)(\tan 32)} = 341.4$$

Eq. (12.19): $\Delta = 0.005\left(1 - \frac{\phi' - 25}{20}\right)\left(\frac{q'}{p_a}\right) = 0.005\left(1 - \frac{32-25}{20}\right)\left(\frac{116.7}{100}\right) = 0.00379$

$$I_{rr} = \frac{341.4}{1 + (341.4 \times 0.00379)} = 148.8$$

$I_{rr} > I_{rc}$. So, $F_{qc} = 1$

$Q_{p(net)} = A_p q'(N_q - 1)F_{qs}F_{qd}F_{qc}$

$= (2.405)(116.7)(23.18 - 1)(1.625)(1.361)(1) = 13{,}767\ \text{kN}$

$$Q_{all(net)} = \frac{13{,}767}{4} \approx \mathbf{3442\ kN}$$

12.6 a. $Q_s = \alpha^* c_u p L_1 = (0.4)(32)(\pi \times 1)(4) = \mathbf{160.8\ kN}$

b. $Q_s = \alpha_i^* c_{u(i)} p(L_1 - 1.5) = (0.55)(32)(\pi \times 1)(4 - 1.5) = \mathbf{138.2\ kN}$

12.7 a. $Q_p = A_p c_{u(2)} N_c^*$

$N_c^* = 1.33[\ln(I_r) + 1]$

$$\frac{c_{u(2)}}{p_a} = \frac{1800}{2000} = 0.9$$

From Eq. (12.41) and Figure 12.15: $I_r = \dfrac{E_s}{3c_{u(2)}} = 237.5$

$N_c^* = 1.33[\ln(237.5) + 1] = 8.61$

$$Q_p = \frac{\pi}{4}(5)^2(1800)(8.61) = 304{,}302 \text{ lb} = \mathbf{304\ kip}$$

b. $Q_s = \alpha^* c_{u(1)} p L_1 + \alpha^* c_{u(2)} p L_2 = (0.4)(\pi \times 5)[(1000)(20) + (1800)(15)]$

$= 295{,}310 \text{ lb} = \mathbf{295.3\ kip}$

c. $Q_w = \dfrac{304.3 + 295.3}{4} \approx \mathbf{149.9\ kip}$

12.8 a. Eq. (12.46):

$$q_p = 6c_{ub}\left(1 + 0.2\frac{L}{D_b}\right) = (6)(2000)\left[1 + (0.2)\left(\frac{35}{3.5}\right)\right] = 36{,}000 \text{ lb/ft}^2$$

Check: $9c_u = (9)(2000) = 18{,}000 \text{ lb/ft}^2$

Use $q_p = 18{,}000 \text{ lb/ft}^2$

$$Q_{p(\text{net})} = q_p A_p = \frac{(18{,}000)\left(\dfrac{\pi}{4}\right)(3.5)^2}{1000} = \mathbf{173.18\ kip}$$

b. $Q_s = \alpha_i^* c_{u(i)} p(L_1 - 5) + \alpha_i^* c_{u(2)} p(L_2 - D_s)$

$= (0.55)(\pi \times 3.5)(1200)(25 - 5) + (0.55)(\pi \times 3.5)(2000)(10 - 3.5)$

$= 223{,}760$ lb $\approx$ **223.76 kip**

c. $Q_w = \dfrac{173.18 + 223.76}{3} =$ **132.3 kip**

12.9 a. Eq. (12.32): $q_p = 57.5 N_{60} = (57.5)(23) = 1322.5 \text{ kN/m}^2$

Since $D_b > 1.27$ m, $q_{pr} = \dfrac{1.27}{D_b} q_p = \left(\dfrac{1.27}{2}\right)(1322.5) = 839.79 \text{ kN/m}^2$

$$\frac{\text{settlement of base}}{D_b} = \frac{25}{2 \times 1000} = 1.25\%$$

Figure 12.9: Using the trend line,

$$\frac{\text{end bearing}}{A_p q_{pr}} \approx 0.39$$

$$Q_{\text{all(net)}} = (0.39)\left(\frac{\pi}{4} \times 2^2\right)(839.79) = \mathbf{1028.9\ kN}$$

b. Eqs. (12.30) and (12.31):

$$Q_s = \sum f_i p \Delta L_i$$

$$f_i = \beta \sigma'_{ozi}$$

$$\sigma'_{ozi} = \left(\frac{L_1}{2}\right)\gamma = \left(\frac{12.5}{2}\right)(19) = 118.75 \text{ kN/m}^2$$

$$\beta = 1.5 - 0.244 z_i^{0.5} = 1.5 - (0.244)\left(\frac{12.5}{2}\right)^{0.5} = 0.89$$

$$f_i = (0.89)(118.75) = 105.69 \text{ kN/m}^3$$

$$Q_s = (105.69)(\pi \times 1)(12.5) = 4150.4 \text{ kN}$$

$$\frac{\text{settlement}}{D_s} = \frac{25}{1 \times 1000} = 2.5\%$$

Figure 12.10: Using the trend line

$$\frac{\text{side load transfer}}{\Sigma f_i\, p\Delta L} \approx 0.9$$

$$Q_{s(\text{net})} = (0.9)(4150.4) = \mathbf{3735.4\ kN}$$

c. $Q_w = 1028.9 + 3735.4 \approx \mathbf{4764.3\ kN}$

12.10 a. Eq. (12.36): $\beta \approx 2.0 - 0.062 L_1^{0.75} = 2.0 - (0.062)\left(\frac{18}{2}\right)^{0.75} = 1.678$

$$\Sigma f_1 p\Delta L_1 = \left(\frac{\gamma L_1 \beta}{2}\right)(\pi D_s)(L_1) = \left(\frac{1}{1000}\right)\left(118 \times \frac{18}{2} \times 1.678\right)(\pi \times 3)(18) = 302.3 \text{ kip}$$

$$q_p A_p = 1.2 N_{60} A_p = (1.2)(29)\left(\frac{\pi}{4} \times 4.5^2\right) = 553.47 \text{ kip}$$

$$Q_u = 302.3 + 553.47 \approx \mathbf{856\ kip}$$

b. $\frac{\text{allowable settlement}}{D_s} = \frac{1}{(3)(12)} = 2.78\%$

From Figure 12.12a trend line, normalized size load ≈ (0.95)(ultimate side load)

$$\frac{\text{allowable settlement}}{D_b} = \frac{1}{(4.5)(12)} = 1.85\%$$

From Figure 12.9 trend line, normalized end bearing ≈ (0.4)(ultimate end bearing)

$$Q = (0.95)(302.3) + (0.4)(553.47) \approx \mathbf{508.6\ kip}$$

12.11 a. $\Delta L_1 = 20 - 5 = 15$ ft; $c_{u(1)} = 1000 \text{ lb/ft}^2$

$\Delta L_2 = 15 - 5 = 10$ ft; $c_{u(2)} = 1800 \text{ lb/ft}^2$

$$\Sigma f_i p\Delta L_1 = (0.55)[(1000)(\pi \times 5)(15) + (2800)(\pi \times 5)(10)] = 472{,}593 \text{ lb} \approx 371.5 \text{ kip}$$

$$q_p = 6c_{ub}\left(1 + 0.2\frac{L}{D_b}\right) = (6)(1800)\left[1 + (0.2)\left(\frac{35}{5}\right)\right] = 25.920 \text{ lb/ft}^2$$

Check: $q_b = 9c_{ub} = (9)(1800) = 16{,}200 \text{ lb/ft}^2$

Use $q_b = 16{,}200 \text{ lb/ft}^2$

$$Q_u = 371.5 + (16.2)\left(\frac{\pi}{4} \times 5^2\right) = \mathbf{689.6 \text{ kip}}$$

b. $$\frac{\text{allowable settlement}}{D_s} = \frac{1 \text{ in.}}{(5)(12)} = 1.66\%$$

From Figure 12.16, normalized side load ≈ (0.87)(ultimate side load)

$$\frac{\text{allowable settlement}}{D_b} = \frac{1}{(5)(12)} = 1.67\%$$

From Figure 12.17, normalized end bearing ≈ (0.77)(ultimate end bearing)

$$Q = (0.87)(371.5) + (0.77)(16.2)\left(\frac{\pi}{4} \times 5^2\right) = \mathbf{568.1 \text{ kip}}$$

12.12 From Problem 12.7(c), $Q_w = 149.9$ kip

$Q_{ws} = 0.8Q_w = (0.8)(149.8) \approx 119.92$ kip

$Q_{wp} = 149.9 - 119.92 = 29.98$ kip kN

Eq. (11.63): $$s_{e(1)} = \frac{(Q_{wp} + \xi Q_{ws})L}{A_p E_p} = \frac{[29.98 + (0.65)(119.92)](35)}{\left[\left(\frac{\pi}{4}\right)(5)^2\right](3.2 \times 10^3 \times 144)}$$

$$= 0.418 \times 10^{-3} \text{ ft} \approx 0.005 \text{ in.}$$

Eq. (11.65): $$s_{e(2)} = \frac{Q_{wp} C_p}{D_b q_p}$$

$q_p = c_{u(2)} N_c^* = (1800)(9) = 16{,}200 \text{ lb/ft}^2$; $C_p = 0.03$

$$s_{e(2)} = \frac{(29.98)(0.03)}{(1.5)(16.2)} = 0.0111 \text{ ft} = 0.133 \text{ in.}$$

Eq. (11.66): $$I_{ws} = 2 + 0.35\sqrt{\frac{L}{D}} = 2 + 0.35\sqrt{\frac{35}{5}} = 2.926$$

Assume $\mu_s = 0.3$; $E_s = 1800 \text{ lb/in.}^2 = (1.8)(144) \text{ kip/ft}^2$

Eq. (11.66):

$$s_{e(3)} = \left(\frac{Q_{ws}}{pL}\right)\frac{D}{E_s}(1-\mu_s^2)I_{ws}$$

$$= \left[\frac{119.92}{(\pi\times 5)(35)}\right]\left(\frac{5}{1.8\times 144}\right)(1-0.3^2)(2.926) = 0.0112 \text{ ft} = 0.134 \text{ in.}$$

Total settlement $= s_{e(1)} + s_{e(2)} + s_{e(3)} = 0.005 + 0.133 + 0.134 \approx$ **0.272 in.**

12.13 From Problem 12.8(c), $Q_w = 132.3$ kip

$Q_{ws} = 0.83 Q_w = (0.83)(132.3) \approx 109.8$ kip

$Q_p = 132.3 - 109.8 = 22.5$ kip

Eq. (11.63): $$s_{e(1)} = \frac{(Q_{wp} + \xi Q_{ws})L}{A_p E_p} = \frac{[22.5 + (0.65)(109.8)](35)}{\left[\left(\frac{\pi}{4}\right)(3.5)^2\right]\left(\frac{3\times 10^6 \times 144}{10^3}\right)}$$

$$= 0.00079 \text{ ft} = 0.0095 \text{ in.}$$

Eq. (11.65): $$s_{e(2)} = \frac{Q_{wp}C_p}{D_b q_p}$$

$C_p = 0.03$

$q_p = c_u N_c^* = (2 \text{ kip/ft}^2)(9) = 18 \text{ kip/ft}^2$

$$s_{e(2)} = \frac{(22.5)(0.03)}{(3.5)(18)} = 0.0107 \text{ ft} \approx 0.13 \text{ in.}$$

Eq. (11.66): $$s_{e(3)} = \left(\frac{Q_{ws}}{pL}\right)\frac{D}{E_s}(1-\mu_s^2)I_{ws}$$

$$I_{ws} = 2 + 0.35\sqrt{\frac{L}{D}} = 2 + 0.35\sqrt{\frac{35}{3.5}} = 3.107$$

$\mu_s = 0.3$; $E_s = 2000 \text{ lb/in.}^2 = 288 \text{ kip/ft}^2$. So

$$s_{e(3)} = \left[\frac{109.8}{(\pi)(3.5)(35)}\right]\left(\frac{3.5}{288}\right)(1-0.3^2)(3.107) = 0.0098 \text{ ft} = 0.118 \text{ in.}$$

Total settlement $= s_{e(1)} + s_{e(2)} + s_{e(3)} = 0.0095 + 0.13 + 0.118 =$ **0.258 in.**

12.14 From Eq. (12.63): $f = 6.564 q_u^{0.5} \le 0.15 q_u$

Since $q_{u\,(\text{concrete})} < q_{u\,(\text{rock})}$, use $q_{u\,(\text{concrete})}$ in Eq. (12.63).

$q_{u\,(\text{concrete})} = 28{,}000 \text{ kN / m}^2$

$f = (6.564)(28{,}000)^{0.5} = 1098.4 \text{ kN / m}^2$

Check: $f = 0.15 q_u = (0.15)(28{,}000) = 4200 \text{ kN / m}^2 > 1098.4 \text{ kN / m}^2$

So use $f = 1098.4 \text{ kN / m}^2$

From Eq. (12.64): $Q_u = \pi D_s L f = (\pi)(1.5)(8)(1098.4) = 41{,}409 \text{ kN}$

From Eqs. (12.65), (12.66), and (12.67): $s_e = \dfrac{Q_u L}{A_c E_c} + \dfrac{Q_u I_f}{D_s E_{\text{mass}}}$

For RQD ≈ 75%, from Eq. (12.69):

$$\frac{E_{\text{mass}}}{E_{\text{core}}} = 0.0266(\text{RQD}) - 1.55 = (0.0266)(75) - 1.66 = 0.335$$

$$E_{\text{mass}} = 0.335 E_{\text{core}} = (0.335)(12.1 \times 10^6) = 4.05 \times 10^6 \text{ kN / m}^2$$

$$\frac{E_c}{E_{\text{mass}}} = \frac{22}{4.05} \approx 5.43$$

$$\frac{L}{D_b} = \frac{8}{1.5} = 5.33$$

From Table 12.1 for $\dfrac{E_c}{E_{\text{mass}}} = 5.43$ and $\dfrac{L}{D_b} = 5.33$, the magnitude of $I_f$ is about 0.42.

Hence

$$s_e = \frac{(41{,}409 \text{ kN})(8)}{\frac{\pi}{4}(1.5)^2(22 \times 10^6 \text{ kN / m}^2)} + \frac{(41{,}409 \text{ kN})(0.42)}{(1.5)(4.05 \times 10^6 \text{ kN / m}^2)}$$

$$= 0.0114 \text{ m} = 11.4 \text{ mm} > 10 \text{ mm}$$

So, From Eq. (12.71):

$$Q_u = 3A_p\left[\frac{3+\frac{c_s}{D_s}}{10\left(1+300\frac{\delta}{c_s}\right)^{0.5}}\right]q_u = (3)\left(\frac{\pi}{4}\times 15^2\right)\left[\frac{3+\frac{500}{1500}}{(10)\left(1+300\frac{3}{500}\right)^{0.5}}\right](28{,}000)$$

= **29,573 kN**

12.15 a. Eq. (12.56):

$$Q_c = 1.57D_s^2(E_pR_I)\left(\frac{\gamma' D_s\phi' K_p}{E_pR_I}\right)^{0.57}$$

$E_p = 22 \times 110^6$ kN / m$^2$

$R_I = 1$

$$I_p = \frac{\pi D^4}{64} = \frac{(\pi)(1.25)^4}{64} = 0.1198 \text{ m}^4$$

$$K_p = \tan^2\left(45+\frac{\phi'}{2}\right) = \tan^2\left(45+\frac{35}{2}\right) = 3.69$$

$$Q_c = (1.57)(1.25)^2(22\times 10^6)(1)\left[\frac{(17.5)(1.25)(35)(3.69)}{(22\times 10^6)(1)}\right]^{0.57} = 326{,}630 \text{ kN}$$

$$\frac{Q_g}{Q_c} = \frac{260}{326{,}630} = 0.0008$$

From Figure 12.21, $x_o/D_s = 0.0025$

$x_o = (0.0025)(1.25) = 0.00313$ m = **3.13 mm**

b. Eq. (12.58):

$$M_c = 1.33D_s^3(E_pR_I)\left(\frac{\gamma' D_s\phi' K_p}{E_pR_I}\right)^{0.4}$$

$$= (1.33)(1.25)^3(22\times 10^6)(1)\left[\frac{(17.5)(1.25)(35)(3.69)}{(22\times 10^6)(1)}\right]^{0.4} = 1{,}586{,}544 \text{ kN - m}$$

From Table 12.3, for $\frac{Q_g}{Q_c} = 0.0008$, $\frac{M_{max}}{M_c} \approx 0.000375$

$$M_{max} = (0.000375)(1{,}586{,}544) = \mathbf{594.9\ kN\text{-}m}$$

c. $$\sigma_{tensile} = \frac{M_{max}\left(\frac{D_s}{2}\right)}{I_p} = \frac{(594.9)\left(\frac{1.25}{2}\right)}{0.1198} = \mathbf{3104\ kN/m^2}$$

d. $$\frac{E_p R_I}{\gamma' D_s \phi' K_p} = \frac{(22 \times 10^6)(1)}{(17.5)(1.25)(35)(3.69)} = 7787.2$$

$$\left(\frac{L}{D_s}\right)_{min} \approx 6$$

$$L_{min} = (6)(1.25) = \mathbf{7.5\ m}$$

# CHAPTER 13

13.1 Eq. (13.5): For collapse, $\gamma_d \le \dfrac{G_s \gamma_w}{1+(\mathrm{LL})(G_s)}$

$G_s = 2.74$; $\gamma_w = 9.81\ \mathrm{kN/m^3}$

| LL | $\gamma_d$ ($\mathrm{kN/m^3}$) below which collapse will occur |
|---|---|
| 20 | **17.36** |
| 25 | **15.95** |
| 30 | **14.75** |
| 35 | **13.72** |
| 40 | **12.82** |

The plot can now be made.

For LL = 27, $\gamma_d = \dfrac{(2.74)(9.81)}{1+(0.27)(2.74)} = 15.45\ \mathrm{kN/m^3}$

Since the given $\gamma_d$ is 14.5 $\mathrm{kN/m^3}$, which is less than $\gamma_d$ = 15.45 $\mathrm{kN/m^3}$, **collapse is likely to occur**.

13.2 $\sigma'_c = 84\ \mathrm{kN/m^2}$; $\sigma'_o = 62\ \mathrm{kN/m^2}$

$$\frac{\sigma'_c}{\sigma'_o} = \frac{84}{62} = 1.35 < 1.5$$

The soil is **normally consolidated**.

13.3 LL = 50; $w$ = 20%; $z$ = 10 ft

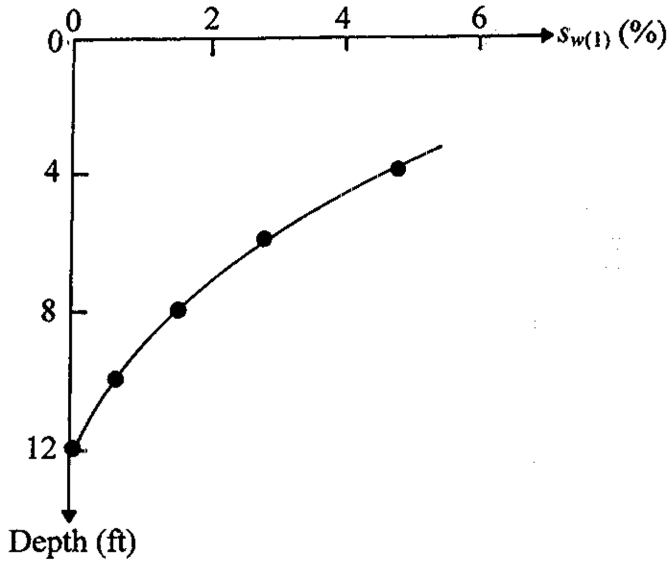
Eq. (13.10): $\Delta S_F = 0.0033 Z s_{w\,(\mathrm{free})}$

From Figure 13.9, $s_{w\,(\mathrm{free})}$ = 3%. So

$\Delta S_F = (0.0033)(10)(3) = 0.099$ ft = **1.19 in.**

13.4 $\Delta S = \frac{1}{100}\left[\frac{1}{2}(0.6+0)(2)+\frac{1}{2}(0.6+1.5)(2)+\frac{1}{2}(1.5+2.75)(2)+\frac{1}{2}(2.75+4.75)(2)\right]$

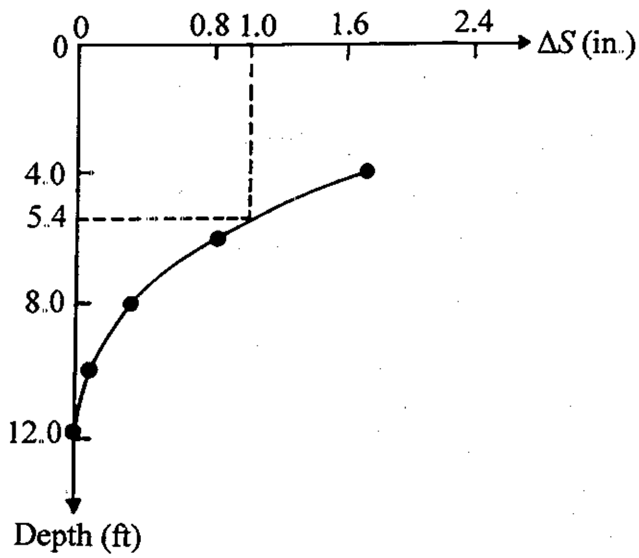
$= 0.145$ ft = **1.73 in.**



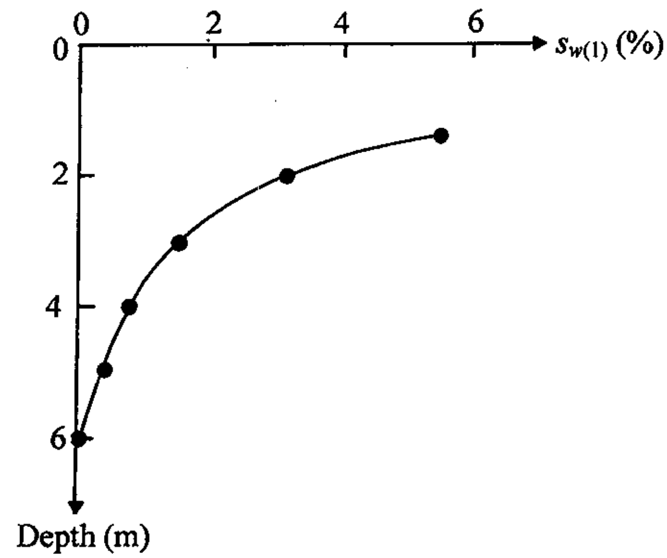

13.5

| Depth (ft) | Total swell, $\Delta S$ (in.) |
|---|---|
| 12 | 0 |
| 10 | $0+\frac{1}{2}(0.6)(2)\left(\frac{1}{100}\right)(12)=0.072$ |
| 8 | $0.072+\frac{1}{2}(1.5+0.6)(2)\left(\frac{1}{100}\right)(12)=0.324$ |
| 6 | $0.324+\frac{1}{2}(1.5+2.75)(2)\left(\frac{1}{100}\right)(12)=0.834$ |
| 4 | $0.834+\frac{1}{2}(2.75+4.75)(2)\left(\frac{1}{100}\right)(12)=1.734$ |

The plot of $\Delta S$ vs. depth is shown in the figure on the next page. From this figure, the depth of undercut is 5.4 − 4 = **1.4 ft below the bottom of the foundation.**



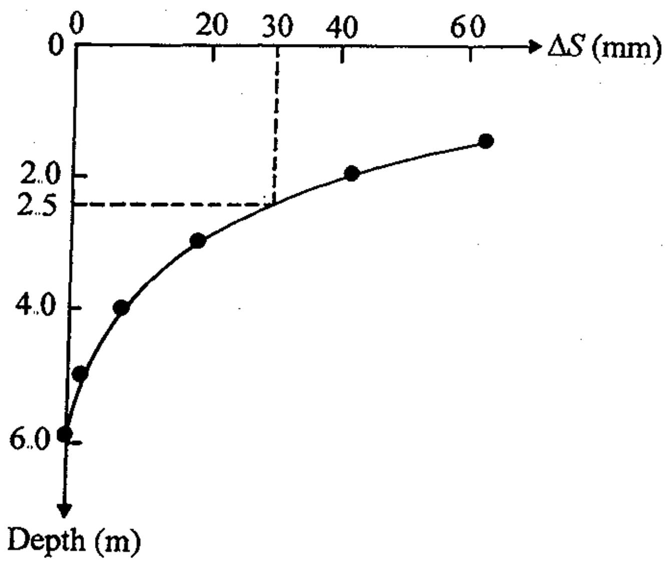

13.6 $\Delta S = \frac{1}{100}\left[\begin{array}{l}\frac{1}{2}(0.4+0)(1)+\frac{1}{2}(0.4+0.75)(1)+\frac{1}{2}(0.75+1.5)(1) \\ \quad +\frac{1}{2}(1.5+3.1)(1)+\frac{1}{2}(3.1+5.5)(0.5)\end{array}\right] = 0.0635\text{ m} = \mathbf{63.5\text{ mm}}$



13.7

| Depth (m) | Total swell, $\Delta S$ (m) |
|---|---|
| 6 | 0 |
| 5 | $0+\frac{1}{2}(0.4+0)(1)\left(\frac{1}{100}\right)=0.002$ |
| 4 | $0.002+\frac{1}{2}(0.75+0.4)(1)\left(\frac{1}{100}\right)=0.00775$ |
| 3 | $0.00775+\frac{1}{2}(0.75+1.5)(1)\left(\frac{1}{100}\right)=0.019$ |
| 2 | $0.019+\frac{1}{2}(1.5+3.1)(1)\left(\frac{1}{100}\right)=0.042$ |
| 1.5 | $0.042+\frac{1}{2}(3.1+5.5)(0.5)\left(\frac{1}{100}\right)=0.0635$ |

The plot of $\Delta S$ vs. depth is shown in the following figure. From this figure, the depth of undercut is 2.5 – 1.5 = **1 m below the bottom of the foundation**.



13.8 Eq. (13.14): $U = \pi D_s Z \sigma'_t \tan\phi'_{ps}$

$D_s = 1$ m; $Z = 9$ m

$U = (\pi)(1)(9)(600)(\tan 20) = 6174.6$ kN

Eq. (13.17): $U = \frac{c_u N_c}{\text{FS}} \frac{\pi}{4}\left(D_b^2 - D_s^2\right)$

$$6174.6 = \left(\frac{(150)(6.14)}{3}\right)\left(\frac{\pi}{4}\right)\left(D_b^2 - 1^2\right) = 241.1\left(D_b^2 - 1\right)$$

or $25.61 + 1 = D_b^2$

$D_b =$ **5.16 m**

13.9 $$\text{FS} = \frac{(c_u N_c)\left(\frac{\pi}{4}\right)(D_b - D_s^2)}{U - D}$$

$$4 = \frac{(150)(6.14)\left(\frac{\pi}{4}\right)(D_b^2 - 1^2)}{6174.6 - 1500} = \frac{723.35\left(D_b^2 - 1\right)}{4674.6}$$

or $25.85 = D_b^2 - 1$

$D_b =$ **5.2 m**

# CHAPTER 14

14.1 Eq. (14.1): $\gamma_{zav} = \dfrac{\gamma_w}{\dfrac{1}{G_s}+w}$; $\gamma_{zav} = 9.81\ \text{kN/m}^3$

| $w$ (%) | $\gamma_{zav}$ (kN/m$^3$) $G_s = 2.60$ | $G_s = 2.65$ | $G_s = 270$ | $G_s = 2.75$ |
|---|---|---|---|---|
| 5 | 22.57 | 22.95 | 23.34 | 23.72 |
| 10 | 20.24 | 20.55 | 20.86 | 21.16 |
| 15 | 18.35 | 18.60 | 18.85 | 19.1 |
| 20 | 16.78 | 16.99 | 17.20 | 17.40 |

Now the plot of $\gamma_{zav}$ vs. $w$ can be plotted.

14.2 a. Eq. (14.2): $\text{RC} = \dfrac{\gamma_{d(\text{field})}}{\gamma_{d(\max)}} = \left(\dfrac{100}{112}\right)(100) = \mathbf{89.3\%}$

b. Eq. (14.4): $D_r(\%) = \dfrac{\text{RC}-80}{0.2} = \dfrac{89.3-80}{0.2} = \mathbf{46.5\%}$

c. Eq. (14.3): $\text{RC} = \dfrac{A}{1-D_r(1-A)}$

$$A = \frac{\gamma_{d(\min)}}{\gamma_{d(\max)}};\quad 0.893 = \frac{\dfrac{\gamma_{d(\min)}}{112}}{1-0.465\left[1-\dfrac{\gamma_{d(\min)}}{112}\right]}$$

$\gamma_{d(\min)} \approx \mathbf{91.5\ lb/ft^3}$

14.3 a. Eq. (14.5): $w_{opt} = [1.95-0.38\log(\text{CE})](\text{PL}) = [1.95-0.38\log(600)](14) = \mathbf{12.5\%}$

Eq. (14.7): $\gamma_{d(\max)} = 22.26-0.28(w_{opt}) = 22.26-(0.28)(12.5) = \mathbf{18.76\ kN/m^3}$

b. Eq. (14.5): $w_{opt} = [1.95 - 0.38\log(2700](14) = \mathbf{9.05\%}$

Eq. (14.7): $\gamma_{d(max)} = 22.26 - 0.28(9.05) = \mathbf{19.73\ kN/m^3}$

14.4 Compacted $\gamma_d = 108\ lb/ft^3$. $\gamma = 108(1+w) = 108(1 + 14/100) = 123.112\ lb/ft^3$

$$\text{Total weight of moist soil needed} = \frac{(123.12\ lb/ft^3)(20{,}000 \times 27\ ft^3)}{2000} = 33{,}242.4\ \text{tons}$$

$$\text{Total volume of soil to be excavated} = \frac{33{,}242.4}{\left(\frac{105}{2000}\right)(27)} = \mathbf{23{,}451.4\ yd^3}$$

$$\text{Truckloads needed} = \frac{33{,}242.4}{20} \approx \mathbf{1662}$$

14.5 For the compacted fill, $\gamma_d = \frac{G_s\gamma_w}{1+0.6} = \frac{G_s\gamma_w}{1.6}\ kN/m^3$

$$\text{The total dry weight of fill needed} = W_s = \frac{8000 G_s\gamma_w}{1.6} = 5000\ G_s\gamma_w\ kN$$

| Borrow pit | Void ratio | Dry unit weight, $\gamma_d$ | Volume of soil to be excavated = $W_s/\gamma_d$ ($m^3$) | Cost ($) |
|---|---|---|---|---|
| A | 0.82 | $G_s\gamma_w/1.82$ | 9100 | 9100×9 = 81,900 |
| B | 0.91 | $G_s\gamma_w/1.91$ | 9500 | 9550×7 = 66,850 |
| C | 0.95 | $G_s\gamma_w/1.95$ | 9750 | 9750×8 = 78,000 |
| D | 0.75 | $G_s\gamma_w/1.75$ | 8750 | 8750×11 = 96,250 |

**Borrow pit B is the cheapest.**

14.6 Eq. (14.11):

$$S_N = 1.7\left[\sqrt{\frac{3}{(D_{50})^2} + \frac{1}{(D_{20})^2} + \frac{1}{(D_{10})^2}}\right] = (1.7)\left[\sqrt{\frac{3}{(2)^2} + \frac{1}{(0.7)^2} + \frac{1}{(0.65)^2}}\right] = \mathbf{3.86}$$

Rating — **Excellent** ($S_N$ between 0 and 10)

14.7 Eq. (14.11): $S_N = (1.7)\left[\sqrt{\frac{3}{(3.2)^2} + \frac{1}{(0.91)^2} + \frac{1}{(0.72)^2}}\right] = \mathbf{3.15}$ **— Excellent**

14.8 a. Eq. (14.12):

$$S_{(p)} = \frac{C_c H_c}{1+e_o} \log \frac{\sigma'_o + \Delta\sigma'_{(p)}}{\sigma'_o} = \frac{(0.27)(8)}{2.02} \log \frac{110+75}{110} = \mathbf{0.241\ m}$$

b. $T_v = \frac{C_v t}{H^2}$. For 80% consolidation, $T_v = 0{,}567$ (Chapter 1).

$$0.567 = \frac{(0.52)(t)}{\left(\frac{8}{2}\right)^2} = \mathbf{17.45\ months}$$

d. For $t_2 = 12$ months (Figure 14.20), $T_v = \frac{C_v t_2}{H^2} = \frac{(0.52)(12)}{\left(\frac{8}{2}\right)^2} = 0.39$

From Figure 14.21, for $T_v = 0.39$, $U = 53\%$. Refer to Eq. (14.15).

$$\frac{\Delta\sigma'_{(p)}}{\sigma'_o} = \frac{75}{110} = 0.682$$

$$0.53 = \frac{\log(1+0.682)}{\log\left\{1+0.682\left[1+\frac{\Delta\sigma'_{(f)}}{\Delta\sigma'_{(p)}}\right]\right\}}; \quad \frac{\Delta\sigma'_{(f)}}{\Delta\sigma'_{(p)}} = 1.445$$

$$\Delta\sigma'_{(f)} = (1.445)(75) = \mathbf{108.4\ kN/m^2}$$

14.9 a. $S_{(p)} = \frac{C_c H_c}{1+e_o} \log \frac{\sigma'_o + \Delta\sigma'_{(p)}}{\sigma'_o} = \frac{(0.3)(15)}{2} \log \frac{1500+1200}{1500} = 0.574\ \text{ft} \approx \mathbf{6.9\ in.}$

b. $T_v = 0.567 = \frac{(2.3\times10^{-2}\ \text{in.}^2/\text{min})t}{\left(\frac{15\times12}{2}\right)^2}$

$t = 1996.8 \times 10^2$ min = 138.67 days = **4.62 months**

c. For $t_2$ = 12 months, $T_v = \frac{C_v t_2}{H^2} = \frac{(2.3\times10^{-2}\text{ in.}^2/\text{min})(12\times30\times1440)}{\left(\frac{15\times12}{2}\right)^2} = 1.47$

From Figure 14.20, $U \approx 95\%$ (by extrapolation)

From Figure 14.18, for $U = 95\%$ and $\frac{\Delta\sigma'_{(p)}}{\sigma \times_o} = 0.8$, the value of $\frac{\Delta\sigma'_{(f)}}{\Delta\sigma'_{(p)}} \approx 0.1$

$\Delta\sigma'_{(f)} = (0.1)(1200) =$ **120 lb / ft²**

14.10 a. Eq. (14.21): $n = \frac{d_e}{2r_w} = \frac{4.5}{(2)(0.25)} = 9$

Eq. (14.22): $S = \frac{r_s}{r_w} = \frac{0.35}{0.25} = 1.4$

Eq. (14.23): $T_r = \frac{C_{vr} t_2}{d_e^2} = \frac{(0.3)(6)}{(4.5)^2} = 0.089$

Eq. (14.20):

$$m = \frac{n^2}{n^2 - S^2}\ln\left(\frac{n}{S}\right) - \frac{3}{4} + \frac{S^2}{4n^2} + \frac{k_h}{k_s}\left(\frac{n^2 - S}{n^2}\right)\ln S$$

$$= \frac{9^2}{9^2 - 1.4^2}\ln\left(\frac{9}{1.4}\right) - \frac{3}{4} + \frac{1.4^2}{(4)(9)^2} + (2)\left(\frac{9^2 - 1.4^2}{9^2}\right)\ln(1.4) = 1.82$$

Eq. (14.19):

$$U_r = 1 - \exp\left(\frac{-8T_r}{m}\right) = 1 - \exp\left(\frac{-8\times0.089}{1.82}\right) = 0.324 = \mathbf{32.4\%}$$

b. $T_v = \frac{C_v t_2}{H_{dr}^2} = \frac{(0.3)(6)}{\left(\frac{9}{2}\right)^2} = 0.089$

$T_v = 0.089 = \frac{\pi}{4}\left(\frac{U_v\%}{100}\right)^2;\quad U_v = 33.7\%$

Eq. (14.18): $U_{v,r} = 1 - (1 - U_r)(1 - U_v) = 1 - (1 - 0.324)(1 - 0.337) = 0.552 =$ **55.2%**

14.11 $C_v = C_{vr} = 0.042\ \text{ft}^2/\text{day} = 15.33\ \text{ft}^2/\text{year}$

Vertical drainage:

$$T_v = \frac{C_v t_2}{H^2} = \frac{15.33 t_2}{\left(\frac{10}{2}\right)^2} = 0.613 t_2 \qquad \text{(a)}$$

Radial drainage:

$$\text{Eq. (14.23):}\quad T_r = \frac{C_{vr} t_2}{d_e^2} = \frac{15.33 t_2}{6^2} = 0.426 t_2 \qquad \text{(b)}$$

$$n = \frac{d_e}{2r_w} = \frac{(6)(12)}{(2)(8)} = 4.5$$

| $t_2$ (yr) | $T_v$ [Eq. (a)] | $U_v$ (Fig. 1.21) | $T_r$ [Eq. (b)] | $U_r$ [Eqs. (14.19) and (14.25)] | $U_{r,v}$ [Eq. (14.18)] |
|---|---|---|---|---|---|
| 0.2 | 0.123 | 0.38 | 0.085 | 0.553 | **0.72** |
| 0.4 | 0.245 | 0.56 | 0.170 | 0.80 | **0.91** |
| 0.8 | 0.49 | 0.76 | 0.341 | 0.96 | **0.99** |
| 1.0 | 0.613 | 0.82 | 0.426 | 0.98 | **0.997** |

14.12 Eq. (14.32): $T_c = \frac{C_v t_c}{H^2} = \frac{(0.015)(30)}{(5.5)^2} = 0.015$

$$T_v = \frac{C_v t_2}{H^2} = \frac{(0.015)(50)}{(5.5)^2} = 0.0248$$

From Figure 14.24, $U_v \approx 15\%$.

For the sand drain, $n = \frac{d_e}{2r_w} = \frac{2.5}{(2)(0.07)} = 17.86$

$$\text{Eq. (14.28):}\quad T_{rc} = \frac{C_{vr} t_c}{d_e^2} = \frac{(0.015)(30)}{(2.5)^2} = 0.072$$

$$T_r = \frac{C_{vr} t_2}{d_e^2} = \frac{(0.015)(50)}{(2.5)^2} = 0.12$$

Eq. (14.27): $U_r = 1 - \frac{1}{AT_{rc}}[\exp(AT_{rc}) - 1]\exp(-AT_{rc})$

Eq. (14.29): $A = \frac{2}{m}$

$$m = \frac{n^2}{n^2-1}\ln(n) - \frac{3n^2-1}{4n^2} = \frac{17.86^2}{17.86^2-1}\ln(17.86) - \frac{(3)(17.86)^2-1}{(4)(17.86)^2} = 2.14$$

$$A = \frac{2}{2.14} = 0.935$$

$$AT_{rc} = (0.935)(0.072) = 0.067$$

$$U_r = 1 - \frac{1}{0.067}[\exp(0.067) - 1]\exp(-0.067) = 0.033 = 3.3\%$$

$U_{v,r} = 1 - (1 - U_r)(1 - U_v) = 1 - (1 - 0.033)(1 - 0.15) = 0.178 =$ **17.8%**

$$S_{(p)} = \frac{C_c H}{1+e_o}\log\left(\frac{\sigma'_o + \Delta\sigma'}{\sigma'_o}\right) = \frac{(0.3)(5.5)}{1+0.76}\log\left(\frac{80+70}{80}\right) = 0.256 \text{ m} = 256 \text{ nm}$$

Settlement at 50 days = (256)(0.178) ≈ **45.6 mm**