**53:139 Foundation Engineering**

# Homework #9 Solutions

**Spring Semester 2009**

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)

$Q_p = (0.2116)(372)(55) = \mathbf{4329\ kN}$

Check: Eq. (11.17):

$Q_p = A_p q_1 = 0.5 p_a A_p N_q^* \tan\phi' = (50)(0.2116)(55)(\tan 30) = 335.96 \text{ kN} \approx \mathbf{336\ kN}$

Use $Q_p = \mathbf{336\ kN}$

b. Eq. (11.20) (for $c' = 0$): $Q_p = A_p \bar{\sigma}'_o N^*_\sigma$

$I_{rr} = 75$; $\phi' = 30°$; $N^*_\sigma = 45$ (Table 11-5)

$$\bar{\sigma}' = \left(\frac{1+2K_o}{3}\right) q'$$

$q' = 372 \text{ kN/m}^2$; $K_o = 1 - \sin\phi' = 0.5$

$$\bar{\sigma}' = \left[\frac{1+(2)(0.5)}{3}\right](372) = 248 \text{ kN/m}^2$$

$Q_p = (0.2116)(248)(45) = 2361.5 \text{ kN} \approx \mathbf{2362\ kN}$

c. Eq. (11.31) (for $c = 0$): $Q_p = A_p q' N_q^*$

$N_q^* = 18.4$ (Table 11.6)

$Q_p = (0.2116)(372)(18.4) = 1448.4 \text{ kN} \approx \mathbf{1448\ kN}$

11.2 Eq. (1137) $L' = 15D = (15)(0.46) = 6.9$ 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): $Q_s = K\overline{\sigma}'_o \tan(0.8\phi')pL$

$$= (0.2)\left(\frac{18.6 \times 20}{2}\right)\tan(24)(4 \times 0.46)(20) = 609.5 \text{ kN}$$

$Q_{all} = \frac{1810.5 + 609.5}{4} =$ **605 kN**

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): $s_{e(3)} = \left(\frac{Q_{ws}}{pL}\right)\frac{D}{E_s}(1 - \mu_s^2) I_{ws}$

$$I_{ws} = 2 + 0.35\sqrt{\frac{50}{\left(\frac{16}{12}\right)}} = 4.13$$

$$s_{e(3)} = \left[\frac{110}{(4 \times 16)(50 \times 12)}\right]\left(\frac{16}{5}\right)(1 - .0.38^2)(4.13) = 0.032 \text{ in.}$$

$$s_e = 0.104 + 0.636 + 0.032 = \mathbf{0.772 \text{ in.}}$$

11.14 $I = \frac{1}{12}bh^3 = \frac{1}{12}(0.305)^4 = 0.0007 \text{ m}^4$

$E_p = 21 \times 10^6 \text{ kN/m}^2$

Eq. (11.80): $T = \sqrt[5]{\frac{E_p I_p}{n_h}} = \sqrt[5]{\frac{(21 \times 10^6)(0.0007)}{9200}} = 1.098 \text{ m}$

$\frac{L}{T} = \frac{30}{1.098} > 5$. 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: $M_{z(\max)} = F_Y \frac{I_p}{\frac{d}{2}} = A_m Q_g T$

$$Q_g = \frac{2F_Y I_p}{d A_m T}$$

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**

11.16 Eq. (11.108): $Q_u = \frac{EH_E}{S+C}$

$H_E = 40$ kip - ft $= 40 \times 12$ kip - in.; $E = 0.85$

$$Q_u = \frac{(0.85)(40 \times 12)}{\frac{1}{10} + 0.1} = 2040 \text{ kip}$$

$$Q_{all} = \frac{2040}{6} = \mathbf{340\ kip}$$

11.17 $Q_u = \frac{EW_R h}{S+C} \frac{W_R + n^2 W_p}{W_R + W_p}$

$$W_p = \text{weight of (pile + cap)} = \frac{90 \times 100}{1000} + 2.4 = 11.4 \text{ kip}$$

$$Q_u = \left[\frac{(0.85)(40 \times 12)}{\frac{1}{10} + 0.1}\right]\left[\frac{12 + (0.35)^2(11.4)}{12 + 11.4}\right] = 1167.9 \text{ kip}$$

$$Q_{all} = \frac{1167}{4} \approx \mathbf{292\ kip}$$

11.18 $Q_u = \frac{EH_E}{S + \sqrt{\frac{EH_E L}{2A_p E_p}}}$; $\sqrt{\frac{EH_E L}{2A_p E_p}} = \sqrt{\frac{(0.85)(40 \times 12)(90 \times 12)}{(2)(29.4)(30 \times 10^3)}} = 0.5$

$$Q_u = \frac{(0.85)(36 \times 12)}{0.1 + 0.5} = 680 \text{ kip}$$

$$Q_{all} = \frac{680}{3} \approx \mathbf{227\ kip}$$

11.22 a. $\eta = \frac{2(n_1 + n_2 - 2)d + 4D}{pn_1n_2}$

$d = 0.92$ 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. $\eta = 1 - \frac{D}{\pi d n_1 n_2}\left[n_1(n_2-1) + n_2(n_1-1) + \sqrt{2}(n_1-1)(n_2-1)\right]$

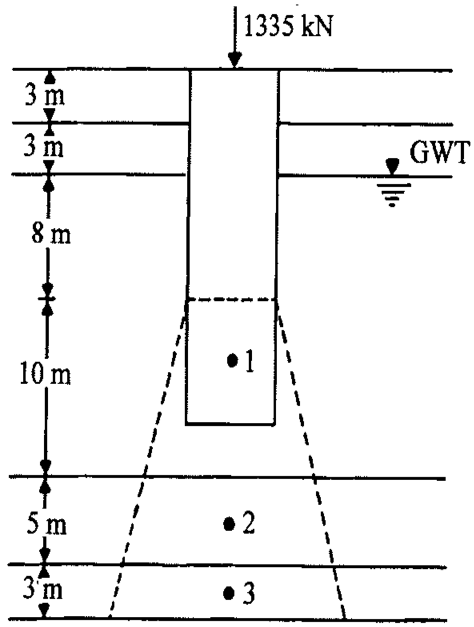
$$= 1 - \frac{0.46}{(\pi)(0.92)(3)(3)}\left[(3)(2)+(3)(2)+\left(\sqrt{2}\right)(2)(2)\right] = 0.688 = \mathbf{68.8\%}$$

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. $\eta = 1 - \frac{0.46}{(\pi)(1.2)(3)(3)}\left[(3)(2)+(3)(2)+\left(\sqrt{2}\right)(2)(2)\right] = 0.76 = \mathbf{76.06\%}$

11.27 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 |

$$\Delta s_{c(1)} = \frac{(0.8)(10)}{1+0.8}\log\left(\frac{217.42}{195.19}\right) = 0.208 \text{ m}$$

$$\Delta s_{c(2)} = \frac{(0.31)(5)}{1+1}\log\left(\frac{268.46}{262.72}\right) = 0.0073 \text{ m}$$

$$\Delta s_{c(3)} = \frac{(0.26)(3)}{1+0.7}\log\left(\frac{301.53}{297.93}\right) = \underline{0.0024 \text{ m}}$$

$$\sum \Delta s_c \approx \mathbf{217.7\ mm}$$

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: $I_r = \dfrac{E_s}{3c_{u(2)}} = 237.5$

$N_c^* = 1.33[\ln(237.5) + 1] = \mathbf{8.61}$

$$Q_p = \frac{\pi}{4}(5)^2(1800)(8.61) = 304{,}302 \text{ lb} = \mathbf{304\ kip}$$

b. $Q_s = \alpha^* c_{u(i)} p L_1 + \alpha^* c_{u(2)} p L_2 = (0.4)(\pi \times 5)[(1000)(20) + (1800)(15)]$

$= 295{,}310 \text{ lb} = \mathbf{295.3\ kip}$

c. $Q_w = \dfrac{304.3 + 295.3}{4} \approx \mathbf{149.9\ kip}$

12.11 a. $\Delta L_1 = 20 - 5 = 15$ ft; $c_{u(1)} = 1000$ lb / ft$^2$

$\Delta L_2 = 15 - 5 = 10$ ft; $c_{u(2)} = 1800$ lb / ft$^2$

$$\sum f_i p \Delta L_1 = (0.55)[(1000)(\pi \times 5)(15) + (2800)(\pi \times 5)(10)] = 472{,}593 \text{ lb} \approx 371.5 \text{ kip}$$

$$q_p = 6c_{ub}\left(1 + 0.2\frac{L}{D_b}\right) = (6)(1800)\left[1 + (0.2)\left(\frac{35}{5}\right)\right] = 25.920 \text{ lb / ft}^2$$

Check: $q_b = 9c_{ub} = (9)(1800) = 16{,}200$ lb / ft$^2$

Use $q_b = 16{,}200$ lb / ft$^2$

$$Q_u = 371.5 + (16.2)\left(\frac{\pi}{4} \times 5^2\right) = \mathbf{689.6\ kip}$$

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)

$$Q = (0.87)(371.5) + (0.77)(16.2)\left(\frac{\pi}{4} \times 5^2\right) = \mathbf{568.1\ kip}$$