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CVG 3106 Winter – 2017
SOIL MECHANICS II

Assignment 3

(Due: 27 February, 2017 by 17:00)

Question 1

A column carrying a load of 650 kN is to be founded on a square footing at a depth of 2 m below the ground surface in a deep clay stratum. What will be the size of the footing for FS = 3 for TSA? The soil parameters are γ_{sat} = 18.5 kN/m^3 and C_u = 55 kPa. The groundwater level is at the base of the footing, but it is expected to rise to the ground surface during rainy seasons.

Solution:

Use General BC eq. for undrained conditione (or TSA):

$q_u = c_u N_c F_{cs} F_{cd} + q_0$

BC factors:

$\phi = 0$ (undrained conditionc) $\rightarrow N_c = 5.14 \quad N_q = 1.0 \quad N_\gamma = 0$

$B = L$ (square footing) ; $B/L = 1.0$

$$F_{cs} = 1 + \left(\frac{B}{L}\right)\left(\frac{N_q}{N_c}\right) = 1 + (1.0)\left(\frac{1.0}{5.14}\right) = 1.195$$

Assume $\frac{D_f}{B} \leq 1.0$ and $\phi = 0$

$$F_{cd} = 1 + 0.4\left(\frac{D_f}{B}\right) = 1 + 0.4\left(\frac{2.0}{B}\right) = 1 + \frac{0.8}{B}$$

$$q_0 = \gamma_{sat} \times D_f = 18.5 \times 2.0 = 37.0 \text{ kN/m}^2$$

$$q_u = (55.0)(5.14)(1.195)\left(1 + \frac{0.8}{B}\right) + 37.0 \simeq 374.83 + \frac{270.26}{B}$$

$$q_{all} = \frac{q_u}{FS} = \frac{1}{3}\left(374.83 + \frac{270.26}{B}\right)$$

$$Q_{all} = q_{all} \times A = q_{all} \times B^2 = Q_{applied} = 650 \text{ kN}$$

$$650 = \frac{B^2}{8}\left(374.83 + \frac{270.26}{B}\right)$$

Solve for B by trial & error:

$B = 1.95\,m$

Question 2

An eccentrically loaded foundation is shown in Figure 2. Use FS of 4 and determine the maximum allowable load that the foundation can carry. Use Meyerhof's effective area method.

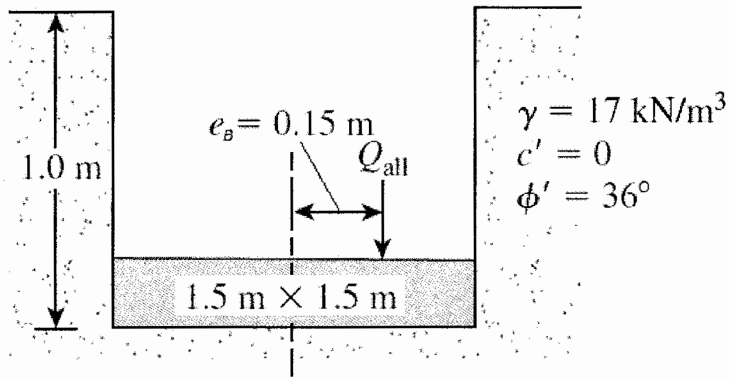


Figure 2

Solution:

For eccentrically loaded foundation use the General BC eq:

$q_u' = q N_q F_{qs} F_{qd} F_{qi} + \frac{1}{2} \gamma B' N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i}$

$q = \gamma \times D_f = 17 \times 1.0 = 17 \text{ kN/m}^2$

For $\phi' = 36° \rightarrow$ The BC factors are: $N_q = 37.75$ $N_\gamma = 56.31$

Effective width: $B' = B - 2e_B = 1.5 - 2 \times 0.15 = 1.2$ m

$L' = L = 1.5$ m

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

$F_{\gamma s} = 1 - 0.4\left(\frac{B'}{L'}\right) = 1 - 0.4\left(\frac{1.2}{1.5}\right) = 0.68$

$F_{qi} = F_{\gamma i} = 1.0$ (vertical load)

$\frac{D_f}{B} = \frac{1.0}{1.5} = 0.67 < 1.0$ and $\phi' = 36° > 0$

$F_{qd} = 1 + 2\tan\phi' (1 - \sin\phi')^2 \left(\frac{D_f}{B}\right)$ use B not B' !

$F_{qd} = 1 + 2\tan 36^\circ (1 - \sin 36^\circ)^2 \left(\frac{1.0}{1.5}\right) = 1.165$

$F_{\gamma d} = 1.0$

$q_u' = (17.0)(37.75)(1.58)(1.0)(1.165) + \frac{1}{2}(17.0)(1.20)(56.31)(0.68)(1.0)(1.0) =$

$= 1571.84 \text{ kN/m}^2$

$q_{all} = \frac{q_u'}{FS} = \frac{1571.84}{4.0} = 392.96 \text{ kN/m}^2$

$Q_{all} = q_{all} \times A = (392.96)(1.20)(1.50) = 707.33 \text{ kN}$

Question 3

A circular foundation of diameter 8 m supports a tank. The base of the foundation is at 1m from the ground surface. The vertical load is 20 MN. The tank foundation was designed for short-term loading conditions (C_u = 80 kPa and γ_{sat} = 19 kN/m^3). The groundwater level when the tank was initially designed was at 4 m below the ground surface and it was assumed that the groundwater level was stable. Fourteen months after the tank was constructed, during a week of intense rainfall, the tank foundation failed. It was speculated that failure occurred by bearing capacity failure.

a) Determine the bearing capacity of the soil using TSA (short-term loading conditions) and ESA (long-term loading conditions). Assume effective friction angle, ϕ' = 25° and c'=0.

b) Compare the results of the two methods of analysis performed in (a) and comment which one governed the observed bearing capacity failure of the tank foundation.

Solution:

The vertical stress applied on the foundation is:

$$q_{app} = \frac{Q}{A} = \frac{20 \times 10^3}{\left(\frac{\pi \times 8^2}{4}\right)} = 397.89 \text{ kN/m}^2$$

Short-term conditions (TSA):

$C_u = 80$ kPA , $\phi = 0$ $\gamma_{sat} = 19$ kN/m^3

$q_u = C_u N_c F_{cs} F_{cd} + q_o$

BC factors: $\phi = 0$

$N_c = 5.14$ $N_q = 1.0$ $N_\gamma = 0$

$B = D = 8.0$ (circular) ; $B/L = 1.0$

$$F_{cs} = 1 + \left(\frac{B}{L}\right)\left(\frac{N_q}{N_c}\right) = 1 + (1.0)\left(\frac{1.0}{5.14}\right) = 1.195$$

$$\frac{D_f}{B} = \frac{1.0}{8.0} = 0.125 < 1.0 \text{ and } \phi = 0$$

$$F_{cd} = 1 + 0.4\left(\frac{D_f}{B}\right) = 1 + 0.4\left(\frac{1.0}{8.0}\right) = 1.05$$

$q_o = \gamma_{sat} \times D_f = 19 \times 1.0 = 19$ kN/m^2

$q_u = (80)(5.14)(1.195)(1.05) + 19.0 = 534.96$ kPa $> q_{app} = 397.89$ kPa

TSA does not predict a BC failure!

Long-term conditions (ESA): $\phi' = 25^\circ$, $c' = 0$

$$q_u = q N_q F_{qs} F_{qd} F_{qi} + \tfrac{1}{2} \gamma B N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i}$$

For $\phi' = 25^\circ \rightarrow N_q = 10.66 \quad N_\gamma = 10.88$

$$F_{qs} = 1 + \left(\frac{B}{L}\right)\tan\phi' = 1 + (1.0)\tan 25^\circ = 1.466$$

$$F_{\gamma s} = 1 - 0.4\left(\frac{B}{L}\right) = 1 - 0.4(1.0) = 0.6$$

$F_{qi} = F_{\gamma i} = 1.0$ (vertical loading)

$$\frac{D_f}{B} = \frac{1.0}{8.0} = 0.125 < 1.0 \text{ and } \phi' = 25^\circ > 0$$

$$F_{qd} = 1 + 2\tan\phi'(1-\sin\phi')^2\left(\frac{D_f}{B}\right) = 1 + 2\tan 25^\circ(1-\sin 25^\circ)^2\left(\frac{1.0}{8.0}\right)$$

$F_{qd} = 1.039$, $F_{\gamma d} = 1.0$

GWT at the surface at failure: $\gamma = \gamma'$ (γ-term)

$\gamma' = \gamma_{sat} - \gamma_w = 19 - 9.81 = 9.19$ kN/m³

$q = \gamma' \times D_f = 9.19 \times 1.0 = 9.19$ kN/m² (q-term)

$$q_u = (9.19)(10.66)(1.466)(1.0)(1.039) + \tfrac{1}{2}(9.19)(8.0)(10.88)(0.6)(1.0)(1.0)$$

$q_u = 389.19$ kPa $< q_{app} = 397.89$ kPa

ESA does predict a BC failure!

b) $q_u(TSA) = 534.96$ kPa $> q_u(ESA) = 389.19$ kPa

TSA overestimates the BC of soil. Failure occurs under effective stress contol and ESA should be performed whenever possible! GWT variations should be accounted for!

Q4: $Q = 1000\ kN$ $\quad D_f = 0.6\,m$

$c' = 30\ kN/m^2$ $\quad B = L = 1.2\,m$

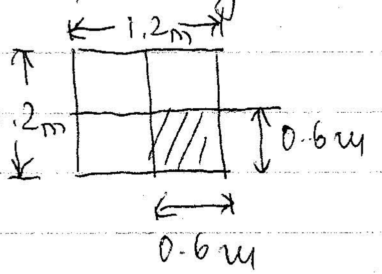
$\phi' = 15^\circ$

$\gamma = 17.5\ kN/m^3$ $\quad \Delta\sigma_z$ (ave, center) $= ?$

$\gamma_{sat} = 18.5\ kN/m^3$.

Solution:

a) using the Boussinesq eq:



$L = B = 0.6\,m$

$m = n = \dfrac{0.6}{z}$

Determine in-situ vertical stress at $z = D_f$:

$\sigma_0' = D_f \times \gamma = 0.6 \times 17.5 = 10.5\ kN/m^2 = q_{ob}$

$q = \dfrac{Q}{A} = \dfrac{1000}{1.2 \times 1.2} = 694.44\ kN/m^2$

$q_0 = q - \sigma_0' = 694.44 - 10.5 = 683.94\ kN/m^2$

$\Delta\sigma_z = 4 q_0 I_{qr}$

For the top, middle and bottom of clay:

z (m)	$m = n$	I_{qz}	$\Delta\sigma_z$ (kN/m^2)
0	–	–	683.94 (= q_0)
3	0.2	0.018	49.24
6	0.1	0.005	13.68

b) using the approximate 2:1 method

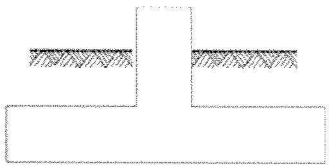
$\Delta\sigma_z = \dfrac{q_0 \times B \times L}{(B+z)(L+z)}$ $\quad$ where $q_0 = 683.94\ kN/m^2$

$L = B = 1.2\,m$

z (m)	$\Delta\sigma_z$ (kN/m^2)
0	683.94
3	55.83
6	19.00

Remark: The main disadvantage of the 2:1 method is that the stress increase under the center of loaded area equals the stress increase under the corner.

Question 5

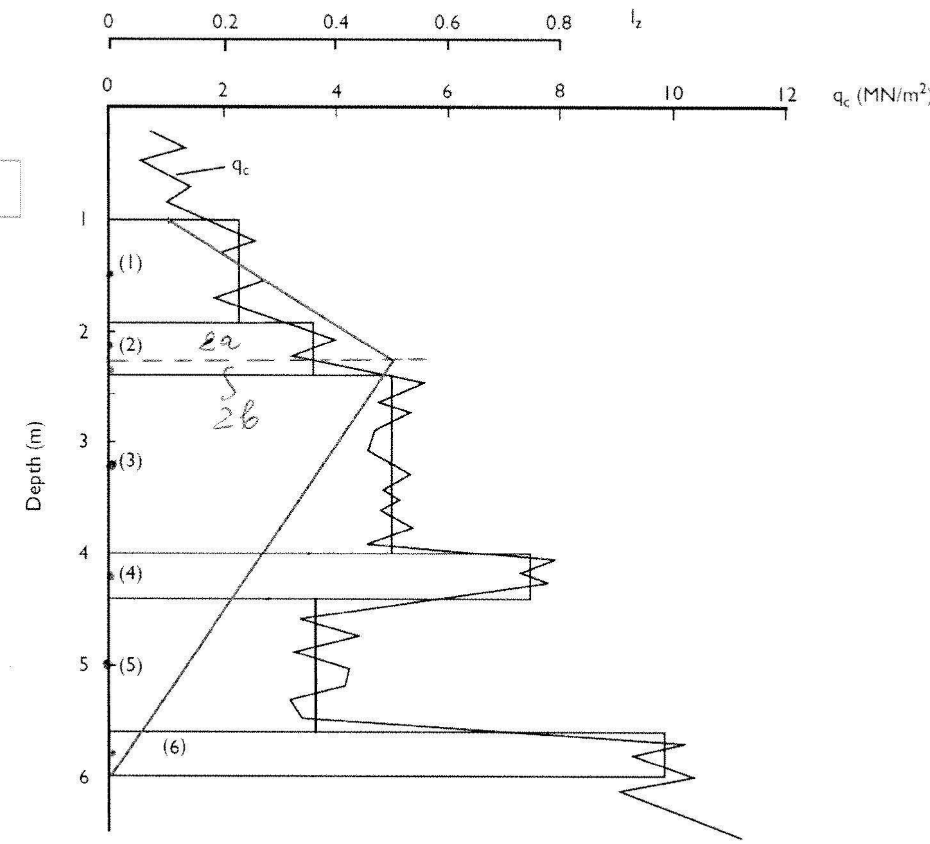


$L = B = 2.5\ m$

$q_0 = 150\ kN/m^2$

$D_f = 1.0\ m$

$\gamma = 17\ kN/m^3$



Using the Schmertmann et. al. (1978) method:

For $L/B = 1.0$ (square)

$I_z = 0.1$ at $z = 0$

$I_z = 0.5$ at $z = z_1 = 0.5B = 0.5 \times 2.5 = 1.25\ m$

$I_z = 0$ at $z = z_2 = 2B = 2 \times 2.5 = 5.0\ m$

Remark: Above z_1 and z_2 are calculated below foundation level!

$E_s = 2.5\,q_c$ – square footing

Layer	Δz (m)	z_{mid} (m)	q_c (MN/m^2)	E_s (MN/m^2)	I_z	$(I_z/E_s)\Delta z$
1	0.90	0.45	2.3	5.75	0.27	0.042
2a	0.35	1.075	3.6	9.00	0.45	0.018
2b	0.15	1.325	3.6	9.00	0.47	0.008
3	1.60	2.20	5.0	12.50	0.37	0.047
4	0.40	3.20	7.5	18.75	0.24	0.005
5	1.20	4.00	3.3	8.25	0.13	0.019
6	0.40	4.80	9.9	24.75	0.03	0.0005
					Σ	0.140 $\left(\frac{m^3}{MN}\right)$

$$q_{net} = \bar{q} - q = 150 \text{ kN/m}^2$$

$$q = \gamma D_f = 17 \times 1.0 = 17 \text{ kN/m}^2$$

$$C_1 = 1 - 0.5\left(\frac{q}{\bar{q} - q}\right) = 1 - 0.5\left(\frac{17}{150}\right) = 0.94$$

$$C_2 = 1 + 0.2\log\left(\frac{\text{time}}{0.1}\right) = 1 + 0.2\log\left(\frac{10}{0.1}\right) = 1.4$$

$$S_e = C_1 C_2 (\bar{q} - q)\sum \frac{I_z}{E_s}\Delta z$$

$$S_e = (0.94)(1.4)(150)\underbrace{(0.140 \times 10^{-3})}_{\text{to convert MN to kN}} = 0.0276 \text{ m} = \underline{27.6 \text{ mm}}$$