Université d'Ottawa
Faculté de genie

Départment de
Génie civil

University of Ottawa
Faculty of Engineering

Department of
Civil Engineering

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CVG 3106
SOIL MECHANICS - II
MIDTERM EXAM

Length of Examination: 1hr 15 min **18th Feb, 2011 (11:30 to 12:45 PM)**
Professor: Won Taek Oh

Family Name: ____

Other Names: ____

Student Number: ___________

Signature ___________________________

(i) This is a closed book exam. No textbooks are allowed
(ii) Formula sheet is available on last pages of this question paper
(iii) If you do not understand a question, clearly state an assumption and proceed.
(iv) Non programmable calculators are permitted
(v) Questions have the values shown next to the question.
(vi) Marks will be taken out for missing units and labels.
(vii) Answers should be succinct.

At the end of the exam, when time is up:
- Stop working and turn your exam upside down.
- Please remain silent.
- Do not move or speak until ALL exams have been picked up, and a TA or the Professor gives the go-ahead to leave.

Question	Max Marks	Marks Awarded
1	30	
2	20	
3	50	
Total	**100%**	

Question 1 (30 Marks)

A soil fill (γ = 1.6 Mg/m^3) is deposited on an overconsolidated clay ground (*OCR* = 1.5). Find the shear strength of the soil at the base of the fill (i.e. point A in Figure 1) just after the height of fill has been raised from 3 m to 6 m (i.e. from *Layer 1* to *Layer 2* in Figure 1). The consolidated-drained test results on two identical specimens collected from the clay ground are shown in Table 1.

Assumption and information:

a) The pore-water pressure after the construction of the *Layer 1* has been completely dissipated.
b) Dissipation of pore pressure during the construction of *Layer 2* is negligible.
c) The lateral pressure at any point is one half of the vertical pressure.
d) G_s = 2.72, e = 0.72, and w = 26% for the clay ground just before the construction of *Layer 2*.
e) Use Figure 2(a) and (b) (see page 3) to estimate the pore pressure parameters A and B, respectively.
f)

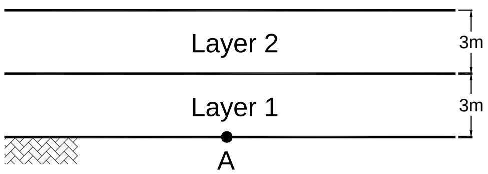
$$\gamma = \frac{G_s + Se}{1+e}\gamma_w$$

$$Se = G_s w$$

$$\tau = c' + \sigma' \tan\phi'$$

$$\Delta u = B\left[\Delta\sigma_3 + A\left(\Delta\sigma_1 - \Delta\sigma_3\right)\right]$$

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

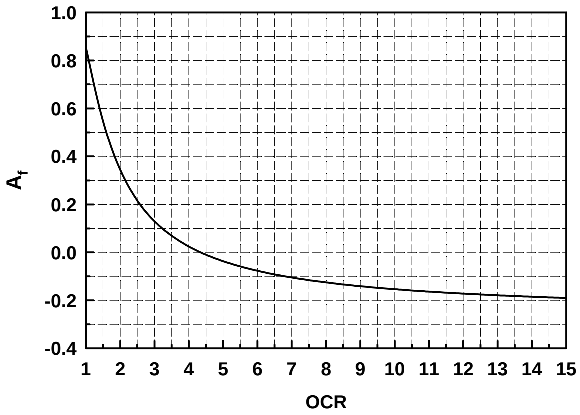


Overconsolidated clay
(G_s = 2.72, e = 0.72, w = 26%)

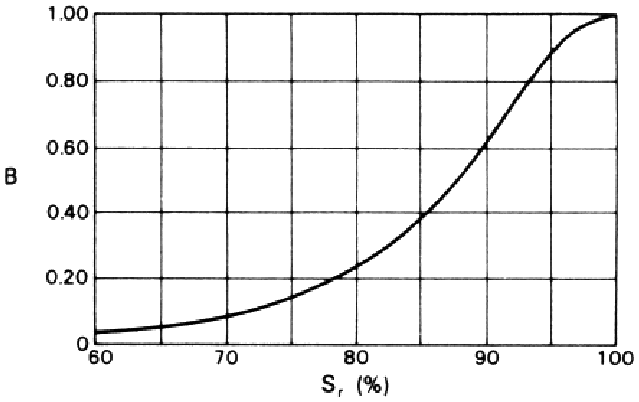
Figure 1

Table 1. Major and minor principal stresses at failure

	σ_3 (kPa)	σ_1 (kPa)
Test 1	82.8	329.2
Test 2	165.6	558.6


1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
A_f
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
OCR

(a)


1.00
0.80
0.60
0.40
0.20
0
B
60 70 80 90 100
S_r (%)

(b)

Figure 2

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

(a) $$329.2 = 82.8 \tan^2\left(45 + \frac{\phi'}{2}\right) + 2c' \tan\left(45 + \frac{\phi'}{2}\right)$$

(b) $$558.6 = 165.6 \tan^2\left(45 + \frac{\phi'}{2}\right) + 2c' \tan\left(45 + \frac{\phi'}{2}\right)$$

Subtracting Equation (a) from Equation (b);

$$229.4 = 82.8 \tan^2\left(45 + \frac{\phi'}{2}\right)$$

$$\phi' = 28^\circ$$

From Equation (a);

$$c' = \frac{329.2 - 82.8 \tan^2(45+14)}{2\tan(45+14)}$$

$$c' = 30 kN/m^2$$

Shear strength = $\tau = c' + \sigma' \tan\phi'$

$$\sigma' = \sigma_{(layer1)} + (\Delta\sigma)_{layer\,2} - (\Delta u)_{layer\,2}$$

$$\sigma_{(layer1)} = 1.6 \times 9.81 \times 3 = 47 kPa$$

$$(\Delta\sigma)_{layer\,2} = 1.6 \times 9.81 \times 3 = 47 kPa$$

$(\Delta u)_{layer\,2} = B\left[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)\right]$ and $\Delta\sigma_3 = \frac{\Delta\sigma_1}{2} = \frac{47}{2} = 23.5 kPa$

$$Se = G_s w$$

$$S = \frac{G_s w}{e} = \frac{2.72 \times 0.26}{0.72} = 0.98$$

From Figure 2, A_f = 0.55 (OCR = 1.5) and B = 0.98

$$\Delta u = B\left[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)\right]$$

$$= 0.98 \times [23.5 + 0.55 \times 23.5] = 35.7 kPa$$

$$\tau = c' + \sigma' \tan\phi' = 30 + (47 + 47 - 35.7) \times \tan 28^\circ = 61 kPa$$

Question 2 (20 Marks)

What is the key information that can be derived from different tests listed in Figure 3.

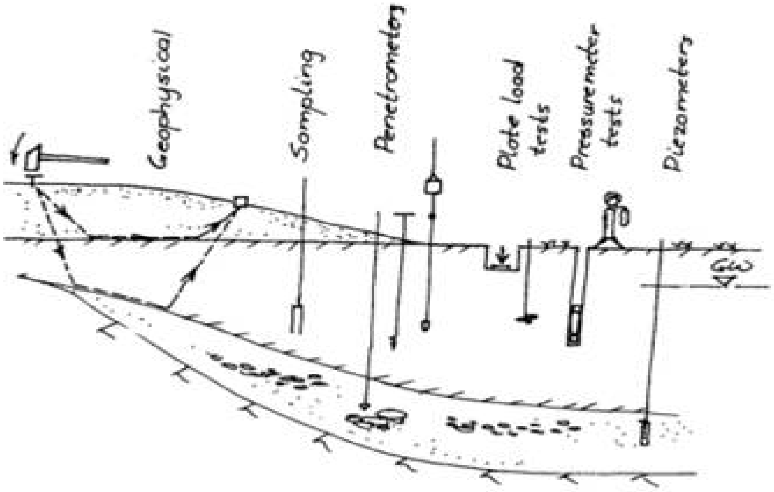


Figure 3

Test	Key information
Geophysical	
Sampling	
Penetrometer	
Plate load	
Pressuremeter	
Piezometer	

Question 3 (50 Marks)

For the continuous (i.e. strip) foundation (B = 1.5m) given in Figure 4

a) Calculate allowable bearing capacity (FS = 3) using ***Terzaghi Bearing Capacity Equation***. The ground water table is at a depth of 1m below the ground surface. **(15 Marks)**

b) Repeat Q3.(a) for a square foundation (i.e. B × L = 1.5m × 1.5m) using ***Terzaghi Bearing Capacity Equation***. The level of ground water table has dropped to 2m below the ground surface in connection with the active use of the groundwater. (assume that *e* and *w* above ground water table are the same as Q3.(a)) **(15 Marks)**

c) Repeat Q3.(b) for a load inclined at an angle of 15° to the vertical using ***General Bearing Capacity Equation***. **(20 Marks)**

(✤ sees pages 6 - 9 for i) Terzaghi bearing capacity equation, ii) General bearing capacity equation, and iii) Bearing capacity factors)

$$\gamma = \frac{W}{V} = \frac{(G_S + Se)}{1+e}\gamma_w, \quad Se = wG_s$$

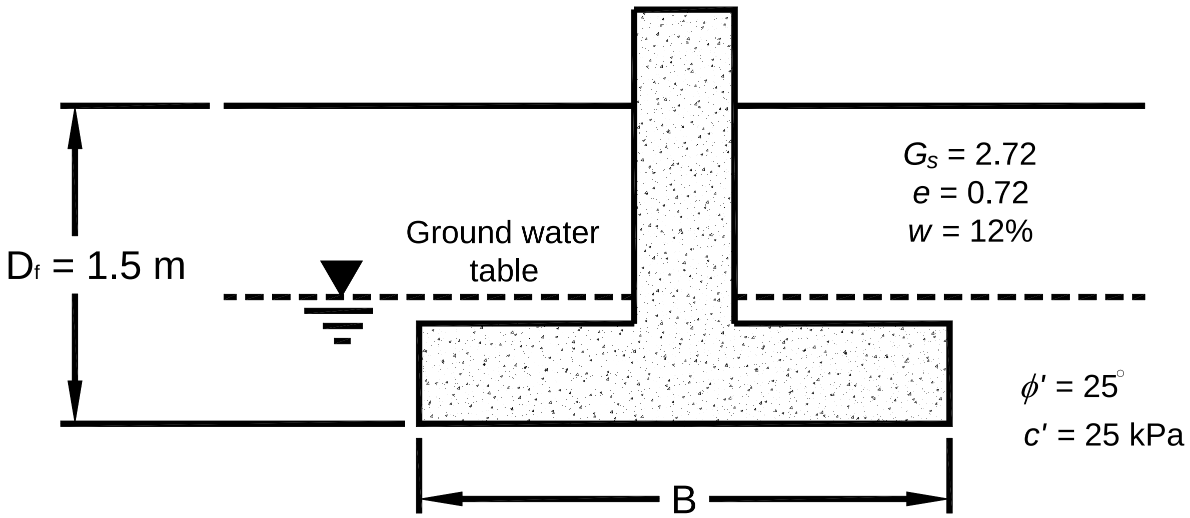


Figure 4

Q3(a)

Local shear failure ($\phi' = 25°$)

$\overline{\phi'} = \tan^{-1}(\tfrac{2}{3}\tan 25°) = 17.27°$

$N'_c = 14.8, N'_q = 5.6, N'_\gamma = 2.25$ for $\phi' = 17.27°$

unit weight of soil above ground water table

$$\gamma = \frac{G_s + Se}{1+e}\gamma_w = \frac{2.72 + 2.72 \times 0.12}{1+0.72} \times 9.81 = 17.4kN/m^3$$

$$\gamma_{sat} = \frac{G_s + Se}{1+e}\gamma_w = \frac{2.72 + 1 \times 0.72}{1+0.72} \times 9.81 = 19.6kN/m^3$$

$$\begin{aligned} q_{ult} &= \tfrac{2}{3}c'N'_c + qN'_q + \tfrac{1}{2}B\gamma N'_\gamma \\ &= \tfrac{2}{3} \times 25 \times 14.8 + [17.4 \times 1 + (19.6 - 9.81) \times 0.5] \times 5.6 + \tfrac{1}{2} \times 1.5 \times (19.6 - 9.81) \times 2.25 \\ &= 388(kPa) \end{aligned}$$

$$\therefore q_{all} = q_{ult}/3 = 388/3 = 129kPa$$

Q3(b)

$$\gamma_b = \frac{1}{B}[\gamma d + \gamma'(B-d)] \qquad for \quad d \le B$$
$$= \frac{1}{1.5}[17.4\times 0.5 + (19.6-9.81)\times(1.5-0.5)]$$
$$= 12.3(kN/m^3)$$

$$q_{ult} = 0.867c'N_c' + qN_q' + 0.4B\gamma N_\gamma'$$
$$= 0.867\times 25\times 14.8 + 17.4\times 1.5\times 5.6 + 0.4\times 1.5\times 12.3\times 2.25$$
$$= 483.6(kPa)$$

$$\therefore q_{all} = q_{ult}/3 = 483.6/3 = 161kPa$$

Q3(c)

$N_c = 20.72, N_q = 10.66, N_\gamma = 10.88$ for $\phi' = 25°$

$$q_{ult} = c'N_cF_{cs}F_{cd}F_{ci} + qN_qF_{qs}F_{qd}F_{qi} + \tfrac{1}{2}\gamma BN_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma i}$$

$$F_{cs} = 1 + \left(\frac{B}{L}\right)\left(\frac{N_q}{N_c}\right) = 1 + \frac{10.66}{10.88} = 1.98$$

$$F_{qs} = 1 + \left(\frac{B}{L}\right)\tan\phi' = 1 + \tan 25° = 1.57$$

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

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

$$F_{qd} = 1 + 2\tan\phi'\left(1 - \sin\phi'\right)^2\left(\frac{D_f}{B}\right) = 1 + 2\left(\tan 25°\right)\left(1 - \sin 25°\right)^2 = 1.3$$

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

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

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

$$\begin{aligned} q_{ult} &= c'N_cF_{cs}F_{cd}F_{ci} + qN_qF_{qs}F_{qd}F_{qi} + \tfrac{1}{2}\gamma BN_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma i} \\ &= 25\times 20.72\times 1.98\times 1.4\times 0.694 + \left(17.4\times 1.5\right)\times 10.66\times 1.57\times 1.3\times 0.694 \\ &\qquad + 0.5\times 12.3\times 1.5\times 10.88\times 0.6\times 1\times 0.16 \\ &= 1400(kPa) \end{aligned}$$

$$\therefore q_{all} = q_{ult}/3 = 1400/3 = 467(kPa)$$

Terzaghi's ultimate bearing capacity theory

❑ ***General*** **shear failure**

✓ **Continuous or strip footing**

$$q_u = c'N_c + qN_q + \tfrac{1}{2}\gamma B N_\gamma$$

✓ **Square footing**

$$q_u = 1.3c'N_c + qN_q + 0.4\gamma B N_\gamma$$

✓ **Circular footing**

$$q_u = 1.3c'N_c + qN_q + 0.3\gamma B N_\gamma$$

$$N_c, N_q, N_\gamma = f(\phi')$$

❑ ***Local*** **shear failure**

✓ **Continuous or strip footing**

$$q_u = \tfrac{2}{3}c'N_c' + qN_q' + \tfrac{1}{2}\gamma B N_\gamma'$$

✓ **Square footing**

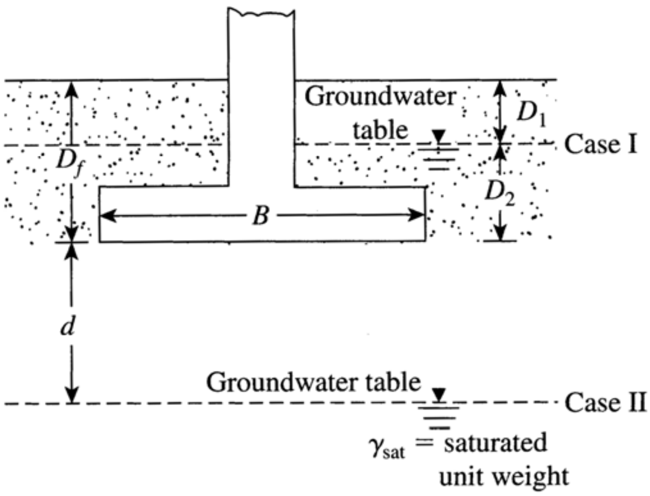
$$q_u = 0.867c'N_c' + qN_q' + 0.4\gamma B N_\gamma'$$

✓ **Circular footing**

$$q_u = 0.867c'N_c' + qN_q' + 0.3\gamma B N_\gamma'$$

$$N_c', N_q', N_\gamma' = f(\overline{\phi'}),\ \overline{\phi'} = \tan^{-1}(\tfrac{2}{3}\tan\phi')$$

Effect of groundwater table on the bearing capacity



❑ **Case I ($0 \le D_1 \le D_f$)**

❑ **Case II ($0 \le d \le B$)**

$$\gamma_b = \gamma' + \frac{d}{B}(\gamma - \gamma')$$

❑ **Case III ($B \le d$): no effect**

Table 2. Bearing capacity factors for Terzaghi bearing capacity equation.

ϕ'	N_c	N_q	N_γ [a]	ϕ'	N_c	N_q	N_γ [a]
0	5.70	1.00	0.00	26	27.09	14.21	9.84
1	6.00	1.10	0.01	27	29.24	15.90	11.60
2	6.30	1.22	0.04	28	31.61	17.81	13.70
3	6.62	1.35	0.06	29	34.24	19.98	16.18
4	6.97	1.49	0.10	30	37.16	22.46	19.13
5	7.34	1.64	0.14	31	40.41	25.28	22.65
6	7.73	1.81	0.20	32	44.04	28.52	26.87
7	8.15	2.00	0.27	33	48.09	32.23	31.94
8	8.60	2.21	0.35	34	52.64	36.50	38.04
9	9.09	2.44	0.44	35	57.75	41.44	45.41
10	9.61	2.69	0.56	36	63.53	47.16	54.36
11	10.16	2.98	0.69	37	70.01	53.80	65.27
12	10.76	3.29	0.85	38	77.50	61.55	78.61
13	11.41	3.63	1.04	39	85.97	70.61	95.03
14	12.11	4.02	1.26	40	95.66	81.27	115.31
15	12.86	4.45	1.52	41	106.81	93.85	140.51
16	13.68	4.92	1.82	42	119.67	108.75	171.99
17	14.60	5.45	2.18	43	134.58	126.50	211.56
18	15.12	6.04	2.59	44	151.95	147.74	261.60
19	16.56	6.70	3.07	45	172.28	173.28	325.34
20	17.69	7.44	3.64	46	196.22	204.19	407.11
21	18.92	8.26	4.31	47	224.55	241.80	512.84
22	20.27	9.19	5.09	48	258.28	287.85	650.67
23	21.75	10.23	6.00	49	298.71	344.63	831.99
24	23.36	11.40	7.08	50	347.50	415.14	1072.80
25	25.13	12.72	8.34				

General bearing capacity equation

❑ Shape factor (De Beer, 1970)

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

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

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

❑ Inclination factor (Meyerhof, 1963; Hanna and Meyerhof, 1981)

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

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

❑ Depth factor (Hansen, 1970)

$for \quad D_f / B \le 1$

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

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

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

$for \quad D_f / B > 1$

$$F_{cd} = 1 + (0.4)\tan^{-1}\left(\frac{D_f}{B}\right)$$

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

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

Table 3. Bearing capacity factors for General Bearing Capacity Equation

ϕ'	N_c	N_q	N_γ	ϕ'	N_c	N_q	N_γ
0	5.14	1.00	0.00	26	22.25	11.85	12.54
1	5.38	1.09	0.07	27	23.94	13.20	14.47
2	5.63	1.20	0.15	28	25.80	14.72	16.72
3	5.90	1.31	0.24	29	27.86	16.44	19.34
4	6.19	1.43	0.34	30	30.14	18.40	22.40
5	6.49	1.57	0.45	31	32.67	20.63	25.99
6	6.81	1.72	0.57	32	35.49	23.18	30.22
7	7.16	1.88	0.71	33	38.64	26.09	35.19
8	7.53	2.06	0.86	34	42.16	29.44	41.06
9	7.92	2.25	1.03	35	46.12	33.30	48.03
10	8.35	2.47	1.22	36	50.59	37.75	56.31
11	8.80	2.71	1.44	37	55.63	42.92	66.19
12	9.28	2.97	1.69	38	61.35	48.93	78.03
13	9.81	3.26	1.97	39	67.87	55.96	92.25
14	10.37	3.59	2.29	40	75.31	64.20	109.41
15	10.98	3.94	2.65	41	83.86	73.90	130.22
16	11.63	4.34	3.06	42	93.71	85.38	155.55
17	12.34	4.77	3.53	43	105.11	99.02	186.54
18	13.10	5.26	4.07	44	118.37	115.31	224.64
19	13.93	5.80	4.68	45	133.88	134.88	271.76
20	14.83	6.40	5.39	46	152.10	158.51	330.35
21	15.82	7.07	6.20	47	173.64	187.21	403.67
22	16.88	7.82	7.13	48	199.26	222.31	496.01
23	18.05	8.66	8.20	49	229.93	265.51	613.16
24	19.32	9.60	9.44	50	266.89	319.07	762.89
25	20.72	10.66	10.88				