UTHM
Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2016/2017

COURSE NAME	:	FOUNDATION ENGINEERING
COURSE CODE	:	BFC 43103
PROGRAMME CODE	:	BFF
EXAMINATION DATE	:	JUNE 2017
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **ALL** QUESTIONS IN **SECTION A**, AND ANY **THREE (3)** QUESTIONS IN **SECTION B**

THIS QUESTION PAPER CONSISTS OF **FOURTEEN (14)** PAGES

SECTION A

Q1 (a) Soil improvement and ground modification techniques are used to improve poor/unsuitable subsurface soils and/or to improve the performance of embankments or structures. **Table 1** shows the category of the ground improvement techniques and its methods to carry it out. List **ONE (1)** function for each category of the ground improvement techniques.

(6 marks)

(b) Mechanical modification and hydraulic modification are methods for improving the ground. List **FOUR (4)** purposes of ground imrpovement.

(4 marks)

(c) An embankment is required to be built for a road surface overlaying a clay layer. Site investigation report shows that the clay layer is normally consolidated with two way drainage and has a thickness, H_c of 6 m. The soil properties for this clay are found to have $C_c = 0.27$, $e_o = 1.02$, $c_v = 0.52$ m^2/month. It is calculated that the current average effective overburden pressure on the clay is 110 kN/m^2.

Due to the construction of the embankment on the clay, it is estimated that the increase in vertical effective stress, [$\Delta\sigma'_{(p)}$] will be about 35 kN/m^2. To increase the rate of consolidation settlement, a surcharge [$\Delta\sigma'_{(f)}$] of 30 kN/m^2 is further placed. **Table 2** shows the variation of degree of consolidation with time factor.

(i) Due to the addition of the embankment, determine the primary consolidation settlement of the clay layer, $\Delta\sigma'_{(p)}$ and the surcharge $\Delta\sigma'_{(f)}$.

(4 marks)

(ii) Determine the time required for 80% of the primary consolidation settlement under the addition of both the embankment and surcharge $\Delta\sigma'_{(f)}$.

(5 marks)

(iii) Determine the "additional" temporary surcharge, $\Delta\sigma'_{(f)}$, that will be required to eliminate the entire primary consolidation settlement calculated in **Q1(c)(i)** above within 6 months using the preloading technique.

(6 marks)

SECTION B

Q2 (a) A Shelby tube sampler has an outer diameter of 75 mm and wall thickness of 1.7 mm. Determine the area ratio of the tube, and give comments whether the tube could be used for obtaining undisturbed or disturbed soil samples. Briefly explain the difference between the characteristics of the soil for undisturbed samples and disturbed samples.

(5 marks)

(b) You as an experience engineer from an established Geotechnical firm are to be interviewed by representatives of the owner of a site, where a high rise building is to be constructed concerning a subsurface investigation at the site. Discuss the various factors that govern the sub soil exploration, bringing out the guiding principles for deciding the location of boreholes in engineering project.

(8 marks)

(c) Another method of soil investigation is by doing in-situ testing and/or field testing. This is done to obtain direct measurments of the soil properties and its Geotechnical parameters. Explain in detail with the aid of sketches the function advantage and disadvantage of the vane shear test (VST).

(12 marks)

Q3 (a) A strip footing having a width, B of 3 m is constructed at a depth of 2 m below the ground surface in a soil having a cohesion c = 30kN/m^2 and angle of shearing resistance ϕ =25°. The water table is at a depth of 5 m below ground level. The dry unit weight of soil above the water table is 17.25 kN/m3.

(i) Determine the ultimate bearing capacity of the soil using the General Bearing Capacity equation.

(6 marks)

(ii) Calculate the net bearing capacity.

(3 marks)

(iii) Calculate the net allowable bearing pressure (Factor of Safety of 3).

(3 marks)

(b) It is known that the total settlement for shallow foundations may control the allowable bearing capacity of the soil.

(i) State and explain in detail the differences between elastic settlement and consolidation settlement.

(3 marks)

(ii) Explain the process of primary and secondary phases of consolidation.

(6 marks)

(c) **Figure Q3(c)** indicates the construction of a shallow foundation that sustains a 200 kN load on top of a 3 m thick saturated normally consolidated clay. The soil parameter obtained from site investigation are given as, $\gamma_{sat} = 17$ kN/m^3, $e_o = 0.8$, $E_s = 6000$ kN/m^2, $C_c = 0.32$, $\mu_s = 0.5$, $C_s = 0.09$, $D_f = 2$. Calculate the stress increase in the clay and find the consolidation settlement by using **Table 4** to assist in your calculations.

(7 marks)

Q4 (a) Piles are structural members that are important in providing support to a superstructure. It can be made out of various types of material and in any cross sectional shape. Categorise the piles according to the types of material used, the type of cross sectional geometry, method of installation and its load transfer mechanism.

(8 marks)

(b) A pile with a diameter of 500 mm is embedded in clay. The pile extends to a depth of up to 12 m into the ground. The effective pile length for shear resistance is 10 m. The dry unit weight of the clay is 18 kN/m^3. The water table is located at a depth of 2 m and the saturated unit weights of the clay is 20 kN/m^3. The recorded undrained shear strength (Cu) profile for the ground is shown in **Table 5**.

(i) What is the ultimate bearing capacity of the pile with the skin friction factor λ of 0.15.

(8 marks)

(ii) What is the safe load of the pile when the factor of safety are as follows;

Overall factor of safety	= 2.5
Factor of safety on bearing	= 3.0
Factor of safety on shaft friction	= 1.1

(3 marks)

(c) Using the group efficiency formula, estimate wether a 3 x 4 rectangular group pile is efficient or not where the centre-to-centre spacing is 1.5 m between the piles. The dimension of the pile is 300 mm x 300 mm in cross section.

(6 marks)

Q5 (a) Conventional retaining walls can be generally classified into four types. Describe with the aid of sketches **THREE (3)** of them and outline the ways in which such retaining walls may fail.

(6 marks)

(b) An anchored sheet pile wall retains 6.4 m of cohesionless soil that has a unit weight of 16 kN/m^3 and a 30^{o} angle of friction. Surface of the soil is level with the top of the wall. The anchor tie rods are installed at a depth of 1.2 m below the top of the wall and are spaced 3 m apart horizontally. Friction on the surface of the piling is negligible.
Assuming "free earth support";

(i) Design the sheet pile wall by calculating the actual depth of penetration

(12 marks)

(ii) Determine the tension in a single anchor tie rod

(7 marks)

-END OF QUESTIONS-

FINAL EXAMINATION

SEMESTER / SESSION : SEM II / 2016/2017 PROGRAMME : BFF
COURSE : FOUNDATION ENGINEERING COURSE CODE : BFC 43103

Table 1: Category of ground improvement

Category	Method
Consolidation	prefabricated vertical drains, and surcharge
Load reduction	geofoam, foamed concrete, and lightweight fill
Densification	vibro compaction, and dynamic compaction by falling weight impact
Reinforcement	stone columns
Deep soil mixing	wet and dry mixing methods
Grouting	permeation grouting, and jet grouting
Load transfer	column supported embankment

Table 2: Variations of U with T_v

U (%)	T_v	U (%)	T_v	U (%)	T_v	U (%)	T_v
0	0	26	0.0531	52	0.212	78	0.529
1	0.00008	27	0.0572	53	0.221	79	0.547
2	0.0003	28	0.0615	54	0.230	80	0.567
3	0.00071	29	0.0660	55	0.239	81	0.588
4	0.00126	30	0.0707	56	0.248	82	0.610
5	0.00196	31	0.0754	57	0.257	83	0.633
6	0.00283	32	0.0803	58	0.267	84	0.658
7	0.00385	33	0.0855	59	0.276	85	0.684
8	0.00502	34	0.0907	60	0.286	86	0.712
9	0.00636	35	0.0962	61	0.297	87	0.742
10	0.00785	36	0.102	62	0.307	88	0.774
11	0.0095	37	0.107	63	0.318	89	0.809
12	0.0113	38	0.113	64	0.329	90	0.848
13	0.0133	39	0.119	65	0.304	91	0.891
14	0.0154	40	0.126	66	0.352	92	0.938
15	0.0177	41	0.132	67	0.364	93	0.993
16	0.0201	42	0.138	68	0.377	94	1.055
17	0.0227	43	0.145	69	0.390	95	1.129
18	0.0254	44	0.152	70	0.403	96	1.219
19	0.0283	45	0.159	71	0.417	97	1.336
20	0.0314	46	0.166	72	0.431	98	1.500
21	0.0346	47	0.173	73	0.446	99	1.781
22	0.0380	48	0.181	74	0.461	100	∞
23	0.0415	49	0.188	75	0.477		
24	0.0452	50	0.197	76	0.493		
25	0.0491	51	0.204	77	0.511		

FINAL EXAMINATION

SEMESTER / SESSION	: SEM II / 2016/2017	PROGRAMME CODE	: BFF
COURSE	: FOUNDATION ENGINEERING	COURSE CODE	: BFC 43103

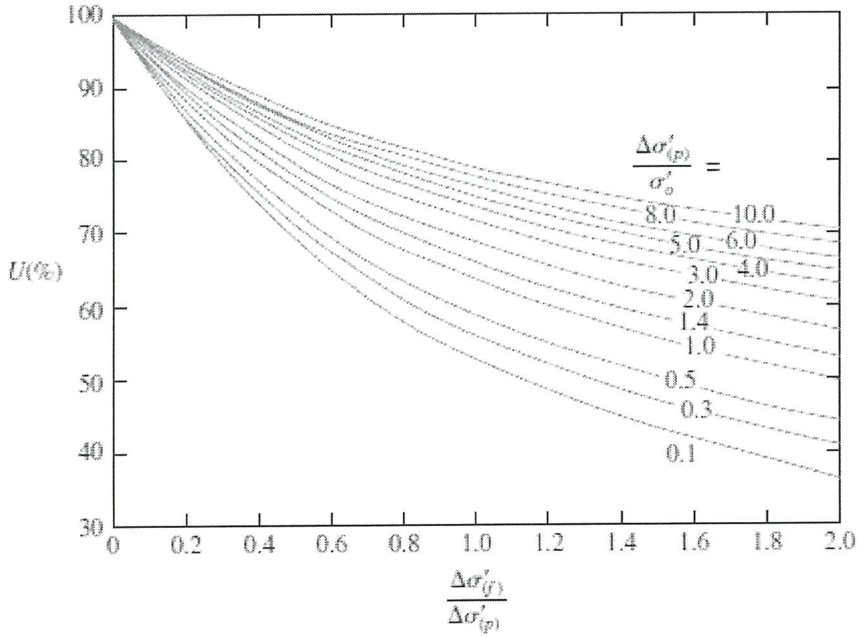

Figure Q2(c)

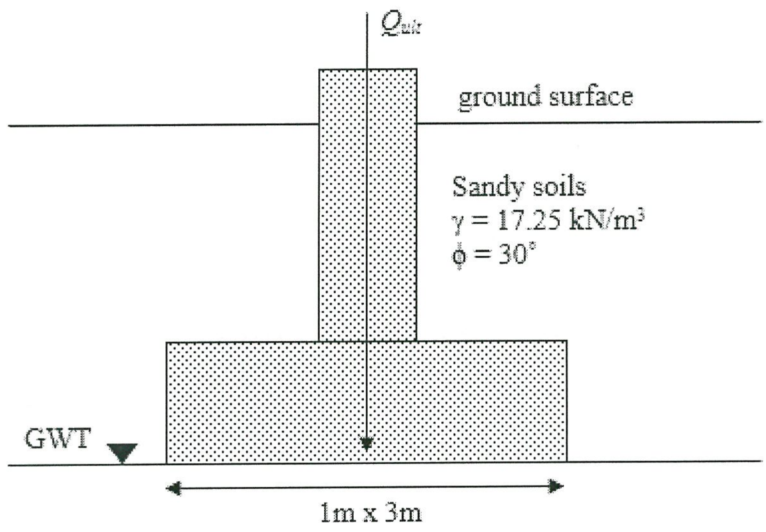

Figure Q3(c)

FINAL EXAMINATION

SEMESTER / SESSION : SEM II / 2016/2017 PROGRAMME CODE : BFF
COURSE : FOUNDATION ENGINEERING COURSE CODE : BFC 43103

Table 3: Bearing Capacity Factors for Shallow Foundations

	Terzhagi's Method						Meyerhof's Method		
	General Shear			Local Shear					
ϕ'	N_c	N_q	N_γ	N_c	N_q	N_γ	N_c	N_q	N_γ
0	5.70	1.00	0.00	5.70	1.00	0.00	5.14	1.00	0.00
1	6.00	1.10	0.01	5.90	1.07	0.005	5.38	1.09	0.07
2	6.30	1.22	0.04	6.10	1.14	0.02	5.63	1.20	0.15
3	6.62	1.35	0.06	6.30	1.22	0.04	5.90	1.31	0.24
4	6.97	1.49	0.10	6.51	1.30	0.055	6.19	1.43	0.34
5	7.34	1.64	0.14	6.74	1.39	0.074	6.49	1.57	0.45
6	7.73	1.81	0.20	6.97	1.49	0.10	6.81	1.72	0.57
7	8.15	2.00	0.27	7.22	1.59	0.128	7.16	1.88	0.71
8	8.60	2.21	0.35	7.47	1.70	0.16	7.53	2.06	0.86
9	9.09	2.44	0.44	7.74	1.82	0.20	7.92	2.25	1.03
10	9.61	2.69	0.56	8.02	1.94	0.24	8.35	2.47	1.22
11	10.16	2.98	0.69	8.32	2.08	0.30	8.80	2.71	1.44
12	10.76	3.29	0.85	8.63	2.22	0.35	9.28	2.97	1.69
13	11.41	3.63	1.04	8.96	2.38	0.42	9.81	3.26	1.97
14	12.11	4.02	1.26	9.31	2.55	0.48	10.37	3.59	2.29
15	12.86	4.45	1.52	9.67	2.73	0.57	10.98	3.94	2.65
16	13.68	4.92	1.82	10.06	2.92	0.67	11.63	4.34	3.06
17	14.60	5.45	2.18	10.47	3.13	0.76	12.34	4.77	3.53
18	15.12	6.04	2.59	10.90	3.36	0.88	13.10	5.26	4.07
19	16.56	6.70	3.07	11.36	3.61	1.03	13.93	5.80	4.68
20	17.69	7.44	3.64	11.85	3.88	1.12	14.83	6.40	5.39
21	18.92	8.26	4.31	12.37	4.17	1.35	15.82	7.07	6.20
22	20.27	9.19	5.09	12.92	4.48	1.55	16.88	7.82	7.13
23	21.75	10.23	6.00	13.51	4.82	1.74	18.05	8.66	8.20
24	23.36	11.40	7.08	14.14	5.20	1.97	19.32	9.60	9.44
25	25.13	12.72	8.34	14.80	5.60	2.25	20.72	10.66	10.88
26	27.09	14.21	9.84	15.53	6.05	2.59	22.25	11.85	12.54
27	29.24	15.90	11.60	16.30	6.54	2.88	23.94	13.20	14.47
28	31.61	17.81	13.70	17.13	7.07	3.29	25.80	14.72	16.72
29	34.24	19.98	16.18	18.03	7.66	3.76	27.86	16.44	19.34
30	37.16	22.46	19.13	18.99	8.31	4.39	30.14	18.40	22.40

FINAL EXAMINATION

SEMESTER / SESSION : SEM II / 2016/2017
COURSE : FOUNDATION ENGINEERING
PROGRAMME CODE : BFF
COURSE CODE : BFC 43103

Table 4: Variation of I_c with m_1 and n_1

	m_1									
n_1	1	2	3	4	5	6	7	8	9	10
0.20	0.994	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997
0.40	0.960	0.976	0.977	0.977	0.977	0.977	0.977	0.977	0.977	0.977
0.60	0.892	0.932	0.936	0.936	0.937	0.937	0.937	0.937	0.937	0.937
0.80	0.800	0.870	0.878	0.880	0.881	0.881	0.881	0.881	0.881	0.881
1.00	0.701	0.800	0.814	0.817	0.818	0.818	0.818	0.818	0.818	0.818
1.20	0.606	0.727	0.748	0.753	0.754	0.755	0.755	0.755	0.755	0.755
1.40	0.522	0.658	0.685	0.692	0.694	0.695	0.695	0.696	0.696	0.696
1.60	0.449	0.593	0.627	0.636	0.639	0.640	0.641	0.641	0.641	0.642
1.80	0.388	0.534	0.573	0.585	0.590	0.591	0.592	0.592	0.593	0.593
2.00	0.336	0.481	0.525	0.540	0.545	0.547	0.548	0.549	0.549	0.549
3.00	0.179	0.293	0.348	0.373	0.384	0.389	0.392	0.393	0.394	0.395
4.00	0.108	0.190	0.241	0.269	0.285	0.293	0.298	0.301	0.302	0.303
5.00	0.072	0.131	0.174	0.202	0.219	0.229	0.236	0.240	0.242	0.244
6.00	0.051	0.095	0.130	0.155	0.172	0.184	0.192	0.197	0.200	0.202
7.00	0.038	0.072	0.100	0.122	0.139	0.150	0.158	0.164	0.168	0.171
8.00	0.029	0.056	0.079	0.098	0.113	0.125	0.133	0.139	0.144	0.147
9.00	0.023	0.045	0.064	0.081	0.094	0.105	0.113	0.119	0.124	0.128
10.00	0.019	0.037	0.053	0.067	0.079	0.089	0.097	0.103	0.108	0.112

Table 5: Variation of Cu with pile embedment length

Depth (m)	0	2	4	7	10	13	16
Undrained shear strength, Cu (kN/m^2)	70	70	70	85	100	115	130

FINAL EXAMINATION

SEMESTER / SESSION	: SEM II / 2016/2017	PROGRAMME CODE	: BFF
COURSE	: FOUNDATION ENGINEERING	COURSE CODE	: BFC 43103

List of formula

SOIL IMPROVEMENT AND GROUND MODIFICATION

$$S_{c(p)} = \frac{C_c H_c}{1+e_o} \log \frac{\sigma'_o + \Delta\sigma'_{(p)}}{\sigma'_o}$$

$$S_{c(p+f)} = \frac{C_c H_c}{1+e_o} \log \frac{\sigma'_o + \left[\Delta\sigma'_{(p)} + \Delta\sigma'_{(f)}\right]}{\sigma'_o}$$

$$U = \frac{\log\left[\dfrac{\sigma'_o + \Delta\sigma'_{(p)}}{\sigma'_o}\right]}{\log\left[\dfrac{\sigma'_o + \Delta\sigma'_{(p)} + \Delta\sigma'_{(f)}}{\sigma'_o}\right]}$$

$$T_v = \frac{c_v t}{H_c^{\,2}}$$

For U%: 0% to 60%; $T_v = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2$

For U% > 60%;
$T_v = 1.781 - 0.931\log\left(100 - U\%\right)$

$$U = \frac{\log\left[1 + \dfrac{\Delta\sigma'_{(p)}}{\sigma'_o}\right]}{\log\left[1 + \dfrac{\Delta\sigma'_{(p)}}{\sigma'_o}\left(1 + \dfrac{\Delta\sigma'_{(f)}}{\sigma'_{(p)}}\right)\right]}$$

SITE INVESTIGATION

Rock quality designation (RQD)

$$= \frac{\Sigma\text{length of recovered pieces equal to or larger than 101.6 mm}}{\text{theoretical length of rock cored}}$$

$$A_R(\%) = \frac{D_o^2 - D_i^2}{D_i^2}(\%)$$

$$N_{corrected} = C_N * N_{field}$$

$$C_N = 0.77\log_{10}\frac{1915}{p'_o}$$

TERBUKA

FINAL EXAMINATION

SEMESTER / SESSION : SEM II / 2016/2017 PROGRAMME CODE : BFF
COURSE : FOUNDATION ENGINEERING COURSE CODE : BFC 43103

SHALLOW FOUNDATIONS

Modification of Bearing Capacity Equations for Water Table

Case I for water within $0 \le D_1 \le D_f$;	Case II for water within $0 \le d \le B$;	Case III when the water table is located so that $d \ge B$, the water will have no effect on the ultimate bearing capacity.
$q = D_1\gamma_{dry} + D_2(\gamma_{sat} - \gamma_w)$ $\gamma' = \gamma_{sat} - \gamma_w$	$q = D_1\gamma_{dry}$ $\bar{\gamma} = \gamma' + \frac{d}{B}(\gamma_{dry} - \gamma')$	

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

Shape Factor

$F_{cs} = 1 + \frac{B}{L}\cdot\frac{N_q}{N_c}$	$F_{qs} = 1 + \frac{B}{L}\tan\phi$	$F_{\gamma s} = 1 - 0.4\frac{B}{L}$

Depth Factor

$D_f/B \le 1, for\ \phi = 0$

$F_{cd} = 1 + 0.4(^{D_f}/_B)$	$F_{qd} = 1$	$F_{\gamma d} = 1$

$^{D_f}/_B \le 1, for\ \phi > 0$

$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c tan\phi'}$	$F_{qd} = 1 + 2tan\phi'(1 - sin\phi')^2\frac{D_f}{B}$	$F_{\gamma d} = 1$

$D_f/B > 1, for\ \phi = 0$

$F_{cd} = 1 + \underbrace{0.4\ tan^{-1}\left(^{D_f}/_B\right)}_{radians}$	$F_{qd} = 1$	$F_{\gamma d} = 1$

$D_f/B > 1, for\ \phi > 0$

$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c tan\phi'}$	$F_{qd} = 1 + 2\tan\phi'(1 - sin\phi')^2\underbrace{tan^{-1}(\frac{D_f}{B})}_{radians}$	$F_{\gamma d} = 1$

where L is the length of the foundation and L>B.

Inclination Factor

$$F_{ci} = F_{qi} = \left(1 - \frac{\beta°}{90°}\right)^2 \qquad F_{\gamma i} = \left(1 - \frac{\beta}{\phi'}\right)^2$$

β is the inclination of the load on the foundation with respect to vertical

Eccentric Loading in Shallow Foundations

$q_{max} = \frac{Q}{BL} \pm \frac{6M}{B^2L}$ $q_{max} = \frac{4Q}{3L(B - 2e)}$	$e = \frac{M}{Q}$ $FS = \frac{Q_{ult}}{Q}$

FINAL EXAMINATION

SEMESTER / SESSION : SEM II / 2016/2017
COURSE : FOUNDATION ENGINEERING
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SHALLOW FOUNDATIONS

$$q'_u = c'N_c F_{cs} F_{cd} F_{ci} + qN_q F_{qs} F_{qd} F_{qi} + \tfrac{1}{2}\gamma' B' N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i}$$

One Way Eccentric Loading in Shallow Foundations

Method 1:

$$B' = B - 2e$$

$$L' = L$$

$$q'_u = c'N_c F_{cs} F_{cd} F_{ci} + qN_q F_{qs} F_{qd} F_{qi} + \tfrac{1}{2}\gamma' B' N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i}$$

$$Q_{ult} = q'_u B' L'$$

Method 2:

$$Q_{ult} = B\left[c'N_{c(e)} + qN_{q(e)} + \frac{1}{2}\gamma B N_{\gamma(e)}\right]$$

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

$$F_{cs(e)} = 1.2 - 0.025\frac{L}{B}$$

$$F_{qs(e)} = 1.00$$

$$F_{\gamma s(e)} = 1.0 + \left(\frac{2e}{B} - 0.68\right)\frac{B}{L} + \left[0.43 - \left(\frac{3}{2}\right)\left(\frac{e}{B}\right)\right]\left(\frac{B}{L}\right)^2$$

Method 3:

$$R_k = 1 - \frac{q_{u(eccentric)}}{q_{u(centric)}}$$

$$R_k = a\left(\frac{e}{B}\right)^k$$

$$q_{u(eccentric)} = q_{u(centric)}\left(1 - R_k\right)$$

$$q_{u(centric)} = qN_q F_{qd} + \tfrac{1}{2}\gamma B N_\gamma F_{\gamma d}$$

$$Q_{ult} = Bq_{u(eccentric)}$$

Primary Consolidation Settlement for Normally Consolidated Clays

$$S_{c(p)} = \frac{C_c H_c}{1+e_o}\log\frac{\sigma'_o + \Delta\sigma'_{av}}{\sigma'_o}$$

Primary Consolidation Settlement for OverConsolidated Clays

for $\sigma'_o + \Delta\sigma'_{av} < \sigma'_c$

$$S_{c(p)} = \frac{C_s H_c}{1+e_o}\log\frac{\sigma'_o + \Delta\sigma'_{av}}{\sigma'_o}$$

for $\sigma'_o < \sigma'_c < \sigma'_o + \Delta\sigma'_{av}$

$$S_{c(p)} = \frac{C_s H_c}{1+e_o}\log\frac{\sigma'_c}{\sigma'_o} + \frac{C_c H_c}{1+e_o}\log\frac{\sigma'_o + \Delta\sigma'_{av}}{\sigma'_c}$$

Average Increase in Pressure

$$\Delta\sigma'_{av} = \tfrac{1}{6}\left(\Delta\sigma'_{top} + 4\Delta\sigma'_{medium} + \Delta\sigma'_{bottom}\right)$$

FINAL EXAMINATION

SEMESTER / SESSION : SEM II / 2016/2017 PROGRAMME CODE : BFF
COURSE : FOUNDATION ENGINEERING COURSE CODE : BFC 43103

PILE FOUNDATIONS

Ultimate Capacity of Piles and Group Piles in Saturated Clay

$$Q_s = \sum f p \Delta L$$
$$f = \beta \sigma_o'$$
$$\beta = K \tan \phi_R'$$
$$K = 1 - \sin \phi_R'$$
$$K = 1 - \sin \phi_R' \sqrt{OCR}$$
$$OCR = \frac{p_c}{P_o}$$
$$Q_p = A_p q_p$$
$$Q_p = A_p q' N_q^*$$
$$Q_p \approx N_c^* c_u A_p$$
$$Q_p = 9 c_u A_p$$
$$f_{av} = \lambda(\bar{\sigma}_o' + 2c_u)$$

$$\sum Q_u = n_1 n_2 \left[9 A_p c_{u(p)} + \sum \alpha p c_u \Delta L \right]$$
$$L_g = (n_1 - 1)d + 2\left(\frac{D}{2}\right)$$
$$B_g = (n_2 - 1)d + 2\left(\frac{D}{2}\right)$$
$$\sum Q_u = L_g B_g c_{u(p)} N_c^* + \sum 2(L_g + B_g) c_u \Delta L$$
$$\Delta s_{c_i} = \left[\frac{\Delta e_i}{1 + e_{o_i}}\right] H_i$$
$$\eta = \frac{[2(n_1 + n_2 - 2)d + 4D]}{p n_1 n_2}$$

CONVENTIONAL GRAVITY AND CANTILEVER WALL

Rankine's Theory

$$P_a = \tfrac{1}{2} K_a \gamma_1 H^2$$
$$P_a = \tfrac{1}{2} K_a \gamma_1 H^2 + q K_a H$$
$$P_v = P_a \sin \alpha°$$
$$P_h = P_a \cos \alpha°$$
$$P_p = \tfrac{1}{2} K_p \gamma_2 D^2 + 2c_2' \sqrt{K_p} D$$
$$K_a = \tan^2\left(45° - \tfrac{1}{2}\phi_1'\right)$$
$$K_p = \tan^2\left(45° + \tfrac{1}{2}\phi_2'\right)$$

$$FS_{overturning} = \frac{\sum M_R}{\sum M_O}$$
$$\sum M_O = P_h \left(\frac{H'}{3}\right)$$
$$P_h = P_a \cos \alpha$$
$$P_v = P_a \sin \alpha$$

$$FS_{sliding} = \frac{\sum F_{R'}}{\sum F_d} = \frac{(\sum V)\tan(k_1 \phi_2') + B k_2 c_2' + P_p}{P_a \cos \alpha}$$

FINAL EXAMINATION

SEMESTER / SESSION : SEM II / 2016/2017
COURSE : FOUNDATION ENGINEERING
PROGRAMME CODE : BFF
COURSE CODE : BFC 43103

LATERAL EARTH PRESSURE AND RETAINING WALLS

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

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

$$L_3 = \frac{\sigma'_2}{\gamma'(K_p - K_a)}$$

$$\sigma'_5 = (\gamma L_1 + \gamma' L_2)K_p + \gamma' L_3(K_p - K_a)$$

$$A_1 = \frac{\sigma'_5}{\gamma'(K_p - K_a)}$$

$$A_2 = \frac{8P}{\gamma'(K_p - K_a)}$$

$$A_3 = \frac{6P\left[2\bar{z}\gamma'(K_p - K_a) + \sigma'_5\right]}{\gamma'^2(K_p - K_a)^2}$$

$$A_4 = \frac{P\left[6\bar{z}\sigma'_5 + 4P\right]}{\gamma'^2(K_p - K_a)^2}$$

$$L_4^4 + A_1L_4^3 - A_2L_4^2 - A_3L_4 - A_4 = 0$$

$$\sigma'_4 = \sigma'_5 + \gamma' L_4(K_p - K_a)$$

$$\sigma'_3 = L_4(K_p - K_a)\gamma'$$

$$L_5 = \frac{\sigma'_3 L_4 - 2P}{\sigma'_3 + \sigma'_4}$$

$$K_{p(design)} = \frac{K_p}{FS}$$

Free Earth Support

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

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

$$L_3 = \frac{\sigma'_2}{\gamma'(K_p - K_a)}$$

$$\sigma'_8 = \gamma'(K_p - K_a)L_4$$

$$L_4^3 + 1.5L_4^2(l_2 + L_2 + L_3) - \frac{3P[(L_1 + L_2 + L_3) - (\bar{z} + l_1)]}{\gamma'(K_p - K_a)} = 0$$

$$P - \frac{1}{2}[\gamma'(K_p - K_a)]L_4^2 - F = 0$$