UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: July 2016

Module Number: CE7252 **Module Name: Ground Improvement Techniques**

[Three Hours]

[Answer **all questions**]
[Each question carries **FIFTEEN** marks]

Q1. Granular Compaction Piles (GCP) is used as one of the ground improvement techniques in the phase 3 of the Outer Circular Highway (OCH) project. The sub surface soil profile consists of 8.0 m thick peaty clay layer followed by 5.0 m thick dense sand layer. Bed rock was encountered at a depth of 13.0 m from the ground surface. The water table is at the existing ground surface. A cross section of the sub surface soil profile is shown in Figure Q1.1.

It was decided to raise the subgrade level from the existing ground level in order to prevent flooding during the rainy season and a fill is placed upto a height of 5.0 m from the existing ground level. The GCPs were installed up to a depth of 8.0 m prior to place the fill for the embankment. The diameter of the GCP is 0.7 m and GCPs were installed at a spacing of 1.5 m in square pattern. At the design stage, it was assumed that the bulk unit weight and drained friction angle of the ABC material in the GCP were 22 kN/m^3 and 36° respectively.

The bulk unit weights of soft peat clay and fill material can be taken as 16.0 kN/m^3 and 20.0 kN/m^3, respectively. The coefficients of consolidation of the peaty clay in vertical and horizontal directions are 1.5 m^2/year and 4.5 m^2/year, respectively. The modified compression index (c_c') and undrained cohesion (c_u) of peaty clay was found as 0.2 and 10 kN/m^2, respectively. The unit weight of water can be taken as 9.81 kN/m^3.

You may use following equations with usual notations for calculations.

$a_s = 0.785\left(\frac{D}{S}\right)^2$ for square pattern

$D_e = 1.13S$ for square pattern

$$\mu_c = \frac{1}{1+(n-1)a_s}$$

$$\mu_s = \frac{n}{1+(n-1)a_s}$$

$$n^* = \frac{D_e}{D'}$$

$$U = 1-(1-U_v)(1-U_h)$$

$$T_h = \frac{C_h t}{D_e^2}$$

$$P = A\left[\frac{a_s \frac{1}{2}\gamma_s B N_\gamma}{F} + (1-a_s)\frac{cN_c}{F}\right]$$

a) Briefly describe the construction procedure of Granular Compaction Pile (GCP) with the aid of sketches.

[1.0 Marks]

b) As a junior geotechnical engineer in the project, how can you make sure that all GCPs were constructed upto the dense sand layer due to highly variable nature of the sub surface soil profile?

[1.0 Marks]

c) According to the contract specification, it is necessary to check 2% of the constructed GCPs for density using Standard Penetration Test (SPT) as a quality control measure. However, due to time constraint, contractor requested to limit the GCP checks only upto 0.5%. As a junior geotechnical engineer in the consultant's office, would you agree for the above request? Justify your answer with suitable explanations.

[1.0 Marks]

d) If width and length of the GCP group are 27.0 m and 70.0 m, respectively, estimate the allowable load of the GCP group taking factor of safety as 2.5. The information provided in Table Q1.1 may useful in the calculations.

[2.0 Marks]

e) If the water table is well below the ground surface in the above GCP group, what would be the most economical GCP spacing?

[2.0 Marks]

f) Assuming that stress concentration ratio (n) is 4.0, estimate the primary consolidation settlement of the composite ground and unimproved ground assuming that peaty clay is normally consolidated. Hence, compute the settlement reduction ratio.

[3.0 Marks]

g) If GCP diameter is reduced by 40% of the original diameter due to smear effect during operation, estimate the overall degree of consolidation 3 months after the installation of GCP. The information provided in Table Q1.2 and Figure Q1.2 may useful in the calculations.

[3.0 Marks]

h) What would be the time required to achieve 90% of the primary consolidation under the situation stated in section (g)? State any assumptions made in the calculations.

[2.0 Marks]

Q2. A 4.0 m height embankment is to be constructed over a 6.0 m thick clay layer, which is underlained by a layer of dense sand in a particular section of a road construction project. A gravel mat together with a geotextile is placed over the clay layer before placing the soil fill.

A series of laboratory tests were conducted to find the index properties and the compressibility characteristics of the soft clay and the results are illustrated in Table Q2.1. The bulk unit weight of the fill material can be taken as 20 kN/m^3. The ground water table was found to be at the existing ground level. The unit weight of water can be taken as 9.81 kN/m^3. The information provided in Table Q1.2 may useful in the calculations.

a) In order to construct the embankment, the contractor has requested use "Replacement method" instead of "Preloading technique". As a junior geotechnical engineer in the consultant's office, would you give approval for the contractor's request? Justify your answer stating advantages and disadvantages of replacement method.

[1.5 Marks]

b) What is the advantage/s of placing a gravel mat together with a geotextile over the clay layer before placing the fill?

[0.5 Marks]

c) In order to achieve 90% of the primary consolidation settlement within 1 year, what would be the expected surcharge height to be placed?

[3.0 Marks]

d) Assuming that secondary consolidation will start at the end of primary consolidation, what would be the expected secondary consolidation 5 years after the end of the primary consolidation due to construction of 4.0 m height embankment?

[2.5 Marks]

e) If no primary and secondary compressions are to be occurred under the design load, what would be the expected surcharge height to be placed assuming that preloading period is 2 years?

[2.5 Marks]

f) During the construction, it was realized that soft soil behavior in the field is quite different than the predicted consolidation behavior based on the labaoratory experimental data. Briefly explain why is it important to monitor soft soil behavior in the field?

[1.0 Marks]

g) Suggest a suitable field monitoring system with the aid of a sketch for the above project. Name the instruments with the relevant parameters to monitor soft soil behavior in the field.

[1.5 Marks]

h) The observed settlement in the field is shown in Table Q2.2. Using Hyperbolic method, determine the degree of consolidation of the soft clay layer.

[2.5 Marks]

Q3. A 3.0 m height embankment is to be constructed over a 6.0 m thick clay layer followed by 4.0 m thick dense sand layer. Based on the laboratory investigations, compressibility characteristics and index properties of peat was found and depicted in Table Q3.1. The bulk unit weight of embankment material is 20 kN/m³. The water table was found to be at the ground surface. The unit weight of water can be taken as 9.81 kN/m³.

It was decided to construct the embankment in stages to avoid shear failure at the edges. The maximum possible height of fill to have a factor of safety of at least 1.25 on slope instability is given in Table Q3.2. The strength gained due to consolidation with usual notations can be expressed by $\Delta c_u = 0.2\Delta\sigma$.

The information provided in Table Q1.2 may be useful in the calculations.

Note:- You may consider the variation of the thickness of the clay layer in different stages. But consider the unit weight to be the same.

a) What would be the suitable maximum fill height for the first step of filling without causing any shear failure at the edges? Hence, calculate the expected primary consolidation settlement and time period to achieve 90% of the primary consolidation settlement.

[2.0 Marks]

b) If the second stage of filling is started after the 90% consolidation of the stage 1 filling, what would be the stage 2 fill thickness? Hence, calculate the expected primary consolidation settlement and time period to achieve 90% of the primary consolidation settlement.

[5.0 Marks]

c) What would be the expected removable preload (fill height) after the end of 90% consolidation of the stage 2?

[1.0 Marks]

d) In order to accelerate the consolidation of the clay layer, it has been decided to install Prefabricated Vertical Drains (PVD) at 1.0 m spacing in square pattern up to a depth of 6.0 m before commencing the construction of embankment. A drainage blanket of the same unit weight as the embankment material is placed over the clay layer before commencing the fill to facilitate the drainage.
The cross sectional dimensions of 100 mm x 4 mm and 120 mm x 60 mm are used for PVD and mandrel, respectively. The discharge capacity of the drain is given as 1000 m^3/year.
The following equations with usual notations and information provided Table Q1.2 may useful in the calculations.

$$U_h = 1 - exp\left[\frac{-8T_h}{F}\right]$$

$$T_h = \frac{C_h t}{D_e^2}$$

$$F = F_{(n)} + F_s + F_r$$

$$F_{(n)} = ln\left[\frac{D_e}{d_w}\right] - \frac{3}{4}$$

$$F_s = \left[\left(\frac{k_h}{k_s}\right) - 1\right] ln\left(\frac{d_s}{d_w}\right)$$

$$F_r = \frac{2}{3}\pi L^2\left(\frac{k_h}{q_w}\right)$$

$$D_e = 1.13S \text{ for square pattern}$$

$$d_s = 2d_m$$

$$C_h = \left(\frac{k_h}{k_v}\right) C_v$$

$$U = 1 - (1 - U_h)(1 - U_v)$$

i) What are the functions of synthetic filter jacket and plastic core in Prefabricated Vertical Drains (PVDs)?

[2.0 Marks]

ii) Estimate the total settlement 3 months after the end of embankment construction.

[5.0 Marks]

Q4. In a port development project, sub surface soil close to the sea mainly consists of loose sandy soil deposit whereas in landside beyond sea line consists of soft clay. In order to increase the bearing capacity and reduce the settlement during operation, it is decided to improve the loose sandy soil deposit by dynamic compaction while soft clay by deep mixing technique.

a) As a junior geotechnical engineer in the project, you are asked to answer the following questions related to deep mixing technique.

i) Briefly explain the mechanism of soil-cement stabilization used in deep mixing technique.

[3.0 Marks]

ii) What are the factors that affect the performance of soil-cement stabilization? Briefly explain 5 numbers of factors.

[2.5 Marks]

iii) Briefly describe the mechanism through which the soil gets stabilized with lime.

[3.0 Marks]

b) The thickness of the loose sandy soil deposit is about 7.0 m. The relative density of the loose sandy soil is about 20%. In order improve the loose sandy soil deposit by dynamic compaction, it was decided to use 20 ton tamper falling from a height of 15 m. The crane employed is 150 ton capacity type. Assume that energy loss during tamping is about 25 % and the compaction energy required to improve loose sandy deposit is 30 tm/m³. The water table is well below the ground surface.

i) What are the factors to be considered in the selection of dynamic compaction technique. Briefly explain 4 numbers of factors.

[2.0 Marks]

ii) Check whether the given tamping weight and falling height are sufficient to improve the entire depth of the loose sandy soil deposit. You may use the following equation with usual notations.

$$D = 0.5\sqrt{WH}$$

[0.5 Marks]

iii) Design a suitable dynamic compaction programme in order to improve the loose sandy soil deposit. Specify the spacing, number of blows per phase and number of phases with a suitable sketch.

[4.0 Marks]

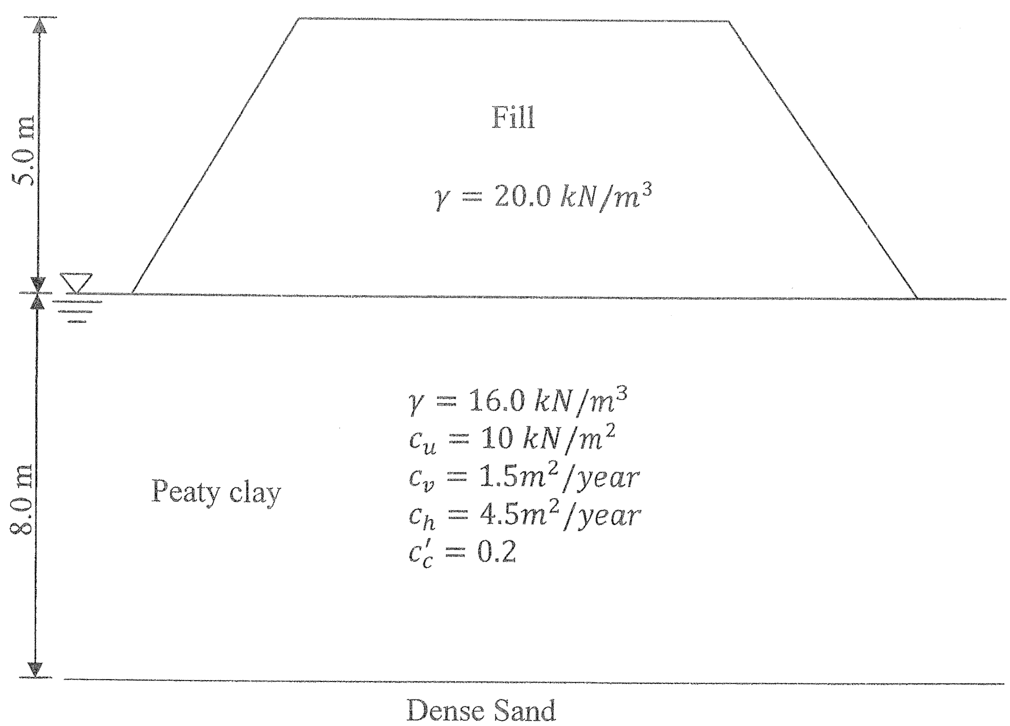


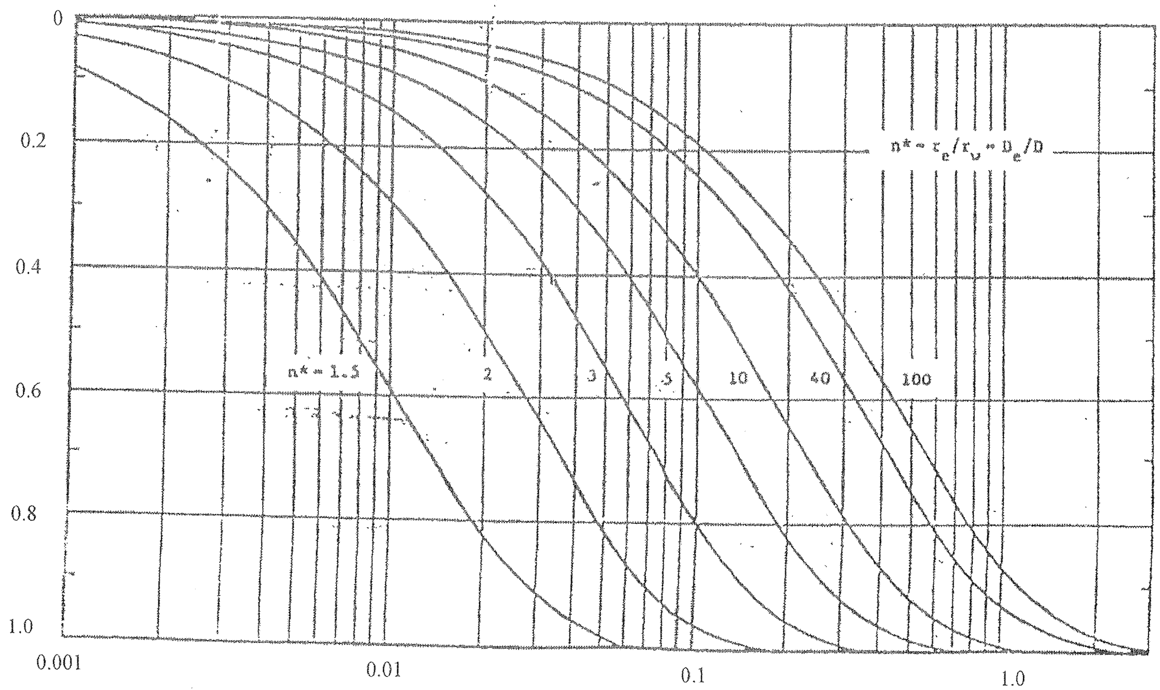
Figure Q1.1 Cross section of the embankment with sub surface soil profile

Table Q1.1 – Bearing capacity factors

ϕ	N_c	N_q	N_γ	N_q/N_c	$\tan\phi$	ϕ	N_c	N_q	N_γ	N_q/N_c	$\tan\phi$
0	5.14	1.00	0.00	0.20	0.00	26	22.25	11.85	12.54	0.53	0.49
1	5.38	1.09	0.07	0.20	0.02	27	23.94	13.20	14.47	0.55	0.51
2	5.63	1.20	0.15	0.21	0.03	28	25.80	14.72	16.72	0.57	0.53
3	5.90	1.31	0.24	0.22	0.05	29	27.86	16.44	19.34	0.59	0.55
4	6.19	1.43	0.34	0.23	0.07	30	30.14	18.40	22.40	0.61	0.58
5	6.49	1.57	0.45	0.24	0.09	31	32.67	20.63	25.99	0.63	0.60
6	6.81	1.72	0.57	0.25	0.11	32	35.49	23.18	30.22	0.65	0.62
7	7.16	1.88	0.71	0.26	0.12	33	38.64	26.09	35.19	0.68	0.65
8	7.53	2.06	0.86	0.27	0.14	34	42.16	29.44	41.06	0.70	0.67
9	7.92	2.25	1.03	0.28	0.16	35	46.12	33.30	48.03	0.72	0.70
10	8.35	2.47	1.22	0.30	0.18	36	50.59	37.75	56.31	0.75	0.73
11	8.80	2.71	1.44	0.31	0.19	37	55.63	42.92	66.19	0.77	0.75
12	9.28	2.97	1.69	0.32	0.21	38	61.35	48.93	78.03	0.80	0.78
13	9.81	3.26	1.97	0.33	0.23	39	67.87	55.96	92.25	0.82	0.81
14	10.37	3.59	2.29	0.35	0.25	40	75.31	64.20	109.41	0.85	0.84
15	10.98	3.94	2.65	0.36	0.27	41	83.86	73.90	130.22	0.88	0.87
16	11.63	4.34	3.06	0.37	0.29	42	93.71	85.38	155.55	0.91	0.90
17	12.34	4.77	3.53	0.39	0.31	43	105.11	99.02	186.54	0.94	0.93
18	13.10	5.26	4.07	0.40	0.32	44	118.37	115.31	224.64	0.97	0.97
19	13.93	5.80	4.68	0.42	0.34	45	133.88	134.88	271.76	1.01	1.00
20	14.83	6.40	5.39	0.43	0.36	46	152.10	158.51	330.35	1.04	1.04
21	15.82	7.07	6.20	0.45	0.38	47	173.64	187.21	403.67	1.08	1.07
22	16.88	7.82	7.13	0.46	0.40	48	199.26	222.31	496.01	1.12	1.11
23	18.05	8.66	8.20	0.48	0.42	49	229.93	265.51	613.16	1.15	1.15
24	19.32	9.60	9.44	0.50	0.45	50	266.89	319.07	762.89	1.20	1.19
25	20.72	10.66	10.88	0.51	0.47						

* After Vesic (1973)

Radial Degree of Consolidation U_r



Radial Time Factor T_r

Figure Q1.2 Variation of degree of consolidation in radial direction with time factor

Table Q1.2 – Variation of T_v with U

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

Table Q2.1 – Properties of soft clay

Saturated unit weight	16.0 kN/m^3
Coefficient of consolidation	2.5 $m^2/year$
Compression index	0.6
Initial void ratio	1.5
Modified secondary compression index	0.05

Table Q2.2 – Variation of settlement with time

Day after end of embankment construction	Settlement (m)
0	1.134
7	1.153
14	1.162
21	1.167
28	1.172
35	1.181
42	1.184
49	1.185
56	1.187
63	1.191
70	1.192

Table Q3.1 – Properties of clay

Saturated unit weight	16.0 kN/m^3
Coefficient of consolidation in vertical direction	2.5 $m^2/year$
Coefficient of consolidation in horizontal direction	10.0 $m^2/year$
Compression index	0.6
Initial void ratio	1.5
Coefficient of horizontal permeability	1×10^{-7} cm/s

Table Q3.2 – Maximum possible height of fill

Shear strength c_u(kN/m^2)	10.0	14.5	16.3	20.8	24.8	35.2
Safe fill height (m)	3.0	3.2	4.5	6.0	6.5	8.6