UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: August 2015

Module Number: CE7237 **Module Name: Ground Improvement Techniques**

[Three Hours]

[Answer **all questions**]

[Each question carries **TWELVE** marks]

Q1. A highway is to be constructed on a low lying area underlain by soft peaty clay of thickness 6.0 m and moderately stiff clay of thickness 4.0 m. Dense sand is found below the clay layer. A cross section of the sub surface soil profile is shown in Figure Q1.1.

The design engineer has decided to raise the road elevation by 3.0 m in order to prevent flooding during the rainy season. In order to compensate settlement due to embankment load and traffic load, it was proposed to place a 5.0 m thick soil fill on the existing ground as shown in Figure Q1.1. The ground water table is found to be at the existing ground level.

It was decided to improve the sub soil by installing Sand Compaction Piles (SCP) up to a depth of 10.0 m prior to construction of the road pavement. The diameter of the SCP is 0.7 m. It is proposed to place SCP at 1.5 m spacing in triangular pattern. The unit weight and friction angle of the material in the SCP is 22 kN/m^3 and 36° respectively.

Bulk unit weight of peat, clay and fill material can be taken as 14.0 kN/m^3, 16.0 kN/m^3 and 20.0 kN/m^3 respectively. Laboratory oedometer tests were conducted on undisturbed samples obtained from the peat and clay layers. It has been found that coefficient of consolidation of peat in vertical and horizontal directions are 2.0 m^2/year and 8.0 m^2/year respectively. Similarly, coefficients of consolidation of clay in vertical and horizontal directions are 1.5 m^2/year and 3.0 m^2/year respectively. The modified compression index $(C_c/1+e_0)$ of peat and clay are 0.2 and 0.1 respectively. The peat and clay have undrained cohesion of 10 kN/m^2 and 30 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.

$a_s = 0.907\left(\frac{D}{S}\right)^2$ for triangular pattern

$D_e = 1.05S$ for triangular pattern

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

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

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

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

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

a) Briefly describe the Sand Compaction Pile (SCP) construction procedure with the aid of sketches.

[1.5 Marks]

b) Taking factor of safety as 3.0, and width and length of the SCP group as 20 m and 50 m respectively, estimate the allowable load of the SCP group. The information provided in Table Q1.1 may useful in the calculations.

[2.0 Marks]

c) If the stress concentration ratio (n) is 5.0, estimate the primary consolidation settlement of the composite ground and unimproved ground assuming that peat and clay are normally consolidated. Hence, compute the settlement reduction ratio.

[5.5 Marks]

d) If the drain diameter is reduced by 50% of the original diameter of the SCP due to smear effect, estimate the overall degree of consolidation 3 months after the installation of SCP. The information provided in Table Q1.2 and Figure Q1.2 may useful in the calculations. Assume that SCP improved ground as a composite ground and use average weighted compressibility properties for the calculations.

[3.0 Marks]

Q2. In road construction projects, preloading with a soil fill is one of the most commonly used methods to improve the soft soil. A 3.0 m height embankment is to be constructed over the 4.0 m thick soft clay layer. A gravel mat is used over the soft clay layer to facilitate the drainage. A dense sand layer is found under the soft clay layer. Series of laboratory tests were conducted to find the compressibility characteristics of the soft clay. Compressibility characteristics of the soft clay together with other index properties are shown in Table Q2.1. The bulk unit weight of 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) What would be the expected settlement and time period to achieve 90% of the primary consolidation?

[3.0 Marks]

b) 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]

c) Assuming that secondary consolidation will start at the end of primary consolidation, what would be the expected secondary consolidation 3 years after the end of primary consolidation due to construction of 3.0 m height embankment?

[3.0 Marks]

d) 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 1 year?

[3.0 Marks]

Q3. A 4.0 m height embankment is to be constructed over a 10.0 m thick clay layer, which is underlained by dense sand. Based on the laboratory investigations, it has been found that the coefficients of consolidation of clay in vertical and horizontal directions are 1.5 m^2/year and 3.0 m^2/year respectively. The coefficient of volume compressibility (m_v) of clay is 0.002 m^2/kN. Bulk unit weight of embankment material and clay are 20 kN/m³ and 16 kN/m³ respectively.

In order to accelerate the consolidation of clay layer, it has been decided to install Prefabricated Vertical Drains (PVD) at 1.2 m spacing in square pattern up to a depth of 10.0 m before commencing the construction of embankment. A drainage blanket of same unit weight as the embankment material is placed over the peat 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 m³/year. The coefficient of horizontal permeability of clay is found to be 1×10^{-7} cm/s. The water table was found to be at the ground surface. The unit weight of water is 9.81 kN/m³.

The following equations with usual notations and information provided Table Q1.2 may useful in the calculations.

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

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

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

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

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

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

$D_e = 1.13S$ for square pattern

$$d_s = 2d_m$$

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

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

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

[2.0 Marks]

b) Estimate the overall degree of consolidation after 6 months of construction of the embankment.

[5.0 Marks]

c) Due to unavailability of the equipment to install PVD up to 10.0 m, contractor has requested permission to install PVD only up to 6.0 m. As a junior geotechnical engineer in the project, would you agree for this request? Justify your answer with suitable calculations.

[4.0 Marks]

d) During a meeting, a sub-contractor who is doing the PVD installation stated that "Vertical drains increase the undrained shear strength of soil due to consolidation". Do you agree with this statement? Justify your answer with suitable sketches.

[1.0 Marks]

Q4. a) Briefly explain the mechanism of soil-cement stabilization used in "Deep mixing" technique.

[3.0 Marks]

b) What are the factors that affect the performance of soil-cement stabilization? Briefly explain 6 numbers of factors.

[3.0 Marks]

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

[4.0 Marks]

d) Briefly describe the "Dry Jet Mixing Method" which is used to stabilize soil.

[2.0 Marks]

Q5. In a port development project, sub surface mainly consists of loose sandy deposit to a thickness of 6.0 m from the ground surface. The relative density of the loose sandy soil is 20%. In order to increase the bearing capacity and reduce the settlement, it is decided to improve the loose sandy layer by dynamic compaction using a 15 ton tamper falling a height of 20 m. The crane employed is 150 ton capacity type. Assume that energy loss during tamping is 25 % and compaction energy required to improve loose sandy deposit is 30 tm/m^3. The water table is well below the ground surface.

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

[2.0 Marks]

b) 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.

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

[1.0 Marks]

c) 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]

d) A junior engineer has proposed to use Vibroflotation technique to improve loose sandy soil deposit instead of dynamic compaction method. In order to do a cost analysis, consultant has asked junior engineer to determine the probe spacing for the 100 hP vibroflot, which is available with the contractor.

i. Briefly describe the vibroflotation technique under wet process with suitable sketches.

[2.0 Marks]

ii. Assuming that you are a junior engineer in this project, estimate the suitable probe spacing in square pattern to improve relative density of loose sandy soil up to 90 % using the D'Appolonia's method. The information provided in Figure Q5.1 may useful in the calculations.

[3.0 Marks]

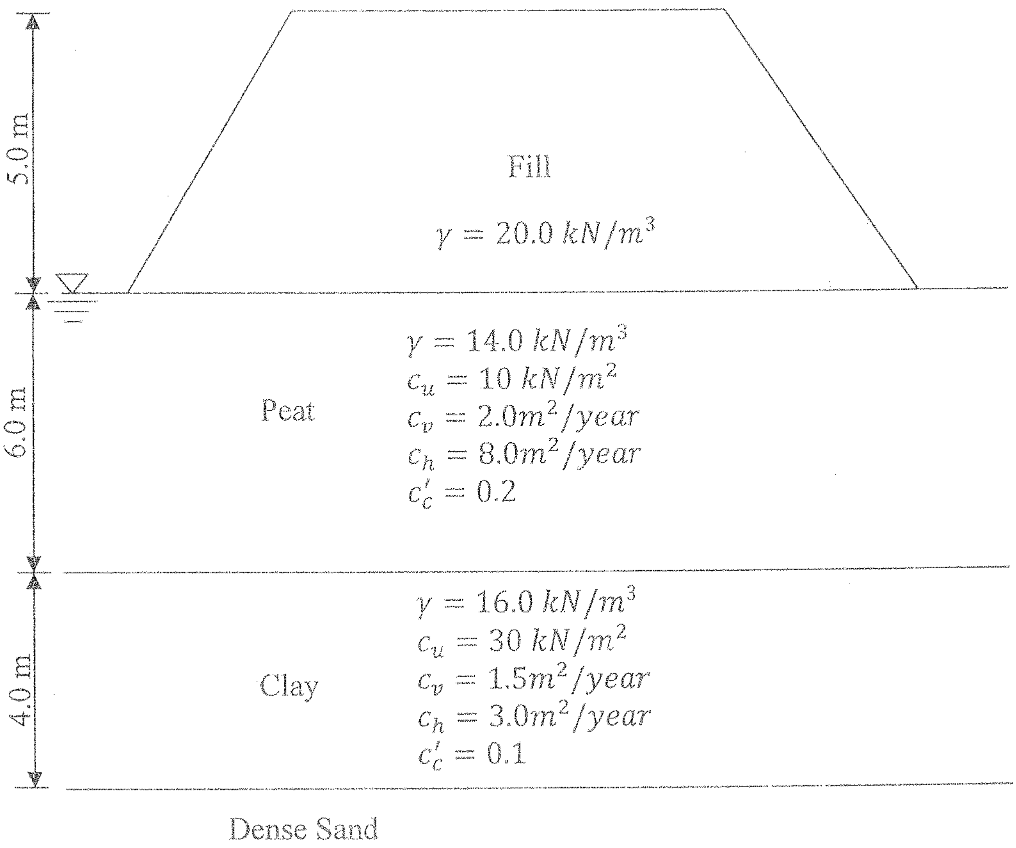

Figure Q1.1 Cross section of the embankment with sub surface soil profile

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)

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		

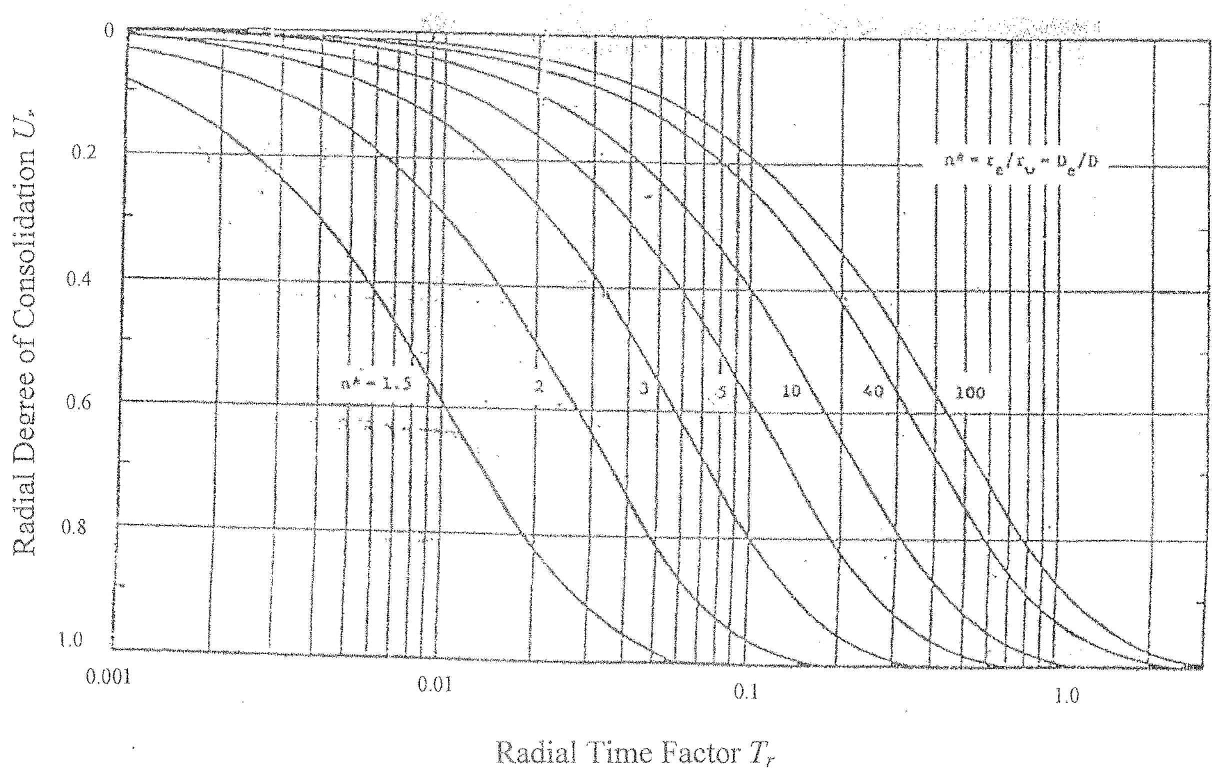

Figure Q1.2 Variation of degree of consolidation in radial direction with time factor

Table Q2.1 - Properties of soft clay

Saturated unit weight	16.0 kN/m^3
Coefficient of consolidation	2.0 m^2/year
Compression index	0.4
Initial void ratio	1.2
Modified secondary compression index	0.05

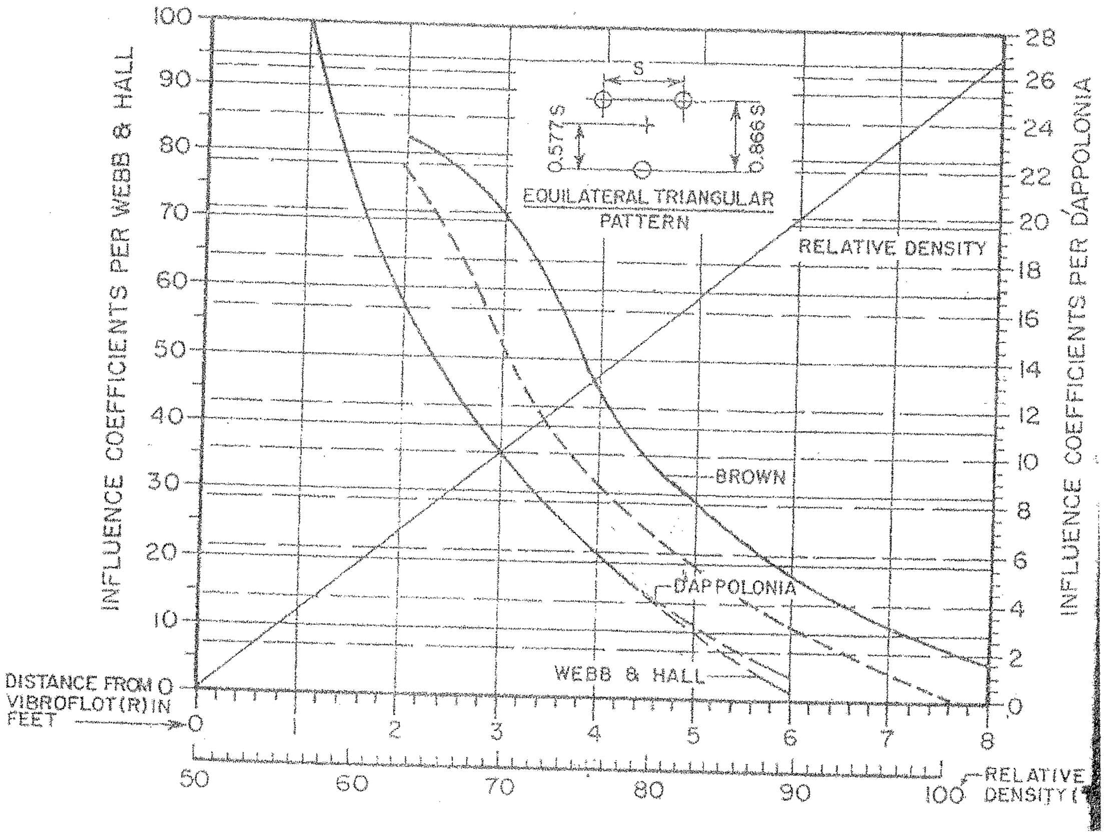

Figure Q5.1 – Area pattern design chart (D'Appolonia's chart)