UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: May 2023

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

[Three Hours]

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

Q1. A road is to be constructed on a low lying area underlain by very soft clay of thickness 8.0 m. Dense sand is found below the very soft clay layer. A cross section of the sub surface soil profile is shown in Figure Q1.1.

It was decided to raise the subgrade level by 5.0 m in order to prevent frequent flooding in the area. To compensate the pavement load, traffic load and consolidation settlement, additional 3.0 m thick soil fill will be placed on the subgrade level 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 Gravel Compaction Piles (GCP) up to a depth of 8.0 m prior to start the embankment construction. The diameter of the GCP is 0.7 m. It is proposed to place GCP at 1.2 m spacing in square pattern. The unit weight and friction angle of the material in the GCP is 22 kN/m^3 and 36° respectively.

Bulk unit weight of very soft clay, dense sand and fill material can be taken as 15.0 kN/m^3, 18.0 kN/m^3 and 20.0 kN/m^3 respectively. Laboratory test results revealed that coefficient of consolidation of very soft clay in vertical and horizontal directions are 1.5 m^2/year and 6.0 m^2/year respectively. The compression index, initial void ratio and undrained shear strength of very soft clay are 0.6, 1.2 and 5 kN/m^2 respectively.

You may use following equations with usual notations for calculations.

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

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

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

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

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

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

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

a) Briefly explain densification and solidification concepts used in ground improvement techniques. List 2 methods under each category.

[2.0 Marks]

b) What are the advantages of Gravel Compaction Pile (GCP) technique over preloading technique.

[1.0 Marks]

c) Why is it important to use singly graded aggregates for GCP rather than well gradated aggregates?

[1.0 Marks]

d) Due to highly variable nature of the sub surface soil profile, list 2 methods to make sure that all GCPs were installed up to the dense sand layer.

[1.0 Marks]

e) After installation of GCPs, Dynamic Cone Penetration Test (DCPT) is used to verify the compaction of the granular material in the GCP. Briefly describe why DCPT is more popular over Standard Penetration Test (SPT) to determine the compaction of granular material within the GCP?

[1.0 Marks]

f) If stress concentration ratio (n) is 5, compute the settlement reduction ratio due to proposed ground improvement technique.

[5.0 Marks]

g) The effective drainage area of the GCP is reduced due to smear effect during operation. If drainage area of GCP is reduced by 80% of the original area, estimate the time required for 90% of the primary consolidation by neglecting the effect of vertical drainage. The information provided in Table Q1.1 and Figure Q1.2 may useful in the calculations.

[3.0 Marks]

h) Suggest a suitable method to minimize the reduction of drainage area of GCP due to smear effect during the operation?

[1.0 Marks]

Q2. An expressway is to be constructed on a marshy land consists of 4.0 m thick soft sandy clay layer. Borehole investigation revealed that completely weathered rock is below the soft sandy clay layer. According to the plan and profile of the expressway, subgrade is 4.0 m above the existing ground level. The water table is at the existing ground surface.

It is suggested to adopt preloading technique to improve the soft sandy clay layer and embankment finished level is decided keep 3.0 m above the subgrade level. A gravel mat together with geotextiles are placed over the soft sandy clay layer before placing the embankment fill. Cross section of the proposed embankment is shown in Figure Q2.1.

A series of laboratory tests were conducted to find the index properties and the compressibility characteristics of the soft sandy 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. Assume that unit weight of gravel mat and embankment material is same. The unit weight of water can be taken as 9.81 kN/m^3. The information provided in Table Q1.1 may 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) Briefly explain the concept of "Preloading" with suitable sketches.

[1.0 Marks]

b) List 2 advantages of placing a gravel mat together with a geotextile over the clay layer before placing the fill?

[1.0 Marks]

c) As first step, it is proposed to place 3.5 m thick compacted fill on the soft sandy clay layer. If filling rate is 0.5 m/week, what would be the degree of consolidation at the end of stage 1 filling?

[1.5 Marks]

d) The second stage of filling is started after the end of stage 1 filling and fill thickness is 4.0 m. If filling rate is 0.5 m/week, what would be the overall degree of consolidation at the end of stage 2 filling?

[5.0 Marks]

e) If preloading period is 120 days, what would be the overall degree of consolidation at the end of preloading period?

[3.5 Marks]

f) What would be the expected primary consolidation settlement at the end of preloading period?

[1.0 Marks]

g) What would be the expected removable fill height after the end of preloading?

[1.0 Marks]

h) If pavement and traffic load is 25 kN/m^2, what would be the expected Over Consolidation Ratio (OCR) of the soft sandy clay layer after construction of the road?

[1.0 Marks]

Q3. A four lane highway was constructed over a low lying area underlain with 6.0 m thick soft clay layer. Dense sand is found under the clay layer. As this area is frequently subjected to flooding, it was decided to raise the elevation of the subgrade level by 4.0 m. In order to compensate the dead and live load of the highway, and consolidation settlement, an additional soil fill of 2.5 m was placed over the embankment.

Compressibility characteristics of soft clay together with other index properties are shown in Table Q3.1. The bulk unit weight of fill material can be taken as 20 kN/m^3. The ground water table is found to be at the existing ground level.

In order to accelerate the consolidation of soft clay layer due to soil fill, Prefabricated Vertical Drains (PVD) were installed in triangular pattern up to a depth of 6.0 m. A gravel mat together with a geotextile was placed over the soft clay layer. 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 900 m^3/year. The unit weight of water can be taken as 9.81 kN/m^3.

The following equations with usual notations and information provided in Table Q1.1 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

$D_e = 1.05S$ for triangular 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) "With the installation of PVD, settlement of the soft ground can be reduced". Do you agree with this statement? Justify your answer with a suitable sketch.

[1.0 Marks]

c) "Vertical drains increase the undrained shear strength of soft soil due to consolidation". Do you agree with this statement? Justify your answer.

[1.0 Marks]

d) Why is it important to do "Depth check" before installation of PVD in the field?

[1.0 Marks]

e) Assuming that soft clay is normally consolidated, what would be the expected primary consolidation settlement of the clay layer due to embankment load after installation of PVD at 1.0 m spacing?

[1.5 Marks]

f) By neglecting the vertical drainage, what would be the expected time to achieve 95% degree of consolidation due to embankment load after installation of PVD?

[7.0 Marks]

g) In order to achieve the required degree of consolidation within 3 months, it was suggested to further reduce the PVD spacing. As a junior geotechnical engineer in the project, would you agree with this decision? Justify your answer and suggest an alternative method to reduce the consolidation period.

[1.5 Marks]

Q4. A large land area was acquired to the Colombo city through the Port city development project and offshore sand was pumped to fill the reclaimed area. Thickness of the loose sandy soil deposit at the reclaimed area is about 6.0 – 10.0 m. Since relative density of the loose sandy soil deposit is 20%, dynamic compaction and vibroflotation techniques were proposed to improve the subsurface.

a) When the loose sandy soil thickness is less than 6.0 m, dynamic compaction technique is proposed to improve the subsurface. It was decided to use 15 ton tamper falling from a height of 10 m. The crane employed is 100 ton capacity type. Assume that energy loss during tamping is about 20 % and the compaction energy required to improve loose sandy deposit is 25 tm/m^3.

i) Briefly explain why Dynamic compaction technique is not suitable to improve very soft clay?

[1.0 Marks]

ii) Briefly explain with neat sketches mechanism and principle of Dynamic Compaction Technique.

[1.5 Marks]

iii) Design a suitable dynamic compaction programme in order to improve the loose sandy soil deposit. Specify the maximum possible depth of improvement, spacing, number of blows per phase and number of phases with a suitable sketch. You may use the following equation with usual notations.

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

[2.5 Marks]

b) Vibroflotation technique is proposed to adopt when the loose sandy soil deposit is greater than 6.0 m.

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

[2.0 Marks]

ii) What is the difference between vibro-compaction and vibro-replacement.

[1.0 Marks]

iii) Estimate the suitable probe spacing in triangular pattern under 30 hp vibroflot unit, to achieve 90 % relative density using the D'Appolonia's method. The information provided in Figure Q4.1 may useful in the calculations.

[2.0 Marks]

c) It was proposed to use soil-cement columns to support the underground sewer pipes in the Port city development area.

i) What are the Primary cementitious products in the soil-cement mixing technique.

[1.5 Marks]

ii) What is Pozzolanic Reaction in soil-cement mixing technique.

[1.0 Marks]

iii) Briefly explain how the "Curing Period" affect on the rate of shear strength gain in soil-cement mixing.

[1.0 Marks]

iv) Briefly describe the "Wet Jet Mixing Method" which is used to stabilize soft clay.

[1.5 Marks]

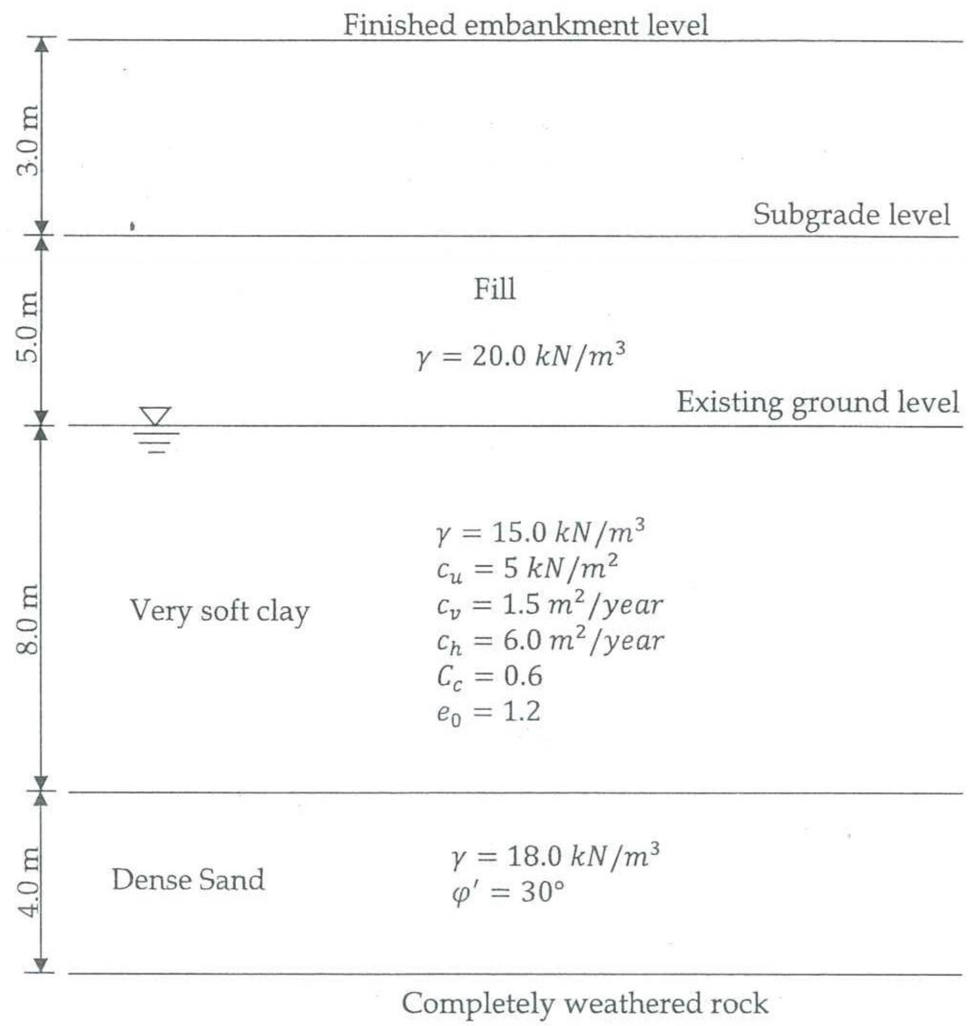

Figure Q1.1 Cross section of the road embankment with sub surface soil profile

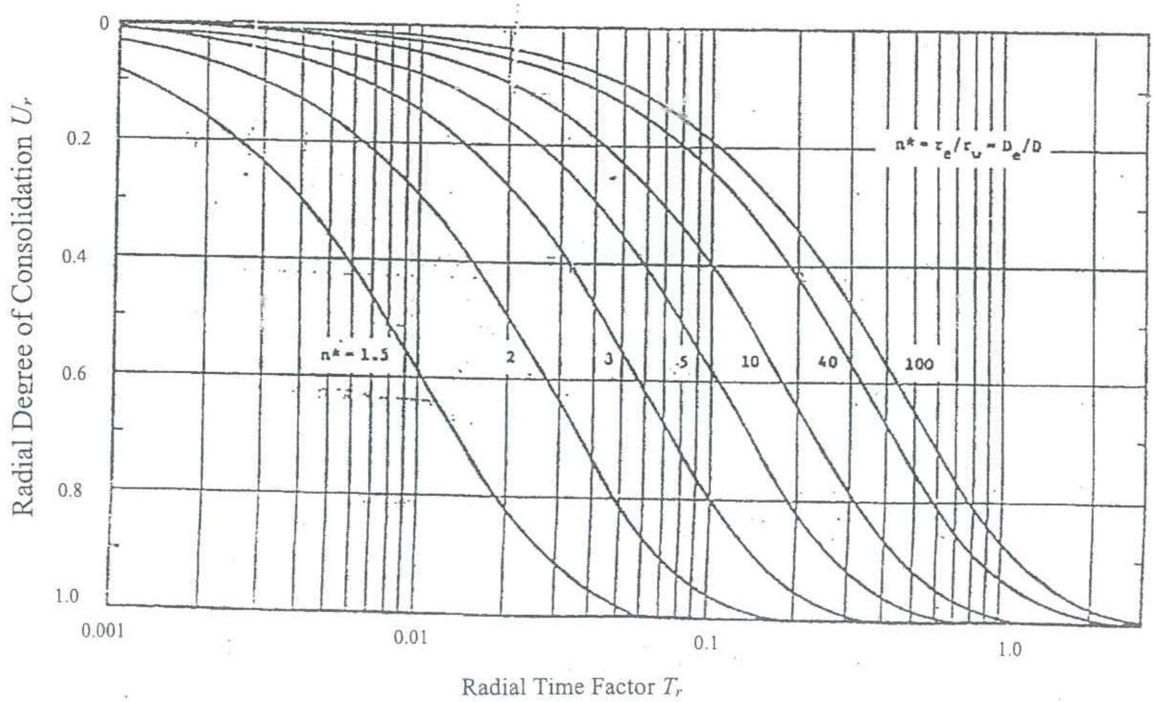

Figure Q1.2 Variation of degree of consolidation in radial direction with time factor

Table Q1.1 – 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		

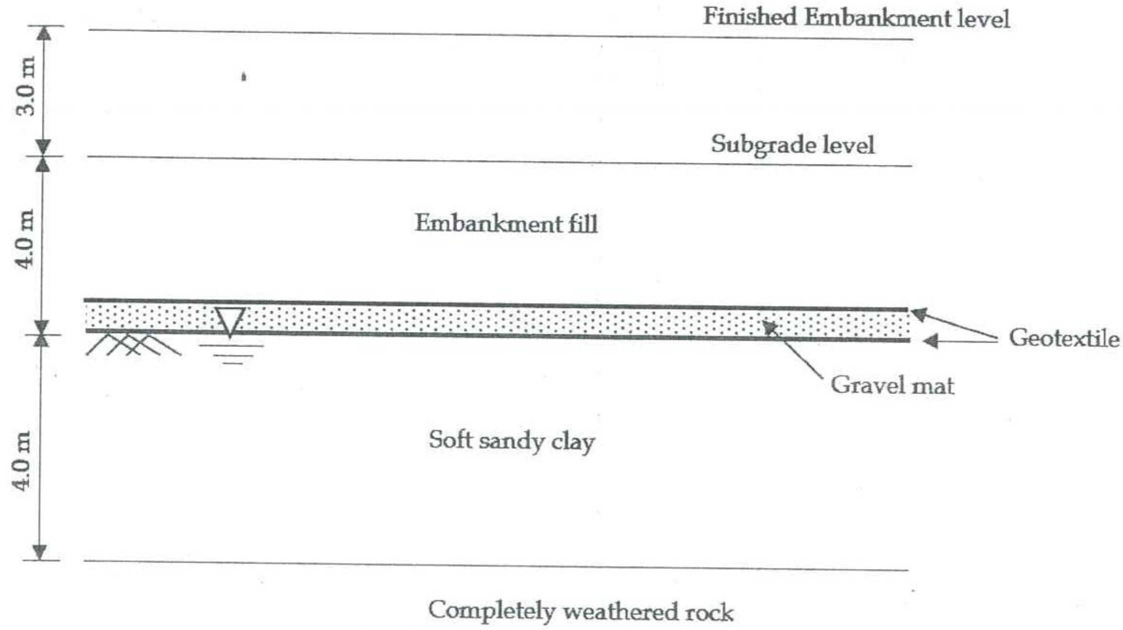

Figure Q2.1 Cross section of the embankment with sub surface soil profile

Table Q2.1 – Properties of soft sandy clay

Saturated unit weight γ_{sat}	15.0 kN/m³
Coefficient of consolidation C_v	8.0 m²/year
Modified Compression index C_c'	0.25
Undrained shear strength c_u	20.0 kN/m²

Table Q3.1 – Properties of soft clay

Saturated unit weight	15.0 kN/m³
Coefficient of consolidation in vertical direction	2.0 m²/year
Coefficient of consolidation in horizontal direction	4.0 m²/year
Compression index	0.6
Initial void ratio	1.2
Coefficient of horizontal permeability	1×10^{-7} cm/s

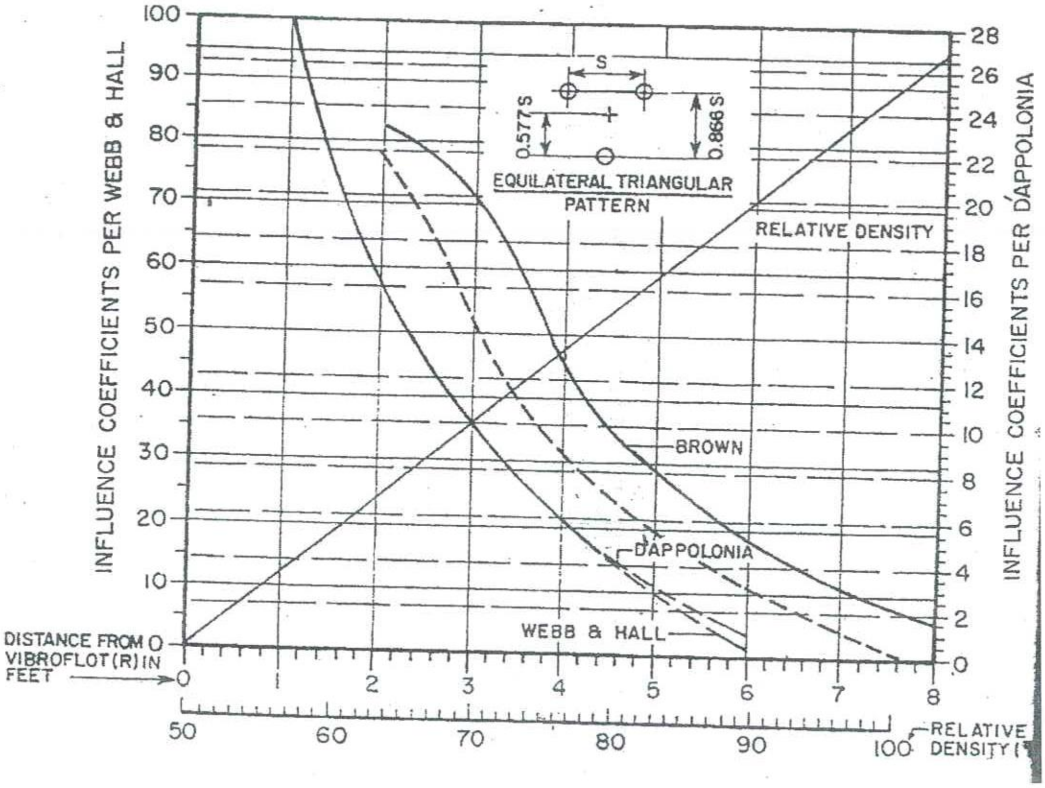

Figure Q4.1 – Area pattern design chart (D'Appolonia's chart)