UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: March 2022

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

[Three Hours]

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

Q1. A road embankment is to be constructed on a low lying area underlain by soft peaty clay of thickness 10.0 m. Dense sand is found below the soft peaty clay layer. A cross section of the sub surface soil profile is shown in Figure Q1.1.

Based on hydrological study, it was decided to keep the subgrade level 4.0 m above the existing ground level. In order to compensate the pavement load, traffic load and consolidation settlement, it was proposed to place a 3.0 m thick soil fill 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 10.0 m prior to start the embankment construction. The diameter of the GCP is 0.7 m. It is proposed to place GCP at 1.3 m spacing in square pattern. The unit weight and friction angle of the material in the GCP is 22 kN/m³ and 36° respectively.

Bulk unit weight of very soft peat clay, dense sand and fill material can be taken as 14.0 kN/m³, 18.0 kN/m³ and 20.0 kN/m³ respectively. Laboratory oedometer tests were conducted on undisturbed samples obtained from the very soft peaty clay layer. It has been found that coefficient of consolidation of very soft peaty clay in vertical and horizontal directions are 2.0 m²/year and 6.0 m²/year respectively. The modified compression index ($C_c' = C_c/1 + e_0$) and undrained cohesion of very soft peaty clay are 0.3 and 5 kN/m² respectively. The shear strength parameters of dense sand was found as $\varphi' = 30°$.

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 the GCP construction procedure with suitable sketches.

[2.0 Marks]

b) 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]

c) 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?

[0.5 Marks]

d) After installation of GCPs, consultant suggested to wait at certain period before start the embankment filling. Suggest a suitable method/s to decide the waiting period?

[0.5 Marks]

e) If stress concentration ratio (n) is 3, compute the settlement reduction ratio due to proposed ground improvement technique.

[4.0 Marks]

f) If GCP diameter is reduced by 80% of the original diameter due to smear effect during operation, 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]

g) If modified secondary compression index is 0.01, what would be the expected secondary consolidation settlement 10 years after the 90% degree of the primary consolidation under the situation stated in section (f)?

[2.0 Marks]

h) If the slope stability of the pile group is evaluated using profile method, calculate the unit weight of fictitious strips of soil placed above the granular pile and unit weight of fictitious strips of soil placed above the insitu soil. Thickness of the fictitious strip is 0.1 m.

[2.0 Marks]

Q2. In an expressway construction project, preloading technique is proposed to improve medium stiff silty clay layer. According to the sub surface soil profile, 4.0 m thick medium stiff silty clay layer is underlained by a layer of dense sand. The subgrade level is 4.0 m above the existing ground surface. In order to compensate the pavement and traffic load, and consolidation settlement, 2.5 m thick additional fill will be placed above the subgrade level. A gravel mat together with a geotextile is placed over the medium stiff silty 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 medium stiff silty 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.

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 is the purpose of placing gravel mat together with a geotextile over the medium stiff silty clay layer before start the embankment filling?

[0.5 Marks]

b) As first step, it is proposed to place 3.0 m thick compacted fill on the medium stiff silty clay layer. If filling rate is 0.5 m/week, what would be the degree of consolidation at the end of stage 1 filling? Assume that unit weight of gravel mat and embankment material is same.

[1.5 Marks]

c) The second stage of filling is started after the end of stage 1 filling and fill thickness is 3.5 m. If filling rate is 0.5 m/week, what would be the remaining excess pore water pressure and overall degree of consolidation at the end of stage 2 filling?

[6.0 Marks]

d) If preloading period is 90 days, what would be the remaining excess pore water pressure and overall degree of consolidation at the end of preloading period?

[4.0 Marks]

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

[1.5 Marks]

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

[1.0 Marks]

g) What would be the undrained shear strength of medium stiff silty clay at the end of stage 2?

[0.5 Marks]

Q3. A road is to be constructed over a low lying area underlain with 7.0 m thick soft clay layer followed by dense sand. As this area is frequently subjected to flooding, it is decided to raise the elevation of the subgrade level by 4.0 m. In order to compensate the dead and live load of the road, and consolidation settlement, an additional soil fill of 2.5 m will be placed over the subgrade level as shown in Figure Q3.1.

Properties of the soft clay were determined based on the site investigation and results are presented in Table Q3.1. The bulk unit weight of fill material can be taken as 20 kN/m³. The 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) are installed in square pattern up to a depth of 7.0 m. A gravel mat together with a geotextile is 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 1000 m³/year. The unit weight of water can be taken as 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

$D_e = 1.05S$ for triangular pattern

$d_s = 2d_m$

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

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

Signature of Supervisor : ....

a) "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]

b) "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]

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

[0.5 Marks]

d) 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]

e) 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?

[6.0 Marks]

f) If PVD is installed only upto 5.0 m at 1.0 m spacing, what would be the expected primary consolidation settlement?

[1.0 Marks]

g) If PVD is installed only upto 5.0 m at 1.0 m spacing, what would be the expected primary consolidation settlement 3 months after the embankment construction?

[4.0 Marks]

Q4. In a road development project, sub surface near coastal area mainly consists of loose sandy soil deposit whereas in paddy area 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 technique and vibroflotation technique 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) Explain the mechanism of soil-cement stabilization used in the deep mixing technique with suitable sketches.

[2.5 Marks]

ii) List 4 factors that affect the performance of soil-cement stabilization?

[2.0 Marks]

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

[2.5 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/m^3. The water table is well below the ground surface.

i) List 4 number of factors to be considered in the selection of dynamic compaction technique.

[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.

[2.0 Marks]

c) Vibroflotation technique is proposed to adopt when the loose sandy soil deposit is greater than 7m. The relative density of the loose sandy soil deposit is about 20%.

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

[1.5 Marks]

ii) Estimate the suitable probe spacing in square pattern under 100 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]

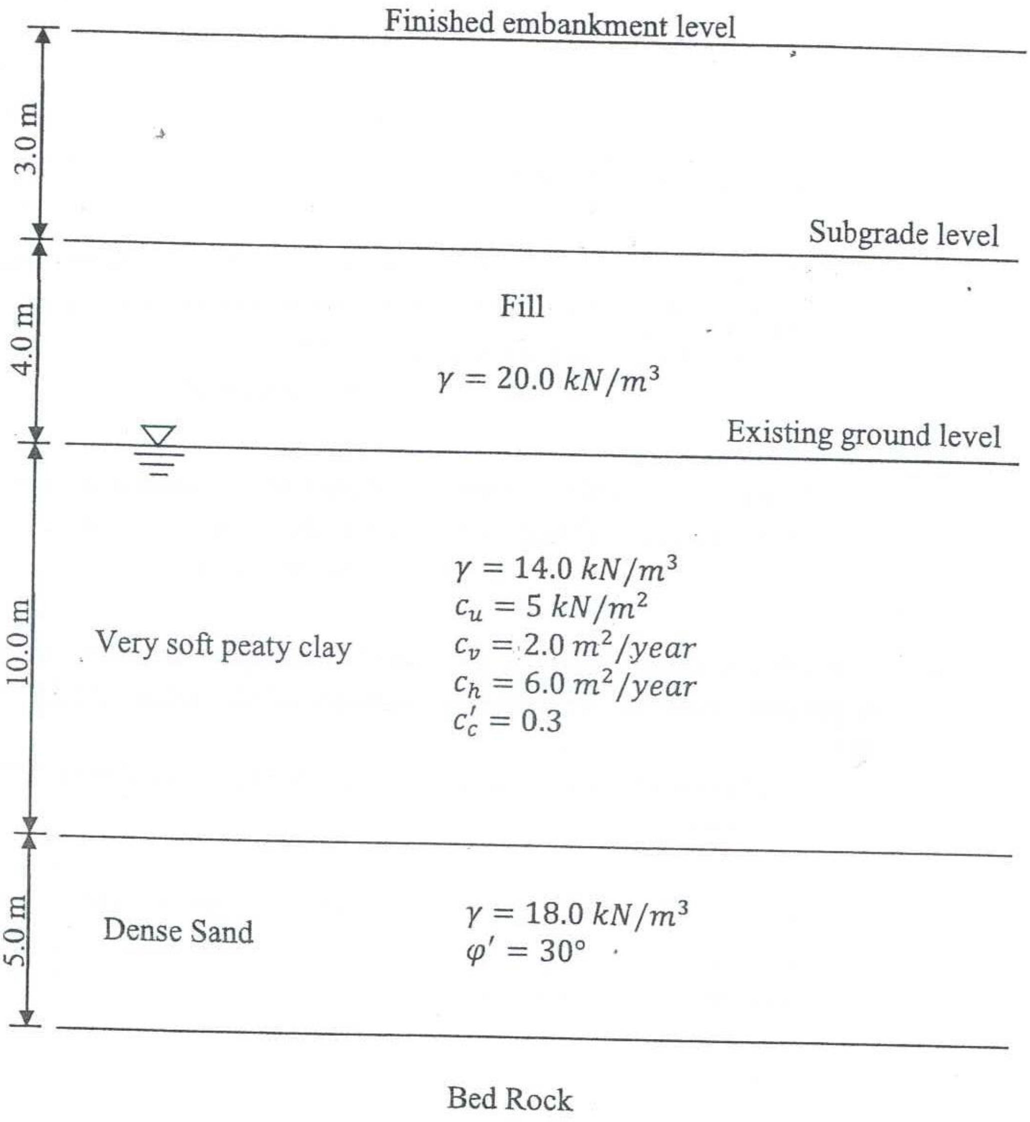

Figure Q1.1 Cross section of the road embankment with sub surface soil profile

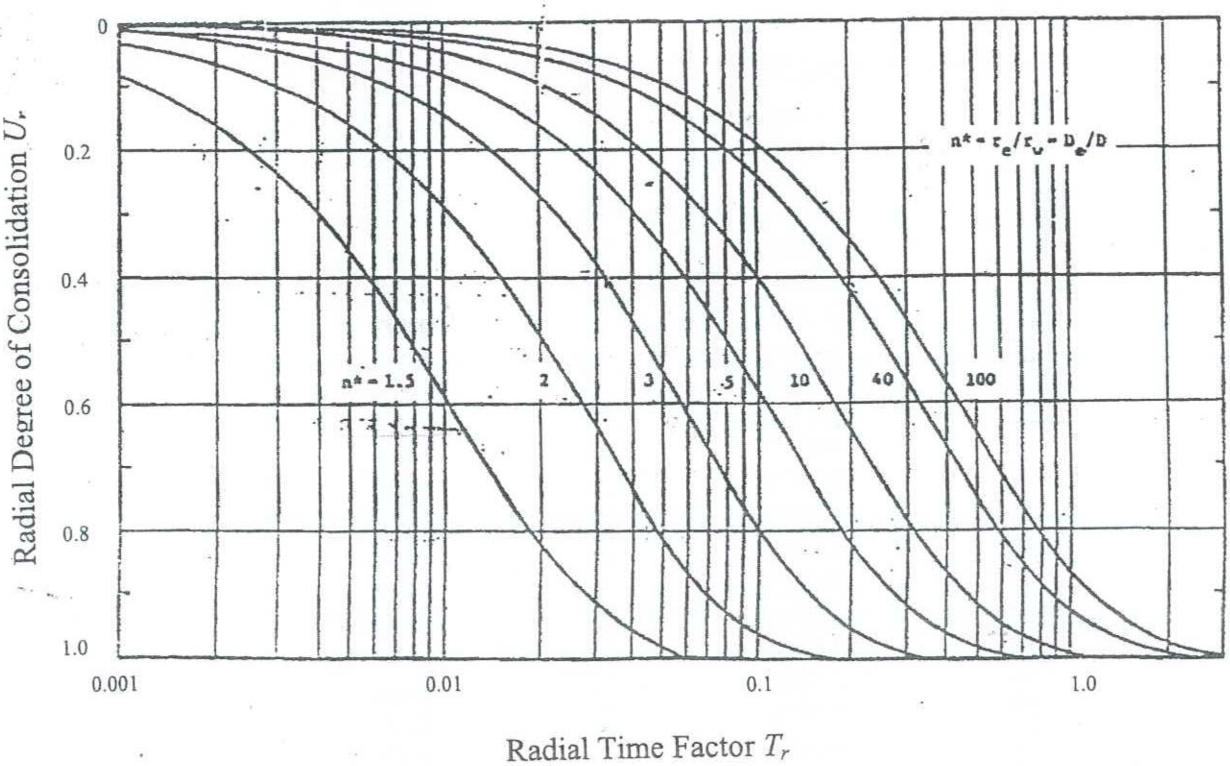

Figure Q1.2 Variation of degree of consolidation in radial direction with time factor

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		

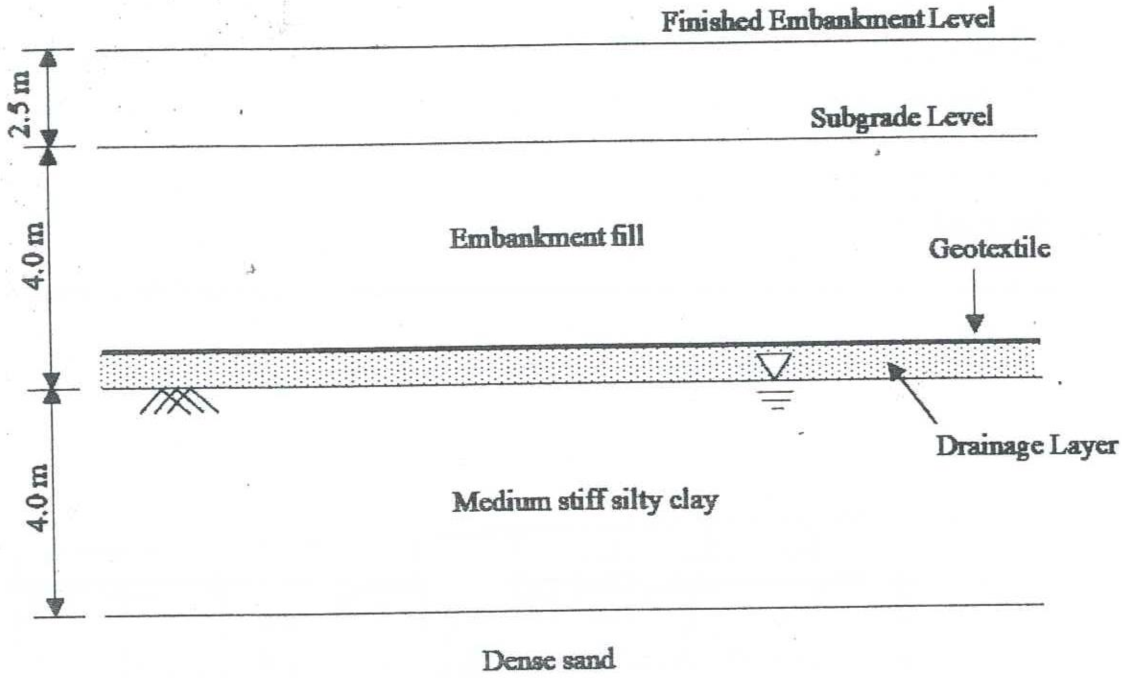

Figure Q2.1 Cross section of the embankment with sub surface soil profile

Table Q2.1 – Properties of medium stiff silty clay

Saturated unit weight γ_{sat}	16.0 kN/m^3
Coefficient of consolidation C_v	10.0 m^2/year
Modified Compression index C_c'	0.2
Undrained shear strength c_u	25.0 kN/m^2

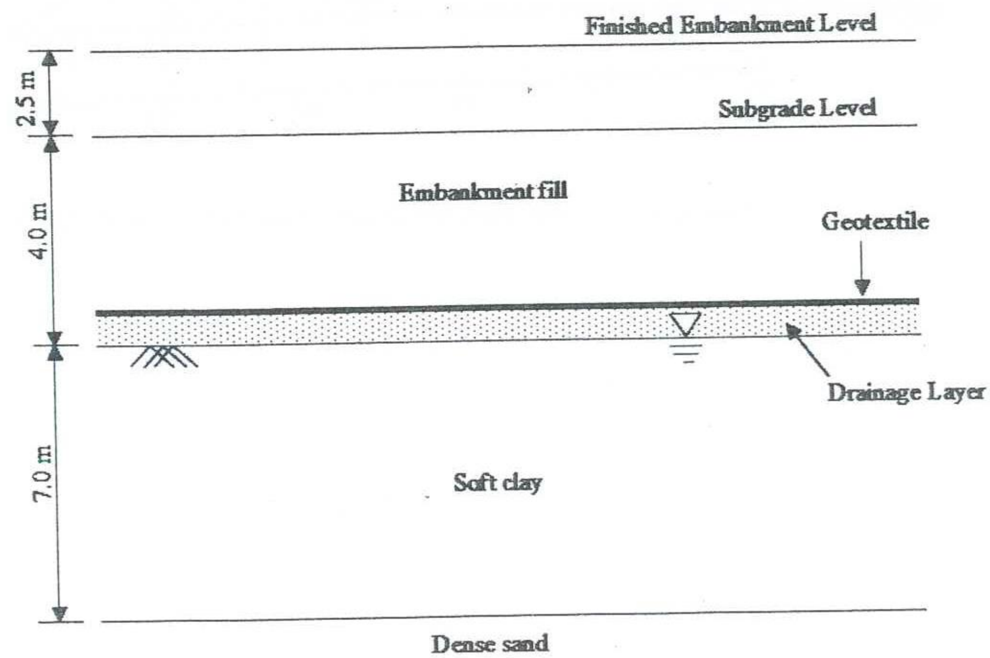

Figure Q3.1 Cross section of the embankment with sub surface soil profile

Table Q3.1 – Properties of soft clay

Saturated unit weight γ_{sat}	15.0 kN/m^3
Coefficient of consolidation in vertical direction C_v	1.5 m^2/year
Coefficient of consolidation in horizontal direction C_h	4.5 m^2/year
Compression index C_c	0.8
Initial void ratio e_0	1.6
Coefficient of horizontal permeability k_h	1 x 10^{-7} cm/s

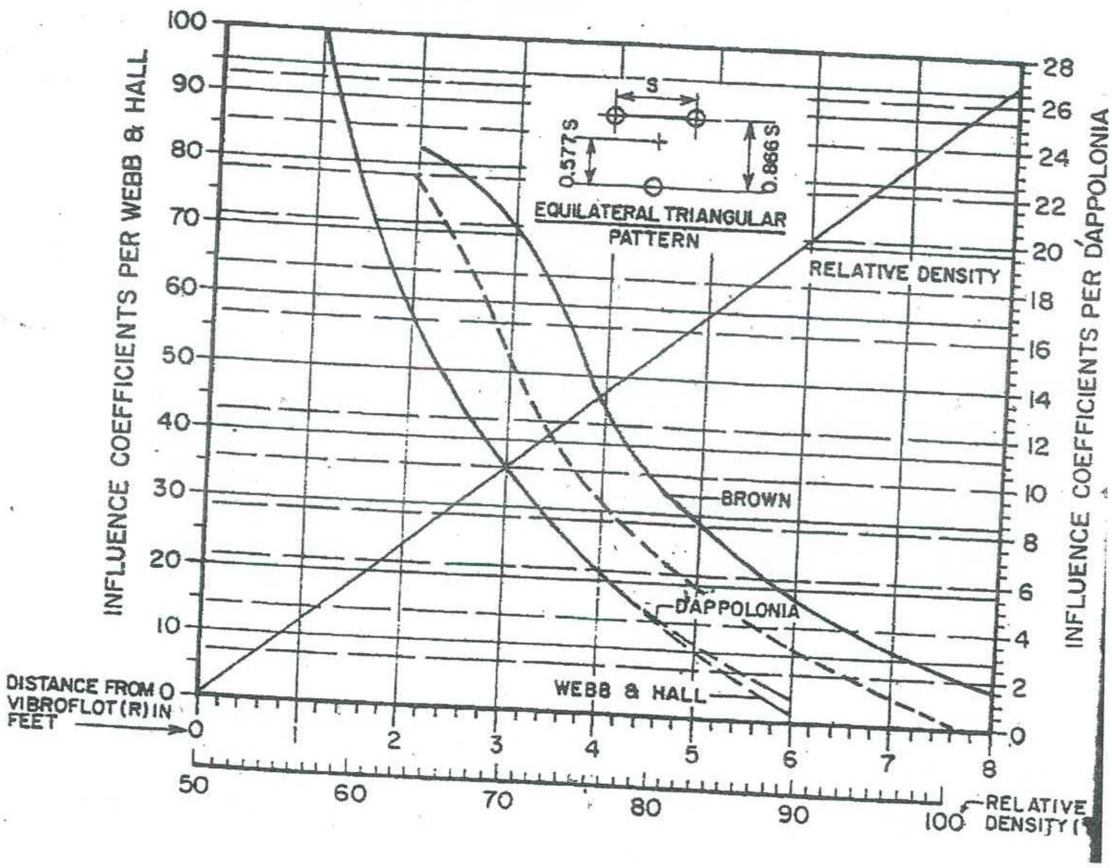

Figure Q4.1 – Area pattern design chart (D'Appolonia's chart)