UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: October 2019

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

[Three Hours]

[Answer **all questions**]

[Marks assigned for each question are indicated]

Q1. To construct an embankment on very soft soil, Granular Compaction Pile (GCP) is used as one the ground improvement techniques in an expressway construction project. The sub surface soil consists of 10.0 m thick very soft clay layer followed by 5.0 m thick silty sand layer. Bed rock was encountered at a depth of 15.0 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.

Subgrade level was decided by considering the 100 years return period of flood. As such, it was decided to raise the subgrade level about 5.0 m above the existing ground level. The GCPs were installed up to the silty sand layer prior to place the compacted fill for the embankment. The diameter of the GCP is 0.7 m and GCPs were installed at a spacing of 1.3 m in square pattern. In order to compensate the traffic and pavement load, and consolidation settlement, embankment has been raised by additional 2.5 m above the design subgrade level as shown in Figure 1.1.

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 very soft clay, silty 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. The coefficients of consolidation of the very soft clay in vertical and horizontal directions are 2.0 m^2/year and 3.0 m^2/year, respectively. The modified compression index (c_c') and undrained shear strength (c_u) of very soft clay was found as 0.25 and 5 kN/m^2, respectively. Shear strength parameters of silty sand were found as $c' = 5\,kPa$ and $\varphi' = 26°$. The unit weight of water can be taken as 9.81 kN/m^3.

You may use following equations with usual notations for calculations.

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

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

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

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

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

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

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

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

a) Due to highly variable nature of the sub surface soil profile, how can you make sure that all GCPs were installed up to the silty sand layer

[1.0 Marks]

b) Briefly describe a suitable method with the aid of sketches to check the compaction of the granular material in the GCP. Also briefly describe how to determine the friction angle of compacted granular material within the GCP.

[2.0 Marks]

c) After installation of GCPs, consultant suggested to wait at least 2 months before start the embankment filling. Do you agree with this decision? Justify your answer.

[0.5 Marks]

d) If width and length of the GCP group are 34.0 m and 75.0 m, respectively, estimate the allowable load of the GCP group taking factor of safety as 3.0. The information provided in Table Q1.1 may useful in the calculations.

[1.0 Marks]

e) If stress concentration ratio (n) is 5, compute the settlement reduction ratio.

[2.5 Marks]

f) If GCP diameter is reduced by 75% of the original diameter due to smear effect during operation, estimate the overall degree of consolidation 2 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]

g) By neglecting the vertical drainage, what would be the time required to achieve 95% degree of the primary consolidation under the situation stated in section (f)?

[1.5 Marks]

h) If slope stability of the GCP group is evaluated using profile method, compute the design parameter. Draw a sketch which may useful to input data to SLOPE/W software and summarize the design parameters in a table. Assume that thickness of the fictitious strip is 0.1 m.

[3.5 Marks]

Q2. During widening of the A24 Matara-Akuressa road, preloading technique is proposed to adapt for soft soil improvement. According to the sub surface soil profile, 4.0 m thick medium stiff clay layer is underlained by a layer of dense sand. The subgrade level is 4.0 m above the 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 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 medium stiff 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.

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

[1.0 Marks]

b) As first step, it is proposed to place 2.0 m thick compacted fill on the medium stiff clay layer. If filling rate is 1.0 m/week, what would be the degree of consolidation at the end of stage 1 filling?

[1.0 Marks]

c) The second stage of filling is started after the end of stage 1 filling and fill thickness is 2.0 m. If filling rate is 1.0 m/week, what would be the remaining excess pore water pressure and overall degree of consolidation at the end of stage 2 filling?

[4.0 Marks]

d) The third stage of filling is started after the end of stage 2 filling and fill thickness is 3.0 m. If filling rate is 1.0 m/week, what would be the remaining excess pore water pressure and overall degree of consolidation at the end of stage 3 filling?

[2.5 Marks]

e) If preloading period is 150 days, what would be the remaining excess pore water pressure and overall degree of consolidation at the end of preloading period?

[2.5 Marks]

f) What would be the expected consolidation settlement at end of each step?

[1.5 Marks]

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

[0.5 Marks]

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

[2.0 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 square 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 1000 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 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) "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.

[1.5 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) 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 1.2 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 at 1.2 m spacing?

[5.5 Marks]

f) 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]

g) The observed settlement in the field is shown in Table Q3.2. Using Asaoka's method, determine the degree of consolidation of the soft clay layer.

[2.0 Marks]

Q4. In Greater Colombo Wastewater Management Improvement Project, trenchless pipe laying was proposed for more than 4.5 km length in order to minimize the traffic congestion during the construction period. According to the design, pipes will be laid at a depth of about 3.5 m from the ground surface. However, according to the soil investigation, it was observed that most of the locations consist of very soft soil especially below the designed pipe trace. As such, Geotechnical Engineer has proposed to adopt deep mixing technique to improve the sub surface soil before laying the pipes.

As a junior geotechnical engineer in this project, you are asked to answer the following questions.

a) Why is it important to improve the soft soil before laying the pipes?

[1.0 Marks]

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

[3.0 Marks]

c) List 5 factors that affect the performance of soil-cement stabilization?

[2.5 Marks]

d) Why is it preferred to use cement instead of lime as admixture in deep mixing technique. List 3 factors.

[1.5 Marks]

Q5. In port city development project, 269 hectares is panned to acquire to Colombo city and offshore sand was pumped to fill the reclaimed area. Thickness of the loose sandy soil deposit at the reclaimed area is about 7.0 m. The relative density of the loose sandy soil deposit is about 20%. To improve the loose sandy soil deposit upto a depth of 7.0 m, dynamic compaction and vibroflotation techniques were used.

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

[1.5 Marks]

b) Estimate the suitable probe spacing in triangular pattern under 100 hp vibroflot unit, to achieve 75 % relative density using the D'Appolonia's method. The information provided in Figure Q5.1 may useful in the calculations.

[2.0 Marks]

c) In order to improve the loose sandy soil deposit by dynamic compaction technique, 20 ton tamper was falling from a height of 15 m. The crane employed was 150 ton capacity type. Assume that energy loss during tamping is about 10 % and the compaction energy required to improve loose sandy deposit is 70 tm/m^3.

i) List 3 factors to be considered in determining the required energy to improve loose sandy soil deposit.

[1.0 Marks]

ii) 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. You may use the following equation with usual notations.

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

[2.5 Marks]

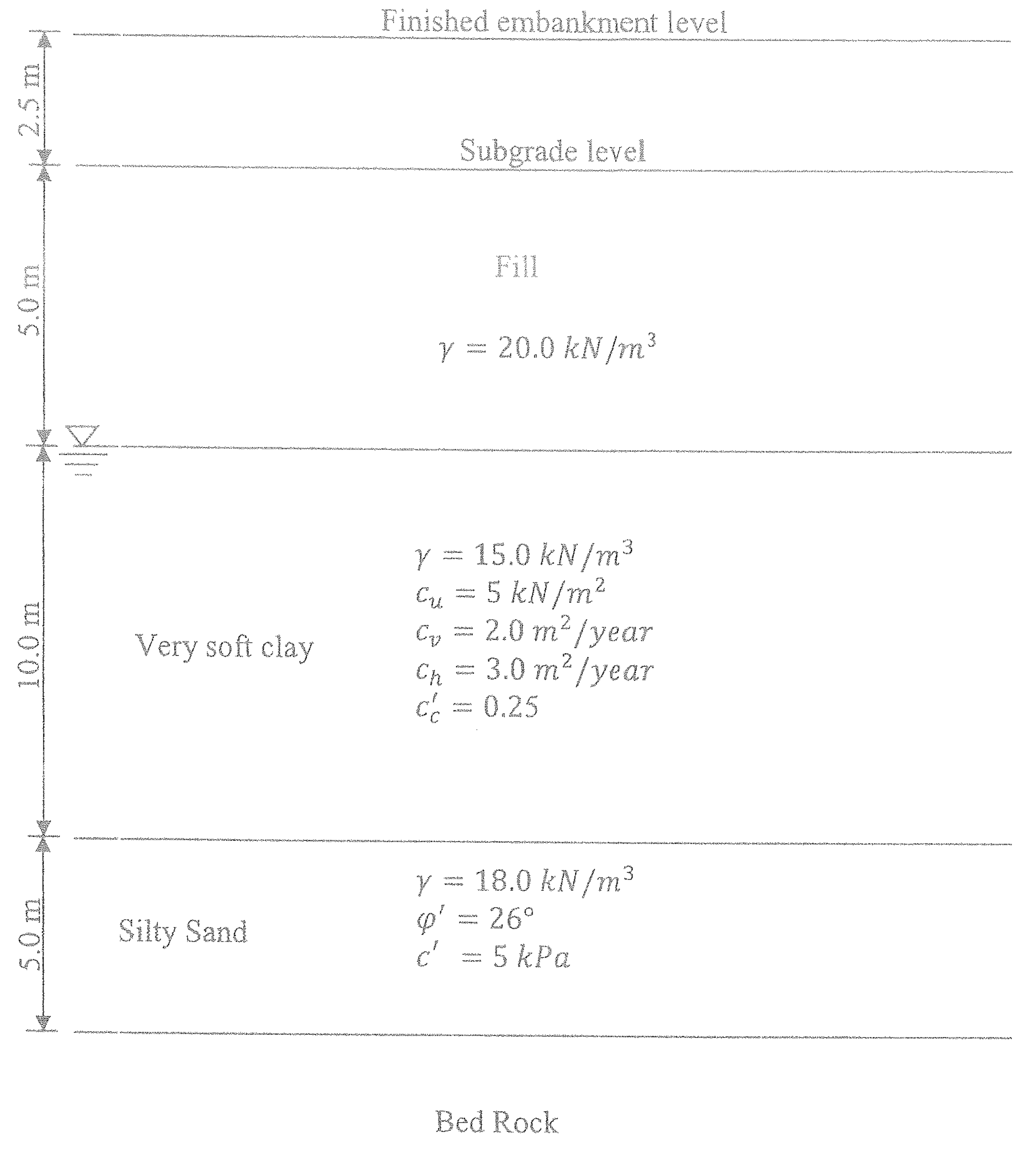

Figure Q1.1 Cross section of the embankment with sub surface soil profile

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						

[a] After Vesic (1973)

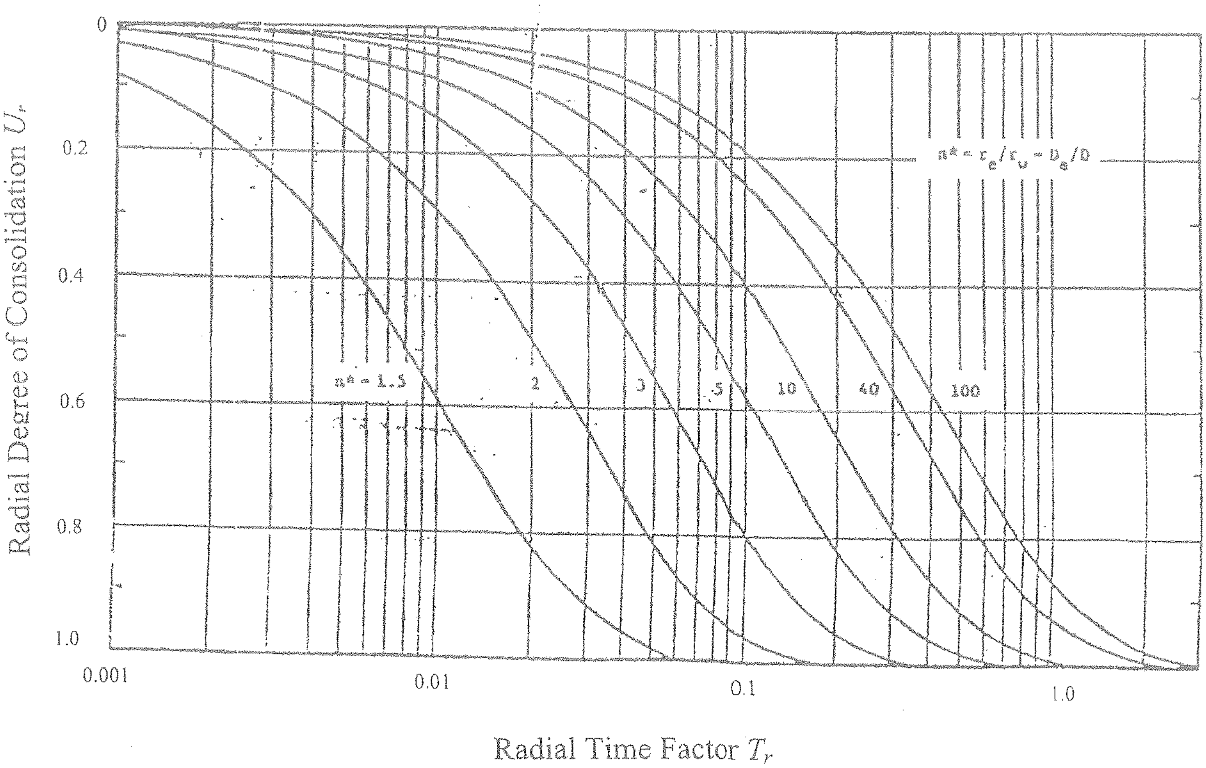

Figure Q1.2 Variation of degree of consolidation in radial direction with time factor

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 medium stiff clay

Saturated unit weight	16.0 kN/m^3
Coefficient of consolidation	10.0 $m^2/year$
Compression index	0.2
Initial void ratio	1.0
Modified secondary compression index	0.005
Undrained shear strength	20.0 kN/m^2

Table Q3.1 – Properties of soft clay

Saturated unit weight	15.0 kN/m^3
Coefficient of consolidation in vertical direction	2.0 $m^2/year$
Coefficient of consolidation in horizontal direction	4.0 $m^2/year$
Compression index	0.6
Initial void ratio	1.2
Coefficient of horizontal permeability	1×10^{-7} cm/s

Table Q3.2 – 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

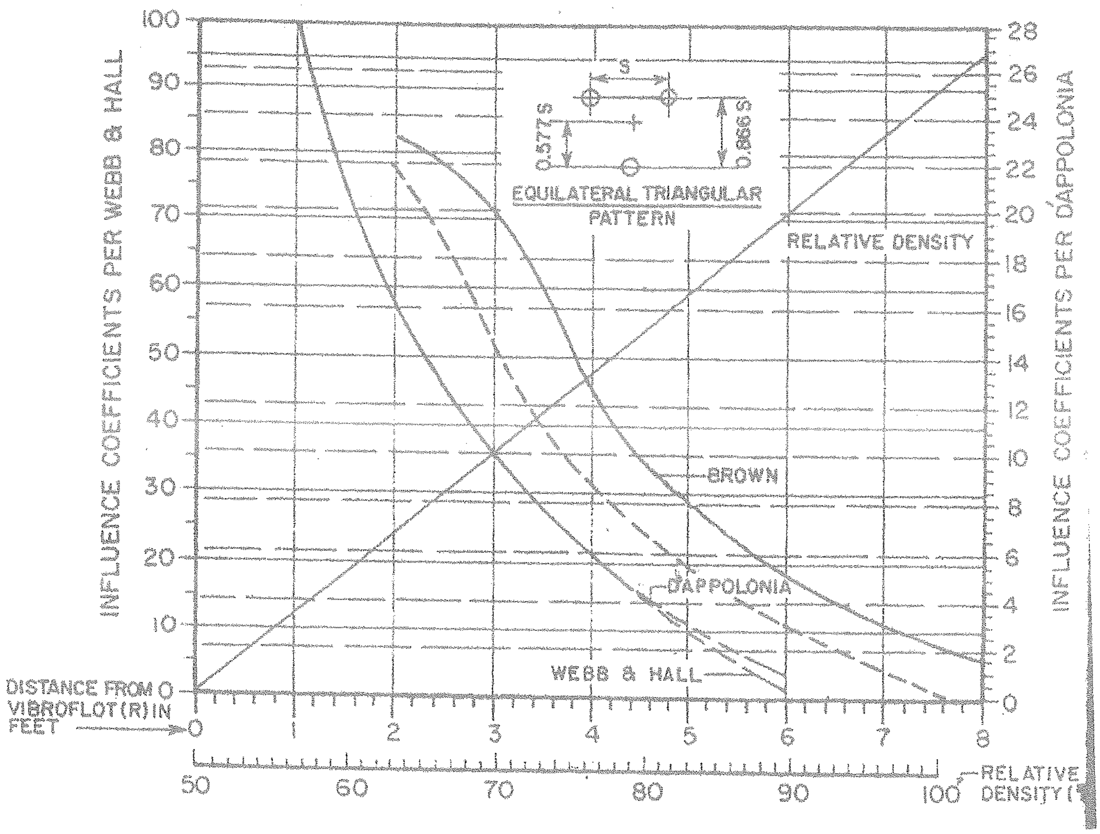

Figure Q5.1 - Area pattern design chart (D'Appolonia's chart)