UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: November 2016

Module Number: CE6305 **Module Name: Geotechnical Engineering**

[Three Hours]

[Answer **all questions**, each question carries twelve marks]

Q1. A highway is to be constructed over a low lying area underlained by a 6.0 m thick clay layer. Based on the borehole tests conducted at the site, sub surface soil profile was idealized as shown in Figure Q1.1. It can be seen that soft clay layer is sandwitched between two sand layers. Water table was found to be at a depth of 3.0 m from the existing ground level.
It was decided to raise the road level by 1.6 m using a soil fill, and the dead and live loads of the highway to be applied on the ground will be 25 kN/m^2. In order to compensate the dead and live loads of the highway, 1.25 m height additional soil fill will be placed on the embankment as shown in Figure Q1.1. The bulk unit weight of the sand above and below the water table can be taken as 18.0 kN/m^3 and 19.0 kN/m^3, respectively. The dry unit weight of the fill material can be taken as is 20.0 kN/m^3. The bulk unit weight of the soft clay is 16.0 kN/m^3. The unit weight of water can be taken as 9.81 kN/m^3.
In order to determine the compressibility characteristics of the soft clay, a series of laboratory oedometer tests were conducted on an undisturbed clay sample obtained from the site and results are presented in Figure Q1.2.
In order to monitor the pore water pressure development during construction, a piezometer was installed at mid depth of the clay layer as shown in the Figure Q1.1. You may use the data in Figure Q1.3 and Table Q1.1 for necessary calculations.

a) What would be the height of the water level in the piezometer immediately after construction of the embankment? You may assume that fill of the embankment is placed instantaneously.

[2.0 Marks]

b) State whether the clay is normally consolidated or over consolidated and calculate the expected primary consolidation settlement of the clay layer due to intended load.

[4.0 Marks]

c) Calculate the expected water level in the piezometer 1 year after the end of embankment construction assuming that coefficient of consolidation (C_v) of the clay is 2.0 m^2/year.

[3.0 Marks]

d) If the piezometer is installed at a depth of 12.5 m from the existing ground surface, what would be the expected water level in the piezometer 1 year after the end of embankment construction?

[1.0 Marks]

e) If the allowable settlement of the road is 50 mm, what would be the earliest time that surfacing can start?

[2.0 Marks]

Q2. A rectangular shallow foundation of 2.0 m × 1.0 m size is to be constructed over a 3.0 m thick clay layer drained in two ways through sand layers, and ground profile of the area is shown in Figure Q2.1. Plan view of the footing is shown in Figure Q2.2. Water table of the area is found to be at a depth of 1.0 m from the existing ground surface. Dry unit weight of sand is found to be 17.5 kN/m³ and saturated unit weights of sand and clay are 18.5 kN/m³ and 16.0 kN/m³, respectively. Specific gravity of the clay is 2.69 and the moisture content is 22%. The compression index of the soft clay was found to be 0.3. The unit weight of water can be taken as 9.81 kN/m³.
It is expected to transfer a load of 660 kN from the superstructure to the ground through the footing and the coefficient of consolidation value of clay can be taken as 2.5 m²/year. You may use the data in Table Q1.1 and Table Q2.1 for necessary calculations.

a) List four factors which affect the rate of consolidation?

[2.0 Marks]

b) Draw the phase diagram and derive following equation with usual notations.

$$\gamma = \frac{G_s \gamma_w (1 + w)}{(1 + e)}$$

[1.5 Marks]

c) Assuming that clay is normally consolidated, calculate the primary consolidation settlement that will be experienced,

i.) at point A and,

ii.) at point B of the footing, 1 year after the construction.

[6.0 Marks]

d) What would be the differential settlement of the footing 1 year after the construction?

[0.5 Marks]

e) What would be the expected secondary consolidation settlement at center of the clay layer (Point B) 3 years after the end of primary consolidation? The modified secondary compression index of clay is 0.005.

[2.0 Marks]

Q3. A cross section of a concrete dam is shown in Figure Q3.1. The upstream water level is 5.0 m above the existing ground level whereas the downstream water level is 1.0 m above the existing ground level. In order to reduce the seepage, a cutoff wall has been constructed as shown in Figure Q3.1. The flow net has been drawn by trial and error manual sketching and presented in Figure Q3.1. The coefficient of permeability of foundation soil is 2.5 x 10^{-5} m/s.

a) Determine the quantity of seepage under the dam.

[2.5 Marks]

b) Determine the pore water pressures on the base of the dam and draw the pressure distribution.

[5.0 Marks]

c) If porosity of the foundation soil is 0.2, estimate the seepage velocity at Point A.

[2.5 Marks]

d) Calculate the factor of safety against piping. The unit weight of foundation soil is 18.5 kN/m³. The unit weight of water can be taken as 9.81 kN/m³.

[2.0 Marks]

Q4. There is a proposal to construct a retaining wall to support a slope as shown in Figure Q4.1. In order to design the retaining wall according to BS8002, it is necessary to find the shear strength parameters of the retained soil. Therefore, an undisturbed soil sample was collected from the retained soil and two numbers of Consolidated Undrained (CU) triaxial tests were conducted in the laboratory and test results are presented in Table Q4.1.

a) Draw a Mohr-Coulomb diagram and derive the following expression for Rankine active earth pressure developed in a soil with usual notations.

$$\sigma_1 = \sigma_3\left(\frac{1+Sin\varphi}{1-Sin\varphi}\right) + 2c\frac{Cos\varphi}{(1-Sin\varphi)}$$

[2.0 Marks]

b) Determine the shear strength parameters in terms of total stress and effective stress of the retained soil.

[4.0 Marks]

c) Using the effective shear strength parameters of the retained soil, determine the resultant force acting on the wall due to trial wedge shown in Figure Q4.1. The trial failure surface is 55° to the horizontal (θ= 55^0). Wall adhesion is 10.0 kPa and friction angle between wall and soil is 20^0. There is an obligatory surcharge of 10.0 kN/m^2 on the surface of the retained side. The unit weight of soil is 19.0 kN/m^3 and α= 78^0, β = 10^0. Assume that the water table is well below the ground surface.

[5.0 Marks]

d) If the water table is at the ground surface of the retained side, suggest a suitable method/s to improve the stability of the retaining wall with the aid of a sketch.

[1.0 Marks]

Q5. a) Briefly explain the importance of conducting site investigation and list the information to be gathered from site investigation?

[2.0 Marks]

b) As a part of site investigation, Standard Penetration Test (SPT) was conducted and sub-surface soil profile with field SPT-*N* values are shown in Figure Q5.1. During sub surface exploration, it was revealed that water table is located at a depth of 1.0 m from the ground surface. Unit weights of fill material in dry condition, fill material in saturated condition, loose sandy soil and dense sand are 16.0 kN/m^3, 17.0 kN/m^3, 18.0 kN/m^3 and 19.5 kN/m^3, respectively. The length of the drilling rod which is used to connect the sampler is 8.0 m. The diameter of the bore hole was found to be 150 mm. The safety hammer with energy ratio of 75 % was used to penetrate the sampler into the ground. There is no liner inside the sampler. The unit weight of water can be taken as 9.81 kN/m^3.

i) Estimate the "Average Standard SPT-*N* value" in the loose sandy soil layer. Table Q5.1 may be referred for correction factors.

[2.5 Marks]

ii) If inner and outer diameter of the split spoon sampler is 34.5 mm and 50.0 mm, respectively compute the degree of disturbance, in terms of area ratio, of the sample obtained from the above sub soil exploration method.

[1.0 Marks]

c) In addition to the borehole investigation, geophysical exploration was used as a site investigation method in order to cover large area of the site. A seismic refraction survey was conducted to determine the layer thicknesses by impacting the surface and observed the first arrival of the stress waves at several points and recorded by geophones. The recorded data are given in Table Q5.2 and the results are graphically presented in Figure Q5.2.

Following equations with usual notations may be useful in the calculations.

$$Z_1 = \frac{1}{2}\sqrt{\frac{(v_2 - v_1)}{(v_2 + v_1)}}.x_c$$

$$Z_2 = \frac{1}{2}\left[T_{i2} - 2Z_1\frac{\sqrt{(v_3^2 - v_1^2)}}{(v_3 v_1)}\right]\frac{(v_3 v_2)}{\sqrt{(v_3^2 - v_2^2)}}$$

i) What are the advantages and disadvantages of geophysical exploration technique in site investigation?

[1.0 Marks]

ii) Calculate the thicknesses of the first and the second layers.

[3.5 Marks]

iii) What are the limitations in seismic refraction survey?

[0.5 Marks]

d) What type of information should be included in a sub soil exploration report?

[1.5 Marks]

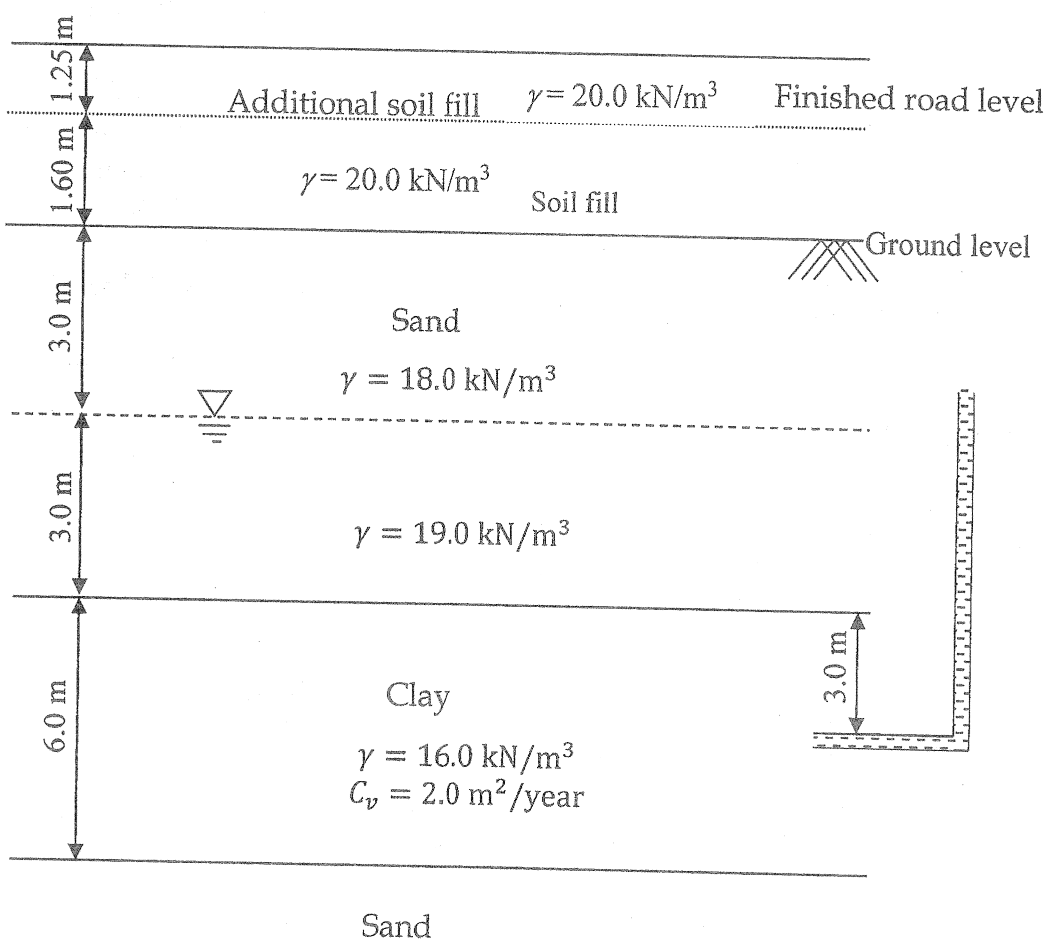

Figure Q1.1 Cross section of the ground profile

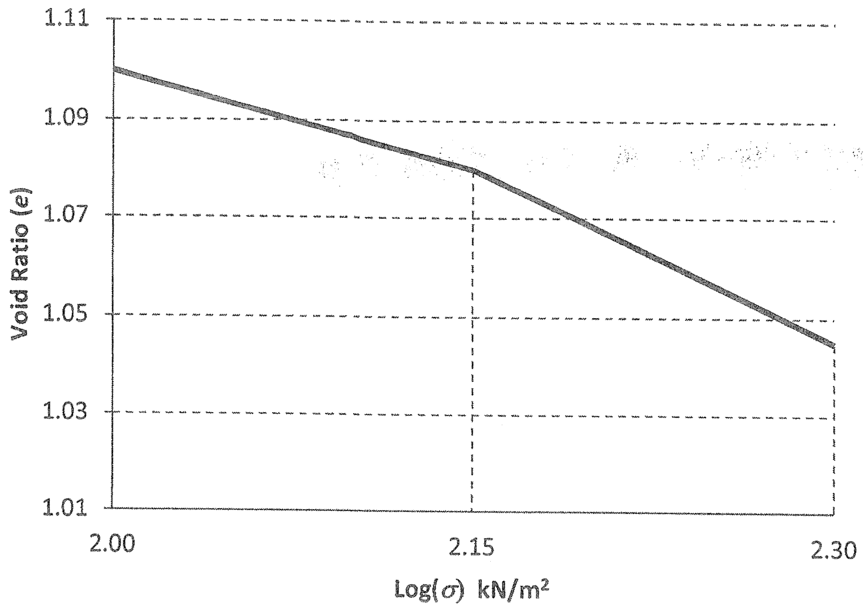

Figure Q1.2 Relationship between void ratio and effective vertical stress

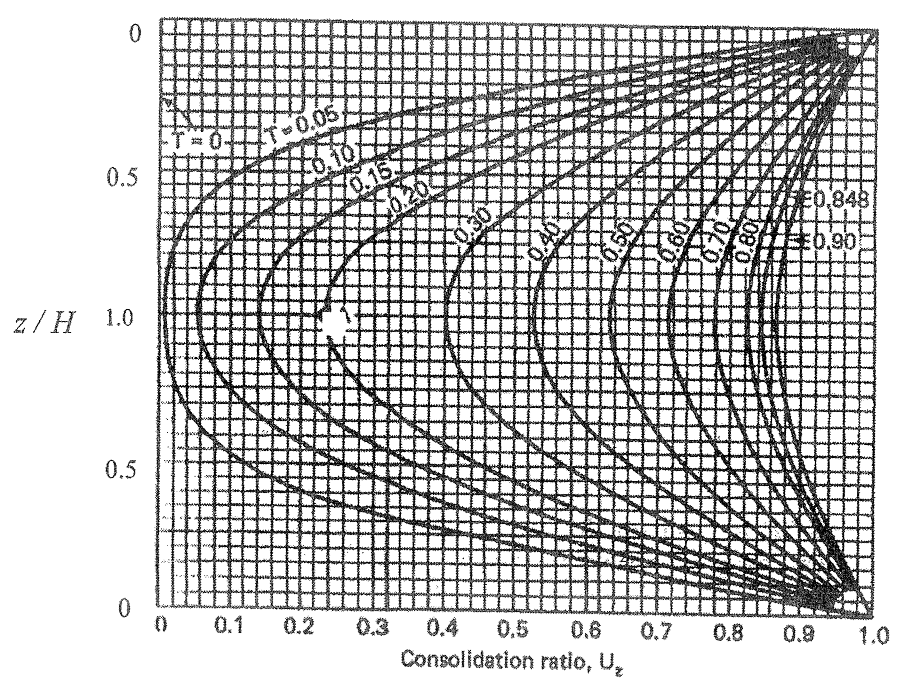

Figure Q1.3 Variation of Tv with z/H and Uz

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		

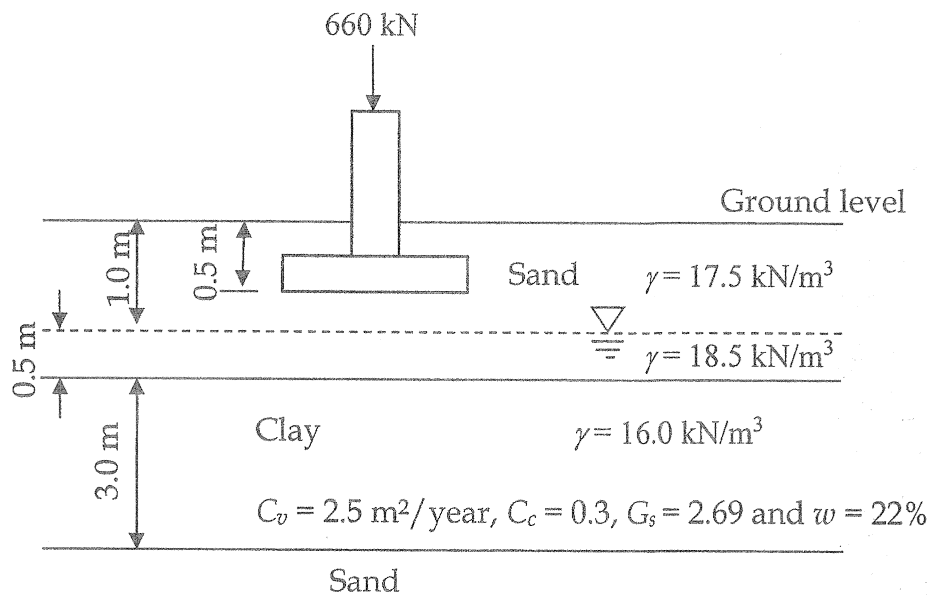

Figure Q2.1 Cross section of the ground profile

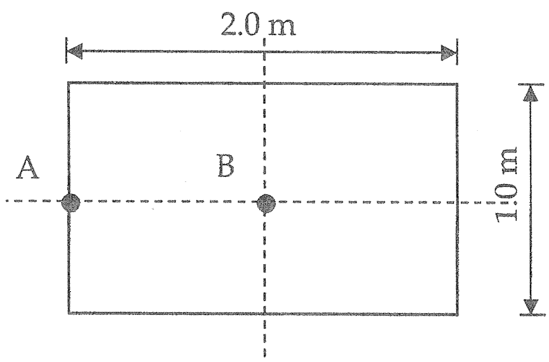

Figure Q2.2 Plan view of the foundation

Table Q2.1 Variation of I_3 with m and n

n	m = 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	1.6	1.8	2.0	2.5	3.0	4.0	5.0	6.0
0.1	0.0047	0.0092	0.0132	0.0168	0.0198	0.0222	0.0242	0.0258	0.0270	0.0279	0.0293	0.0301	0.0306	0.0309	0.0311	0.0314	0.0315	0.0316	0.0316	0.0316
0.2	0.0092	0.0179	0.0259	0.0328	0.0387	0.0435	0.0474	0.0504	0.0528	0.0547	0.0573	0.0589	0.0599	0.0606	0.0610	0.0616	0.0618	0.0619	0.0620	0.0620
0.3	0.0132	0.0259	0.0374	0.0474	0.0559	0.0629	0.0686	0.0731	0.0766	0.0794	0.0832	0.0856	0.0871	0.0880	0.0887	0.0895	0.0898	0.0901	0.0901	0.0902
0.4	0.0168	0.0328	0.0474	0.0602	0.0711	0.0801	0.0873	0.0931	0.0977	0.1013	0.1063	0.1094	0.1114	0.1126	0.1134	0.1145	0.1150	0.1153	0.1154	0.1154
0.5	0.0198	0.0387	0.0559	0.0711	0.0840	0.0947	0.1034	0.1104	0.1158	0.1202	0.1263	0.1300	0.1324	0.1340	0.1350	0.1363	0.1368	0.1372	0.1374	0.1374
0.6	0.0222	0.0435	0.0629	0.0801	0.0947	0.1069	0.1168	0.1247	0.1311	0.1361	0.1431	0.1475	0.1503	0.1521	0.1533	0.1548	0.1555	0.1560	0.1561	0.1562
0.7	0.0242	0.0474	0.0686	0.0873	0.1034	0.1169	0.1277	0.1365	0.1436	0.1491	0.1570	0.1620	0.1652	0.1672	0.1686	0.1704	0.1711	0.1717	0.1719	0.1719
0.8	0.0258	0.0504	0.0731	0.0931	0.1104	0.1247	0.1365	0.1461	0.1537	0.1598	0.1684	0.1739	0.1774	0.1797	0.1812	0.1832	0.1841	0.1847	0.1849	0.1850
0.9	0.0270	0.0528	0.0766	0.0977	0.1158	0.1311	0.1436	0.1537	0.1619	0.1684	0.1777	0.1836	0.1874	0.1899	0.1915	0.1938	0.1947	0.1954	0.1956	0.1957
1.0	0.0279	0.0547	0.0794	0.1013	0.1202	0.1361	0.1491	0.1598	0.1684	0.1752	0.1851	0.1914	0.1955	0.1981	0.1999	0.2024	0.2034	0.2042	0.2044	0.2045
1.2	0.0293	0.0573	0.0832	0.1063	0.1263	0.1431	0.1570	0.1684	0.1777	0.1851	0.1958	0.2028	0.2073	0.2103	0.2124	0.2151	0.2163	0.2172	0.2175	0.2176
1.4	0.0301	0.0589	0.0856	0.1094	0.1300	0.1475	0.1620	0.1739	0.1836	0.1914	0.2028	0.2102	0.2151	0.2184	0.2206	0.2236	0.2250	0.2260	0.2263	0.2264
1.6	0.0306	0.0599	0.0871	0.1114	0.1324	0.1503	0.1652	0.1774	0.1874	0.1955	0.2073	0.2151	0.2203	0.2237	0.2261	0.2294	0.2309	0.2320	0.2323	0.2325
1.8	0.0309	0.0606	0.0880	0.1126	0.1340	0.1521	0.1672	0.1797	0.1899	0.1981	0.2103	0.2183	0.2237	0.2274	0.2299	0.2333	0.2350	0.2362	0.2366	0.2367
2.0	0.0311	0.0610	0.0887	0.1134	0.1350	0.1533	0.1686	0.1812	0.1915	0.1999	0.2124	0.2206	0.2261	0.2299	0.2325	0.2361	0.2378	0.2391	0.2395	0.2397
2.5	0.0314	0.0616	0.0895	0.1145	0.1363	0.1542	0.1704	0.1832	0.1938	0.2024	0.2151	0.2236	0.2294	0.2333	0.2361	0.2401	0.2420	0.2434	0.2439	0.2441
3.0	0.0315	0.0618	0.0898	0.1150	0.1368	0.1555	0.1711	0.1841	0.1947	0.2034	0.2163	0.2250	0.2309	0.2350	0.2378	0.2420	0.2439	0.2455	0.2461	0.2463
4.0	0.0316	0.0619	0.0901	0.1153	0.1372	0.1560	0.1717	0.1847	0.1954	0.2042	0.2172	0.2260	0.2320	0.2362	0.2391	0.2434	0.2455	0.2472	0.2479	0.2481
5.0	0.0316	0.0620	0.0901	0.1154	0.1374	0.1561	0.1719	0.1849	0.1956	0.2044	0.2175	0.2263	0.2324	0.2366	0.2395	0.2439	0.2460	0.2479	0.2486	0.2489
6.0	0.0316	0.0620	0.0902	0.1154	0.1374	0.1562	0.1719	0.1850	0.1957	0.2045	0.2176	0.2264	0.2325	0.2367	0.2397	0.2441	0.2463	0.2482	0.2480	0.2492

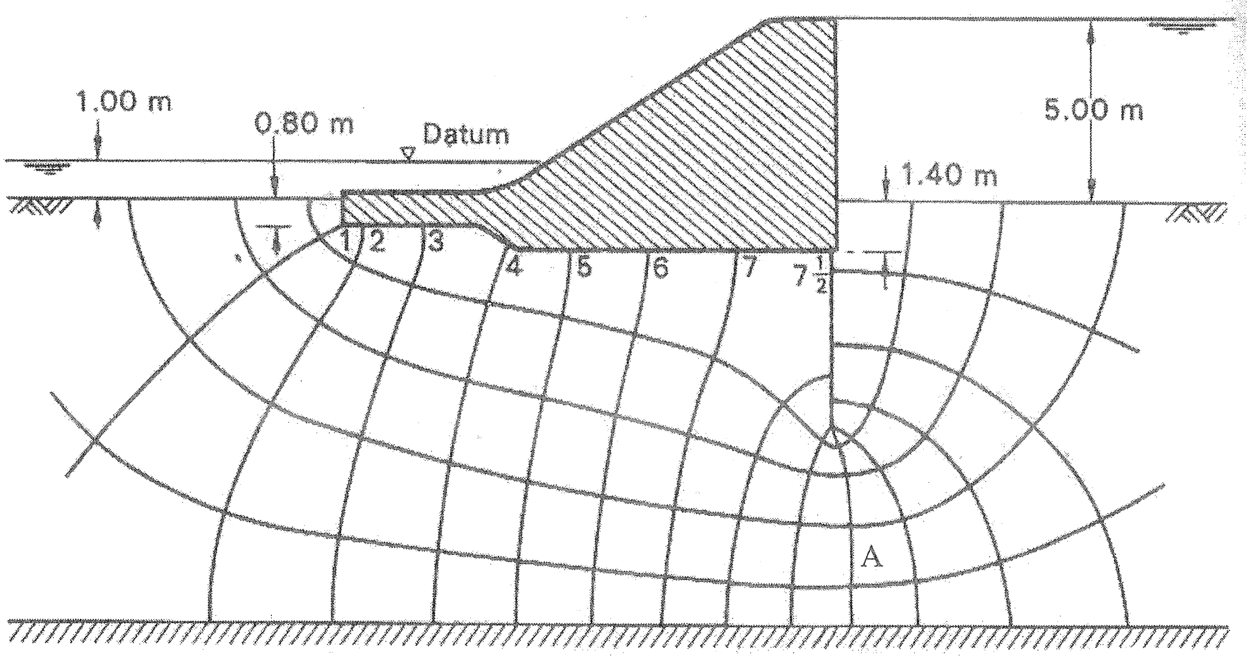

Figure Q3.1 – Flow net for the concrete dam with a cutoff wall

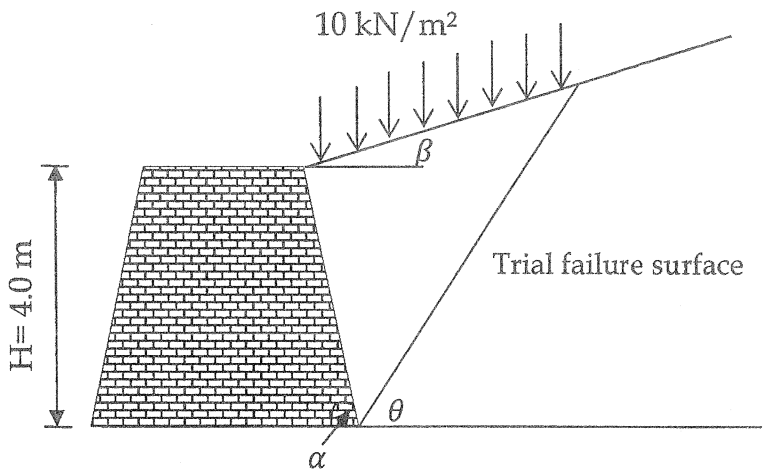

Figure Q4.1 Cross section of the proposed retaining wall

Table Q4.1 Triaxial test results (CU)

Test Number	σ_3 (kPa)	σ_1 (kPa)	u (kPa)
1	50	203.7	25
2	100	388.2	50

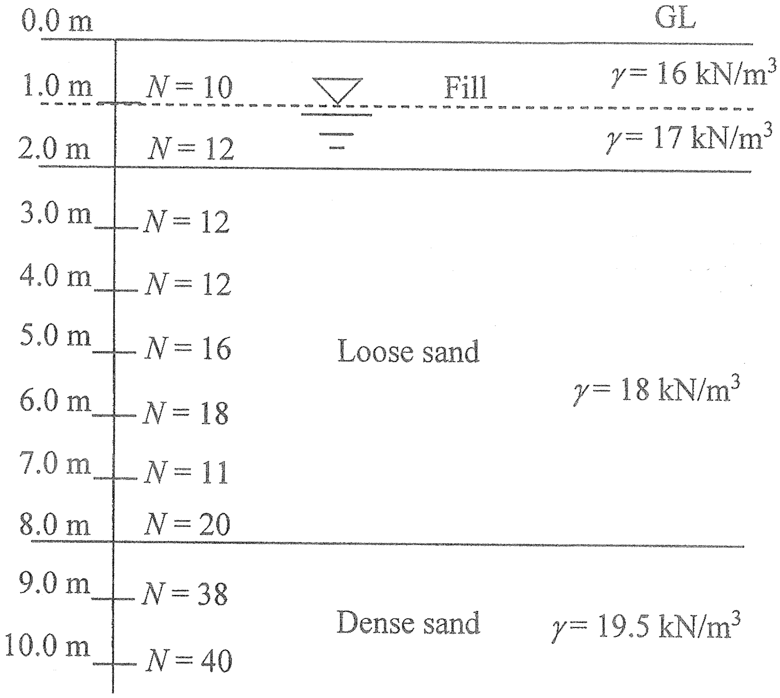

Figure Q5.1 Sub surface soil profile

Table Q5.2 Seismic refraction survey data

Distance from the source of disturbance (m)	Time of first arrival ($s \times 10^{-3}$)
2	12.5
5	30
8	48
12	72
18	90
24	105
30	118
35	124
40	128
45	132
55	138

Table Q5.1 Correction factors

	Hammer for η_1				Remarks
	Average energy ratio E_r				
	Donut		Safety		
Country	**R-P**	**Trip**	**R-P**	**Trip/Auto**	R-P = Rope-pulley or cathead
United States					$\eta_1 = E_r / E_{rb}$
North America	45	-	70-80	80-100	For U.S. trip / auto $w/E_r = 80$
Japan	67	78	-	-	$\eta_1 = 80 / 70 = 1.14$
United Kingdom	-	-	50	60	
China	50	60	-	-	
	Rod length correction η_2				
Length	> 10 m	$\eta_2 = 1.00$			N is too high for L < 10 m
	6-10 m	$\eta_2 = 0.95$			
	4-6 m	$\eta_2 = 0.85$			
	0-4 m	$\eta_2 = 0.75$			
	Sampler correction η_3				
Without liner		$\eta_3 = 1.00$			Base value
With liner : Dense sand, clay		$\eta_3 = 0.80$			N is too high with liner
With liner : Loose sand		$\eta_3 = 0.90$			
	Bore hole diameter correction η_4				
Hole diameter	60-120 mm		$\eta_4 = 1.00$		Base value; N is too small when have an oversize hole
	150 mm		$\eta_4 = 1.05$		
	200 mm		$\eta_4 = 1.15$		

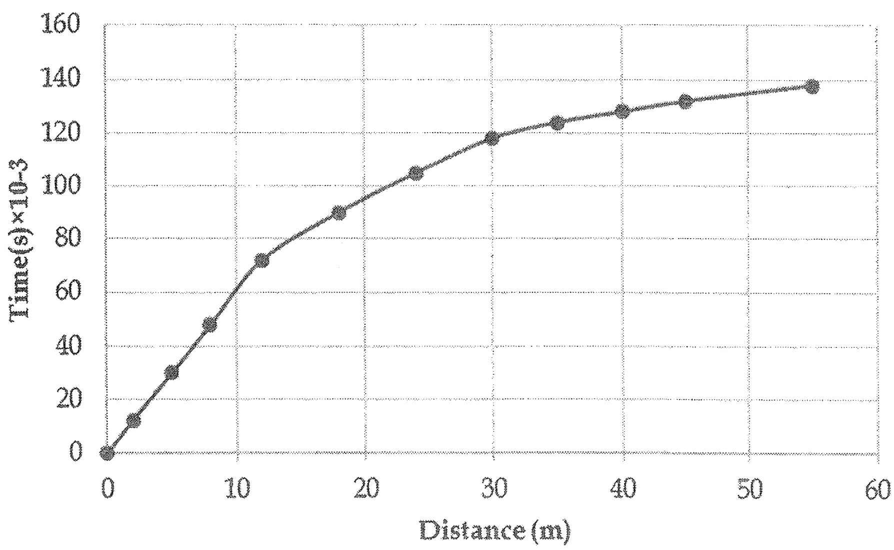

Figure Q5.2 Seismic refraction survey results