UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: February 2020

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

[Three Hours]

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

Q1. In a highway construction project, a part of the road is going through a paddy field area. Based on the borehole investigations, subsurface soil profile at the site can be idealized as shown in Figure Q1.1. It can be seen that subsurface consists of 6.0 m thick soft clay layer followed by 4.0 m thick dense sand layer. Bed rock is at a depth of 10.0 m from the existing ground surface. Water table was found to be at the existing ground level.

Based on flood records of the area, it was decided to raise the subgrade by 4.0 m from the exiting ground level. A drainage layer of 1.0 m thickness together with geotextiles will be placed on the existing ground surface before place the fill to provide doubly drain condition. In order to compensate the pavement and traffic load (25.0 kN/m^2) of the road and to accelerate the consolidation, 2.5 m thick compacted soil fill will be placed on the subgrade level as shown in Figure Q1.1.

The bulk unit weights of the soft clay, drainage layer and compacted fill can be taken as 16.0 kN/m^3, 18.0 kN/m^3 and 20.0 kN/m^3, respectively. The unit weight of water can be taken as 9.81 kN/m^3.

The compressibility characteristics of the soft clay were determined by conducting a series of laboratory oedometer tests. Coefficient of consolidation (C_v), compression index (C_c) and void ratio (e_0) were found as 5.0 m^2/year, 0.3 and 0.5, respectively.

You may refer Table Q1.1 and Figure Q1.2 for necessary calculations.

a) List four factors that affect the rate of consolidation.

[1.0 Marks]

b) What are the purposes of placing geotextiles above and below the drainage layer?

[1.0 Marks]

c) What would be the expected pore water pressure at a depth of 1.5 m from the existing ground surface, 6 months after the embankment construction?

[3.0 Marks]

d) What would be the expected primary consolidation settlement of the soft clay layer due to construction of 6.5 m height embankment assuming that clay is normally consolidated?

[1.0 Marks]

e) If modified secondary compression index is 0.01, what would be the expected secondary consolidation settlement 3 year after the end of primary consolidation? Hence, determine the total settlement 3 year after the end of primary consolidation?

[3.0 Marks]

f) If excess soil is removed upto the subgrade level after 95% of the primary consolidation, what would be the expected removable fill height?

[1.5 Marks]

g) What would be the Over Consolidation Ratio (OCR) of clay after removal of the fill upto the subgrade level?

[1.5 Marks]

Q2. For a development project on a marshy land, it was decided to conduct comprehensive site investigation. Borehole investigations together with Cone Penetration Tests (CPT) were conducted to identify the subsurface soil profile and it was found that sub surface mainly consists of saturated soft clay. Consolidation test was conducted on an undisturbed soil sample obtained from the soft clay layer at a depth of 5.0 m from the ground surface and results are presented in Figure Q2.1, Figure Q2.2 and Table Q2.1. The saturated 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.

You may refer Table Q1.1 for necessary calculations.

[Note: The Figure Q2.1 and Figure Q2.2 (Page 7)should be attached to the answer book]

a) List four types of information expected from site investigation.

[2.0 Marks]

b) What are the advantages and disadvantages of Cone Penetration Test (CPT) over Standard Penetration Test (SPT)? List two factors for each.

[2.0 Marks]

c) Determine the Coefficient of consolidation (C_v) of soft clay in m^2/year for the stress range of 100-200 kN/m^2?

[2.5 Marks]

d) Determine the Coefficient of volume compressibility (m_v) of soft clay in m^2/kN for the stress range of 100-200 kN/m^2.

[1.0 Marks]

e) Based on the Oedometer test data provided, what would be the initial void ratio of the soft clay?

[2.5 Marks]

f) Based on $e\ Vs\ Log(\sigma_v')$ plot as shown in Figure Q2.2, determine whether clay soil is normally consolidated or over consolidated.

[1.5 Marks]

g) What would be the Coefficient of permeability of the soft clay?

[0.5 Marks]

Q3. There is a proposal to construct a 5 storied building at a site. In order to find the sub surface soil profile, borehole investigation was conducted prior to the construction. The sub surface consists of 4.0 m thick medium dense sand layer followed by medium stiff clay layer as shown in Figure Q3.1. Completely weathered rock is encountered 8.0 m below the ground surface. Water table is encountered at a depth of 2.5 m from the ground surface. Dry unit weight and specific gravity of medium dense sand are 17.0 kN/m^3 and 2.7 respectively. Saturated unit weight of medium stiff clay is 16.0 kN/m^3. The unit weight of water can be taken as 9.81 kN/m^3.

a) To determine the shear strength parameters of medium dense sand, a direct shear was conducted and results are summarized in Table Q3.1.

   i) Determine the shear strength parameters of sand.

   [1.5 Marks]

   ii) Determine the magnitude of principal stresses in the zone of failure.

   [2.0 Marks]

iii) Draw the phase diagrams for dry and saturated zones of medium dense sand layer and derive following equations with usual notations.

- $\gamma_d = \frac{G_s \gamma_w}{1+e}$
- $\gamma_{sat} = \frac{(G_s + e)\gamma_w}{1+e}$

[1.5 Marks]

iv) Determine the void ratio and saturated unit weight of medium dense sand.

[1.0 Marks]

v) What is the shear strength of medium dense sand along a horizontal plane at a depth of 4.0 m from the ground surface? When the water table rise up to the ground surface, what would be the change in shear strength?

[2.5 Marks]

b) To determine the shear strength parameters of medium stiff clay, Consolidated Undrained (CU) triaxial test was conducted using an undisturbed sample collected from the medium stiff clay layer. Based on the data gathered from the CU tests, effective shear strength parameters of medium stiff clay were found as $c' = 16\ kN/m^2$ and $\varphi' = 29°$. Cell pressure, deviator stress and shear stress at failure of a sample are shown in Table Q3.2.

i) Draw a Mohr circle *(not to scale)* and show the failure plane, and determine the angle that the failure plane makes with the major principal plane.

[1.0 Marks]

ii) Determine the effective normal stress σ' and shear stress τ_f on the failure plane.

[1.5 Marks]

iii) If a soil sample is subjected to an effective normal stress σ' of 150 kN/m^2 together with shear stress τ of 70 kN/m^2, determine whether the soil sample is stable or not? Justify your answer.

[1.0 Marks]

Q4. A river bed consists of a layer of sand of thickness 8.25 m overlying impermeable bed rock. The river water level is 2.5 m above the river bed level. A long cofferdam of 5.5m wide is formed by driving 2 lines of sheet piling to a depth of 6.0 m below the river bed level in order to do an excavation of 2.0 m below the river bed level for foundation construction as shown in Figure Q4.1. Saturated unit weight of the sand is 16.0 kN/m^3. The water level within the cofferdam (inside the excavation) is kept at excavation level by continuous pumping. Outside the excavation, the water table remained at the initial water level. The flow net drawn for the above case is presented in Figure Q4.1. At steady state, the pumping rate within the cofferdam is 0.25 m^3/hr per unit length. The unit weight of water can be taken as 9.81 kN/m^3.

a) What would be the coefficient of permeability of the sand?

[2.5 Marks]

b) Determine the pore water pressures at points A and B.

[3.0 Marks]

c) If porosity of the sand is 0.3, estimate the seepage velocity at the shaded element **X**.

[2.0 Marks]

d) What would be the maximum exit gradient?

[0.5 Marks]

e) Calculate the factor of safety against piping.

[2.0 Marks]

f) What would be the effective stress at point A?

[1.0 Marks]

g) What would be the maximum seepage force per unit volume?

[1.0 Marks]

Q5. A vertical cut is supported by a 4.0 m high mass concrete retaining wall as shown in Figure Q5.1. The obligatory surcharge on the retained side is 10 kN/m². Soil on the retained side has effective shear strength parameters of $\varphi' = 26°$ and $c' = 8\ kN/m^2$. Bulk unit weight of the soil is 15 kN/m³. The water table is well below the ground surface. The unit weight of water can be taken as 9.81 kN/m³.
To design this retaining wall, it is necessary to estimate the lateral force exerted from the retained side.

a) Assuming a frictionless retaining wall, determine the active force per unit length of the retaining wall?

[3.5 Marks]

b) When the wall surface is rough, Coulomb's trial wedge approach is used to determine active force on the retaining wall. In order to find the active force on the retaining wall, a trial wedge ABD was selected as shown in Figure Q5.2. For a conservative design, it is assumed that water table is at the ground surface and to facilitate for proper drainage, weep holes are provided at regular intervals in the retaining wall. The interface friction angle (δ) and adhesion (c_w) between mass concrete retaining wall and soil can be taken as $\delta = 20°$ and $c_w = 6\ kN/m^2$ respectively. Further, it is assumed that an impermeable bed rock is at a depth of 4.0 m from the ground surface as shown in Figure Q5.2.

i) Briefly explain why is it important to provide rubble packing together with a geotextile behind the retaining wall?

[1.0 Marks]

ii) Briefly explain a method to estimate pore water force (U) on the trial failure surface **AB** with suitable sketches.

[1.5 Marks]

iii) Draw ABD trial wedge and mark all the forces acting on the trial wedge.

[1.5 Marks]

iv) If pore water force on the trial failure surface is 56 kN, determine the active force on the retaining wall by using Coulomb's graphical method without considering the effect of tension crack.
(*Note: You may plot to a scale of 1 mm = 1 kN*)

[4.5 Marks]

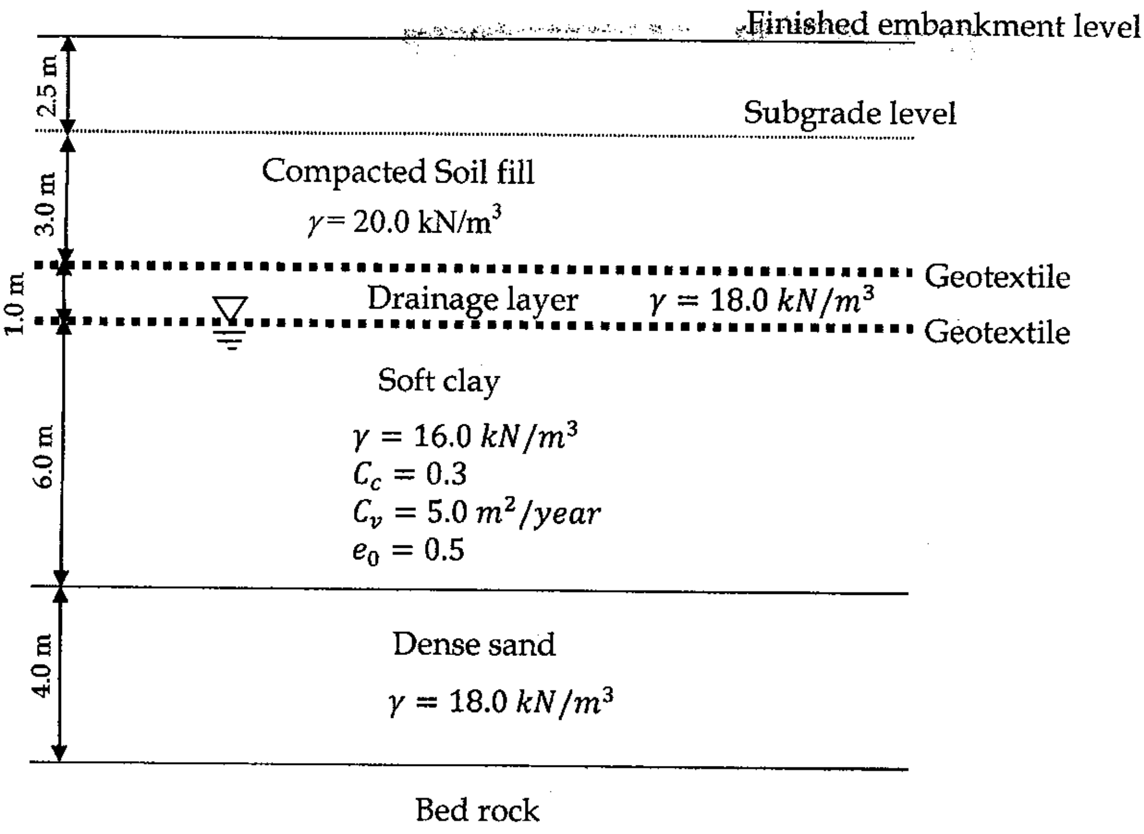

Figure Q1.1 Cross section of ground profile

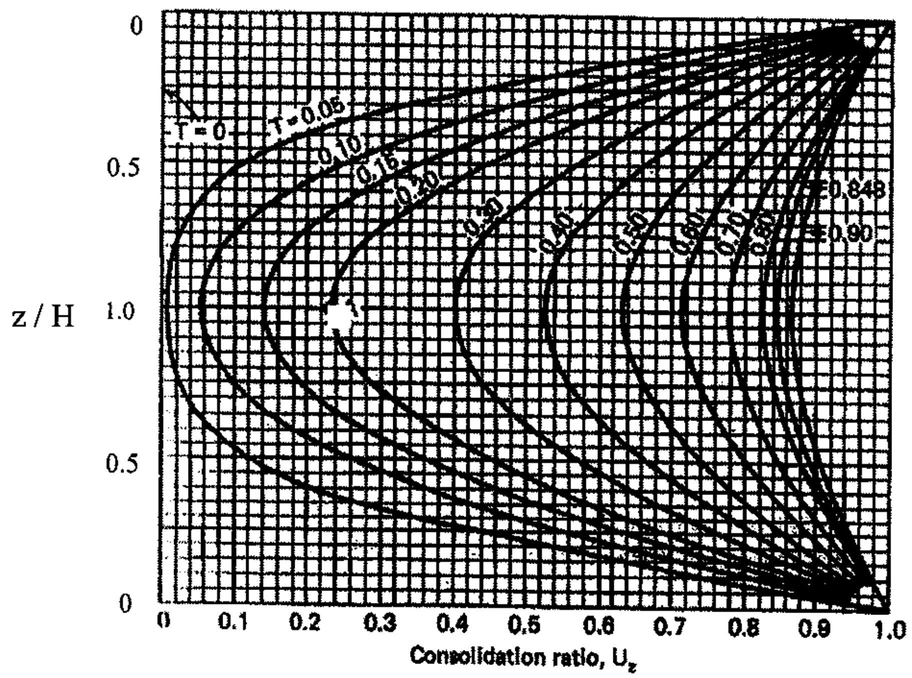

Figure Q1.2 Variation of T_v with z/H and U_z

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		

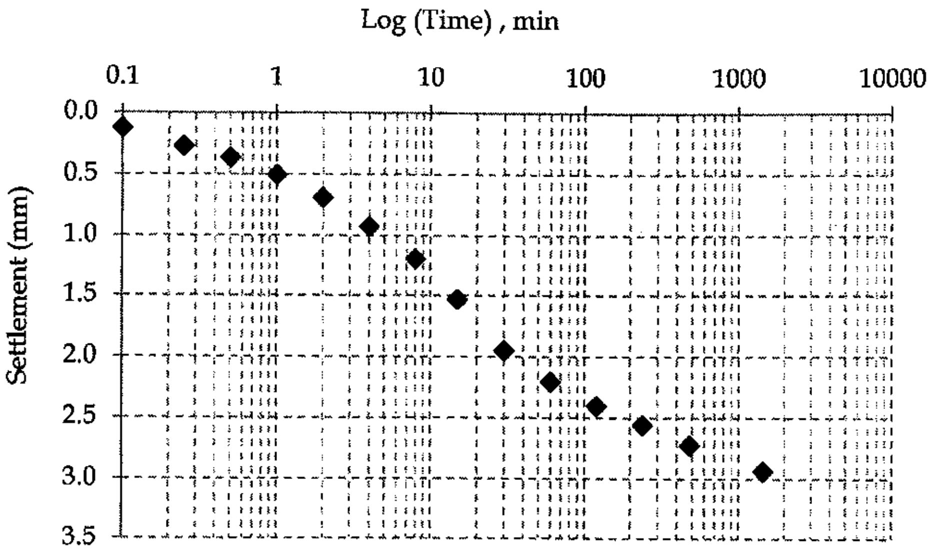

Figure Q2.1 - Variation of settlement over time for stress range of 100-200 kPa

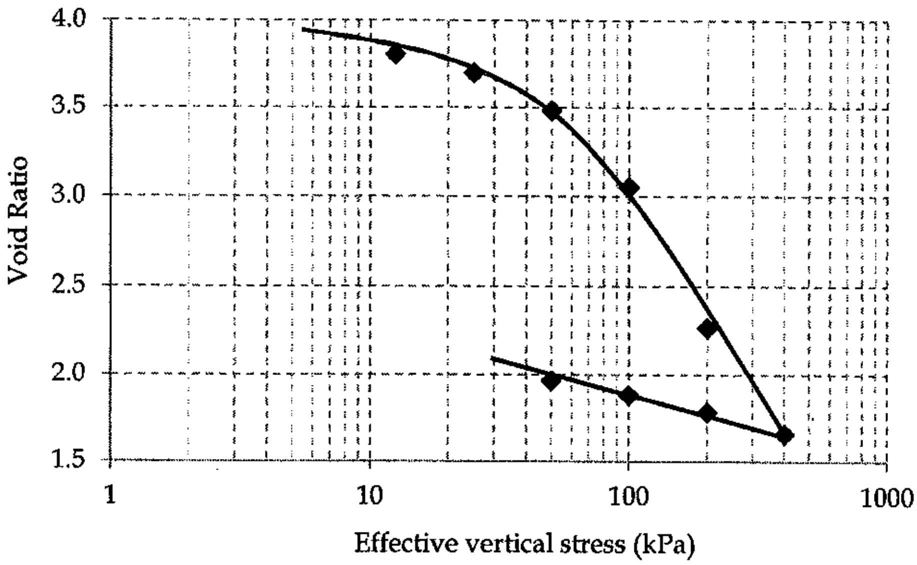

Figure Q2.2 Variation of void ratio over effective vertical stress

Table Q2.1 Consolidation test data

Sample diameter	= 5.0 cm
Sample height	= 2.0 cm
Initial moisture content of soft clay	= 178%
Specific gravity of soft clay	= 2.19
Initial weight of sample	= 48.0 g

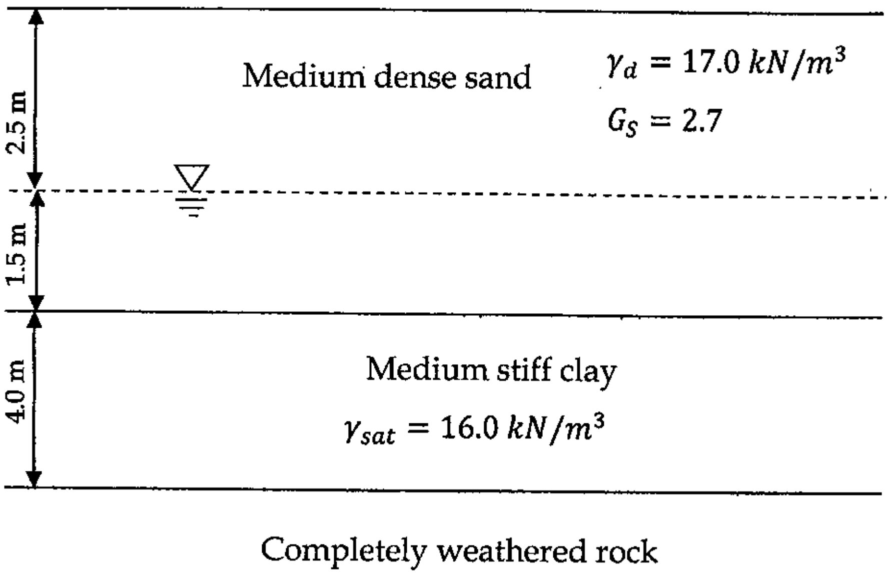

Figure Q3.1 Sub surface soil profile

Table Q3.1 Direct shear test results on medium dense sand

Normal force	= 200 N
Shear force at failure	= 140 N
Cross sectional area of sample	= 36 cm^2

Table Q3.2 Consolidated Undrained Triaxial test results on medium stiff clay

Cell pressure	= 150 kN/m^2
Deviator stress at failure	= 192 kN/m^2
Pore water pressure at failure	= 80 kN/m^2

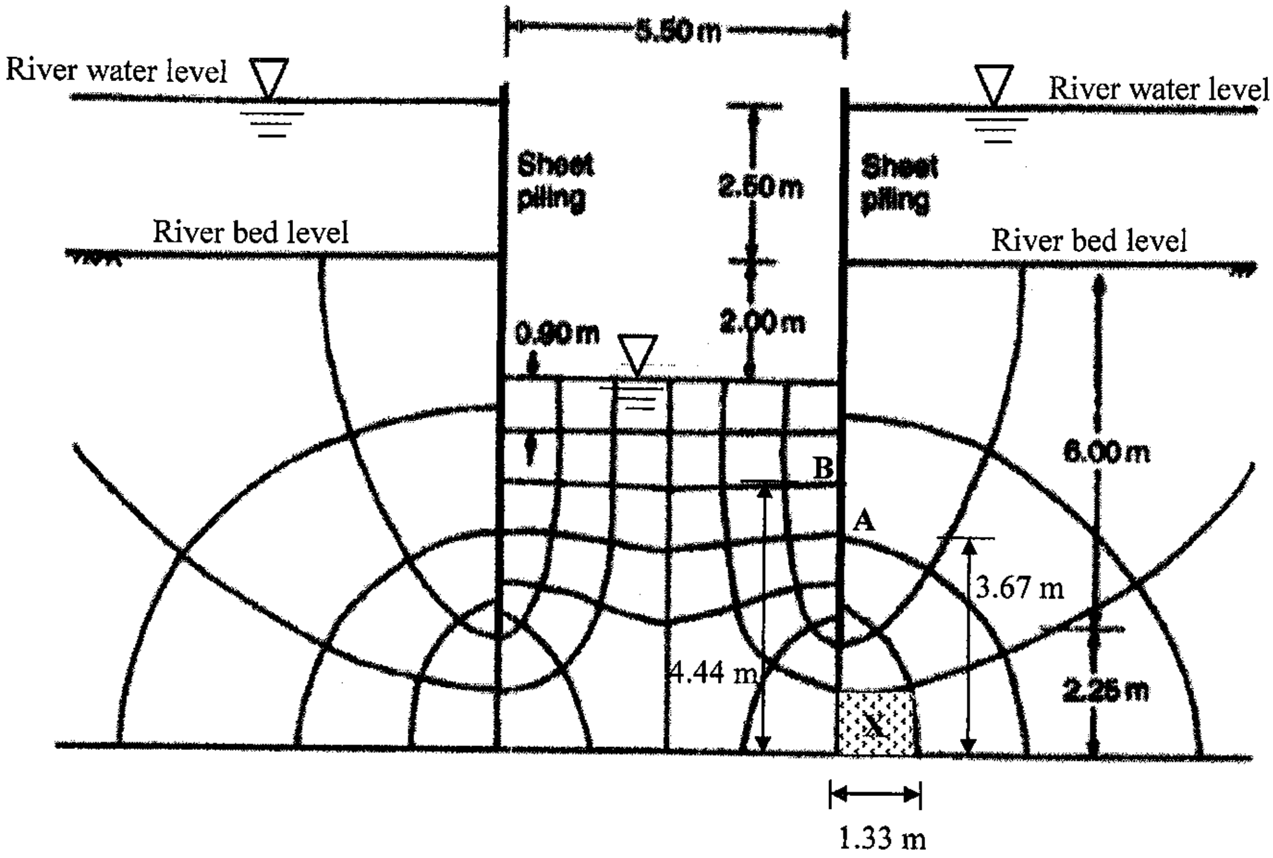

Figure Q4.1 - Flow net for the proposed excavation

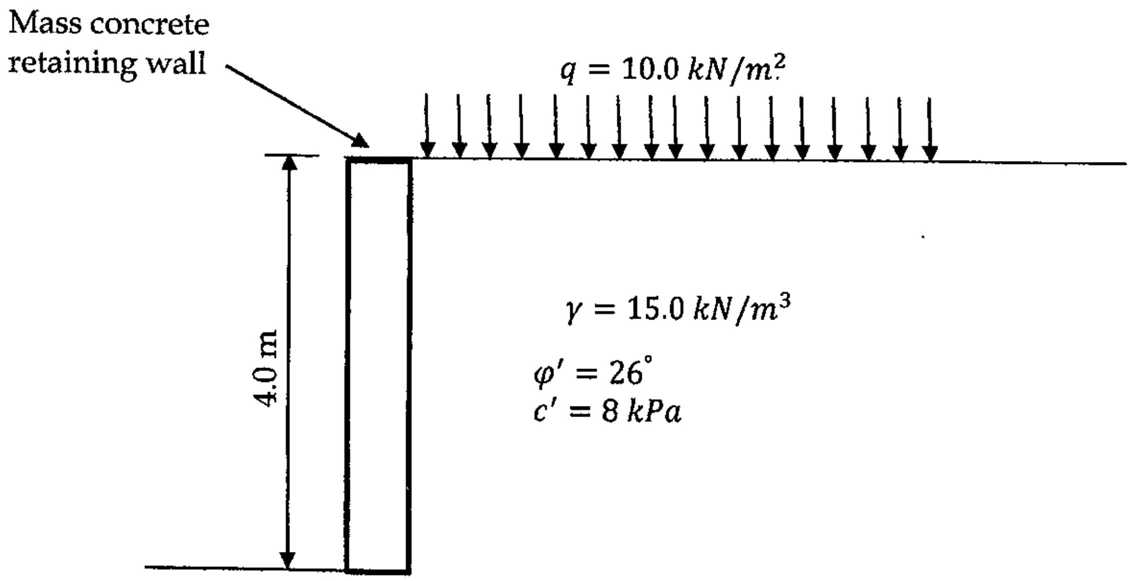

Figure Q5.1 Cross section of the proposed retaining wall

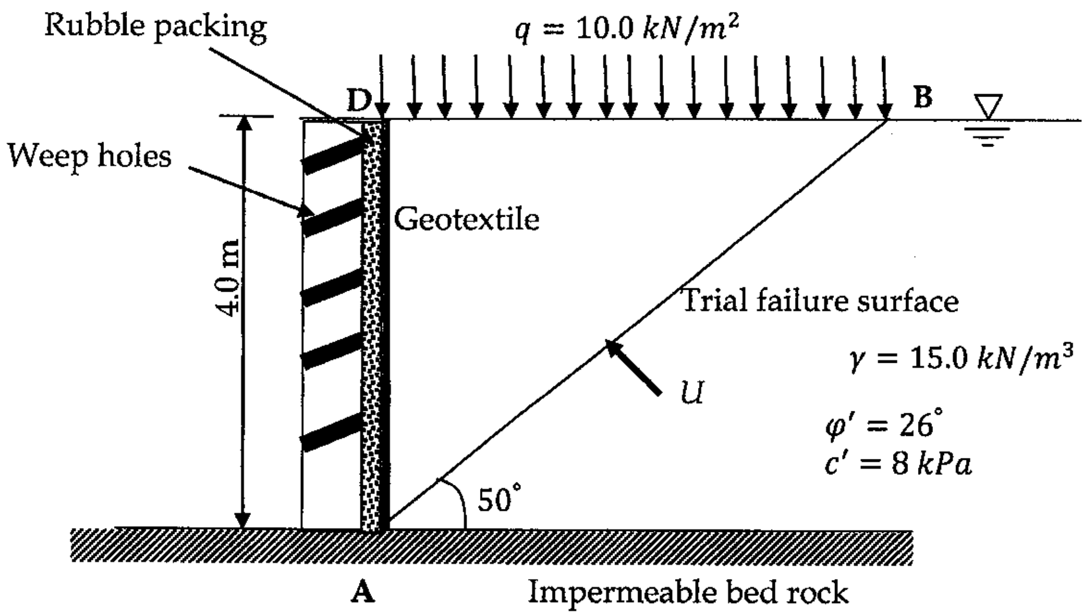

Figure Q5.2 Trial wedge