UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: November 2022

Module Number: CE6304 **Module Name: Geotechnical Engineering**

[Three Hours]

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

Q1. A road is to be constructed on a low-lying area and based on the site investigation, subsurface soil profile 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 2.0 m thick dense sand layer. Completely weathered rock is 8.0 m below the existing ground surface. Water table was found to be at the existing ground level.

In order avoid the frequent flooding in the area, it was decided to raise the road finish level by 2.0 m. To compensate the pavement and traffic load of the road and to accelerate the consolidation, additional 3.0 m high compacted soil fill will be placed on the road finish level as shown in Figure Q1.1. A thin drainage layer together with a geotextile will be placed on the existing ground to provide doubly drain condition.

The bulk unit weights of soft clay and compacted fill can be taken as 16.0 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 4.0 m^2/year, 0.5 and 1.5, respectively.

Other information that maybe useful in the calculations are given in Table Q1.1 and Figure Q1.2.

a) Briefly explain why consolidation settlement is not defined in the sandy soil.

[0.5 Marks]

b) What would be the expected primary consolidation settlement of the soft clay layer due to 5.0 m thick compacted fill assuming that soft clay is normally consolidated?

[2.0 Marks]

c) What would be the time required for 95% of the primary consolidation to be occurred?

[1.0 Marks]

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

[2.5 Marks]

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

[1.5 Marks]

f) What would be the Over Consolidation Ratio (OCR) of soft clay after removal of the compacted fill upto the road finish level?

[2.5 Marks]

g) What would be the expected pore water pressure at middle of the soft clay layer 6 months after place the fill?

[2.0 Marks]

Q2. Building with a plan area of 20 m x 10 m is to be constructed on a site. Building is on a raft foundation. Foundation is to be at a depth of 1.0 m from the natural ground. Site investigations were done using Standard Penetration Test (SPT) together with Cone Penetration Tests (CPT) to identify the subsurface soil profile. Subsurface soil consists of a 4.0 m thick clay layer sandwitched between two dense sand layers. Water table is at the top of the clay layer. The cross section of the subsurface soil profile and the foundation arrangement is presented in Figure Q2.1. Building is estimated to impose a contact stress of 100 kN/m² due to super structure and foundation loading. Unit weights of dense sand and clay are 18.5 kN/m³ and 16.0 kN/m³ respectively.

Results of a consolidation test conducted on an undisturbed soil sample obtained from mid of the clay layer are presented in Figure Q2.2. The unit weight of water can be taken as 9.81 kN/m³.

a) As you are a junior engineer in the project, what are the four types of information expected from this site investigation?

[2.0 Marks]

b) List 4 types of sources to gather information?

[2.0 Marks]

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

[2.0 Marks]

d) Determine whether clay soil is normally consolidated or over consolidated before placing the foundation.

[2.0 Marks]

e) Calculate the coefficient of volume compressibility (m_v) of clay for the stress range of 100-200 kN/m².

[2.0 Marks]

f) Assuming that there is no any stress release due to excavation for the foundation construction and transmission of stress into the subsurface follows outward fanning lines at a slope of 1 horizontal to 2 vertical, estimate the expected average settlement of the building.

[2.0 Marks]

Q3. In a building construction project, sub surface soil profile was determined using borehole investigation. The sub surface consists of 2.5 m thick medium dense sand layer followed by stiff clay layer as shown in Figure Q3.1. Completely weathered rock is encountered at a depth of 4.0 m below the ground surface. Water table is 1.5 m below the ground surface. Dry unit weight and specific gravity of medium dense sand are 16.0 kN/m³ and 2.6 respectively. Saturated unit weight of stiff clay is 18.0 kN/m³. The unit weight of water can be taken as 9.81 kN/m³.

a) The shear strength parameters of medium dense sand were determined using direct shear test and results are summarized in Table Q3.1.

   i) Determine the shear strength parameters of sand.

[0.5 Marks]

ii) Determine the magnitude and the inclination of the failure plane to the major principal plane.

[2.5 Marks]

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

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

[2.0 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 3.0 m from the ground surface? When the water table rise up to the ground surface, what would be the change in shear strength?

[1.5 Marks]

b) To determine the shear strength parameters of stiff clay, Consolidated Undrained (CU) triaxial test was conducted. Based on the data gathered from the CU tests, effective shear strength parameters of stiff clay were found as $c' = 16\ kN/m^2$ and $\varphi' = 29°$. Cell pressure, deviator stress and pore water pressure at failure of the 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.

[2.0 Marks]

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

[1.5 Marks]

Q4. An excavation is to be done to a depth of 4.0 m in order to construct a basement for a building. The water table is at the ground surface and bed rock is at a depth of 11.2 m from the ground surface. The soil up to the bed rock is found to be silty sand which has a saturated unit weight of 20 kN/m^3. The unit weight of water can be taken as 9.81 kN/m^3.

The excavation is supported by sheet pile shoring system. Water level inside the excavation is reduced to the bottom level by continuous pumping. Outside the excavation, the water table remained at the original ground level. The flow net drawn for the above case is presented in Figure Q4.1. The coefficient of permeability of silty sand can as taken as 2.5×10^{-5} m/s.

a) Estimate the rate of pumping required to remain the water level just below the excavation level.

[2.0 Marks]

b) Determine the pore water pressures at points **3 (Side A)** and **7 (Side B)**.

[3.5 Marks]

c) If porosity of the soil is 0.2, 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.

[1.5 Marks]

f) What would be the effective stress at point **4 (Side A)**?

[1.5 Marks]

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

[1.0 Marks]

Q5. A slope is supported by a 5.0 m high retaining wall as shown in Figure Q5.1. There is a two-story building at 5.0 m away from the retaining wall. The drained shear strength parameters of the retained soil were found to be $\varphi' = 30°$ and $c' = 10\ kPa$, where φ' is the friction angle and c' is the cohesion. The saturated unit weight and dry unit weight of the soil were 20 kN/m^3 and 17 kN/m^3 respectively. The water table is 2.0 m below the ground surface. The unit weight of water can be taken as 9.81 kN/m^3.

To design this retaining wall, it is necessary to estimate the lateral force exerted from the retained side. The obligatory surcharge (unexpected load) on the retained side can be simplified as a uniformly distributed load of intensity 10 kN/m^2.

a) With the aid of a sketch, justify that stress due to 2 story building is not within the active zone of stress behind the retaining wall.

[1.0 Marks]

b) Estimate the lateral force on the retaining wall using the Rankine equation.

[4.0 Marks]

c) In order reduce the lateral force on the retaining wall, it was decided to provide weep holes at regular intervals as shown in Figure Q5.2. The Coulomb's trial wedge approach is used to estimate the lateral force. It is assumed that water table will rise upto the ground surface during the heavy rainy period as shown in Figure Q5.2.

i) Assuming that wall surface is rough, draw ABD trial wedge and mark all the forces acting on the trial wedge.

[2.0 Marks]

ii) The soil-wall interface friction angle (δ) is 20° and adhesion (c_w) is 5 kPa. If pore water force on the trial failure surface is 80 kN, determine the active force on the retaining wall by using the Coulomb's graphical method for the trial wedge shown in Figure Q5.2 without considering the effect of tension crack. (*Note: You may plot to a scale of 1 mm = 2 kN*)

[5.0 Marks]

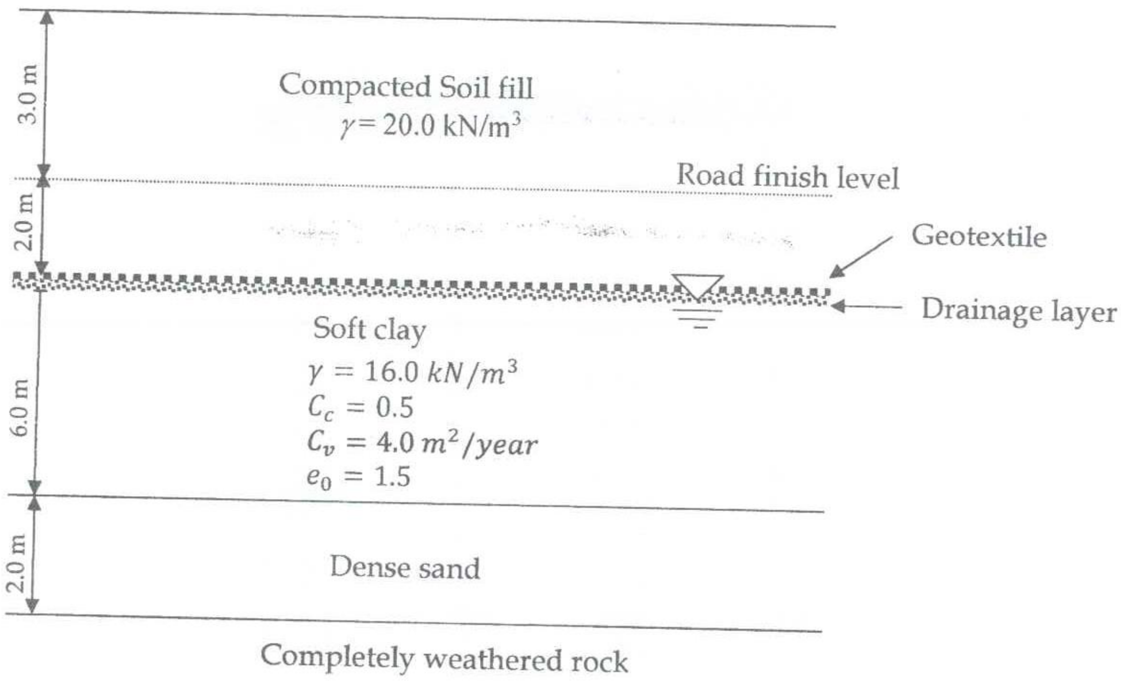

Figure Q1.1 Cross section of ground profile

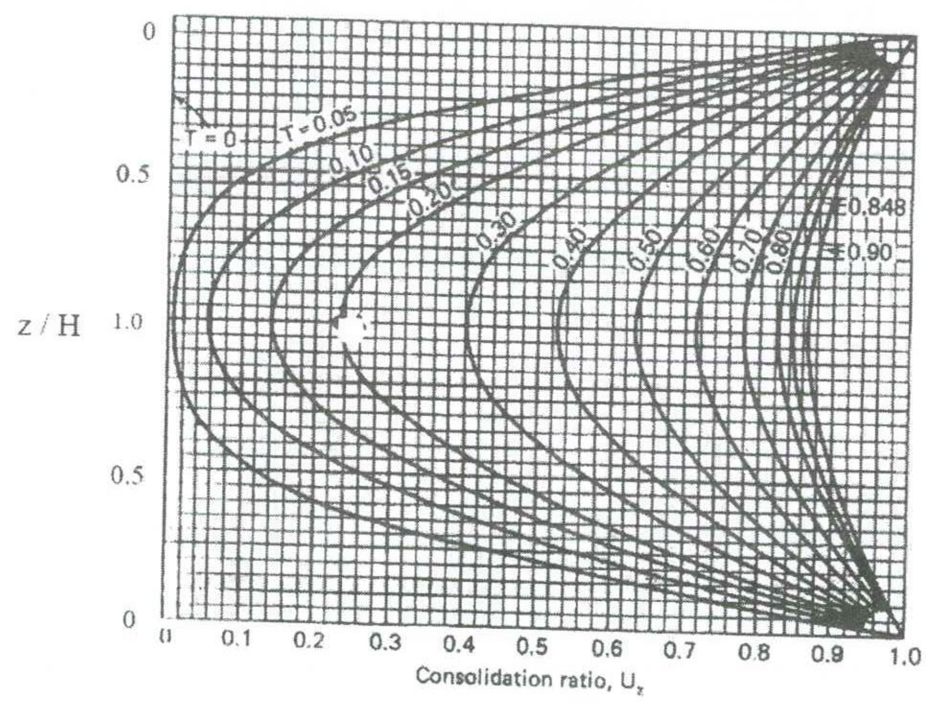

Figure Q1.2 Variation of T_v with z/H and U_z

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		

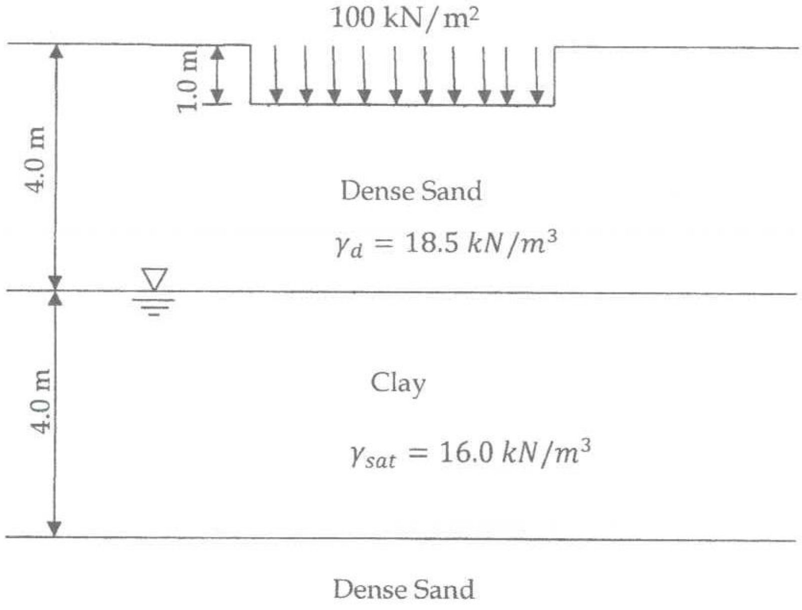

Figure Q2.1 – Subsurface soil profile and foundation arrangement

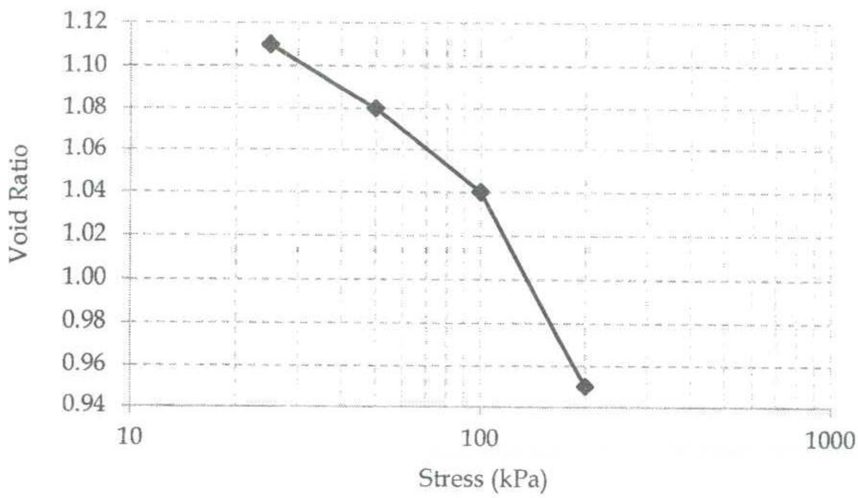

Figure Q2.2 - Consolidation test data

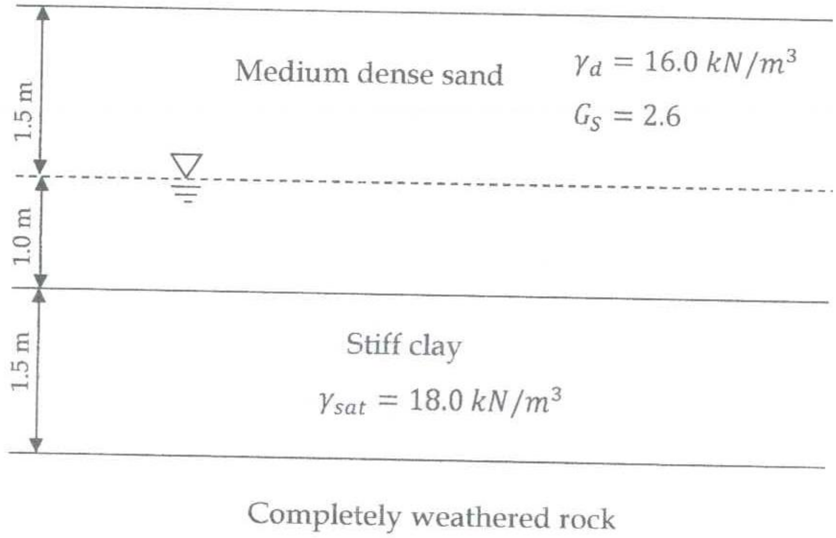

Figure Q3.1 Sub surface soil profile

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

Normal stress	= 100 kPa
Shear stress at failure	= 57.73 kPa

Table Q3.2 Consolidated Undrained Triaxial test results on 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

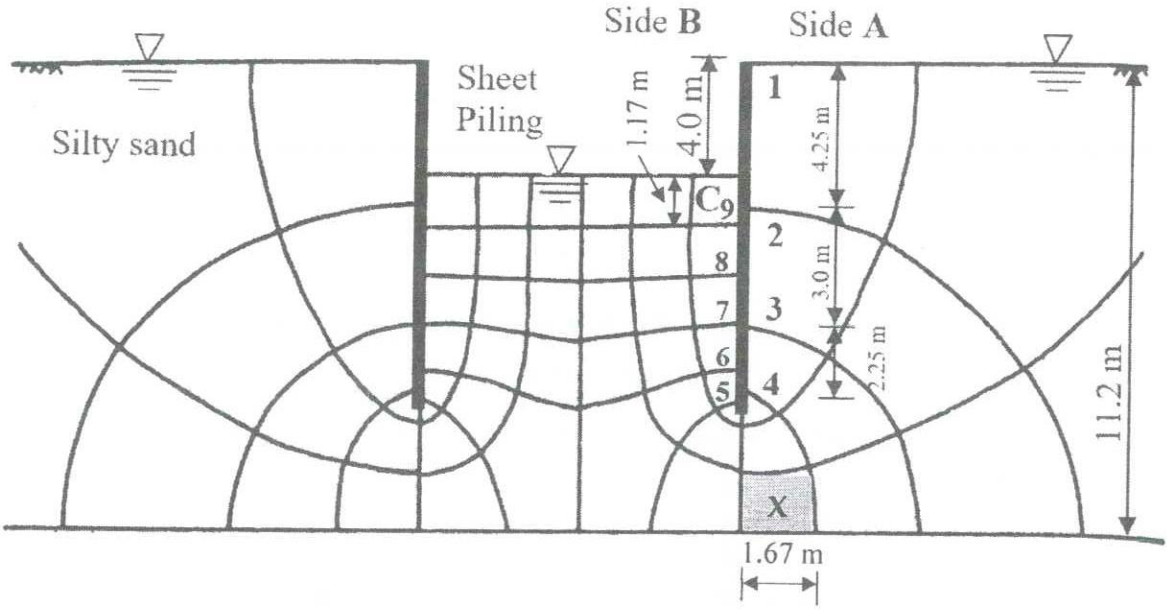

Figure Q4.1 - Flow net

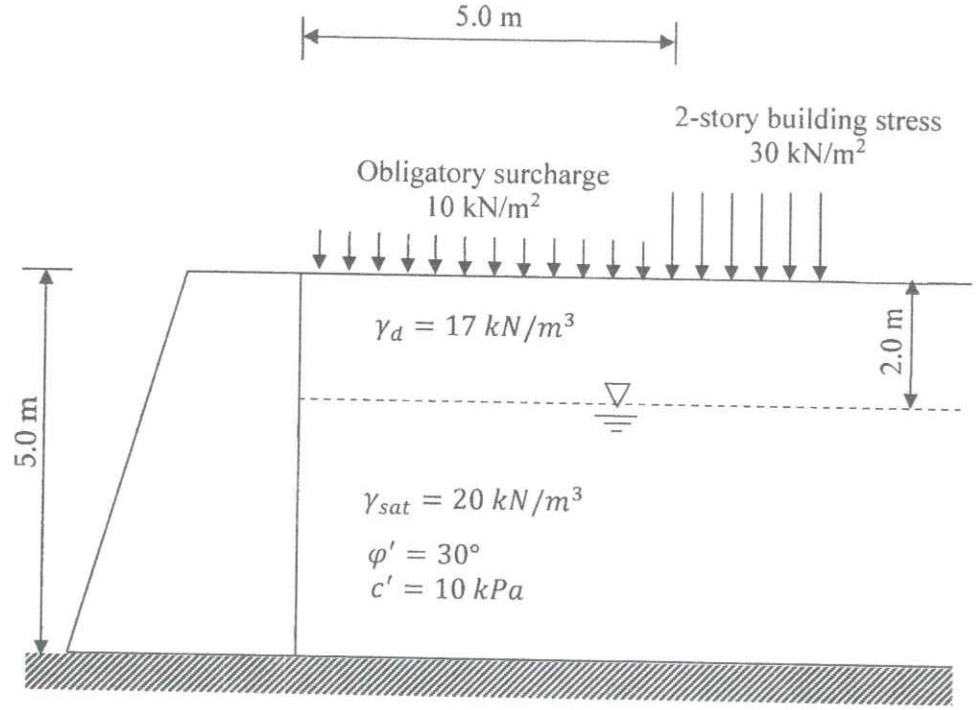

Figure Q5.1 Cross section of the 5.0 m high Retaining structure

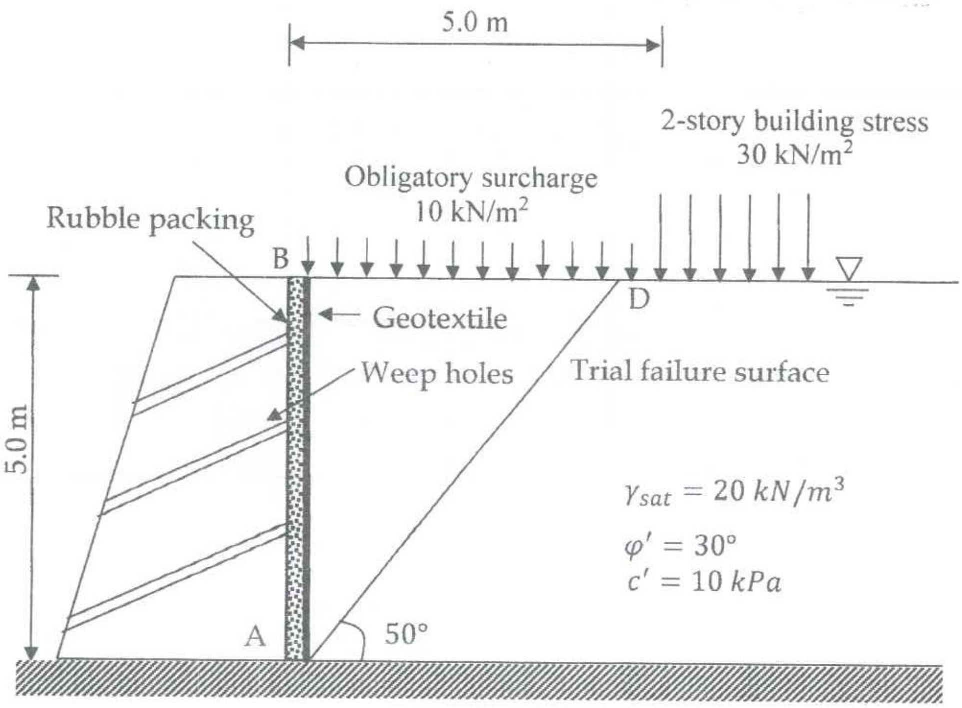

Figure Q5.2 Trial failure surface