UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: March 2022

Module Number: CE7304 **Module Name: Geotechnical Engineering Design**

[Three Hours]

[Answer **all questions**, the marks associated with each question are indicated]

Q1. a) Explain how downdrag force on piles that develop due to negative skin friction is treated in the overall design of a pile.

[1.0 Marks]

b) A multistorey residential building is to be constructed at a site located in the coastal low-lying zone of southern Sri Lanka. Subsurface profile at the site consists of a soft clay deposit underlain by a very dense sand deposit of limited thickness defined by the encounter of the bedrock. As a part of early earthworks at the site, the ground surface is to be raised by placement of a 3 m thick granular fill. Considering the presence of the clay layer, the structure is to be founded on piles. Precast piles of 0.5 m x 0.5 m cross section are to be used for the purpose. The subsurface profile to be used in the geotechnical engineering design of the piles are presented in Figure Q1.1 while, necessary soil engineering parameters are provided in Table Q1.1. The design groundwater table is taken to be located 2 m below the finished ground surface. The unit weight of water can be taken as 9.81 kN/m^3. The below listed equation with usual notations may be useful in performing the calculations required by following sections.

$Q_p = A_p q' N_q^* \leq A_p q_1$; where $q_1 = 50 N_q^* tan\varphi$

Figure Q1.2 and Figure Q1.3 may be also useful in performing the calculations.

i) Estimate the total downdrag force that may develop on a pile due to consolidation of the clay layer induced by surficial fill placement. You may assume, with usual notations, that $\beta = 0.3$. Clearly state any assumptions that may be used in the calculations.

[2.0 Marks]

ii) Estimate the ultimate axial load carrying capacity of a pile in compression and determine the allowable load considering an overall factor of safety of 2.5. You may assume the following relationships with usual notations. $\delta' = \varphi'$ and $K = (1 - \sin\varphi')$

[5.0 Marks]

iii) Estimate the load carrying capacity derived from the stable zone and comment on the adequacy of the design to limit the settlements that occur under the effect of negative skin friction and application of the allowable load calculated in Section (ii).

[2.0 Marks]

c) Given the magnitude of structural load transferred via a certain set of single columns at the proposed construction described in Section (b), it is required to consider other foundation options. Accordingly, perform design calculations as required by the following sections. The necessary material parameters can be obtained from Table Q1.1. The below listed equations with general notations may be useful in performing the calculations.

$\eta = 1 - \frac{\theta}{90}\left[\frac{(n-1)m+(m-1)n}{mn}\right]$; where $\theta = tan^{-1}(D/s)$

$q_p = q_u(N_\varphi + 1)$; where $N_\varphi = tan^2(45 + \varphi/2)$

i) Estimate the ultimate capacity of a group of precast piles arranged into a grid of 4 x 2 piles assuming 1.0 m grid spacing.

[2.0 Marks]

ii) Estimate the ultimate point bearing capacity of a single pile driven to near refusal on the bedrock.

[2.0 Marks]

d) Pile load testing is often recommended to verity pile capacity estimates. Briefly describe the 'Constant Rate of Penetration Test' procedure for testing piles under axial compression and recognize two numbers of different criteria that may be used for interpretation of failure load.

[4.0 Marks]

e) "When considering conduct of load testing on piles, it is important to take into account the time lapse after the end of pile driving". Explain the above statement with respect to the driven precast piles and the subsurface conditions described in Section (b).

[2.0 Marks]

Q2. Construction of a gravity wall is proposed to retain a cut slope in clayey sand along the northern boundary of a school playground. The base width of the wall is 3.0 m and the retained height of backfill is 5.0 m. A schematic drawing of the proposed wall with the geometric parameters is provided in Figure Q2.1. The groundwater table is located far below the base of the wall. The base of the wall may be considered as cast against soil. The unit weight of wall material can be taken as 20 kN/m³. The characteristic values of soil parameters to be used in the design calculations are provided in Table Q2.1. The variation of the coefficient of effective horizontal active earth pressure (K_a) with φ'_d is illustrated in Figure Q2.2. Perform following design calculations in accordance with the Design Approach 1-Combination 2 of the Eurocode 7. Combinations of sets of partial factors ($A2 + M2 + R1$) to be used with Design Approach 1 of Eurocode 7 are given in Table Q2.2, Table Q2.3, and Table Q2.4. Clearly state any assumptions that may be used in the calculations.

a) Construct a diagram to illustrate the lateral stress distribution on the wall and determine the force components that act on the wall.

[4.0 Marks]

b) Check if the wall has adequate resistance against sliding at the base.

[4.0 Marks]

c) Check if the wall has adequate stability against overturning.

[2.0 Marks]

Q3. a) The design of the retaining wall described in Question Q2 needs to be checked for adequacy of bearing resistance. For this purpose, the base of the wall may be considered as a shallow strip footing of 3.0 m width (and 30 m length) constructed at grade (i.e., $D_f = 0$) and loaded vertically at an eccentricity to the longitudinal axis. The clayey sand layer can be assumed to extend 6 m below the base of the wall. The groundwater table is located far below the base of the wall. The characteristic values of soil parameters to be used in the design calculations are the same as those provided in Table Q2.1.

i) Based on the calculations performed in Question Q2, determine the eccentricity of the vertical action (e) and check if the wall has satisfactory base width.

[2.0 Marks]

ii) Clearly stating any assumptions that may be used in the calculations, determine the design bearing resistance of the footing in accordance with the Design Approach 1-Combination 2 of the Eurocode 7 using Vesic's form of the general bearing capacity equation and the effective area method. Irrespective of the eccentricity estimated in Section (i) you may assume an eccentricity of 0.3 m in the determination of bearing resistance. Combinations of sets of partial factors ($A2 + M2 + R1$) to be used with Design Approach 1 of Eurocode 7 are given in Table Q2.2, Table Q2.3, and Table Q2.4. Following equations with usual notations may be used in the calculations.

The general bearing capacity equation:

$$q_u = c' N_c F_{cs} F_{cd} F_{ci} + q N_q F_{qs} F_{qd} F_{qi} + \frac{1}{2} \gamma B N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i}$$

The bearing capacity factors N_c, N_q, and N_γ may be obtained from Table Q3.1.

F_{cs}, F_{qs}, and $F_{\gamma s}$ are the shape factors.

F_{cd}, F_{qd}, and $F_{\gamma d}$ are the depth factors.

F_{ci}, F_{qi}, and $F_{\gamma i}$ are the inclination factors

Shape factors

$$F_{cs} = 1 + \frac{B}{L} \frac{N_q}{N_c}$$

$$F_{qs} = 1 + \frac{B}{L} \tan \varphi'$$

$$F_{\gamma s} = 1 - 0.4 \frac{B}{L}$$

Depth factors when $\frac{D_f}{B} \leq 1$

$$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c tan\varphi'}$$

$$F_{qd} = 1 + 2tan\varphi'(1 - sin\varphi')^2 \frac{D_f}{B}$$

$$F_{\gamma d} = 1$$

Depth factors when $\frac{D_f}{B} > 1$

$$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c tan\varphi'}$$

$$F_{qd} = 1 + 2tan\varphi'(1 - sin\varphi')^2 tan^{-1}\left(\frac{D_f}{B}\right)$$

$$F_{\gamma d} = 1$$

Inclination factors

$$F_{ci} = F_{qi} = \left(1 - \frac{\beta}{90^0}\right)^2$$

$$F_{\gamma i} = \left(1 - \frac{\beta}{\varphi'}\right)^2$$

β = inclination of the load on the foundation with respect to the vertical

[6.5 Marks]

b) The 'Plate Load Test' is often used to verify the bearing resistance and settlement of shallow footings. Identify the limitations of the plate load test in predicting the bearing resistance and settlement of shallow footings.

[1.5 Marks]

Q4. a) Using a suitable sketch briefly describe the variation of factor of safety against slope instability from initial state through end of construction to final state reached after dissipation of excess pore pressure as relevant to construction of a cut slope in saturated fine-grained soil.

[2.0 Marks]

b) A construction project requires a cutting to be performed in nearly saturated silty clay. The short-term stability of the slope may be evaluated using undrained shear characteristics of soil material. Based on field testing, the undrained shear strength (c_u) of silty clay at the site was found to increase linearly with depth below ground surface (h) in accordance with the relationship $c_u = 5h + 35$, where h is measured in meters and c_u is measured in kN/m^2. A preliminary assessment of the short-term stability of the cut slope is to be carried out for the circular trial slip surface AC shown in Figure Q4.1. For the purpose of accommodating the variation of c_u with depth the soil above the trial slip surface is divided into several vertical slices. Along the base of each slice, approximately at mid-height an average value of c_u may be calculated. The trial slip surface AC is associated with a radius of 16.25 m. The following calculations may be completed using Table Q4.1.

Note: The Table Q4.1 should be detached from the question paper and attached to the answer book.

i) Estimate the destabilizing moment that tends to cause slip along the trial surface AC.

[4.0 Marks]

ii) Estimate the available resistance in soil against slip along the trial surface AC and hence determine the factor of safety (F_s) against slip along the trial surface AC.

[4.0 Marks]

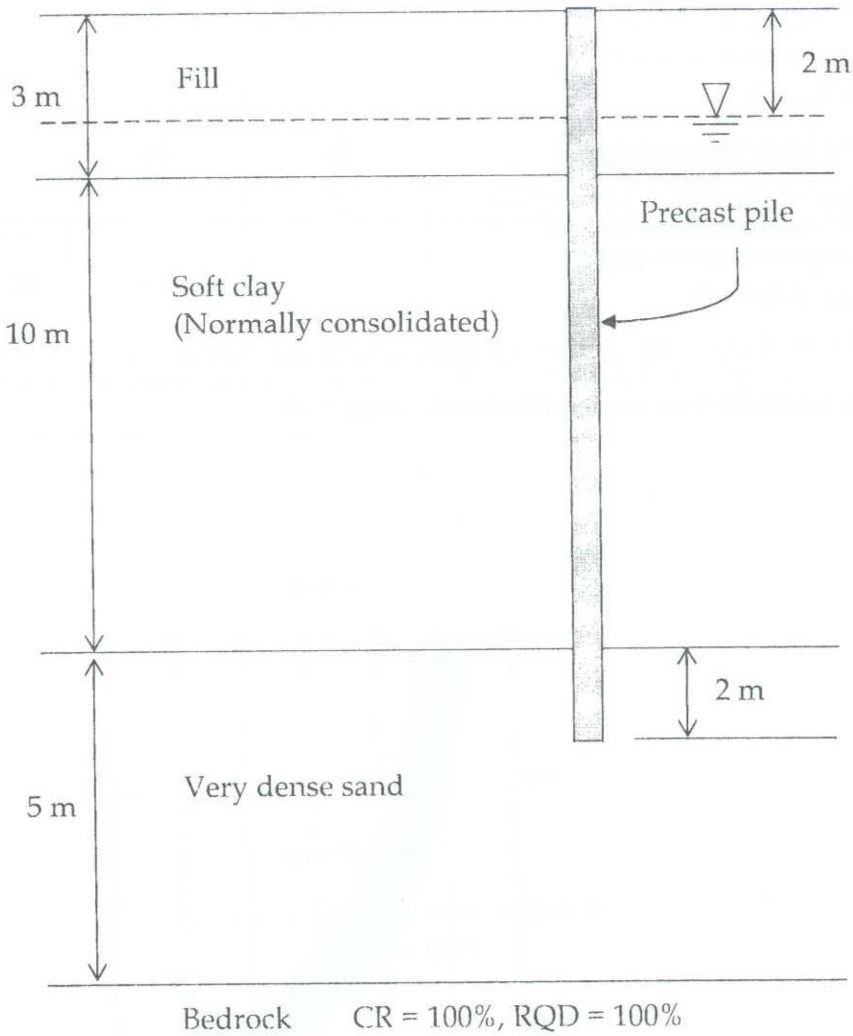

Figure Q1.1: Subsurface profile at the proposed site

Table Q1.1: Engineering parameters of soil

Soil parameters	Fill – Above water table	Fill – Below water table	Soft clay	Very dense sand
Drained cohesion, c' (kN/m^2)	0	0	-	0
Undrained cohesion, c_u (kN/m^2)	-	-	25	-
Friction Angle, φ' (deg)	30	30	-	38
Dry unit weight, γ_d (kN/m^3)	17	-	-	-
Saturated unit weight, γ_{sat} (kN/m^3)	-	19	16.5	22
Unconfined compressive strength of bedrock (MPa) = 60				
Drained friction angle of bedrock (deg) = 40				

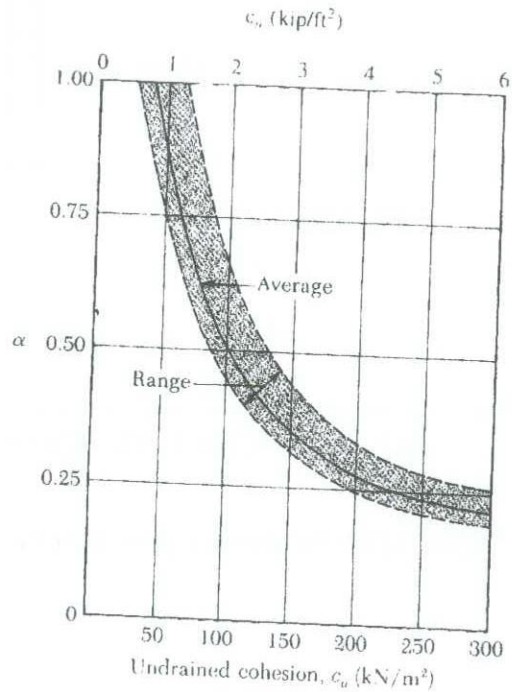

Figure Q1.2: Variation of α with undrained cohesion of clay

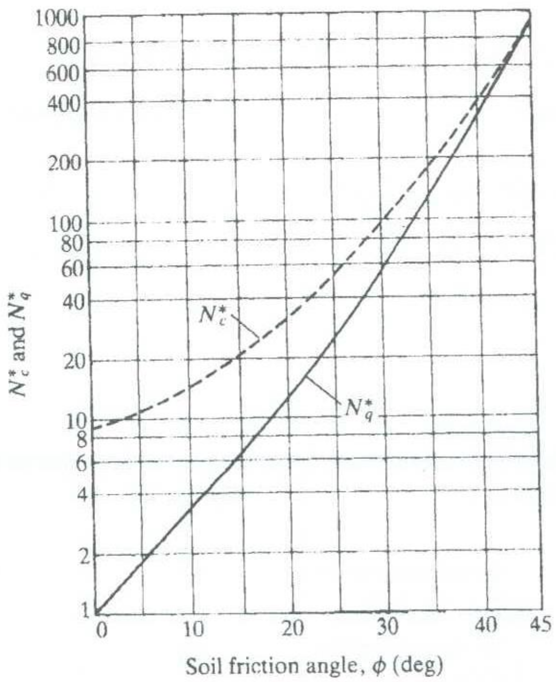

Figure Q1.3: Variation of N_c^* and N_q^* with soil friction angle

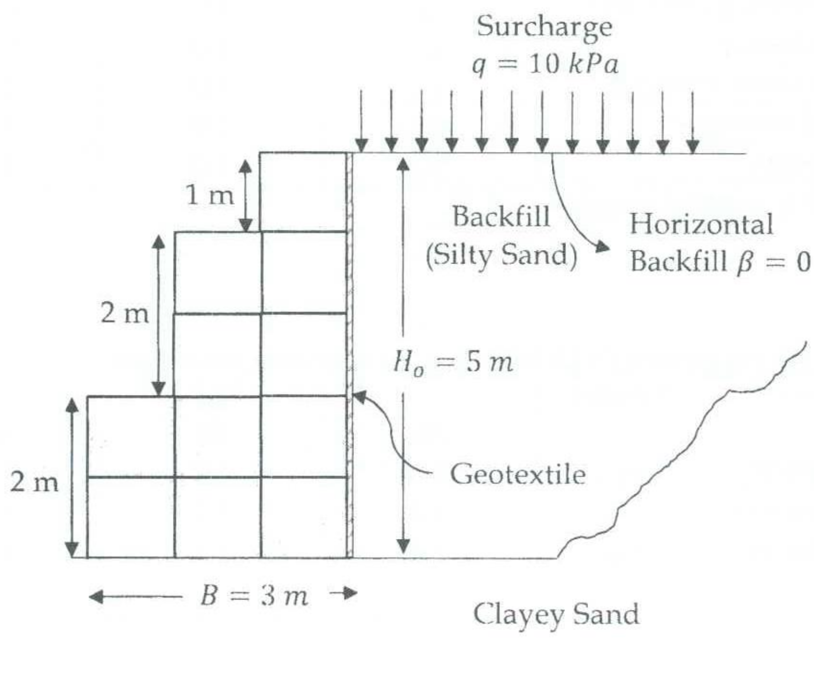

Figure Q2.1: Cross section of the proposed retaining wall

Table Q2.1: Characteristic values of soil parameters

Soil Properties	Backfill (Silty Sand)	Clayey Sand
Dry unit weight, γ_{dry} (kN/m^3)	18.5	20
Friction angle, φ' (deg)	33	28
Cohesion, c' (kN/m^2)	0	12

Table Q2.2: Partial factors on actions (γ_F) or the effects of actions (γ_E)

Action		Symbol	Set	
			A1	A2
Permanent	Unfavourable	γ_G	1.35	1.0
	Favourable		1.0	1.0
Variable	Unfavourable	γ_Q	1.5	1.3
	Favourable		0	0

Table Q2.3: Partial factors for soil parameters (γ_M)

Soil Parameter	Symbol	Set	
		M1	M2
Angle of shearing resistance [a]	$\gamma_{\varphi'}$	1.0	1.25
Effective cohesion	$\gamma_{c'}$	1.0	1.25
Undrained shear strength	γ_{cu}	1.0	1.4
Unconfined strength	γ_{qu}	1.0	1.4
Weight Density	γ_{γ}	1.0	1.0
[a] The factor is applied to tan φ'			

Table Q2.4: Partial resistance factors (γ_R) for retaining structures

Resitance	Symbol	Set		
		*R*1	*R*2	*R*3
Bearing capacity	$\gamma_{R,v}$	1.0	1.4	1.0
Sliding resistance	$\gamma_{R,h}$	1.0	1.1	1.0
Earth resistance	$\gamma_{R,e}$	1.0	1.4	1.0

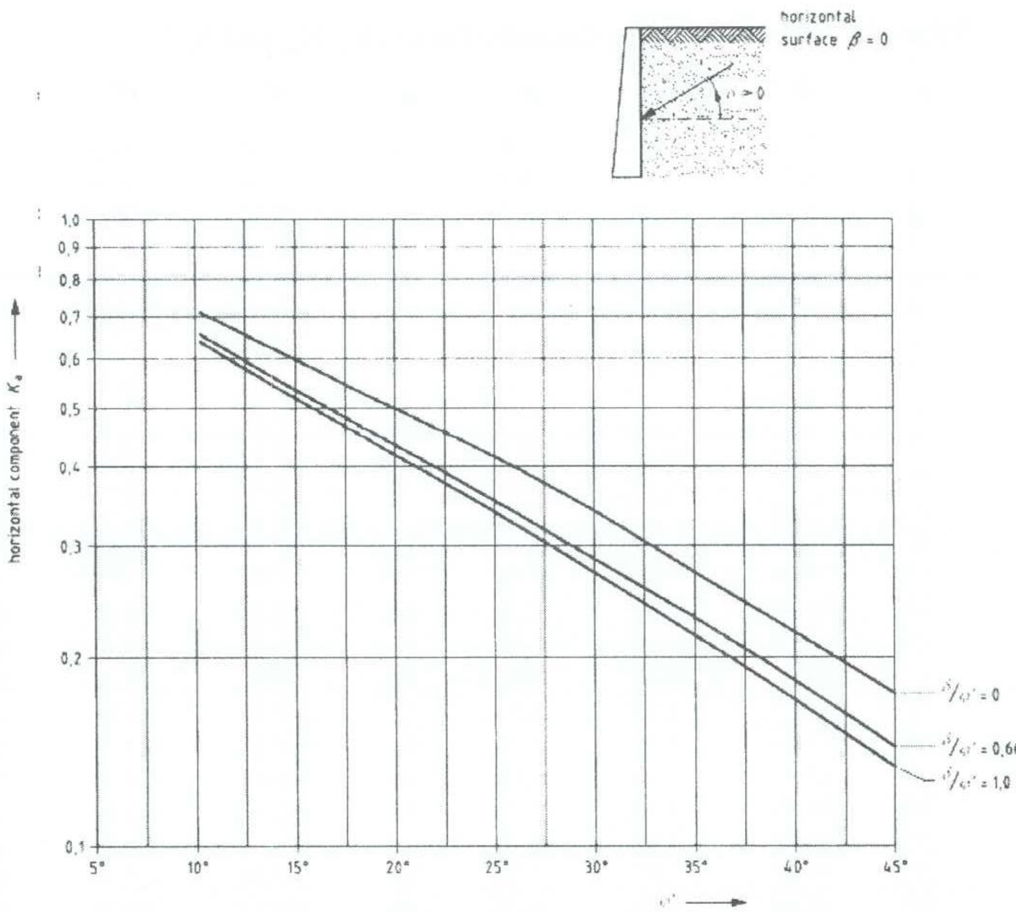

Figure Q2.2: Variation of the coefficient of effective horizontal active earth pressure (K_a) with φ'_d

Table Q3.1: Vesic's Bearing Capacity Factors N_c, N_q, and N_γ

ϕ'	N_c	N_q	N_γ	ϕ'	N_c	N_q	N_γ
0	5.14	1.00	0.00	26	22.25	11.85	12.54
1	5.38	1.09	0.07	27	23.94	13.20	14.47
2	5.63	1.20	0.15	28	25.80	14.72	16.72
3	5.90	1.31	0.24	29	27.86	16.44	19.34
4	6.19	1.43	0.34	30	30.14	18.40	22.40
5	6.49	1.57	0.45	31	32.67	20.63	25.99
6	6.81	1.72	0.57	32	35.49	23.18	30.22
7	7.16	1.88	0.71	33	38.64	26.09	35.19
8	7.53	2.06	0.86	34	42.16	29.44	41.06
9	7.92	2.25	1.03	35	46.12	33.30	48.03
10	8.35	2.47	1.22	36	50.59	37.75	56.31
11	8.80	2.71	1.44	37	55.63	42.92	66.19
12	9.28	2.97	1.69	38	61.35	48.93	78.03
13	9.81	3.26	1.97	39	67.87	55.96	92.25
14	10.37	3.59	2.29	40	75.31	64.20	109.41
15	10.98	3.94	2.65	41	83.86	73.90	130.22
16	11.63	4.34	3.06	42	93.71	85.38	155.55
17	12.34	4.77	3.53	43	105.11	99.02	186.54
18	13.10	5.26	4.07	44	118.37	115.31	224.64
19	13.93	5.80	4.68	45	133.88	134.88	271.76
20	14.83	6.40	5.39	46	152.10	158.51	330.35
21	15.82	7.07	6.20	47	173.64	187.21	403.67
22	16.88	7.82	7.13	48	199.26	222.31	496.01
23	18.05	8.66	8.20	49	229.93	265.51	613.16
24	19.32	9.60	9.44	50	266.89	319.07	762.89
25	20.72	10.66	10.88				

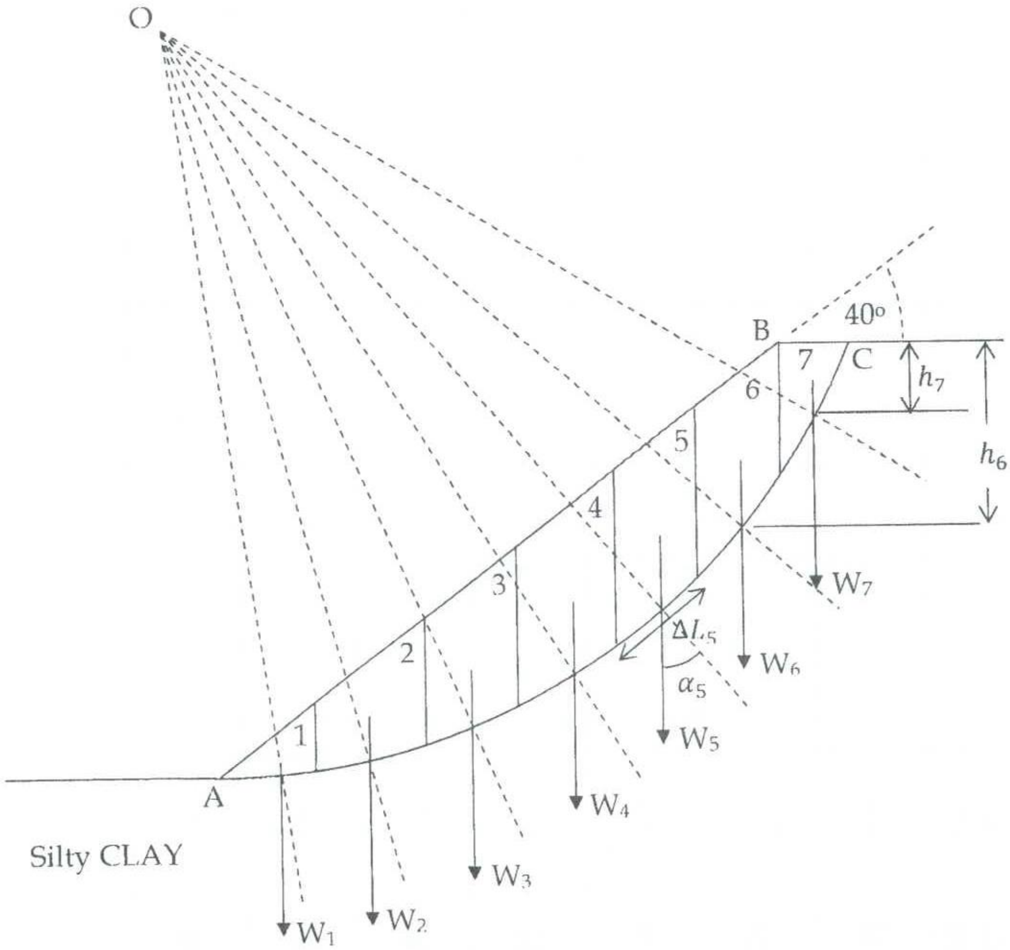

Figure Q4.1: The profile of the cut slope and the trial slip surface AC

Table Q4.1: Estimation of factor of safety against slip along the trial slip surface AC

Slice No.	W_n (kN/m)	α_n (deg)	ΔL_n (m)	h_n (m)				
1	29.8	10	1.32	9.6				
2	78.8	15	2.28	9.3				
3	105.0	33	2.38	7.3				
4	126.0	40	2.61	6.1				
5	113.3	47	2.64	4.7				
6	101.1	52	2.92	3.6				
7	29.4	63	2.86	1.0				