UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: March 2022

Module Number: CE7305 **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) Explain two number of situations, other than that presented in Section (c) below, where negative skin friction would develop on piles. You may use suitable sketches to support your answer.

[4.0 Marks]

c) 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]

d) Given the magnitude of structural load transferred via a certain set of single columns at the proposed construction described in Section (c), 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]

e) 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]

f) "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 (c).

[2.0 Marks]

Q2. An anchored sheet pile wall is proposed to support a 6 m deep urban excavation in medium dense sand. The static groundwater table in the region is encountered at a depth of 7.5 m below existing ground surface. A schematic drawing of the proposed wall system with the geometric parameters is provided in Figure Q2.1 together with the subsurface profile and the characteristic values of the soil parameters. Unit weight of water, γ_w may be taken as 9.81 kN/m³. The variation of the coefficient of effective horizontal active earth pressure (K_a) with φ'_d and variation of the coefficient of effective horizontal passive earth pressure K_p with φ'_d are illustrated in Figure Q2.2 and Figure Q2.3, respectively. The wall may be assumed to have a smooth surface resulting in 'zero' wall-soil interface friction.

a) Construct a diagram to illustrate the lateral stress distribution on the wall.

[4.0 Marks]

b) Determine the force components that act on the wall.

[4.0 Marks]

c) Using the free earth support method check if the given depth of embedment of the sheet piles is adequate to prevent rotational failure of the wall.

[2.0 Marks]

d) Given the ground anchors are installed at a spacing of 3 m, determine the tensile force that induces in a ground anchor.

[1.0 Marks]

e) Briefly explain how the assumption of 'smooth wall' affects the design check.

[1.0 Marks]

Q3. a) A proposed warehouse building is to be founded on shallow strip footings. Based on the structural design a certain strip footing is subjected to the action of vertical loading at an eccentricity of 0.15 m to the longitudinal axis. The strip footing is of 1.5 m width (and 20 m length) and is founded at a depth of 1.0 m below the existing ground surface in a clayey sand layer that extends 6 m below the foundation depth. The groundwater table is located far below the base of the footing. The soil parameters to be used in geotechnical engineering design calculations are provided in Table Q3.1.

i) Determine the effective width of the footing.

[1.0 Marks]

ii) Clearly stating any assumptions that may be used in the calculations, determine the ultimate bearing capacity of a footing using Vesic's form of the general bearing capacity equation and the effective area method. Following equations with usual notations may be used in the calculations.

The general bearing capacity equation:

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

The bearing capacity factors N_c, N_q, and N_γ may be obtained from Table Q3.2.

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]

iii) Using a safety factor of 2.5, determine the allowable bearing capacity and the load that the footing can carry.

[1.0 Marks]

b) The 'Plate Load Test' is often used to verify the bearing resistance and settlement of shallow footings. Briefly describe the test procedure.

[1.5 Marks]

c) Explain two numbers of situations where the plate load test can produce erroneous estimations of bearing capacity and settlement of shallow footings.

[2.0 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 the following constructions in/on saturated fine-grained soil:

i) a cut slope, and
ii) an embankment

[4.0 Marks]

b) A construction project requires a cutting to be performed in nearly saturated silty clay. While, the long-term stability of the wall may be evaluated using effective stress parameters, 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/m². 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]

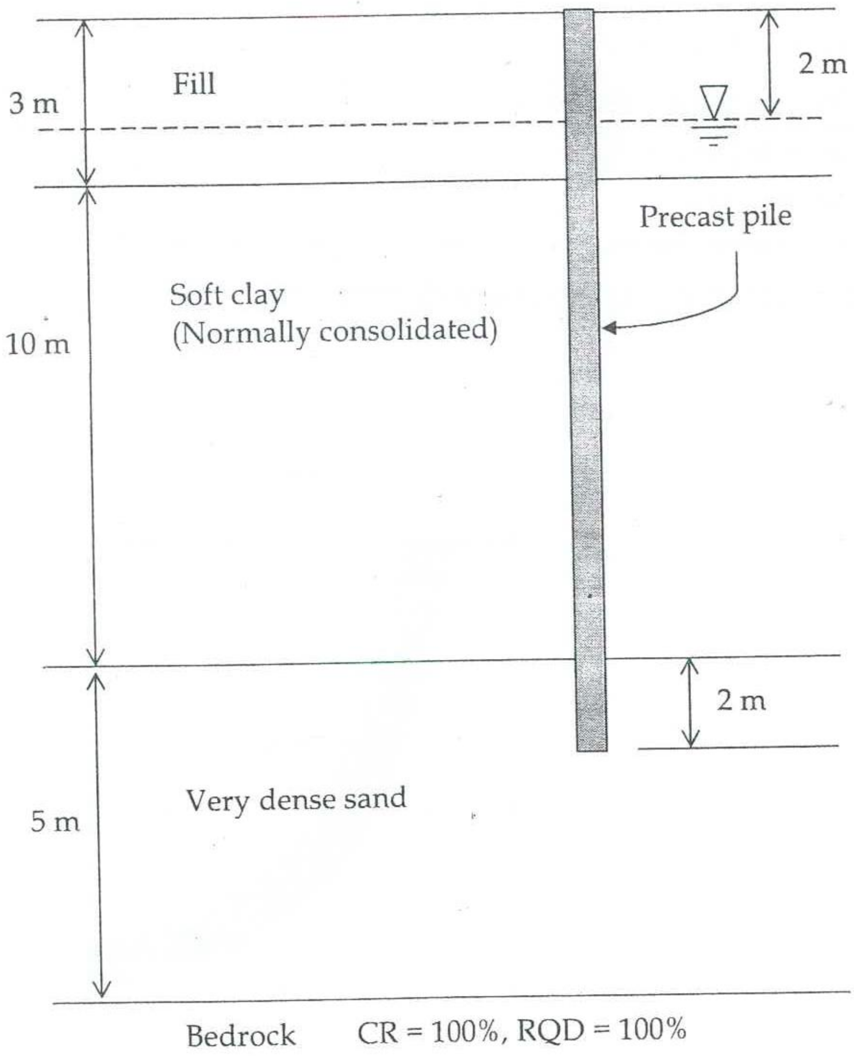

Figure Q1.1: Subsurface profile at the proposed site

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				

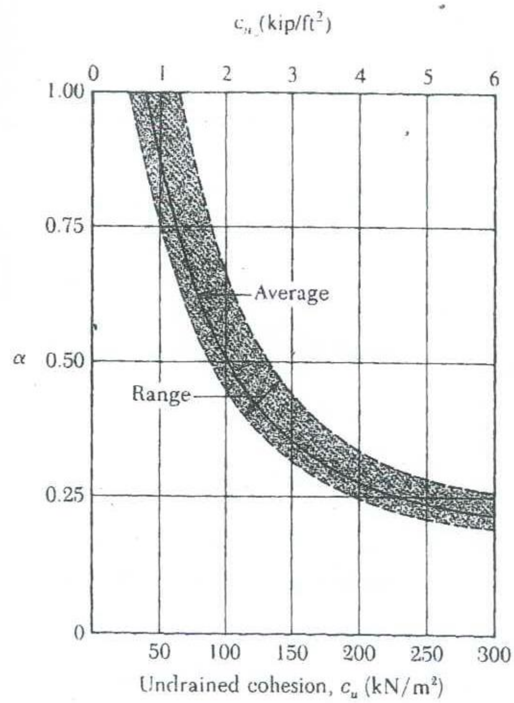

Figure Q1.2: Variation of α with undrained cohesion of clay

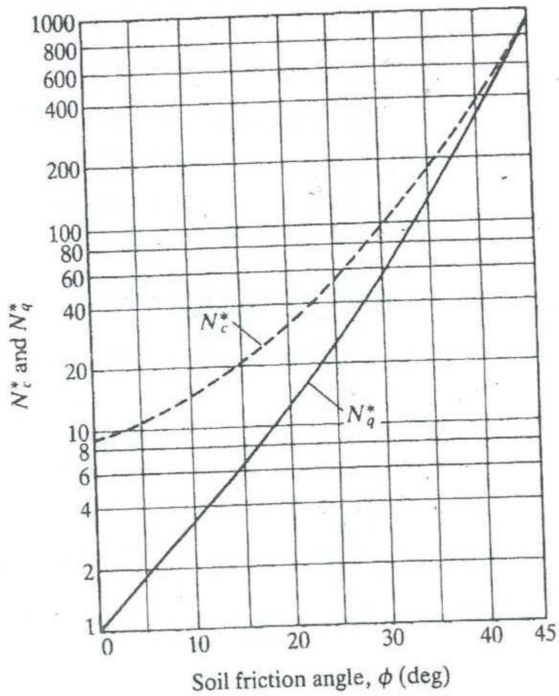

Figure Q1.3: Variation of N_c^* and N_q^* with soil friction angle

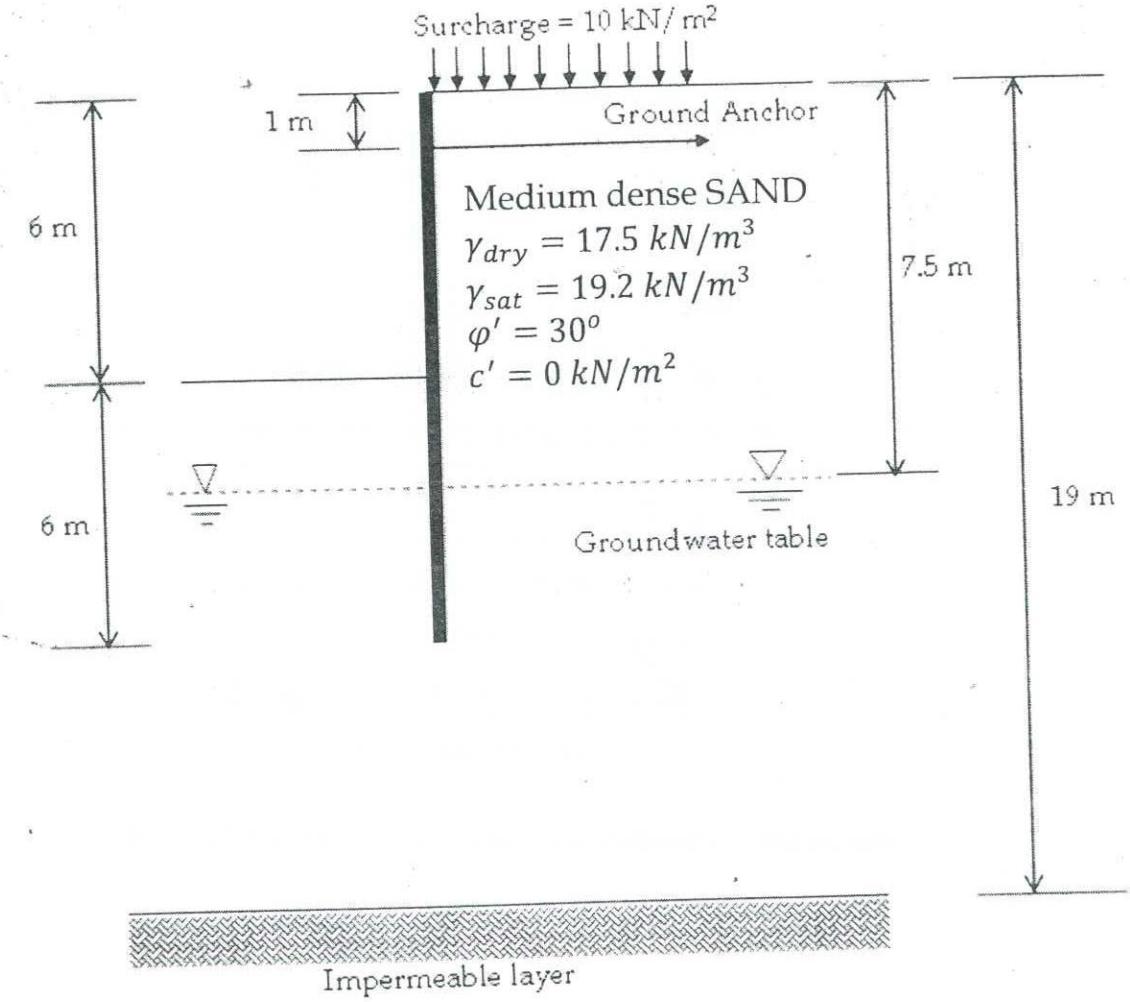

Figure Q2.1: Proposed anchored sheet pile wall arrangement

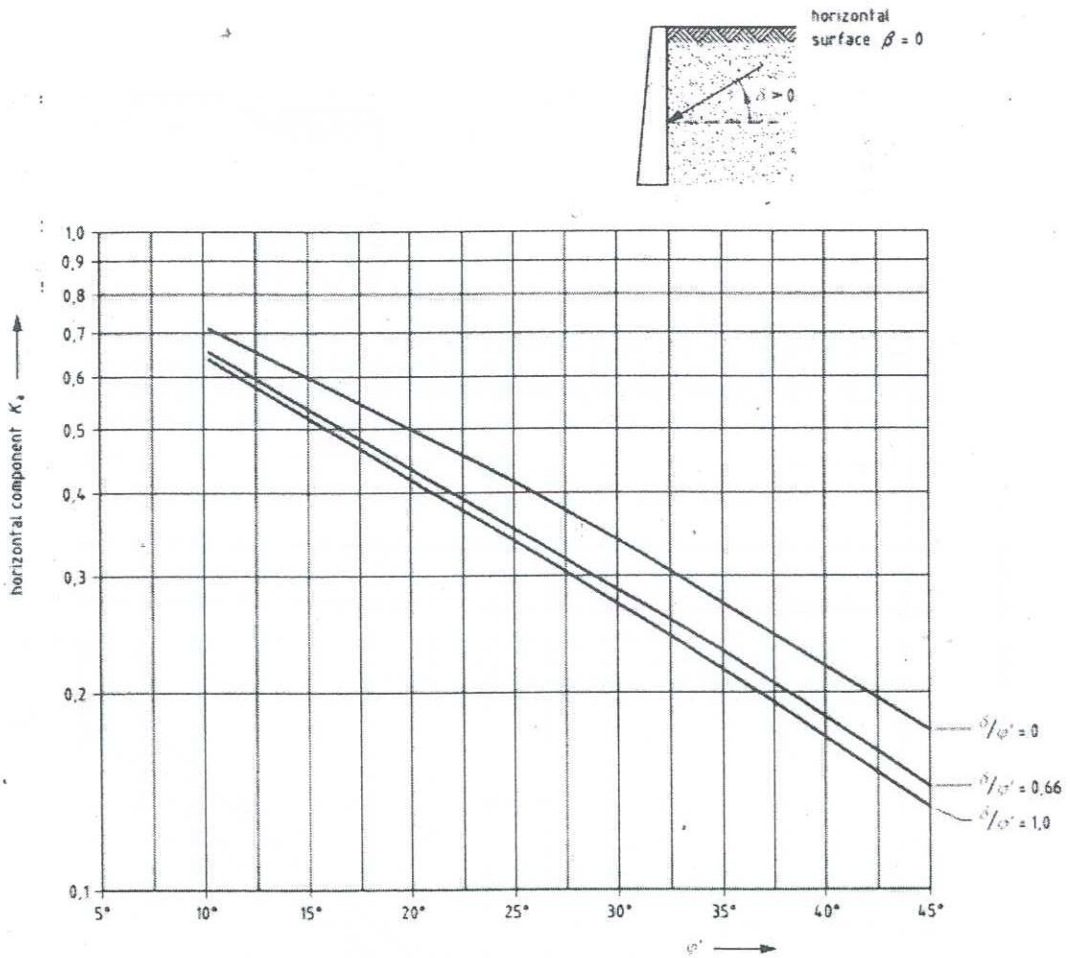

Figure Q2.2: Variation of the coefficient of effective horizontal active earth pressure (K_a) with φ'_d

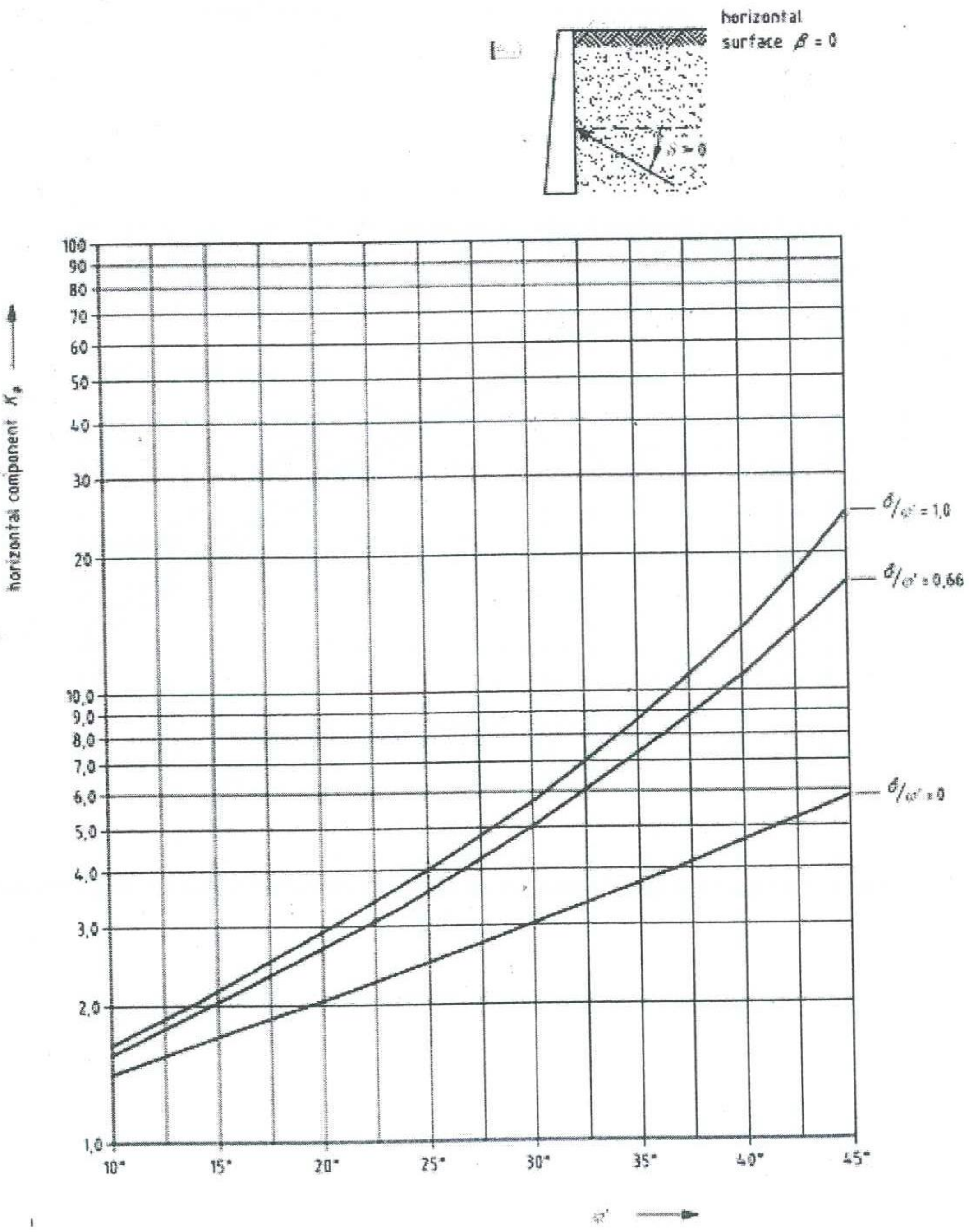

Figure Q2.3: Variation of the coefficient of effective horizontal passive earth pressure (K_p) with φ'_d

Table Q3.1: Soil parameters

Soil Properties	Clayey Sand
Dry unit weight, γ_{dry} (kN/m³)	20
Friction angle, φ' (deg)	28
Cohesion, c′ (kN/m²)	12

Table Q3.2: 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				

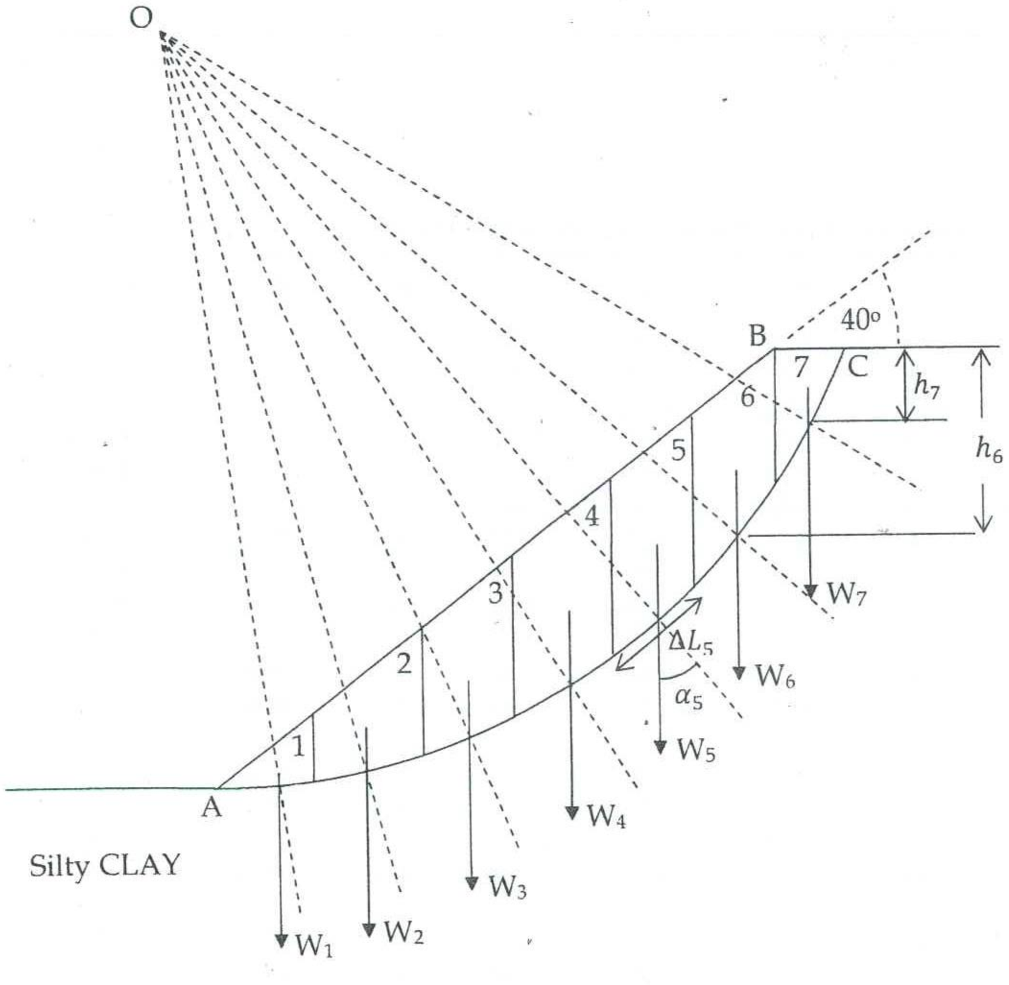

Figure Q4.1: The profile of the cut slope and the trial slip surface AC

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				