UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: October 2019

Module Number: CE7305 **Module Name: Geotechnical Engineering Design**

[Three Hours]

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

Q1. a) Briefly describe the situations in which pile foundations are required. Briefly explain 4 numbers of situations.

[1.0 Marks]

b) Briefly explain two numbers of situations where negative skin friction would develop on piles.

[1.0 Marks]

c) There is a proposal to construct a multi storied building. Sub-surface soil profile at the site is shown in Figure Q1.1 together with SPT-N values, and Core Recovery (CR) and Rock Quality Designation (RQD) of bed rock obtained from the site investigation. A series of laboratory tests were conducted to find the engineering properties of soil and results are illustrated in Table Q1.1. The water table was found to be at the existing ground surface. The unit weight of water can be taken as 9.81 kN/m³.

Based on the structural analysis, critical ultimate column load was found to be 3200 kN.

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

$$\eta = 1 - \frac{\theta}{90}\left[\frac{(n-1)m + (m-1)n}{mn}\right]$$

$$\theta = tan^{-1}(d/s)$$

$$Q_p = A_p q' N_q^* \leq A_p q_1$$

$$q_1 = 50 N_q^* tan\varphi$$

$$q_p = q_u\left(N_\phi + 1\right)$$

where $N_\phi = \tan^2\left(45 + \phi/2\right)$

Figure Q1.2, Figure 1.3 and Figure Q1.4 may be also useful in the calculations.

i) The geotechnical engineer in the project has decided to install 0.4 m x 0.4 m precast concrete piles upto a depth of 12.0 m from ground surface at each column location to carry the structural load. What would be the expected carrying capacity of a single pile?

[6.5 Marks]

ii) Since capacity of a single pile is not sufficient to carry the structural load of a column, it is proposed to drive 2 x 2 precast concrete piles with the same diameter at 1.0 m spacing as a pile group to carry the structural load. What would be the expected pile group capacity?

[1.5 Marks]

iii) If piles are driven upto the bed rock level, how many piles are required at a particular column location to carry the intended structural load?

[2.0 Marks]

Q2. A proposed machine-shop complex is to be founded on shallow spread footings. Consider a rectangular footing of dimensions 1.5 m x 2 m loaded vertically with an eccentricity as shown in Figure Q2.1. The footing is to be founded at a depth of 1.0 m below ground surface. The subsurface ground profile at the site (as shown in Figure Q2.2) consists of a slightly clayey sand which extends to a depth of 6 m below ground surface. The characteristic values of soil parameters are given in Table Q2.1. Assume that the groundwater table is located well below the ground surface.

a) Obtain the effective width and the effective length of the footing.
Following equations with usual notations may be used in the calculations.
When $e_L/L < {}^1\!/_6$ and $e_B/B < {}^1\!/_6$,
Effective area $A' = L_2B + \frac{1}{2}(B + B_2)(L - L_2)$
Effective width, $B' = A'/L$
Effective length, $L' = L$
The parameters L_2 and B_2 can be obtained from Figure Q2.3.

[2.0 Marks]

b) Determine the ultimate 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. Combinations of sets of partial factors 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:
$q_u = c'N_cF_{cs}F_{cd}F_{ci} + qN_qF_{qs}F_{qd}F_{qi} + \frac{1}{2}\gamma BN_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma i}$
The bearing capacity factors N_c, N_q, and N_γ may be obtained from Table Q2.5.
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 $\frac{D_f}{B} \leq 1$

$$F_{cd} = 1 + 0.4\frac{D_f}{B}$$

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

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

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

$$F_{cd} = 1 + 0.4\ tan^{-1}\left(\frac{D_f}{B}\right)$$

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

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

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

[5.0 Marks]

c) Determine the ultimate design load that the footing can sustain.

[1.0 Marks]

d) A permanent characteristic vertical load of 180 kN and a variable characteristic vertical load of 95 kN will be transferred to the foundation soils via the footing in consideration. Based on the structural engineer's analysis, the footing is also subjected to lateral loading of significant magnitude. Therefore, it is important to check the footing's ability to resist sliding at the base. Using the provided loading data, determine the footing's design resistance to sliding (R_d) in accordance with the Design Approach 1-Combination 2 of the Eurocode 7. Considering the shallow depth of embedment of the footing, ignore any resistance to sliding that develops due passive and active earth pressure components acting on the sides of the footing.

[2.0 Marks]

e) Explain how the design resistance to sliding (R_d) will be affected if the groundwater table in the area should rise above the foundation depth.

[2.0 Marks]

Q3. a) Briefly describe the 'Plate Load Test' procedure.

[4.0 Marks]

b) Identify the limitations of the plate load test in predicting the bearing capacity and settlement of shallow footings.

[4.0 Marks]

c) The subsurface profile encountered at a building site consists of a predominantly loose formation of sand which extends to a depth of 5.5 m below ground surface. A plate load test was carried out in order to verify the design bearing capacity of proposed column footings. The results of the plate load test are shown in Figure Q3.1. The test was carried out using a 0.3 m diameter plate set at the center of a 2 m x 2 m pit excavated to a depth of 1 m.

Given a serviceability limit of 25 mm settlement, determine design bearing capacity of a 1.5 m x 1.5 m column footing placed at a depth of 1 m.

For a given intensity of load q_o, and for granular soils:

$S_F = S_P \left(\frac{2B_F}{B_F+B_P}\right)^2$; where

S_F = Settlement of the foundation
S_P= Settlement of the plate
B_F = Width of the foundation
B_P = Width of the plate

[4.0 Marks]

Q4. a) Using suitable sketches briefly describe the variation of factor of safety against slope instability from original state through end of construction to final state reached after dissipation of excess pore pressure as relevant to construction of:

i) a cut slope, and
ii) an embankment

[2.0 Marks]

b) A preliminary assessment of stability of a cut slope is to be carried out with the use of the 'Ordinary Method of Slices'. The ordinary method of slices is used to determine the factor of safety against slip along an arc of a circle which represents the trial failure surface. The method divides the soil above the trial surface into several vertical slices.

i) Considering the forces that act on a typical slice (as shown in Figure Q4.1) with the groundwater table located at great depth, list the assumptions associated with the ordinary method of slices and obtain the following expression for the factor of safety (F_s) with usual notations.

$$F_s = \frac{\sum_{n=1}^{n=p}(c'\Delta L_n + W_n \cos\alpha_n \tan\varphi')}{\sum_{n=1}^{n=p}(W_n \sin\alpha_n)}$$

Approximately, $\Delta L_n = \frac{b_n}{\cos\alpha_n}$; where b_n is the width of the nth slice. φ' and c' are the soil parameters.

[4.0 Marks]

ii) Figure Q4.2 illustrates the profile of the cut slope section and the trial slip surface AC. The soil above the trial surface is divided into 7 vertical slices. Using the ordinary method of slices, find the factor of safety against slip along the trial surface AC. The calculation of the factor of safety can be completed using Table Q4.1 which should be attached to the answer book.

[4.0 Marks]

iii) Consider a rise in groundwater table such that the trial slip surface AC is intersected as shown in Figure Q4.3. Reconsider the forces that act on those slices that are intersected by the elevated groundwater table and review the derivation of the expression for factor of safety to briefly explain the groundwater effect on slope stability.

[2.0 Marks]

Q5. 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 Q5.1 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/m^3.

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 Q5.2 and Figure Q5.3, 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.

[3.5 Marks]

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

[3.5 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) Explain how the assumption of 'smooth wall' affects the design check.

[2.0 Marks]

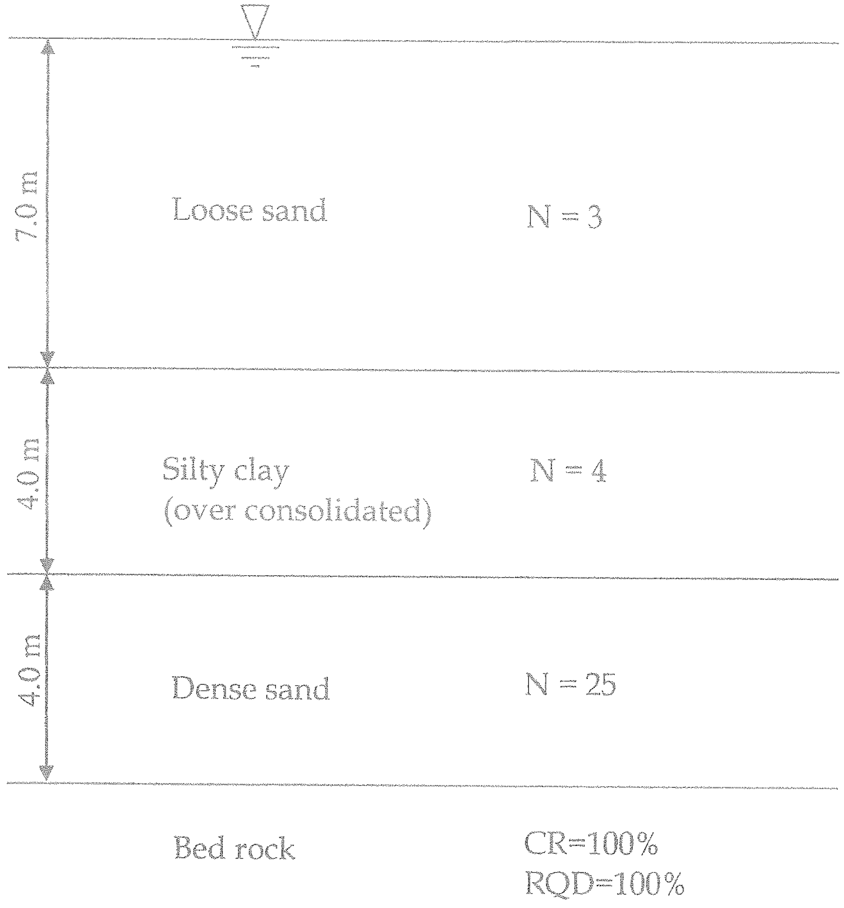


Figure Q1.1 Sub-surface soil profile at the proposed hotel site

Table Q1.1 - Engineering properties of subsurface soil

	Loose sand	Silty clay	Dense sand
Drained cohesion (kN/m^2)	0	5	0
Undrained cohesion (kN/m^2)	0	30	0
Internal friction angle (^{0})	20	18	35
Bulk unit weight (kN/m^3)	17.0	16.0	18.0
Poisson's ratio	0.25	0.40	0.50
Young's Modulus (kN/m^2)	30,000	20,000	50,000
Unconfined Compressive strength of bed rock = 50 MPa Drained friction angle of bed rock = 40°			

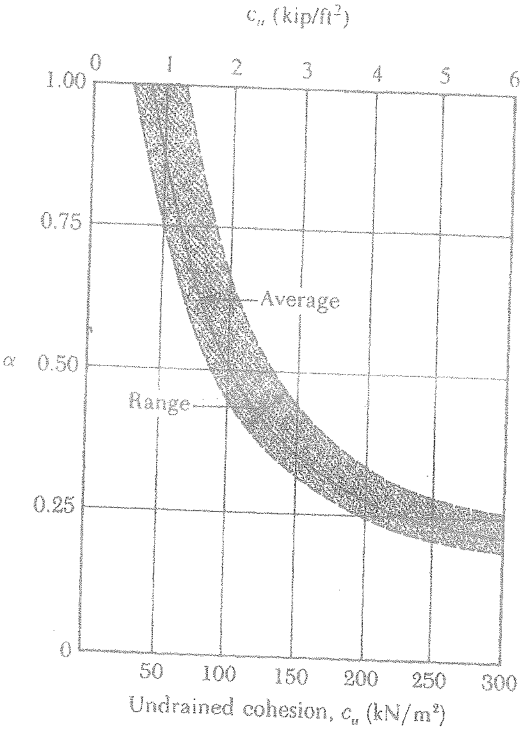


Figure Q1.2 - Variation of α with undrained cohesion of clay

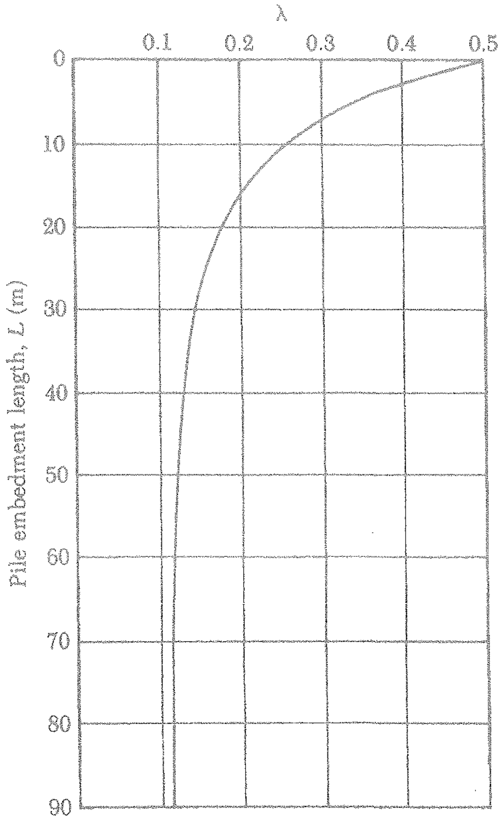


Figure Q1.3 - Variation of λ with pile embedded length

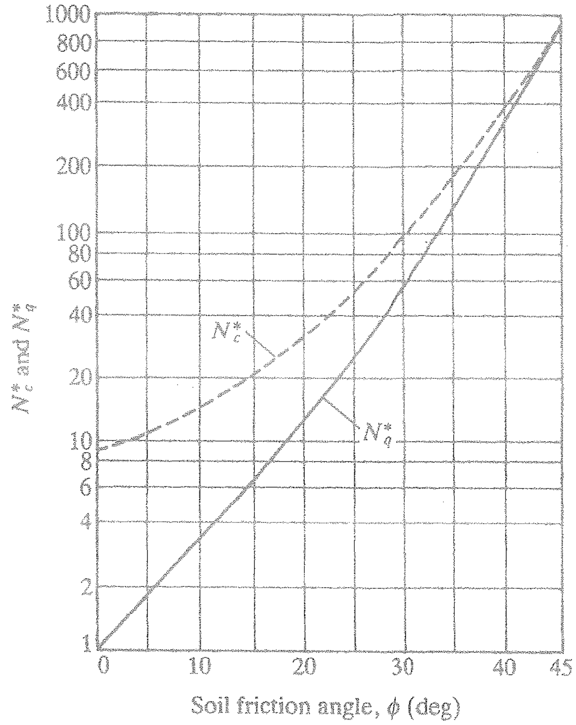


Figure Q1.4 - Variation of N_c^* and N_q^* with soil friction angle

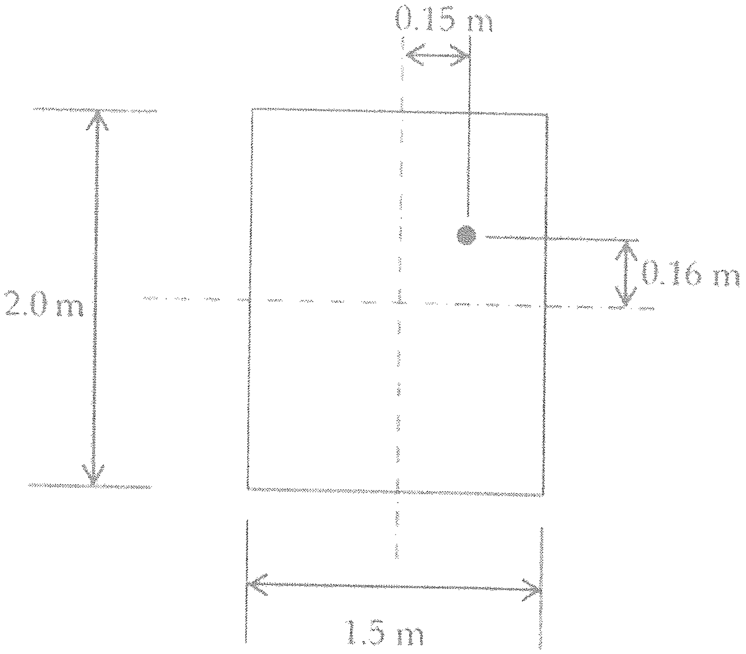


Figure Q2.1: Location of the column load with respect to footing

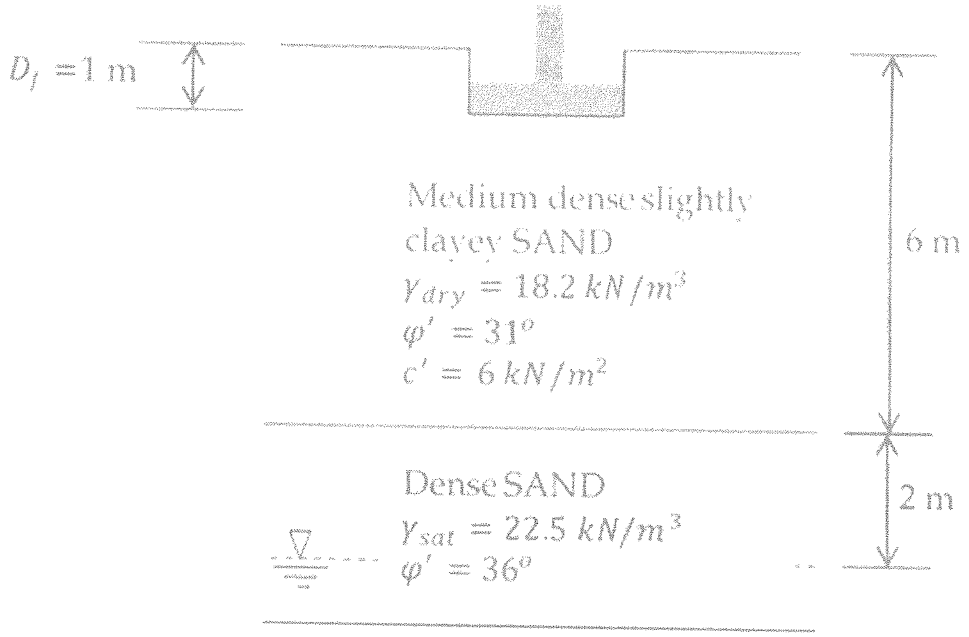
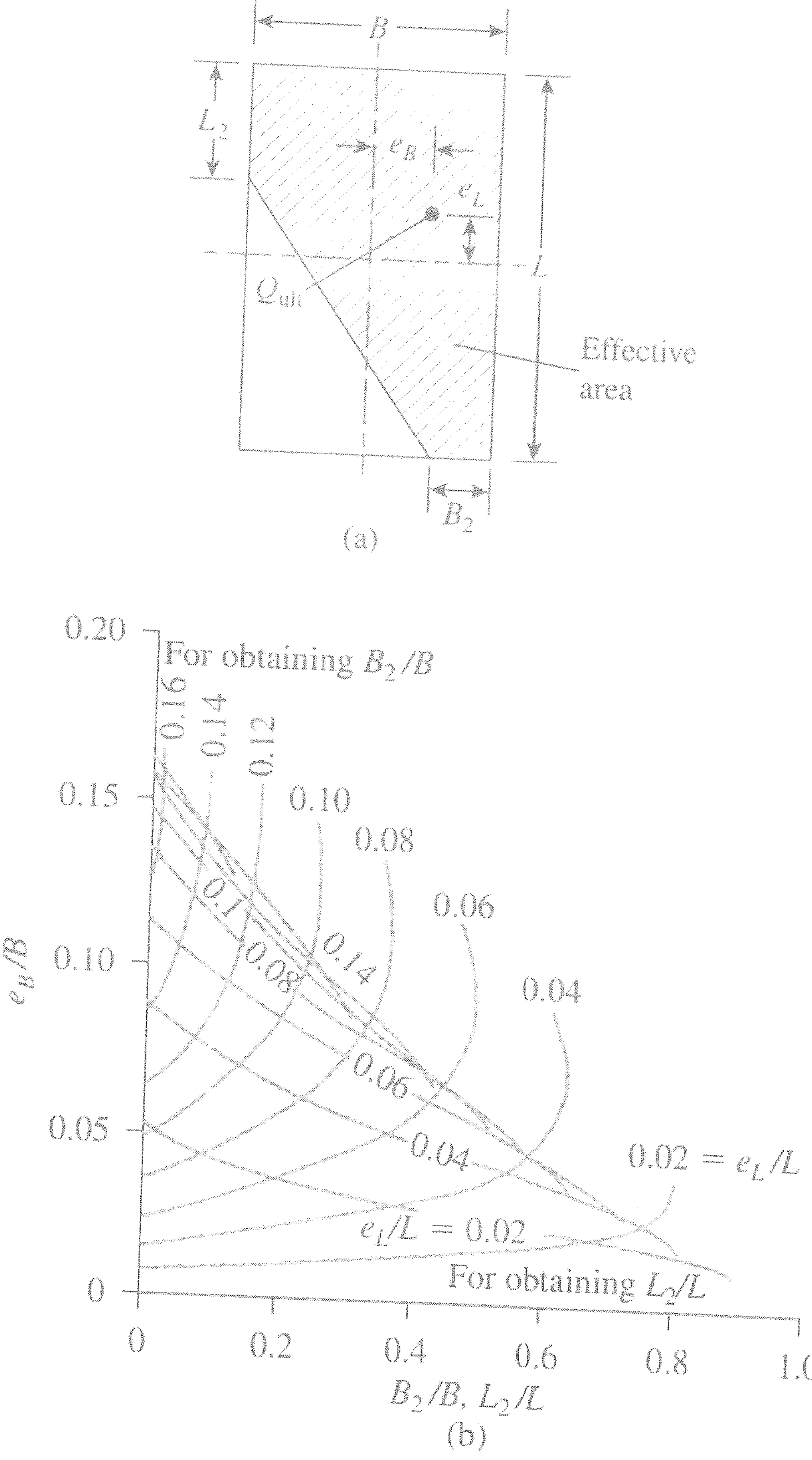


Figure Q2.2: subsurface profile at the site

Table Q2.1: Characteristic values of soil parameters

Soil parameters [slightly clayey SAND]	Characteristic value
Dry unit weight γ_{dry} (kN/m^3)	18.2
Friction angle φ' (deg)	31
Cohesion c' (kN/m^2)	6
Footing-soil interface friction angle at the base, δ_{base}	$k.\varphi_{cv,d}$; $k = 1$ for footings cast against soil
Footing-soil interface adhesion at the base, a_{base}	0



(a)

(b)

Figure Q2.3: The parameters L_2 and B_2 for determining effective dimensions of eccentrically loaded shallow footings

Design Approach 1:

Combination 1: *A1* "+" *M1* "+" *R1*
Combination 2: *A2* "+" *M2* "+" *R1*; where "+" implies: "to be combined with".

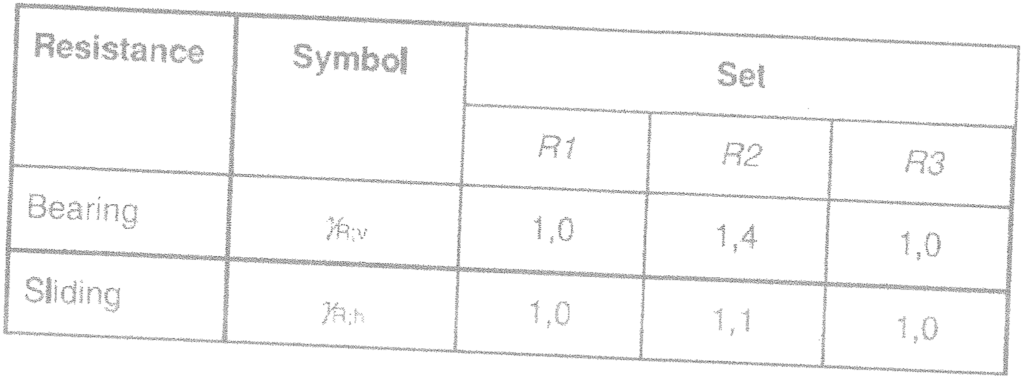
Table Q2.2: Partial factors on actions (γ_F) or the effects of actions (γ_E)

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)

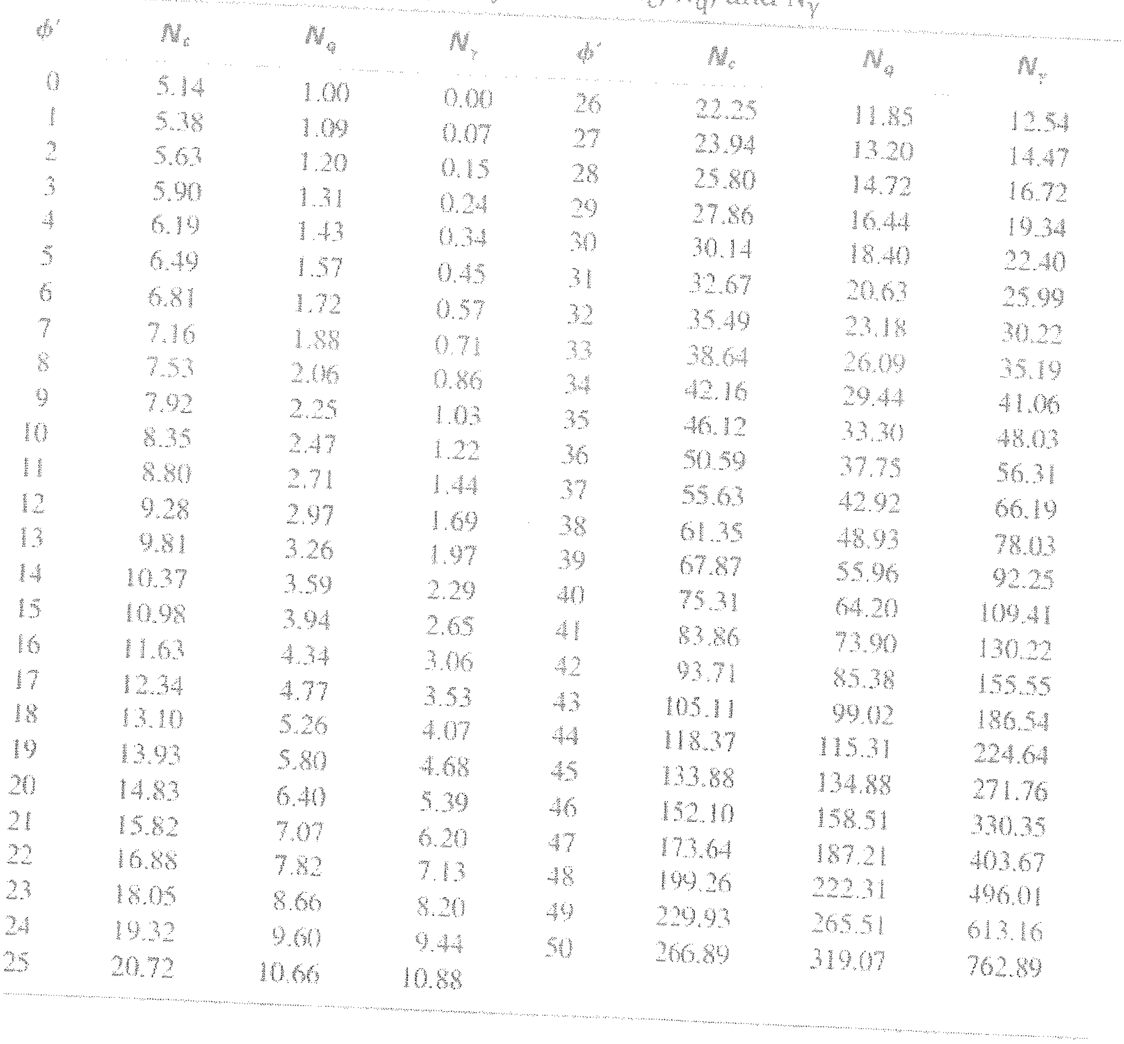
Soil parameter	**Symbol**	**Set**	
		M1	*M2*
Angle of shearing resistance[a]	$\gamma_{\varphi'}$	1,0	1,25
Effective cohesion	$\gamma_{c'}$	1,0	1,25
Undrained shear strength	γ_{cu}	1,0	1,4
Unconfined strength	γ_{qu}	1,0	1,4
Weight density	γ_{γ}	1,0	1,0
[a] This factor is applied to $\tan \varphi'$			

Table Q2.4: Partial resistance factors (γ_R) for spread foundations



Resistance	Symbol	Set		
		R1	R2	R3
Bearing	$\gamma_{R;v}$	1,0	1,4	1,0
Sliding	$\gamma_{R;h}$	1,0	1,1	1,0

Table Q2.5: 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				

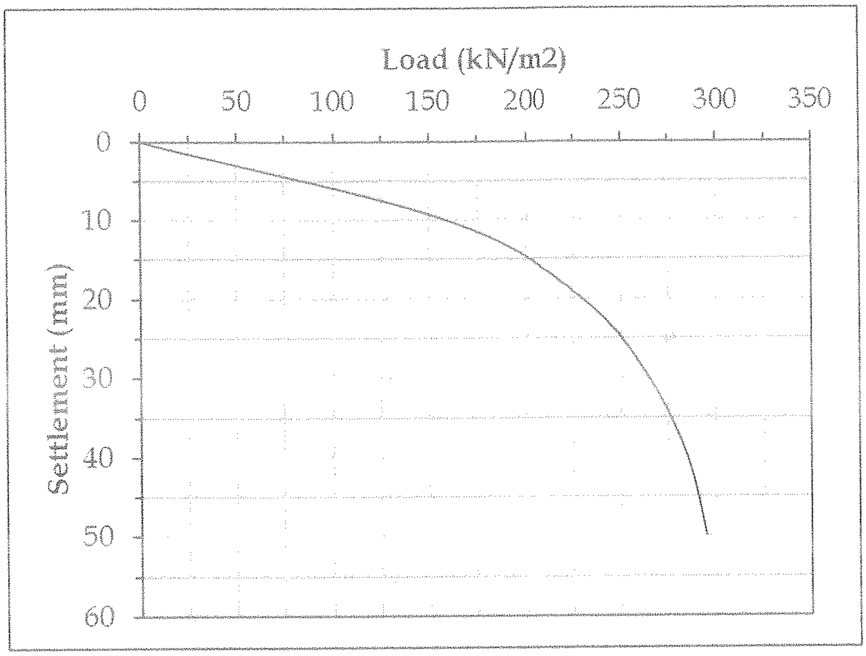
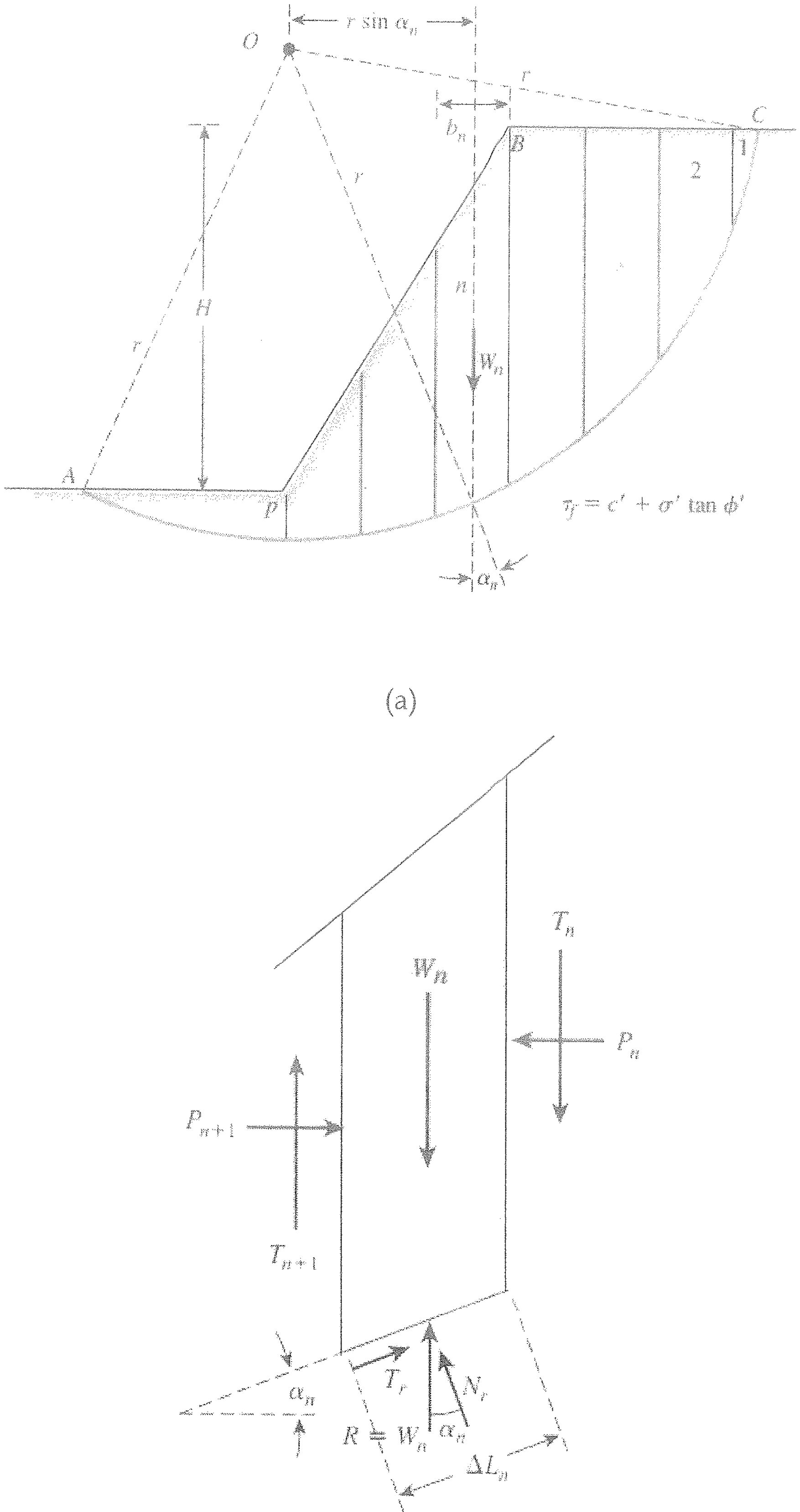


Figure Q3.1: Plate load test results



(a)

(b)

Figure Q4.1: Stability analysis with methods of slices – (a) trial failure surface (b) forces acting on nth slice

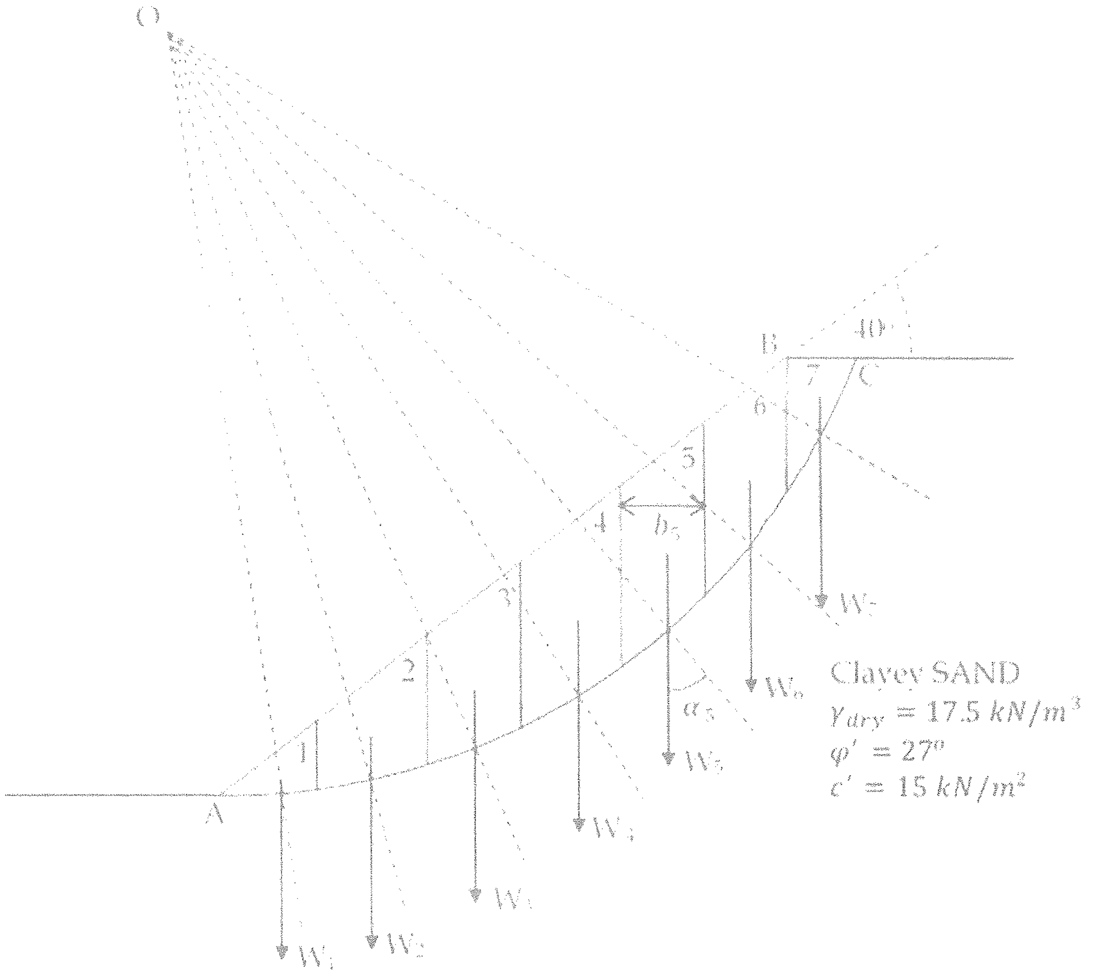


Figure Q4.2: The profile of the cut slope section and the trial slip surface AC

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

Slice No.	W (kN/m)	α_n (deg)	ΔL_n (m)				
1	29.8	10	1.32				
2	78.8	15	2.28				
3	105.0	33	2.38				
4	126.0	40	2.61				
5	113.3	47	2.64				
6	101.1	52	2.92				
7	29.4	63	2.86				

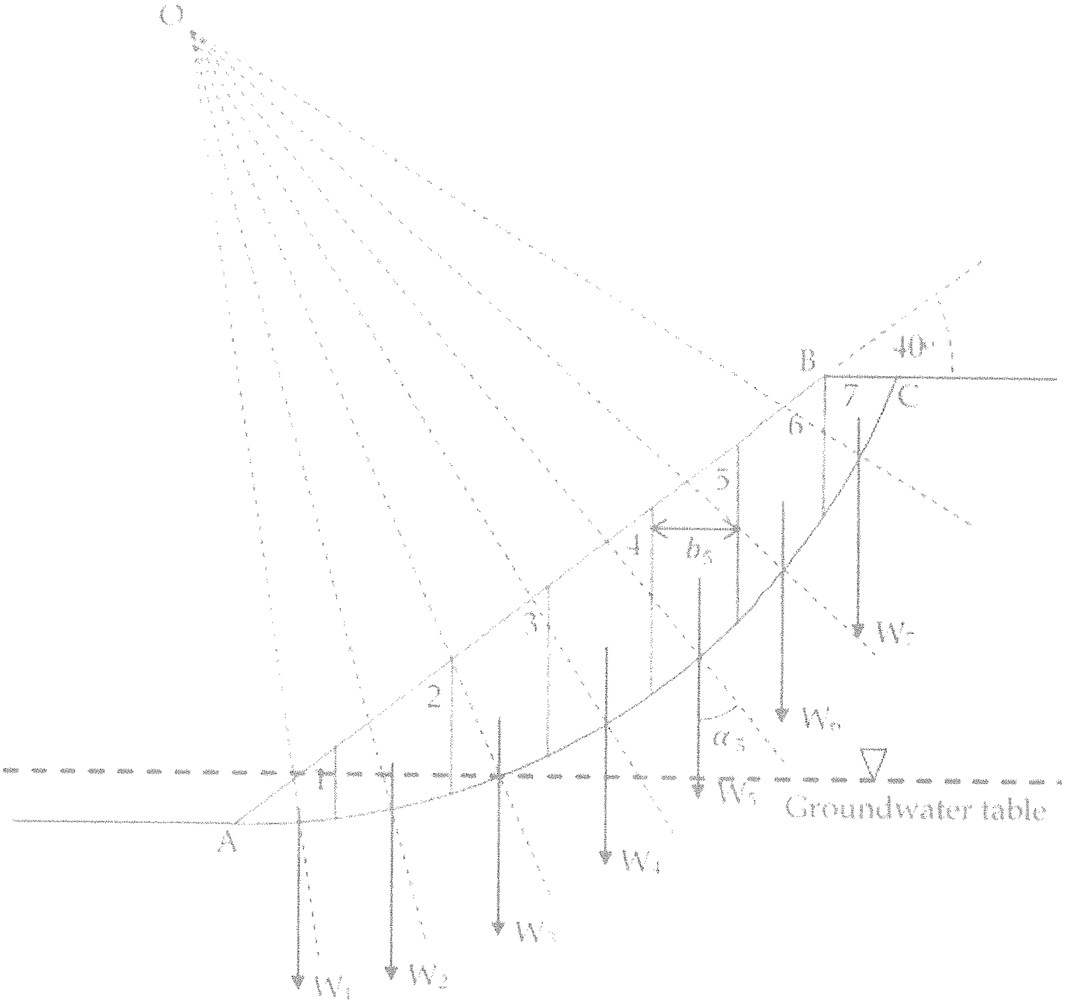


Figure Q4.3: The trial slip surface AC intersected by the groundwater profile

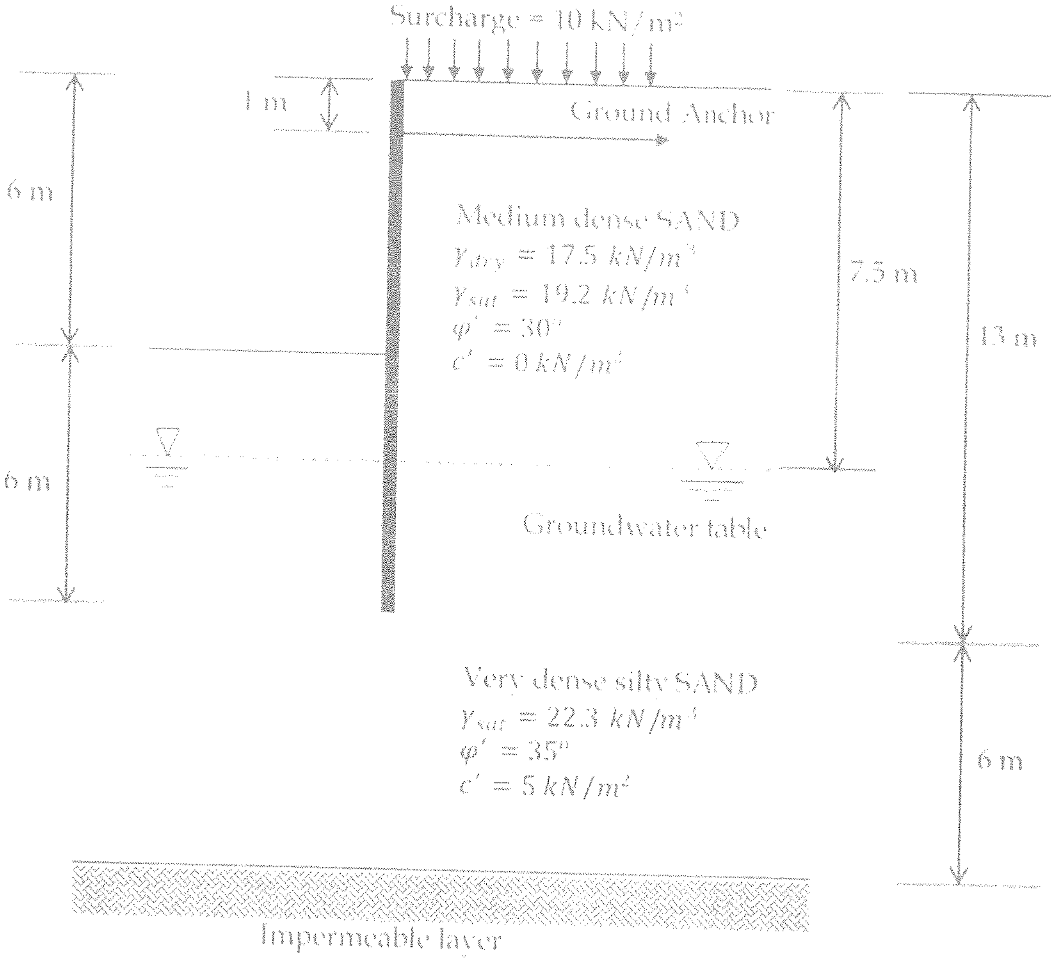


Figure Q5.1: Proposed anchored sheet pile wall arrangement

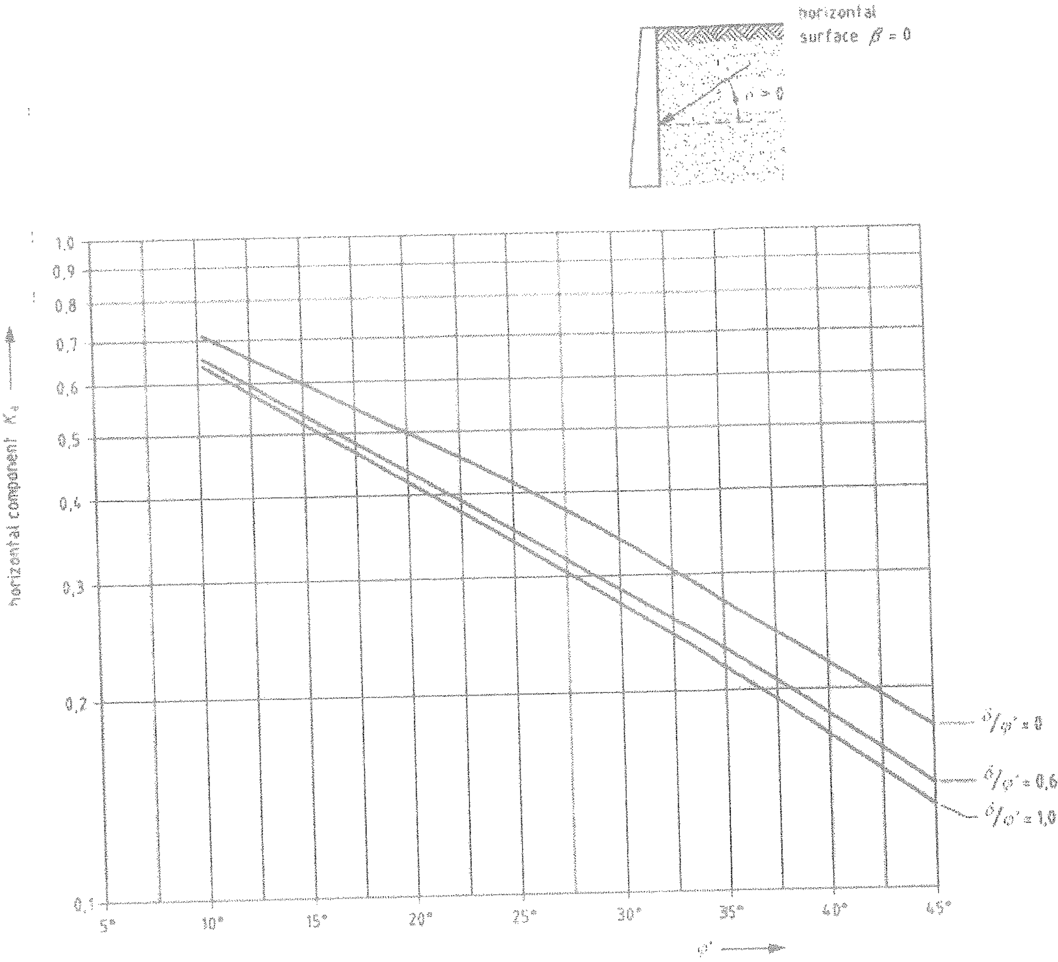


Figure Q5.2: Variation of the coefficient of effective horizontal active earth pressure (K_a) with φ'_d

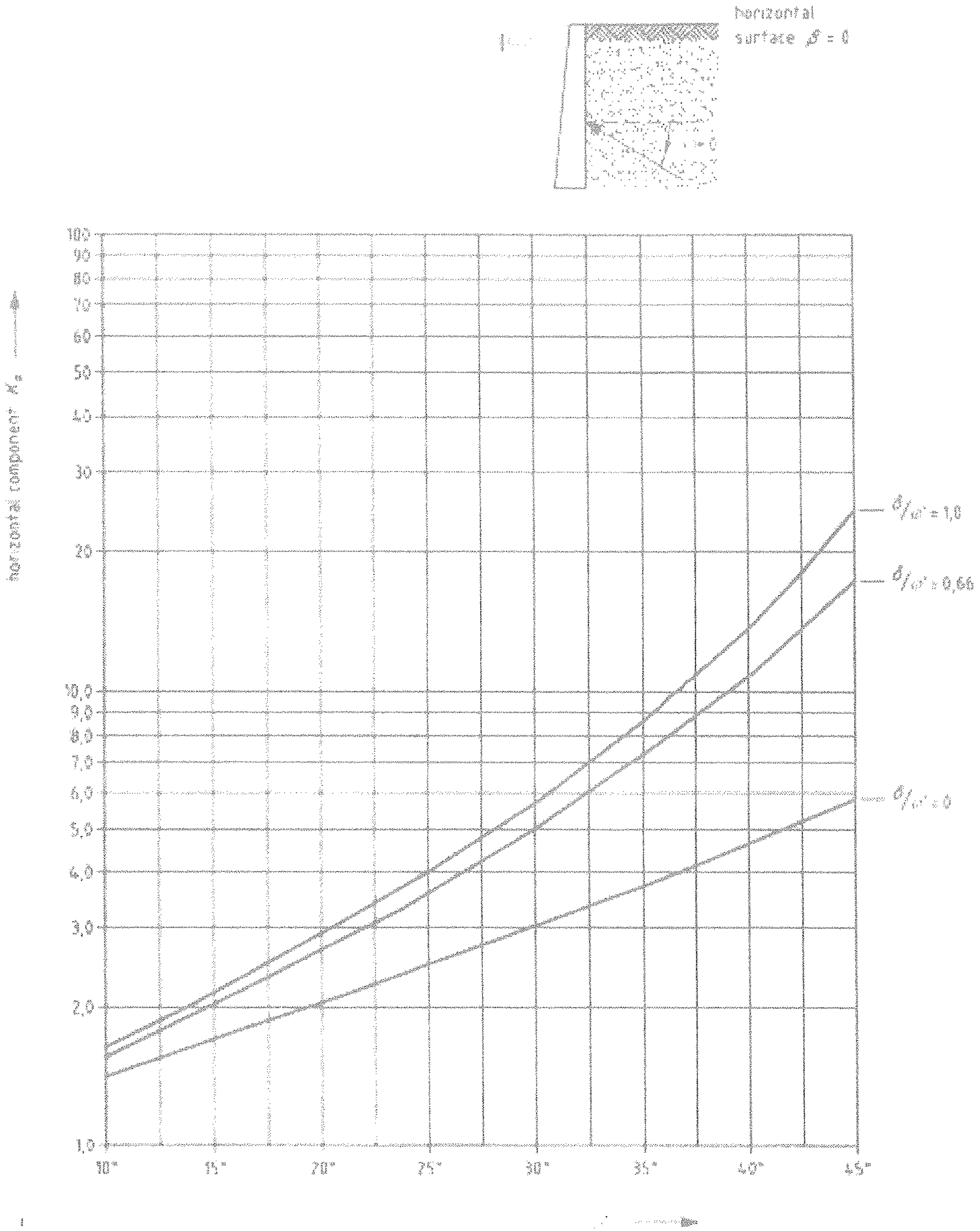


Figure Q5.3: Variation of the coefficient of effective horizontal passive earth pressure (K_p) with φ'_d