UNIVERSITY OF BOLTON

OFF CAMPUS DIVISION

WESTERN INTERNATIONAL COLLEGE

BENG (HONS) CIVIL ENGINEERING

SEMESTER ONE EXAMINATION 2023/24

GEOTECHNICAL ENGINEERING

MODULE NO: CIE6020

Date: Saturday 06 January 2024 **Time:10:00 AM – 1:00 PM**

INSTRUCTIONS TO CANDIDATES:

There are FIVE questions on this paper.

Answer any FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

This examination paper carries a total of 100 marks.

Formula sheet / supplementary information is provided on page 16

All working must be shown. A numerical solution to a question obtained by programming an electronic calculator will not be accepted.

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Question 1

(a) A 400 mm diameter concrete pile is driven for a 10.00 m into layered soils and the details are as follows:

Loose sand	2.50m thick	(γ=17.0 kN/m^3; N = 18)
Dense sand	2.0m thick	(γ = 20.0 kN/m^3; N = 21)
Compact Sand	10.0m thick	(γ_{sat} = 22.0 kN/m^3; N = 33)

The water table is at 4.50m from ground level. Determine the safe working load of this pile by adopting factors of safety of 1.50 and 2.50 for the shaft and end bearing resistance respectively.

Use **Figures Q1-1, Q1-2, and Q1-3** on **Pages 12 to 13** and the formulae provided in the supplementary sheet. (12 marks)

(b) In a site of almost similar conditions, instead of dense sand if there is a layer of soft clay for 2m (γ= 18.0 kN/m^3), what might be the possible effect on the safe load-bearing capacity of the pile? Justify your findings with the help of suitable sketches/equations. (6 marks)

(c) A large diameter under-reamed bored pile is to be installed in stiff clay with an undrained shear strength value of 215 kN/m^2. The main shaft of the pile is 1.2m diameter and the base of the under ream is 3.5m diameter with a height of 2.5m. The total length of the pile from the ground level to the base of the under-ream is 15 m. Determine the working load of the pile in MN, assuming the following factors for adhesion, α = 0.3 and end bearing N c = 9.0. Apply a factor of safety of 3.0 to the base load. Full mobilisation of shaft adhesion can be assumed. Clearly state all assumptions made in your analysis. (7 marks)

Total 25 marks

Please turn the page

Question 2

(a) A reinforced concrete gravity wall, 1.5m wide at its top and 2m wide at its base is resting upon and also retains 6.0m of soil. Assume the water table is at greater depth.

A cross-section through the wall is shown in **Figure Q2** on **Page 4.**

Other relevant parameters are:

Soil 1: Bulk Unit weight 17.0 kN/m^3

Effective friction angle φ = 18°

Soil depth: 3m

Soil 2: Bulk Unit weight 19.0 kN/m^3

Effective friction angle φ´= 32°

Soil depth: 2m

Surcharge : 15kN/m^2 on upper retained surface

Reinforced concrete Unit weight: 24 kN/m^3

(i) Sketch the earth pressure diagram for the retained soil, labelling all relevant values. Determine, by calculation, the resultant thrust acting on the back of the retaining wall. (17 marks)

(ii) Determine the height of the resultant thrust above the base of the retaining wall and hence determine the Factor of Safety against overturning (Ignore water pressures on the base of the foundation) (3 marks)

Question 2 continued over…

Please turn the page

Question 2 continued…

(iii) What are the advantages and disadvantages of using an "embedded secant pile wall" instead of a gravity retaining wall in the above scenario? Ensure that your answer discusses construction practicality as well as technical aspects concerning the development of earth pressures on either side of the embedded wall. (5 marks)

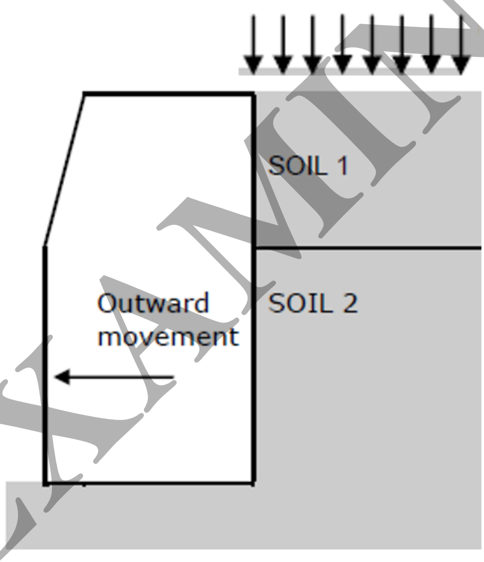

Figure Q2

Total 25 marks

Question 3

(a) A 7m height cutting is excavated in a thick stratum of saturated clay with the following properties:

Question 3 continued over…
Please turn the page

Question 3 continued…

Saturated Unit weight, ©$_{sat}$ = 20 kN/m^3

Strength parameters with respect to effective stress,

C’ = 20 kN/m^2 ,)’ = 30^0

A trial slip surface of radius 12m and sector angle 71^0 is dividing the sector into 6 slices as shown in **Figure Q3-1** on **Page 14.**

i) Complete the table shown in **Table Q3** on **Page 15** and hence determine the long-term factor of safety, F, of the trial slip surface using **Swedish (Fellenius)** analysis. (13 marks)

ii) In the above scenario, if earthquake forces are expected what factors should be considered for determining the factor of safety? (2 marks)

(b) Explain why regular inspections of the ground behind the crest is advisable when a cutting is being excavated. Explain your answer with the help of diagram. (5 marks)

(c) A cutting in saturated clay has a vertical height of 8.0m. Hard bedrock is located at a depth of 4.0m below the floor of the cutting. The clay has the following properties;

Undrained cohesion, C_u = 40.0kN/m^2

Undrained angle of friction, φu = 0^o

Question 3 continued over…

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Question 3 continued…

Unit weight, γ = 19.0kN/m^3

Using **Figure Q3-2** on **Page 6**, determine the factor of safety against short-term failure, if the cutting has a side slope of 10^0.

(5 marks)

Total 25 marks

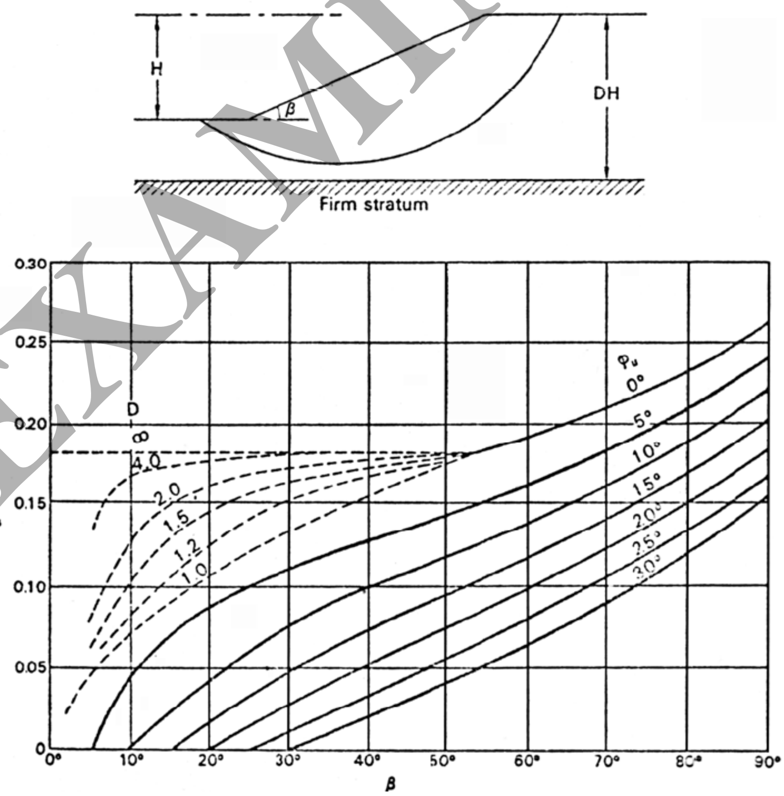

Figure Q3-2 – Taylor's Chart

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Question 4

(a) **Figure Q4-1** on **page 7** shows a layer of sand 6 m thick lies above a layer of clay soil. The water table is at a depth of 2 m below the ground surface. The void ratio of the sand layer is 0.6 and the degree of saturation of the sand layer above the water table is 40%. The void ratio of the clay layer is 0.7. Assume specific gravity of the sand and clay soil as 2.65 and 2.7. Consider the unit weight of water $\gamma_w = 9.81\ kN/m^3$.

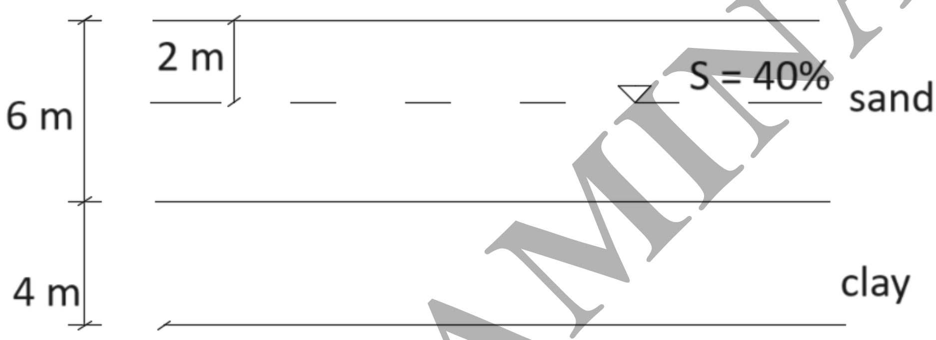

Figure Q4-1

Calculate the following:

i) Bulk unit weight of sand, saturated unit weights of sand and clay.

(3 marks)

ii) The total stress, neutral stress, and effective stress at a point 10 m below the ground surface.

(6 marks)

iii) Draw the diagram showing the variation of effective stress, neutral stress and total stress.

(3 marks)

Question 4 continued over…

Please turn the page

Question 4 continued…

(b) A foundation 2 m x 2 m square is installed 1.2 m below the surface of a uniform sandy gravel. The strength parameters with respect to effective stress are c′ = 0 and φ′ = 30°. Take the unit weight of water $\gamma_w = 9.81\ kN/m^3$. Consider the following soil densities.

$$\gamma = 19.2 kN/m^3$$
$$\gamma_{sat} = 21.4 kN/m^3$$

i) Calculate the ultimate bearing capacity of soil when water table is at a depth of 6m from ground level.

(3 marks)

(ii) Determine the safe bearing capacity of soil when the water table is level with the foundation base. Choose a minimum FOS from **Table Q4 a** on **page 9.**

(6 marks)

(iii) Calculate the ultimate bearing capacity of soil when water table rises to 0.5 m below the ground level.

(4 marks)

NOTE: Clearly state any assumptions made in your calculations to determine the safe bearing capacity. Use **Tables Q4 b and Q4 c** on **pages 9-10** and the formulae provided on **Supplementary Information.**

Total 25 marks

Question 4 continued over…
Please turn the page

Question 4 continued …

Table Q4 a: Minimum factors of safety for shallow foundation

Category	Characteristics of category	Extent of site investigation		Typical Structure
		Thorough	Limited	
A	Maximum design load: likely to occur often. Consequences of failure: disastrous	3.0	4.0	Railway bridges warehouses Blast furnaces Reservoir embankments Retaining walls / silos
B	Maximum design load: May occur occasionally. Consequences of failure: serious	2.5	3.5	Highway bridges Light industrial Public buildings
C	Maximum design load: Unlikely to occur.	2.0	3.0	Apartments Office buildings.

Table Q4 b: Shape Factors

Shape of footing	S_C	S_q	S_γ
Strip	1.0	1.0	1.0
Rectangle	$1.0+(B/L)(N_q/N_c)$	$1.0+(B/L)\tan\phi'$	$1.0-(B/L)\,0.4$
Circle or Square	$1.0+(N_q/N_c)$	$1.0+\tan\phi'$	0.6

Question 4 continued over…
Please turn the page

Question 4 continued …

Table Q4 c: Bearing capacity factors

ϕ	N_c	N_q	N_γ
0	5.14	1.0	0
1	5.4	1.1	0
2	5.6	1.2	0
3	5.9	1.3	0
4	6.2	1.4	0
5	6.5	1.6	0.1
6	6.8	1.7	0.1
7	7.2	1.9	0.2
8	7.5	2.1	0.2
9	7.9	2.3	0.3
10	8.4	2.5	0.4
11	8.8	2.7	0.5
12	9.3	3.0	0.6
13	9.8	3.3	0.8
14	10.4	3.6	1.0
15	11.0	3.9	1.2
16	11.6	4.3	1.4
17	12.3	4.8	1.7
18	13.1	5.3	2.1
19	13.9	5.8	2.5
20	14.8	6.4	3.0
21	15.8	7.1	3.5
22	16.9	7.8	4.1
23	18.1	8.7	4.9
24	19.3	9.6	5.7
25	20.7	10.7	6.8
26	22.3	11.9	7.9
27	23.9	13.2	9.3
28	25.8	14.7	10.9
29	27.9	16.4	12.8
30	30.1	18.4	15.1
31	32.7	20.6	17.7
32	35.5	23.2	20.8
33	38.6	26.1	24.4
34	42.2	29.4	28.8
35	46.1	33.3	33.9
36	50.6	37.8	40.0
37	55.6	42.9	47.4
38	61.4	48.9	56.2
39	67.9	56.0	66.8
40	75.3	64.2	79.5

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Question 5

(a) A saturated soil has a compression index of 0.25. The void ratio of this soil at a stress of 10 kN/m^2 is 2.02 and the permeability is 3.4 x 10^7 mm/sec. Calculate:

(i) Change in void ratio, Coefficient of compressibility and coefficient of volume compressibility, if the stress is increased to 19 kN/m^2.

(4 marks)

(ii) Settlement of the above scenario, if the soil stratum is 5 m thick.

(3 marks)

(iii) Time required for 40% consolidation if drainage is one way.

(5 marks)

(b)

(i) A clay layer 4 m thick is subjected to a pressure of 55 kN/m^2. If the layer has a double drainage and undergoes 50% consolidation in one year, determine the coefficient of consolidation. Take $T_v = 0.196$. If the coefficient of permeability is 0.020 m/yr, determine the settlement in one year and rate of flow of water per unit area in one year.

(8 marks)

(ii) Illustrate the pressure – void ratio relationship for a typical sand under one-dimensional compression.

(5 marks)

Total 25 marks

Question 5 continued over…

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Question 5 continued…

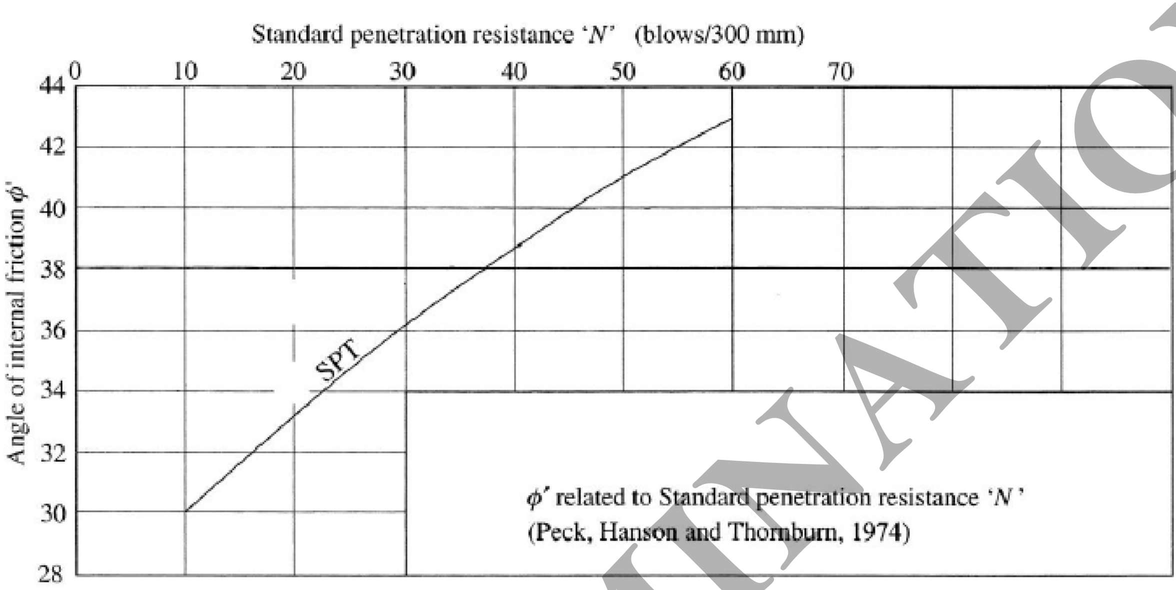

Figure Q1-1

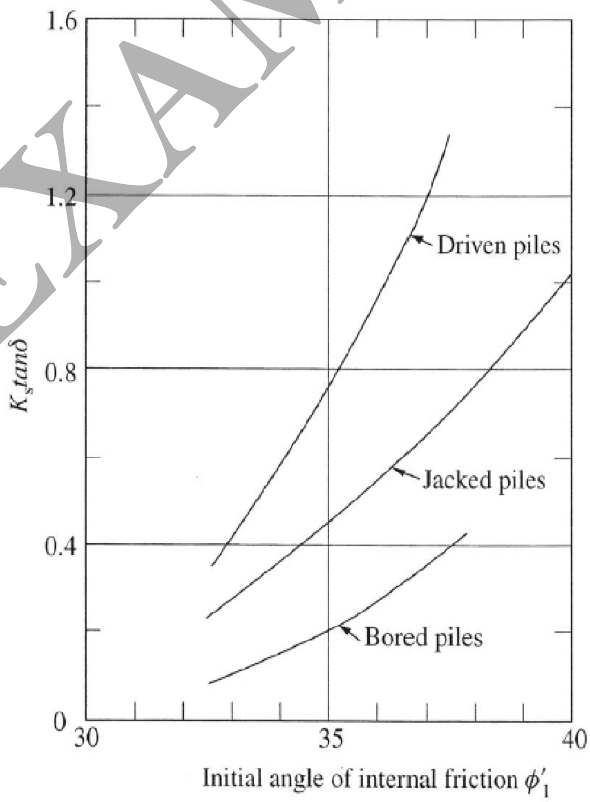

Figure Q1-2

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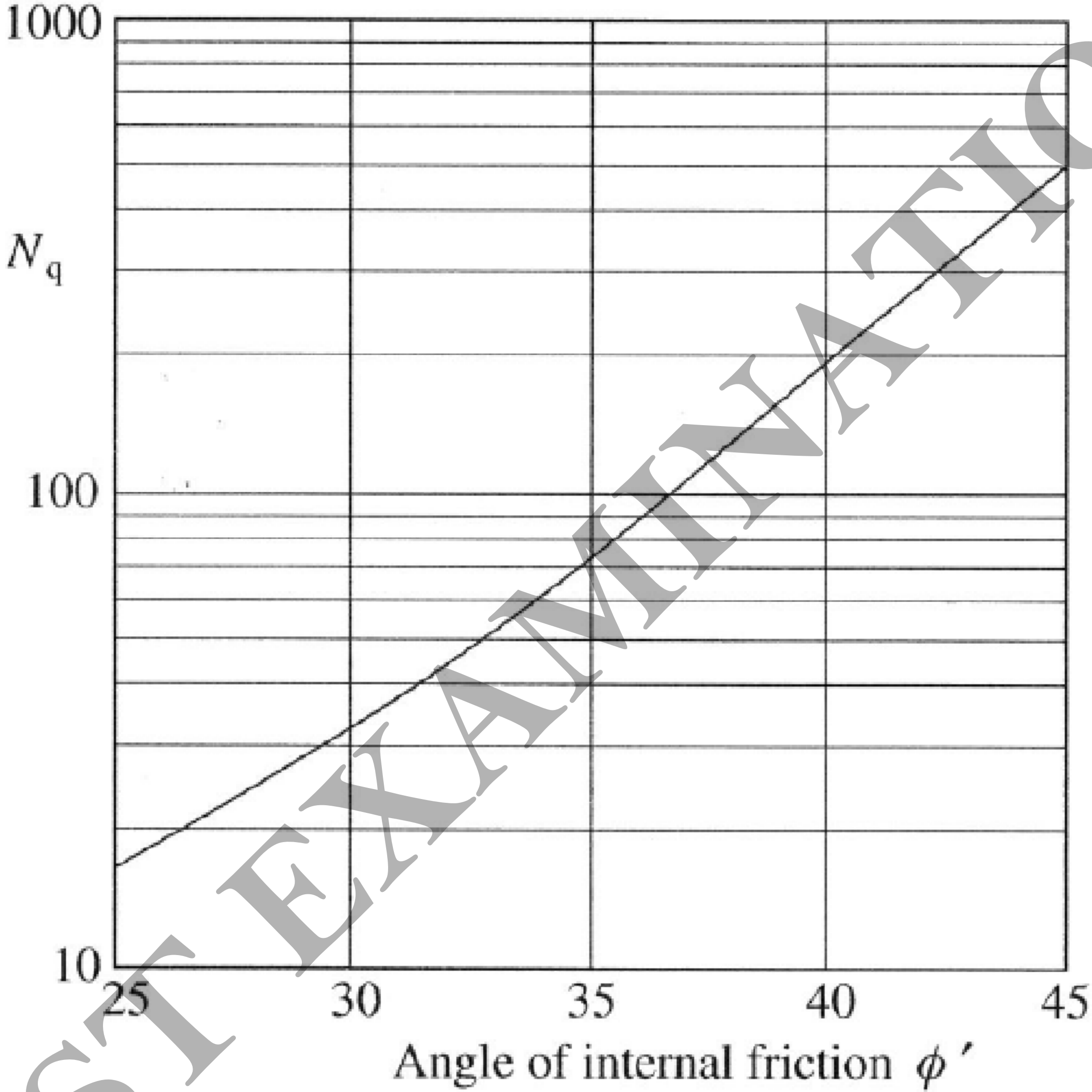

(From Berezantsev et al 1961)

Figure Q1-3

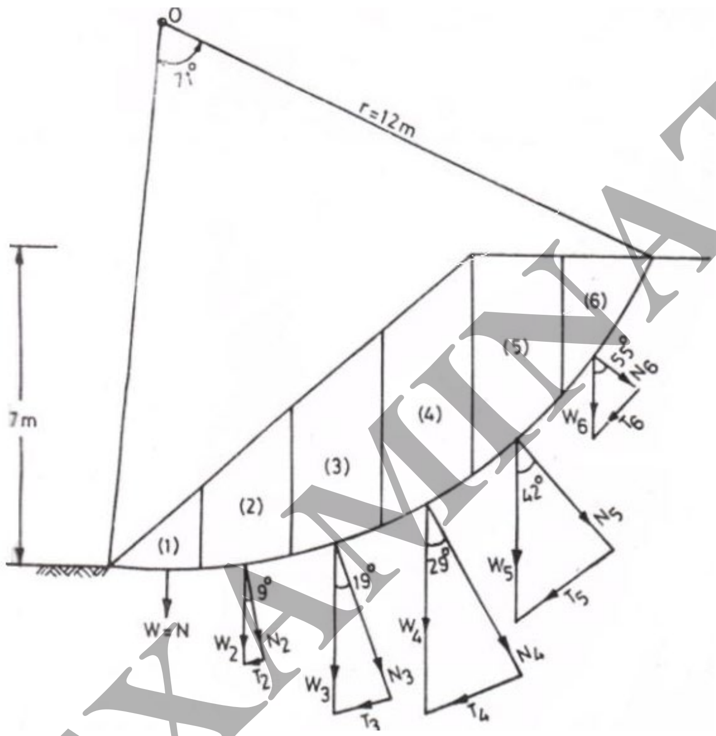

Figure Q3-1

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Question 4 continued…

TO BE HANDED IN WITH ANSWER BOOK **CANDIDATE NUMBER ……………………………………………………….**

Table Q3

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)
Slice No:	b	h	〈	hw	l	ul	W	sin〈	cos〈	Wcos〈	Wcos〈-ul	Wsin〈
	(m)	(m)	(deg)	(m)	(b/cos〈)		kN					
1	2.0	0.9	0	0.9								
2	2.0	2.4	9	2.4								
3	2.0	3.6	19	3.6								
4	2.0	4.5	29	4.5								
5	2.0	4.0	42	4.0								
6	2.0	1.80	55	1.0								
										©		

END OF QUESTIONS

Please turn the page (for Supplementary Geotechnical Information)

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Supplementary Geotechnical Information

	Density kg/m^3	**Unit weight kN/m^3**
1	$\rho_b = \rho_w \frac{(G_s+eS_r)}{1+e}$	$\gamma_b = \gamma_w \frac{(G_s+eS_r)}{1+e}$
2	$\rho_b = \rho_w G_s \frac{(1+w)}{1+e}$	$\gamma_b = \gamma_w G_s \frac{(1+w)}{1+e}$
3	$\rho_b = \frac{\rho_w G_s}{1+e}$	$\gamma_d = \frac{\gamma_w G_s}{1+e}$
4	$\rho_{sat} = \rho_w \frac{(G_s+e)}{1+e}$	$\gamma_{sat} = \gamma_w \frac{(G_s+e)}{1+e}$

Shallow Foundations:

Terzaghi's equation:

$$q_u = CN_cS_c + \gamma DN_qS_q + 0.5\gamma BN_\gamma S_\gamma$$

$$q_{net\ safe} = \frac{q_u - \gamma D}{F} + \gamma D$$

$\gamma_{sub} = \gamma_{sat} - \gamma_w$, *when water table is affecting bearing capacity*

$$C_c = \frac{\Delta e}{log_{10}(\frac{\sigma_1}{\sigma_0})}$$

$$a_v = \frac{\Delta e}{\Delta \sigma}$$

$$m_v = \frac{a_v}{(1+e_0)}$$

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$$m_v = \frac{\Delta e}{(1 + e_0)} \cdot \frac{1}{\Delta \sigma}$$

$$s = \frac{H.C_c}{(1 + e_0)} log_{10} \left(\frac{\underline{\sigma_0} + \underline{\Delta\sigma}}{\underline{\sigma_0}} \right)$$

$$= \frac{H.C_c}{(1 + e_0)} log_{10} \left(\frac{\underline{\sigma_1}}{\underline{\sigma_0}} \right)$$

$$S_f = m_v H_0 \Delta \underline{\sigma}$$

$$C_v = \frac{k}{m_v \cdot \gamma_w}$$

$$C_V = \frac{T_V d^2}{t}$$

Time factor, $T = \frac{c_v.t}{H^2}$

when U < 60%, $T = (\frac{\pi}{4}) U^2$

when U> 60%, $T = -0.9332 \, log_{10}(1 - U) - 0.0851$

$\Delta H = m_v \, \Delta\sigma \, H_o$

Earth Pressure:

$$k_a = \frac{1 - \sin\phi}{1 + \sin\phi}$$

Pile Foundations,

Please turn the page

$$Q_u = Q_s + Q_b$$

$$For\ Cohesive\ Soil, \quad Q_b = C_u N_c A_b\ , \quad Q_s = \alpha . \underline{C_u}^{-} A_s$$

$$For\ Cohesionless\ soil, \quad Q_b = N_q . \sigma_v' . A_b, \quad Q_s = K_s . tan\ tan\ \delta\ . \underline{\sigma_v}^{-} . A_s$$

$$\sigma_v = \gamma . D$$

Slope Stability,

$$F = \frac{C_u . R . \theta_c . \left(\frac{\pi}{180}\right) + \Sigma \quad (W cos\alpha - ul) tan\emptyset'}{W sin\alpha}$$

END OF PAPER