UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

MSc CIVIL ENGINEERING

SEMESTER 1 EXAMINATION 2023/2024

ADVANCED GEOTECHNICAL MODELLING ANALYSIS AND DESIGN

MODULE NO: CIE7001

Date: Monday 8th January 2024 **Time: 2:00 – 5:00**

INSTRUCTIONS TO CANDIDATES:

There are FOUR questions.

Answer ALL FOUR questions.

Marks for parts of questions are shown in brackets.

Supplementary Geotechnical information is provided on pages 7-13.

Lined Graph Paper and Supplementary Answer Sheets are available for use.

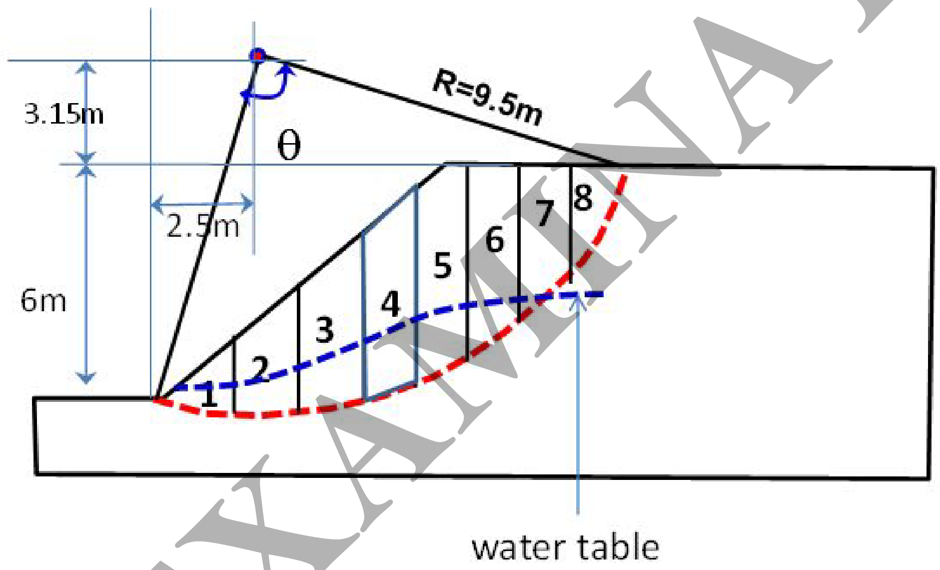
Ensure that you write your Candidate Number or Desk Number on each Figure, Supplementary Sheet or Sheet of Graph Paper you use to answer the selected questions.

State all assumptions made.

Question 1

a) What are the common causes of slope failure? Explain your answer. And what makes a slope stable? **(5 marks)**

b) A 6.0m high slope of soil with the following properties is shown in (Q1 – Figure 1); The characteristic unit weight of the soil, both above and below the groundwater table, is 20 kN/m^3, and the characteristic shear strength parameters in terms of effective stress are c'=10kN/m^2 and ϕ'=29^o. The breadth of all slices is 1.5m (b=1.5m). Data is given in (Q1 – Table 1) below.



Q1 - Figure 1

Slice	Height (m)	α (º)	u (kN/m^2)
1	0.76	-11.3	5.9
2	1.80	-3.2	11.8
3	2.73	8.4	16.2
4	3.40	17.1	18.1
5	3.87	26.9	17.1
6	3.89	37.2	11.3
7	2.94	49.8	0
8	1.10	59.9	0

Q1 – Table 1

Question 1 continues over the page….
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Question 1 continued….

Determine the Factor of Safety by using Bishop's Method (Conventional method).

Slice	Height h (m)	α (º)	u (kN/m²)	Breadth b	Area of each slice A (bxh)	Weight of each slice W (γxA)	**Cos** α	**Sec** α	l=b/cos(α)	r_u (u/γh)	cos α − $r_u$sec α	c'l + W(cos α − $r_u$sec α)tan ϕ'	$W \sin \alpha$
1	0.76	-11.3	5.9										
2	1.80	-3.2	11.8										
3	2.73	8.4	16.2										
4	3.40	17.1	18.1										
5	3.87	26.9	17.1										
6	3.89	37.2	11.3										
7	2.94	49.8	0										
8	1.10	59.9	0										
											$\sum =$		

(20 marks)

NOTE: Use the Supplementary Geotechnical Data sheets provided.

Total 25 marks

Question 2

a) Determine the ultimate capacity and the safe load carrying capacity of the pile (in kN) of a 300mmx300mm pre-cast pile to be installed 16m into a clay stratum. Soil tests have shown that the shear strength of the soil, C_u, varies from ground level C_u=70 *kPa* to a depth of 11m (C_u=169 *kPa*), thereafter, at 16m (C_u=210 *kPa*). You may assume α = 0.5 and N_c = 9.

(13marks)

Question 2 continues over the page….
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Question 2 continued….

b) A pile group consists of a rectangular 4x3 group of bored piles, each 0.75m in diameter and 15m in length. The spacing between the pile centres is 1.875m in a clay of undrained strength 50 kN/m^2. The shaft adhesion factor is 1.

(i) Determine the efficiency of the pile group with f_{ave} = 32 kN/m^2

(6 marks)

(ii) Calculate the ultimate load of pile group with C_u = 50 kN/m^2 and N_c = 8.6

(6 marks)

NOTE: Use the Supplementary Geotechnical Data sheets provided.

Total 25 marks

Question 3

A reinforced soil wall with a vertical face is to be constructed at the edge of an embankment which is 8.0 m high. The fill used throughout the embankment and wall is dry and has a unit weight $\gamma = 18\,kN/m^3$ and an internal friction angle $\phi = 30^{\circ}$. The reinforced soil block forming the wall has uniform width 6.0 m. At 4.4 m depth in the wall it is proposed to use geogrid reinforcement with design strength 25 kN/m and frictional resistance at geogrid-soil interface $\delta_r = 25^{\circ}$. A 1.0 m wide strip of geogrid supports a section of the face of the wall which is 1.0 m wide and 0.8 m high.

a) For a strip of geogrid at 4.4 m depth, calculate the Factor of Safety (FoS) for tensile and pull out failure. Assume that the active zone behind the wall is an unmodified 'active wedge', that any changes in stress due to compaction can be ignored, and neglect the effect of rotational equilibrium on vertical stress in the reinforced soil block.

(8 marks)

b) Revise the estimates of FoS for tensile and pull-out failure for the geogrid at 4.4 m depth if an eccentricity represented by a rectangular distribution of vertical stress in the reinforced fill is assumed (Schlosser method).

(11 marks)

NOTE: Use the Figures in the Supplementary Geotechnical Data sheet provided to represent the locus of maximum tension in the geogrid, and to account for the effects of compaction for K on the face of the wall.

Question 3 continues over the page….
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Question 3 continued….

c) Name <u>three</u> different systems of reinforced earth retention and briefly describe the design principles for each, highlighting the key benefits and limitations of each system and their typical maximum retained heights.

(6 marks)

Total 25 marks

NOTE: Use the Supplementary Geotechnical Data sheets provided.

Question 4

A retaining wall is to retain 6.0m of soil. From the top of the wall downwards the soil is composed of 4.0m of sand overlying 2.0m of clay. The water table is at depth of 2.0m from the top. The properties of sand and clay is given below in (Q4 – Figure 2).

a) Calculate the lateral earth pressure on the retaining wall.

(8 marks)

b) Given the values that you calculated in part a) draw the pressure distribution on the back of the wall (i.e. how the pressure changes with depth).

(5 marks)

c) Based on the drawing in part b), calculate the total force applied to the wall.

(6 marks)

d) Determine the position of the line of action (above the base of the wall).

(6 marks)

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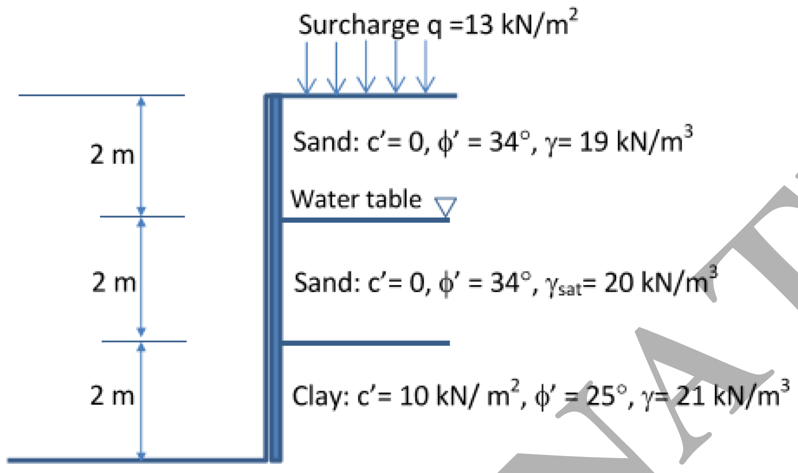
Question 4 continued….



Q4 – Figure 2

Total 25 marks

NOTE: Use the Supplementary Geotechnical Data sheets provided.

END OF QUESTIONS

Supplementary Geotechnical Information follows over the page…

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Supplementary Geotechnical Information

Q1 - Slope stability

$$m = \frac{c'}{FH\gamma}$$

($\boldsymbol{m}$ ***is the stability number,*** $\boldsymbol{F}$ ***is the factor of safety and*** $\boldsymbol{H}$ ***is the height of the slope***)

$$m = cos^2\beta(tan\beta - \tan\phi_m)$$

($\boldsymbol{\beta}$ ***is the angle of the slope,*** $\boldsymbol{\phi_m = \frac{tan\phi}{F}}$)

$$F = \frac{\Sigma(c' \times R \times \theta_{rad}) + \Sigma(W \times cos\alpha - r_u \times sec\alpha)tan\phi'}{\Sigma(W \times sin\alpha)}$$

$$F = \frac{1}{\Sigma(W \times sin\alpha)}[\Sigma(c'l + W(cos\alpha - r_u \times sec\alpha)tan\phi']$$

$$r_u = \frac{pore\ water\ pressure}{total\ stress} = \frac{u}{\gamma z}$$

$$u = r_u \times \gamma \times z = r_u \times \frac{W}{b}$$

$$l = \frac{b}{cos\alpha} \quad or \quad b = l \times cos\alpha \quad and \quad sec\alpha = \frac{1}{cos\alpha}$$

$$u = \frac{r_u \times W}{l} \times sec\alpha$$

($\boldsymbol{W}$ ***is the weight,*** $\boldsymbol{\alpha}$ ***is the angle of the base of a slice and*** $\boldsymbol{l}$ ***is the length of the base of a slice***)

$$F = \frac{c_u R\theta}{\sum W \sin\alpha}$$

$$F = \frac{c' R^2\theta}{Wd}$$

($\boldsymbol{R}$ ***is the radius of the slip circle,*** $\boldsymbol{\theta}$ ***is the included angle and*** $\boldsymbol{d}$ ***is the eccentricity of the centre of mass***)

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Q2 - Pile Foundations

Shaft Resistance: Circular: $Q_s = \alpha c_u \pi d L$
Square: $Q_s = \alpha c_u P L$ where P is the perimeter

Base Resistance: Circular: $Q_b = c_u N_c \pi d^2 / 4$
Square: $Q_b = c_u N_c A_b$ where A_b is the base area

$Q_u = Q_b + Q_s$

$Q_{safe} = Q_b/3 + Q_s$ OR $Q_{safe} = (Q_b + Q_s) / 2.5$

$$\eta = \frac{Q_{g(u)}}{\sum Q_u}$$

η: *efficiency*

$Q_{g(u)}$: *ultimate load capacity of group pile*

Q_u: *ultimate load capacity of single (individual) pile*

In clay:

As individual

$Q_u = \sum(Q_b + Q_s)$

$Q_s = \sum \alpha c_u A_s$

$Q_b = c_u N_c A_b$

As block

$$Q_{g(u)} = Q_{g(s)} + Q_{g(b)}$$
$$Q_{block} = A_s \times c_u + A_b \times N_c \times c_u$$

A_b: is the base surface area of the pile group as a block
A_s: is the side surface area of the pile group as a block

Q3 - Reinforced Soil Wall

- The locus of maximum tension force in reinforcement is usually approximated by the two lines shown in Figure 3.

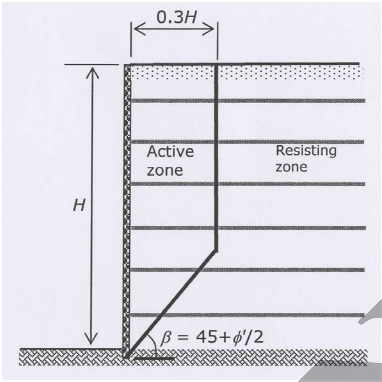


Figure 3

- The coefficient of lateral earth pressure acting on facing is given in Figure 4.

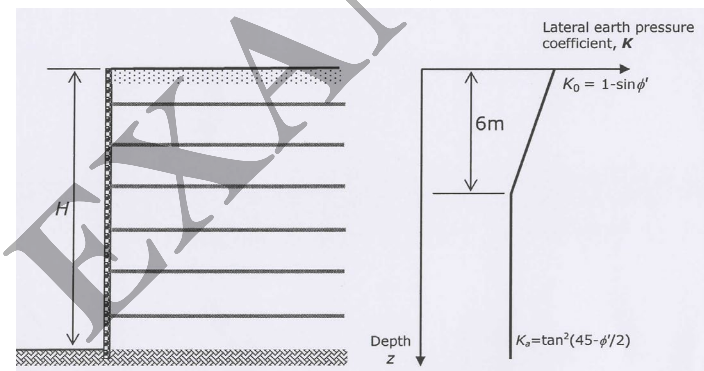
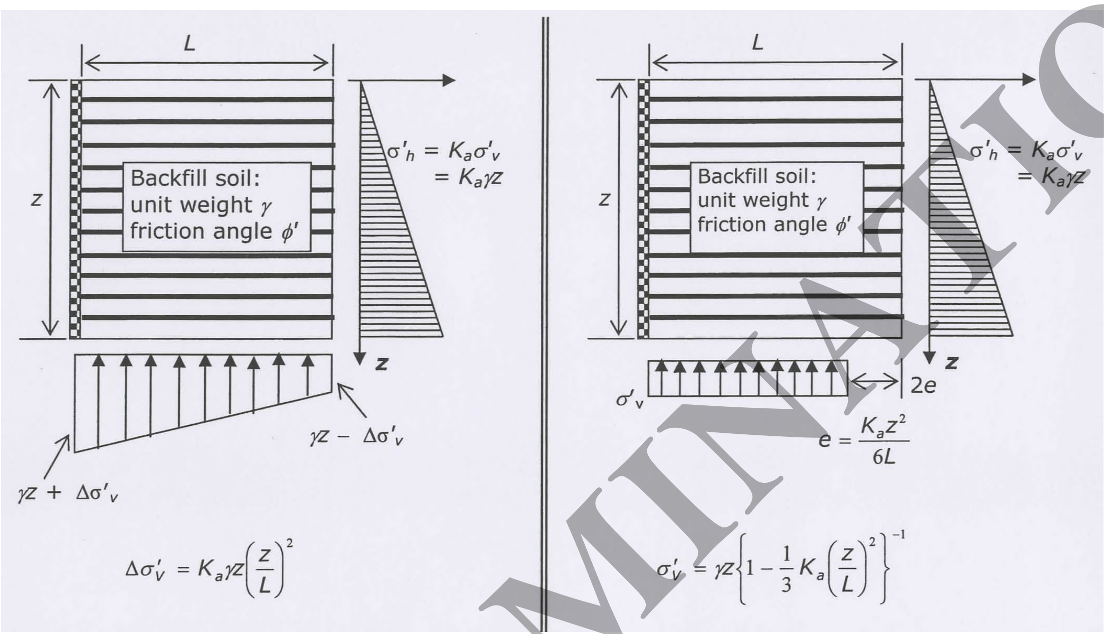


Figure 4

$K_a = \frac{1-\sin\phi}{1+\sin\phi} = tan^2\left(45 - \frac{\phi}{2}\right)$

$K_0 = 1 - \sin\phi$

- The vertical stress in a horizontal plane in the reinforced soil wall can be approximated by two methods: (1) Bolton (1977) and (2) Schlosser (1978), which are shown in Figure 5.



Bolton method **Schlosser method**

Figure 5

- Factor of safety against **tensile** failure for strip reinforcement:

$$T_{r,max} = K_a \sigma'_v A_f$$

$$Fs_{,T} = \frac{T_{r,des}}{T_{r,max}} = \frac{\sigma_r \times b_r \times t_r}{T_{r,max}}$$

- Factor of safety against **pull out** failure for strip reinforcement with uniform vertical stress distribution:

$$Fs_{,po} = \frac{2 \times b_r \times l_{r,po} \times \sigma'_V \times \tan(\delta_r)}{T_{r,max}}$$

- Pullout a (Figure 6)

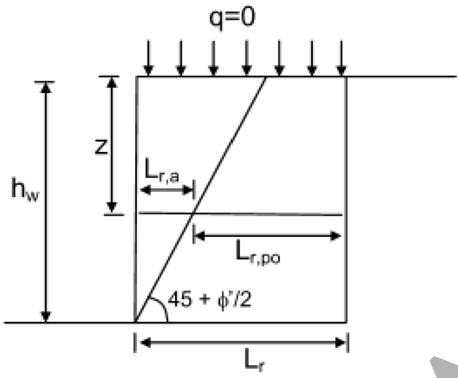


Figure 6

- Pullout b (Figure 7)

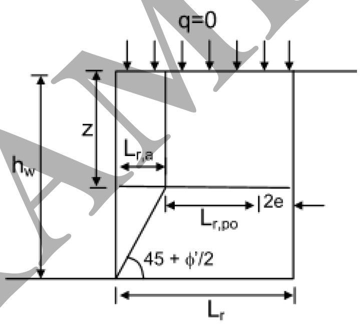


Figure 7

- Detailed Design b

$K = K_a + [(6.0-z)/6.0] x (K_0 - K_a)$

$e/l_r = K_a (z/l)^2/6$

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Q4 - Retaining walls

$$K_a = \frac{1-sin\phi}{1+sin\phi} \quad ; \qquad K_p = \frac{1+sin\phi}{1-sin\phi}$$

$$\sigma_{ha} = K_a\sigma_v - 2c\sqrt{K_a} \quad ; \qquad \sigma_{hp} = K_p\sigma_v + 2c\sqrt{K_p}$$

$$\sigma'_V = \sigma_V - u$$

$$u = \gamma_w z$$

$$\sigma_V = \gamma z + q$$

$$\sigma_h = \sigma'_h + u$$

$$\sigma'_h = K_a(\sigma'_V) - 2c\sqrt{K_a}$$

$$p_A = K_A(\gamma z + q) - 2c'\sqrt{K_A} \quad K_A = \frac{1-sin\,\phi'}{1+sin\,\phi'} = tan^2\left(45 - \frac{\phi'}{2}\right)$$

$$p_P = K_P(\gamma z + q) + 2c'\sqrt{K_P} \quad K_P = \frac{1+sin\,\phi'}{1-sin\,\phi'} = tan^2\left(45 + \frac{\phi'}{2}\right)$$

$(\boldsymbol{p_A, p_P, K_A and\ K_P\ are\ the\ active\ and\ passive\ pressures\ and\ coeffecients\ respectively, z\ is\ the\ depth, \gamma\ is\ the\ unit\ weight\ and\ q\ is\ the\ surcharge})$

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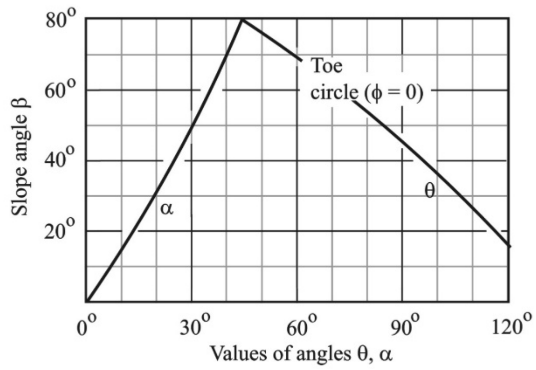
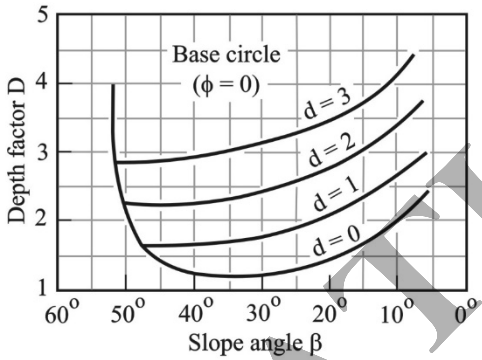
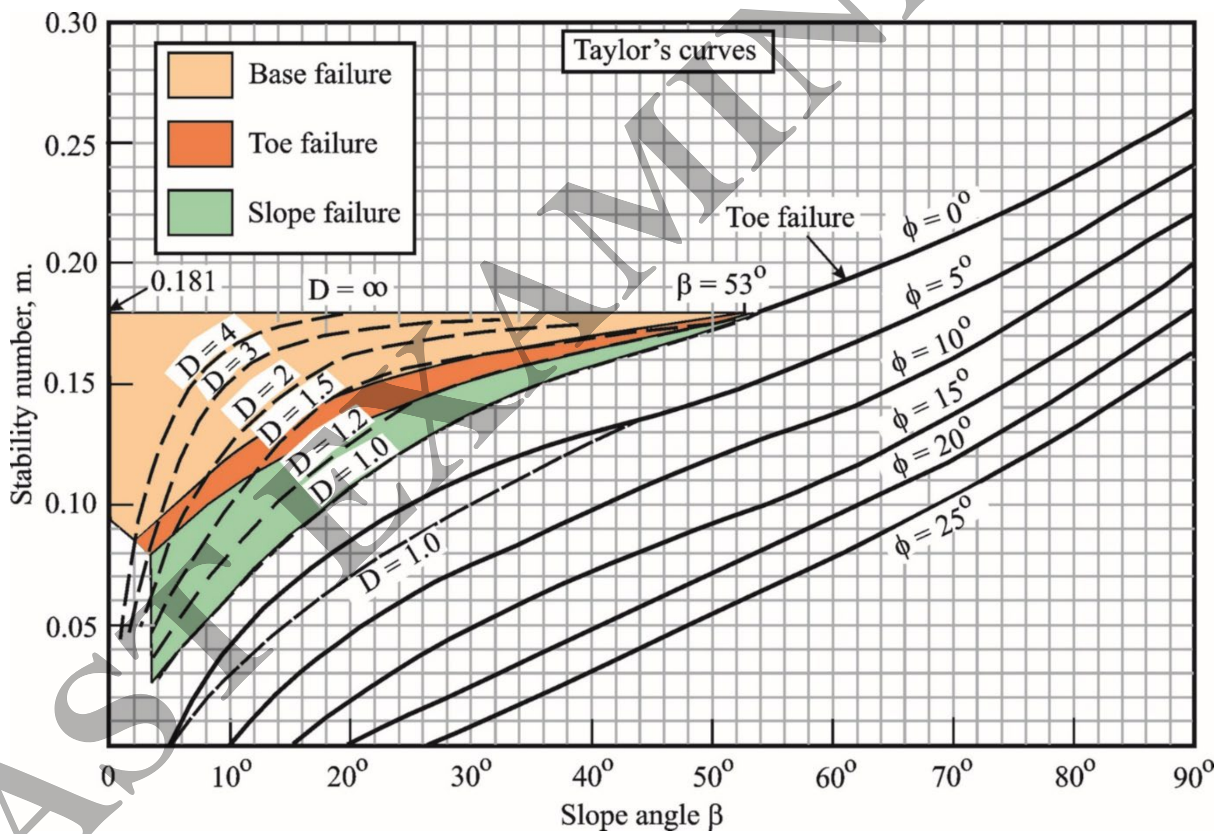
Additional Data







Taylor and Fellenius charts for slopes in saturated clay

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