UNIVERSITY OF GREATER MANCHESTER

SCHOOL OF ENGINEERING AND BUILT ENVIRONMENT

MSc IN CIVIL ENGINEERING

SEMESTER ONE EXAMINATION 2025/2026

ADVANCED GEOTECHNICAL MODELLING ANALYSIS AND DESIGN

MODULE NO: CIE7001

Date: Friday 16th January 2026 **Time: 10am – 1pm**

INSTRUCTIONS TO CANDIDATES:

There are FOUR questions.

Answer ALL 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.

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

Supplementary Geotechnical information is provided on pages 8-11.

Question 1

a) For slope stability of an embankment, what are the main factors that influence slope stability? And what makes a slope globally stable? Explain your answer.

(5 marks)

b) An embankment made from silt is to be constructed upon the ground surface **(See Figure 1.1 below)**. The completed embankment can be assumed to be homogenous and thus will possess constant density and constant shear strength throughout its mass. The undrained cohesion **(c_u) of the silt is 25 kN/m²** and the unit weight **(γ) is 19 kN/m³**. **R=12m** and **$\theta=70^0$**. Determine the factor of safety in the short term (undrained state). Area and angle of base for each slice is calculated in **(Table 1.1)** below.

(12 marks)

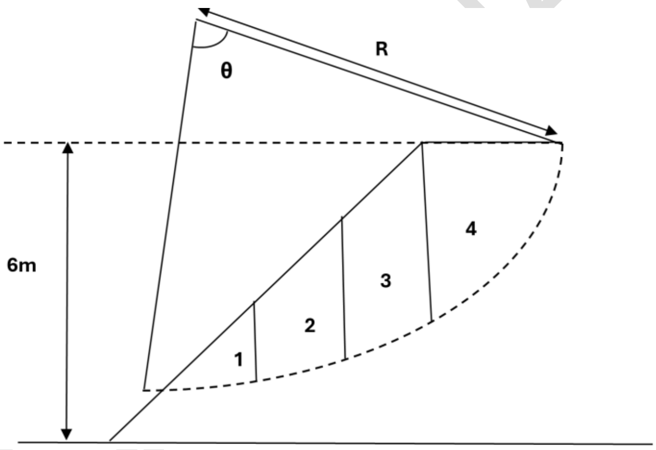

Figure 1.1

Slice	Area (m^2)	Angle of base α (^{o})
1	5.2	- 8.5
2	10.5	18.2
3	13.8	35.5
4	9.2	50.1

Table 1.1

Question 1 continues over the page 3
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Question 1 continued

c) A 10m excavation is required in a soft clay where a dense sandstone is known to be 15m below ground level. The soft clay has a cohesion of 12 kN/m² and a unit weight of 17 kN/m³. Using Taylor's curves below in **(Figure 1.2)**, what is the angle of the critical slope.

(8 marks)

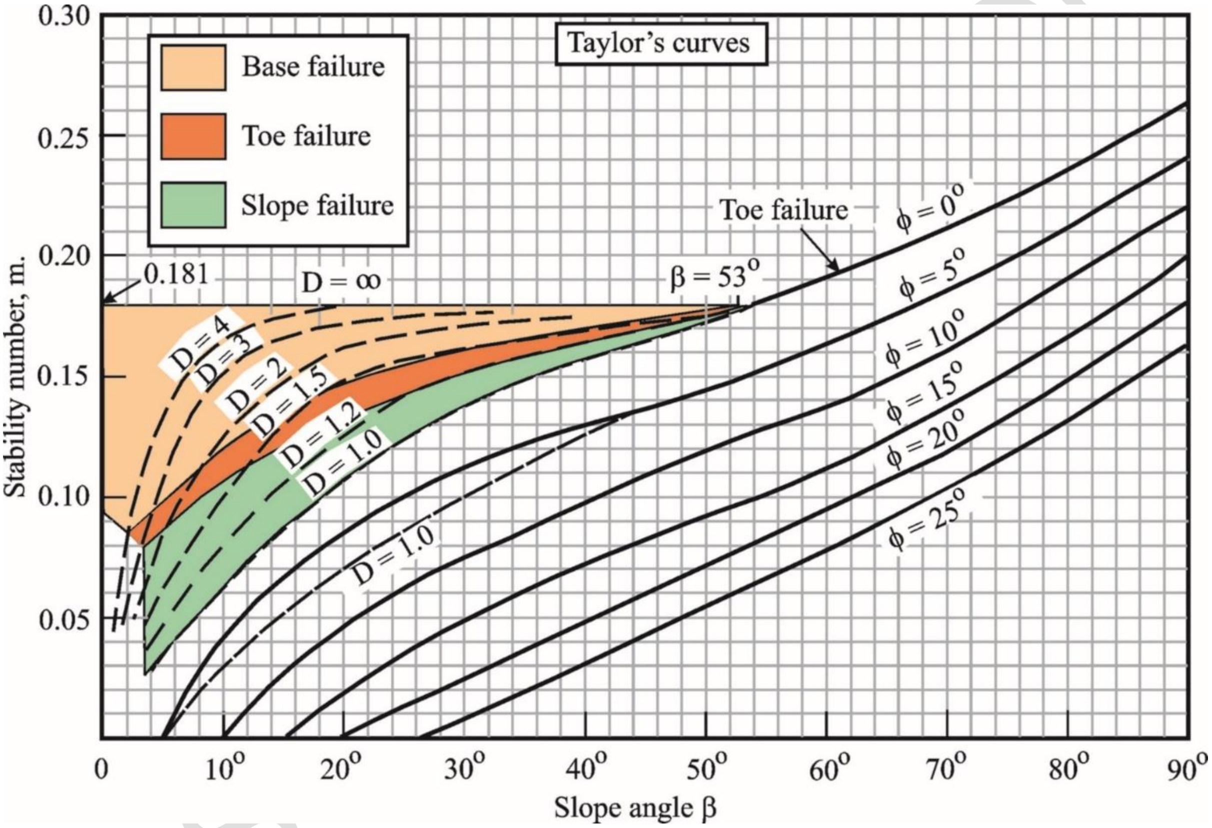

Figure 1.2

NOTE: Use the Supplementary Geotechnical Data sheets provided.

(Total 25 marks)

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Question 2

a) What are the main types of failures and controls in excavated slopes? List 4 failures and 4 controls.

(8 marks)

b) A 8.0m high slope of soil with the following properties is shown in **(Figure 2.1)**; The characteristic unit weight of the soil, both above and below the groundwater table, is 19 kN/m³, and the characteristic shear strength parameters in terms of effective stress are c'=8 kN/m² and φ'=32°. The breadth of all slices is 2.0m (b=2.0m). Data is given in **(Table 2.1 and Table 2.2)** below.

Determine the Factor of Safety by using <u>**Bishop's Method**</u> (Conventional method).

(17 marks)

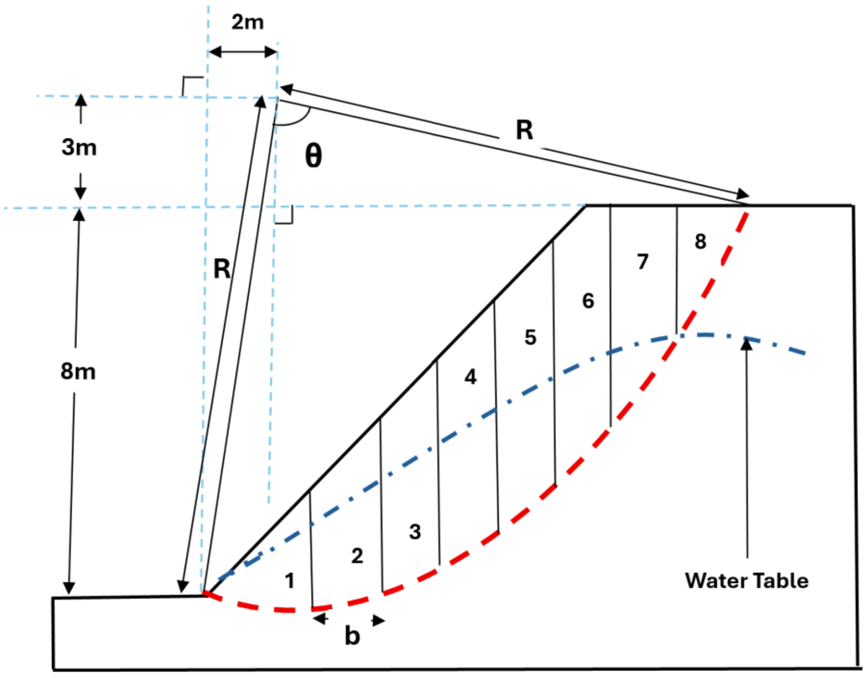

Figure 2.1

Question 2b continues over the page 5

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Question 2b continued

Slice	Height (m)	α (º)	u (kN/m²)
1	0.85	-5.5	4.5
2	2.10	6.0	13.1
3	3.15	12.5	18.9
4	3.85	22.3	21.5
5	4.20	31.6	20.1
6	4.05	42.8	12.8
7	2.75	55.5	11.2
8	1.25	65.2	0

Table 2.1

Copy this table to your answer booklet to help you determine the factor of safety

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	0.85	-5.5	4.5										
2	2.10	6.0	13.1										
3	3.15	12.5	18.9										
4	3.85	22.3	21.5										
5	4.20	31.6	20.1										
6	4.05	42.8	12.8										
7	2.75	55.5	11.2										
8	1.25	65.2	0										
											$\sum$ =		

Table 2.2

NOTE: Use the Supplementary Geotechnical Data sheets provided.

(Total 25 marks)

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Question 3

A reinforced soil wall with a vertical face is to be constructed at the edge of an embankment which is 9.0 m high. The fill used throughout the embankment and wall is dry and has a unit weight (γ) of 20 kN/m³ and an internal friction angle (ϕ) of 34°.

The reinforced soil block forming the wall has uniform width 6.0 m. At 5.0 m depth in the wall it is proposed to use geogrid reinforcement with design strength 30 kN/m and frictional resistance at geogrid-soil interface ($\delta_r = 26^{\circ}$). A 1.2 m wide strip of geogrid supports a section of the face of the wall which is 1.2 m wide and 1.0 m high.

a) For a strip of geogrid at 5.0 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.

(10 marks)

b) Revise the estimates of FoS for tensile and pull-out failure for the geogrid at 5.0 m depth if an eccentricity represented by a rectangular distribution of vertical stress in the reinforced fill is assumed (Schlosser method).

(15 marks)

NOTE: Use the Figures in the data sheet 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).

NOTE: Use the Supplementary Geotechnical Data sheets provided.

(Total 25 marks)

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Question 4

a) Name three 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.

(9 marks)

b) Soil has no tensile strength. So, how is it possible that a reinforced soil wall can stand vertically? What is the fundamental mechanical principle that allows this to work?

(4 marks)

c) In your own words, what is the difference between checking the "external stability" and the "internal stability" of a reinforced soil wall? What different failure modes are considered in each case?

(8 marks)

d) From the sliding stability equation, the Factor of Safety is proportional to the ratio of reinforcement length to wall height (l_r/h). If you want to make a wall safer against sliding, you can make this block wider. What is the major downside or trade-off of doing this?

(4 marks)

NOTE: Use the Supplementary Geotechnical Data sheets provided.

(Total 25 marks)

END OF QUESTIONS

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Supplementary Geotechnical Information

<u>Q1 and Q2 - Slope stability</u>

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

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

M=D.H

(M can be expressed in terms of the height of the slope via D which is known as the Depth factor)

L=d.H

(L is the horizontal distance of the slip circle from the toe of the slope, it can be expressed in terms of H via d which is known as the distance factor)

Swedish Method:

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

Bishop's Method:

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

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

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

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

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

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

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Weight of each slice W = (γxA)

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

$$F = \frac{c' R^2 \theta}{W.d}$$

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

<u>Q3 and Q4 - Reinforced Soil Wall</u>

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

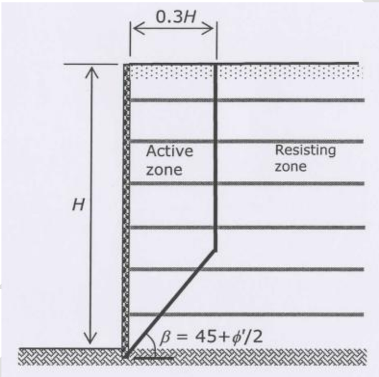

Figure a

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

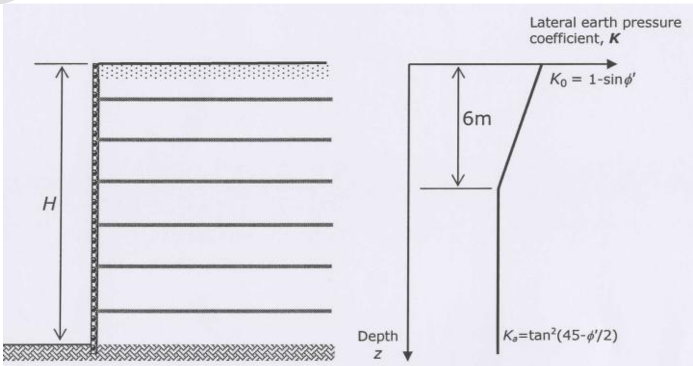

Figure b

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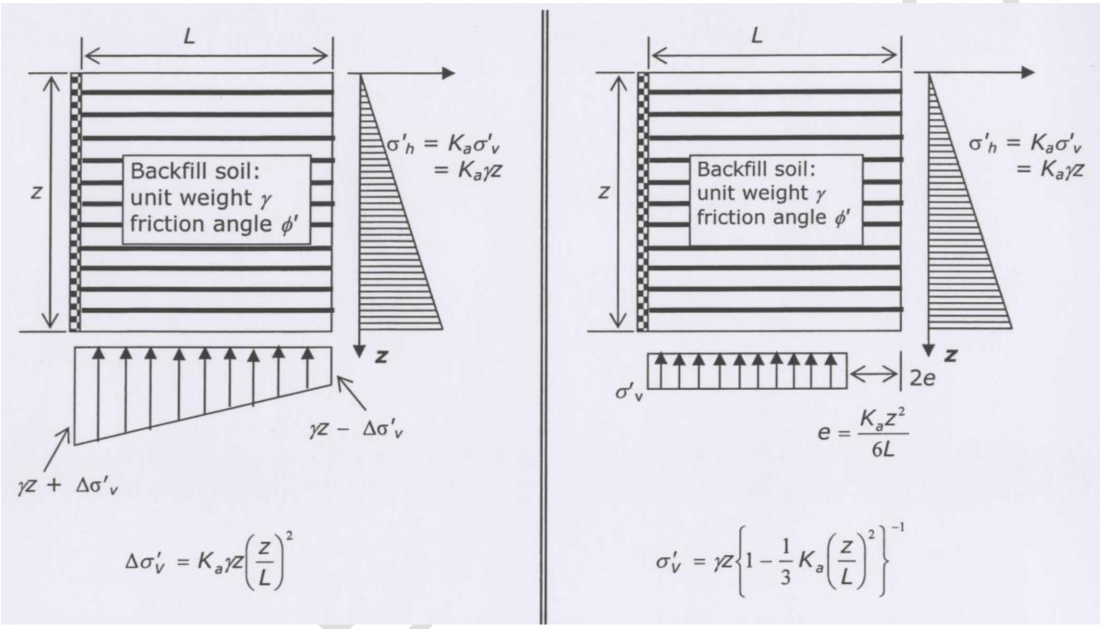
$$K_a = \frac{1 - \sin\phi}{1 + \sin\phi} = \tan^2\left(45 - \frac{\phi}{2}\right)$$

$$K_0 = 1 - \sin\phi$$

- 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 c.



Bolton method **Schlosser method**

Figure c

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

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

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

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- 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 d)

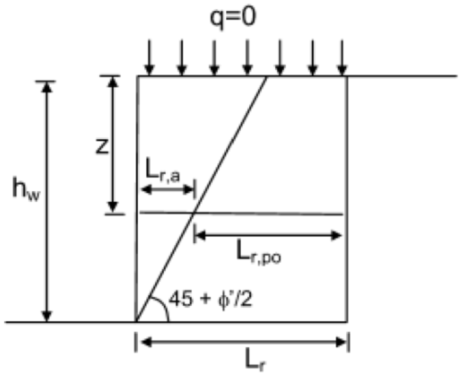

Figure d

- Pullout b (Figure e)

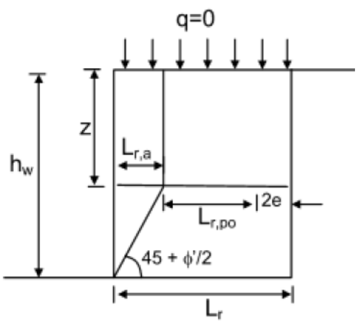

Figure e

- 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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