UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

MSc IN CIVIL ENGINEERING

SEMESTER ONE EXAMINATION 2024/25

ADVANCED GEOTECHNICAL MODELLING ANALYSIS AND DESIGN

MODULE NO: CIE7001

Date: Monday 13th January 2025 **Time: 10:00am – 1:00pm**

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 7-13.

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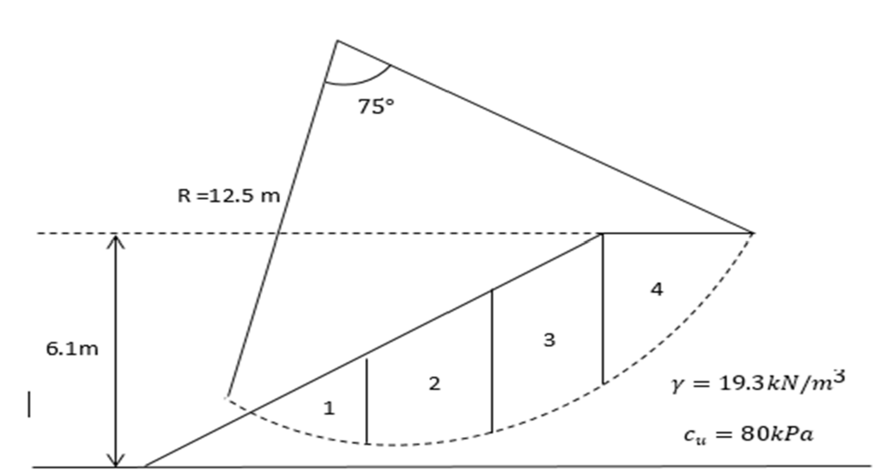
Semester ONE Examination 2024/25
Advanced Geotechnical Modelling Analysis & Design
Module No. CIE7001

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 clay is to be constructed upon the ground surface **(See Q1 - Figure 1 below)**. The completed embankment can be assumed to be homogenous and thus will possess constant density and constant shear strength throughout its mass. Determine the factor of safety in the short term (undrained state). Area and angle of base for each slice is calculated in **(Q1 – Table 1)** below.
(12 marks)



Q1 - Figure 1

Slice	Area (m^2)	Angle of base (°)
1	4.6	-6.6
2	9.8	15.6
3	12.7	32.2
4	8.7	47.5

Q1 – Table 1

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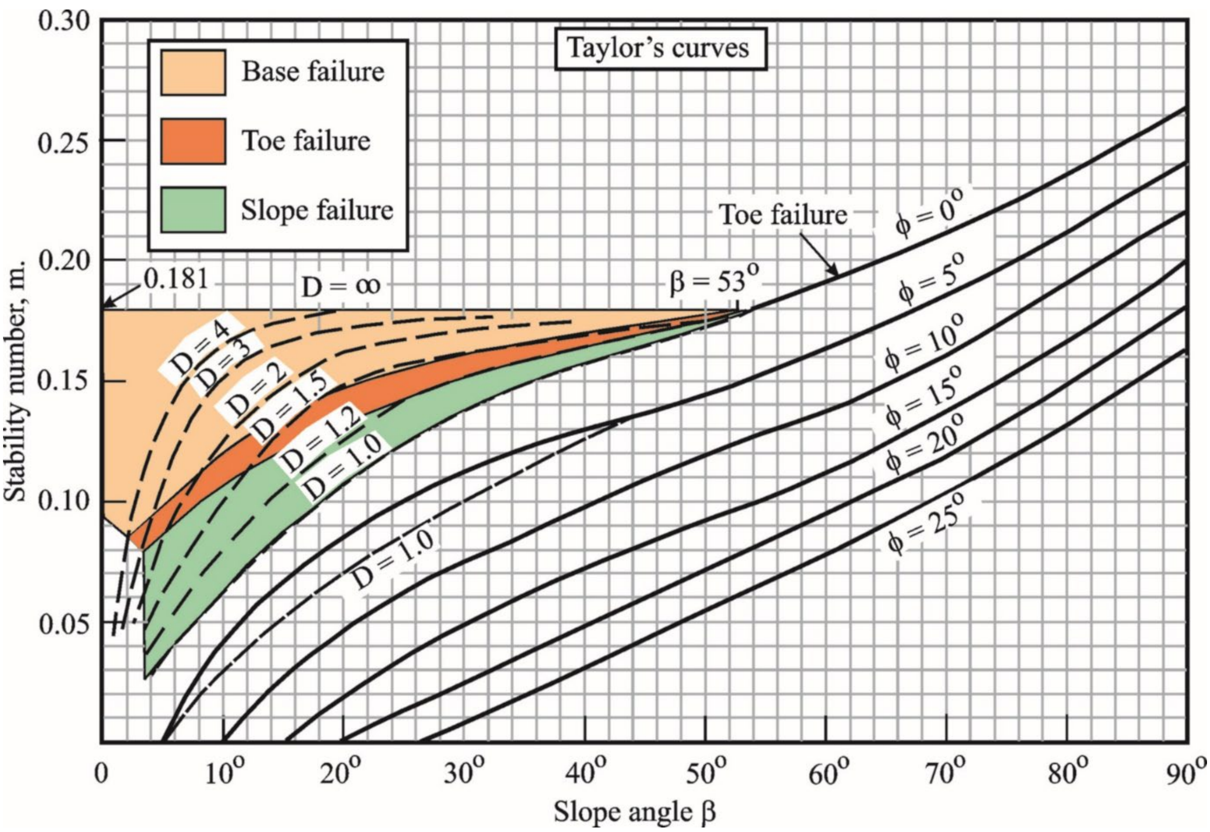
Question 1 continued….

c) An 8m excavation is required in a mudrock where a hard limestone is known to be 12m below ground level. The mudrock has a cohesion of 10kNm^{-2} and a unit weight of 18kNm^{-3}. Using Taylor's curves below in **(Q1 – Figure 2)**, what is the angle of the critical slope.

(8 marks)



Q1 – Figure 2

NOTE: Use the Supplementary Geotechnical Data sheets provided.

Total 25 marks

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Question 2

a) Determine the ultimate capacity and the safe load carrying capacity of the pile (in kN) of a 0.5 m pre-cast pile to be installed 11m into a clay stratum. Soil tests have shown that the shear strength of the soil, C_u, varies from ground level (C_u=80 *kPa*) to a depth of 7m (C_u=160 *kPa*), thereafter, at 11m (C_u=220 *kPa*). You may assume α = 0.5 and N_c = 9.

(13 marks)

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

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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 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 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).

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.

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Question 4

A retaining wall is to retain 5.0m of sand. The water table is at depth of 2.0m from the top. The property of sand is given below in **(Q4 – Figure 3)**.

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).

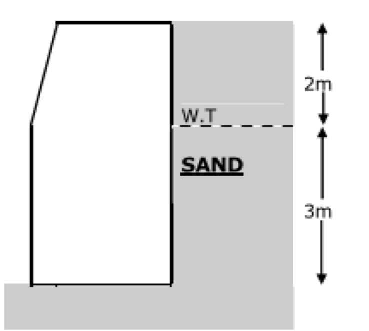
(6 marks)

Soil 1:

$z_1 = 2.0m$
$\phi_1 = 27^0$
$\gamma_1 = 17.41k\,N/m^3$

Soil 2:

$z_2 = 3.0m$
$\phi_2 = 27^0$
$\gamma_2 = 21.05k\,N/m^3$



Q4 – Figure 3

Total 25 marks

NOTE: Use the Supplementary Geotechnical Data sheets provided.

END OF QUESTIONS
Supplementary Geotechnical Information follows over the page…

Supplementary Geotechnical Information

Q1 - Slope stability

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

(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)

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

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

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

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

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

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

(W *is the weight*, α *is the angle of the base of a slice and* l *is the length of the base of a slice*)

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

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

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

Q2 - Piled 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
$Q_u = \sum(Q_b + Q_s)$

$Q_s = \sum \alpha\, c_u\, A_s$

$Q_b = c_u\, N_c\, A_b$

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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

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

- The locus of maximum tension force in reinforcement is usually approximated by the two lines shown in Figure 4.

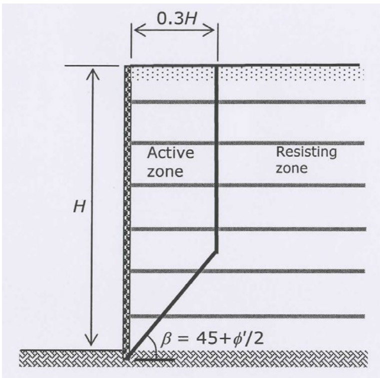

Figure 4

- The coefficient of lateral earth pressure acting on facing is given in Figure 5.

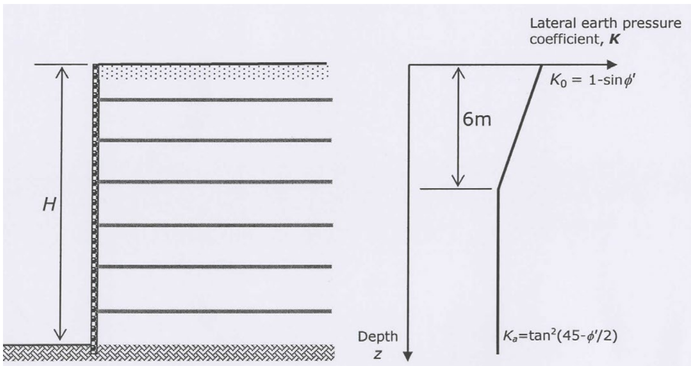

Figure 5

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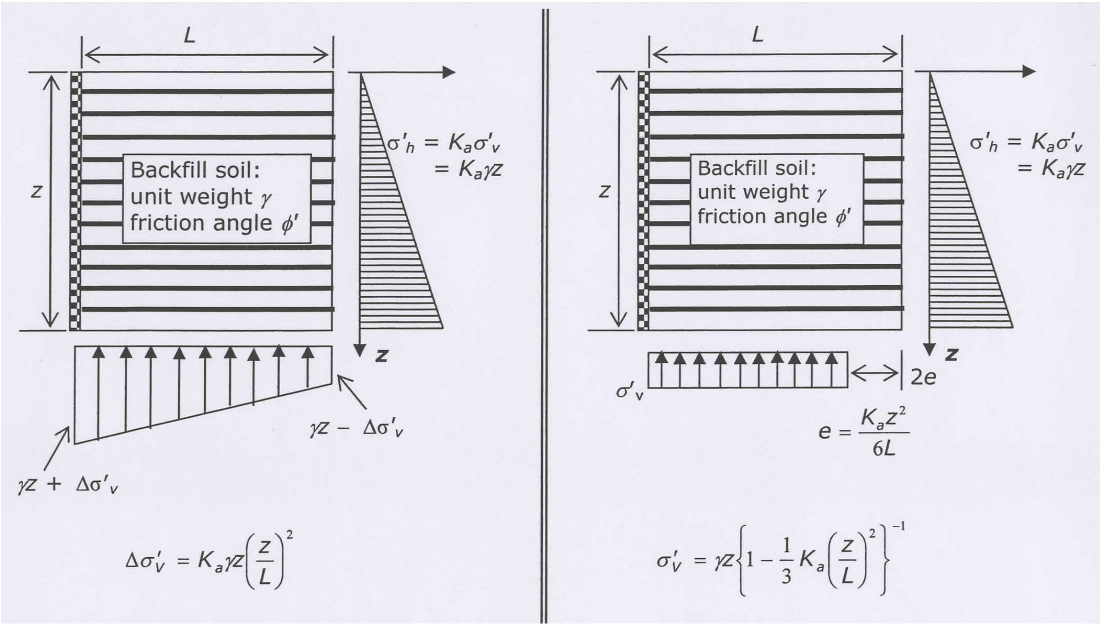
$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \tan^2\left(45 - \frac{\phi}{2}\right)$

$K_0 = 1 - \sin\phi$

- 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 6.



Bolton method **Schlosser method**

Figure 6

- 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)

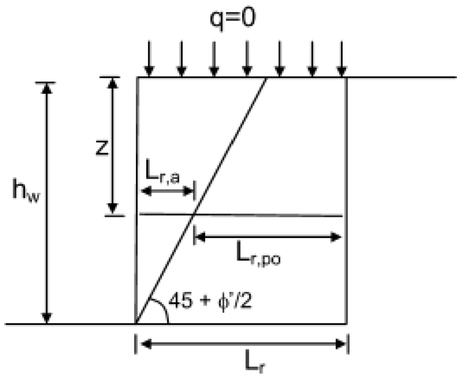


Figure 6

- Pullout b (Figure 7)

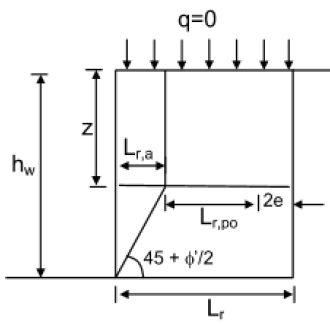


Figure 7

- 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

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

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

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

$$u = \gamma_w z$$

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

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

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

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

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

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

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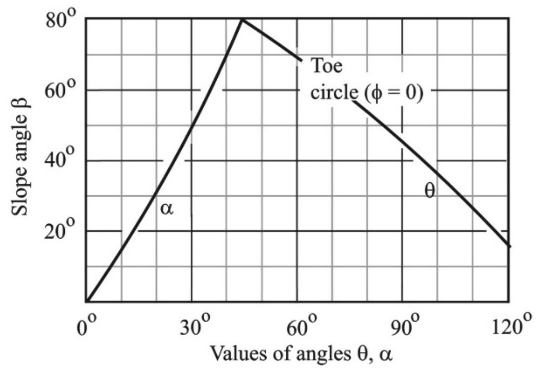
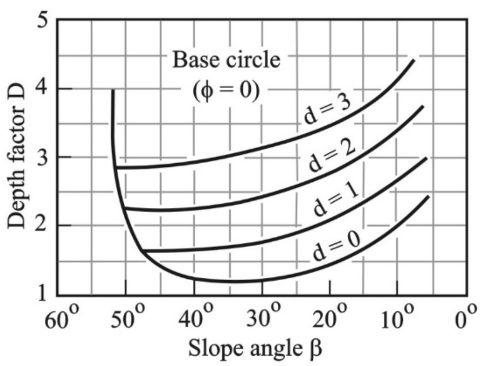
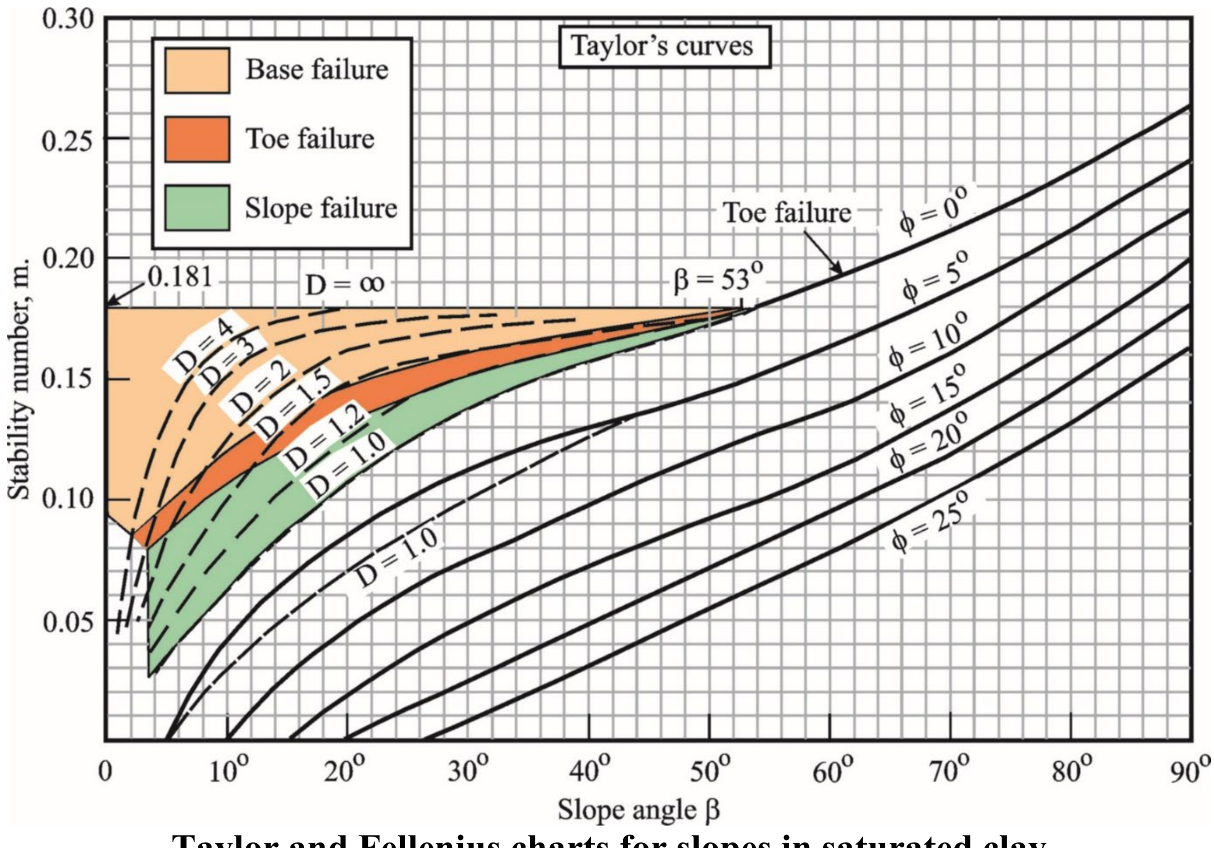
Additional Data







Taylor and Fellenius charts for slopes in saturated clay

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