UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

MSc IN CIVIL ENGINEERING

SEMESTER ONE EXAMINATION 2021/2022

ADVANCED GEOTECHNICAL MODELLING ANALYSIS AND DESIGN

MODULE NO: CIE7001

Date: Wednesday 12th January 2022   Time: 10:00 – 13:00

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 6-14.

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.

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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 1.1); The characteristic unit weight of the soil, both above and below the groundwater table, is 20 kN/m³, and the characteristic shear strength parameters in terms of effective stress are c'=10kN/m² and ϕ'=29°. The breadth of all slices is 1.5m (b=1.5m). Data is given in (Q1 – Table 1.1) below.
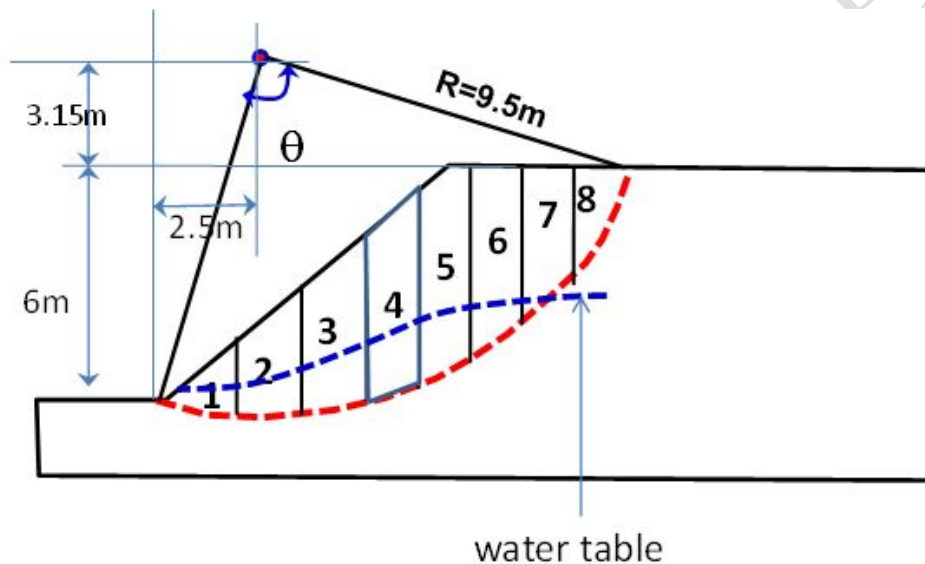
Q1 - Figure 1.1

Slice	Height (m)	α (°)	u (kN/m²)
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 1.1

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

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

(10 marks)

    (ii)   Determine the Factor of Safety by using the Swedish Method (Fellenius' method).

(10 marks)

NOTE: Use the Supplementary Geotechnical Data sheets provided.

Total 25 marks

Question 2

a) A 0.6m diameter conventional bored pile is to be installed on a site which underlain by 2.0m of newly placed granular fill ($\gamma_{dry} = 18\frac{kN}{m^3}, \delta = 35°, K = 0.7$) over 1.0m of soft peat ($c_u = 20\frac{kN}{m^2}$, $\alpha = 1.0$) over a layer of firm clay ($c_u = 110\frac{kN}{m^2}$, $\alpha = 0.5$) of considerable thickness. The peat and granular fill are expected to exert negative skin friction on the pile as the peat compresses under the newly placed fill.

    i)   What is the required length of pile, if the pile is to carry a working load of 900kN with a factor of safety against failure of 2.5?

(10 marks)

    ii)   In an effort to minimise cost, an underreamed pile is to be used. If the shaft is to be 0.6m diameter and 10m in length, what is the required diameter of the underream?

(5 marks)

b) A pile group consists of a rectangular 4x3 group of bored piles, each 0.5m in diameter and 10m in length. The spacing between the pile centres is 1.5m in a clay of undrained strength 100 kPa. The shaft adhesion factor is 0.5. Calculate the capacity of the group and the pile efficiency.

(10 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 $\phi = 30°$. 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 $\delta_r = 25°$. 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 sheets 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

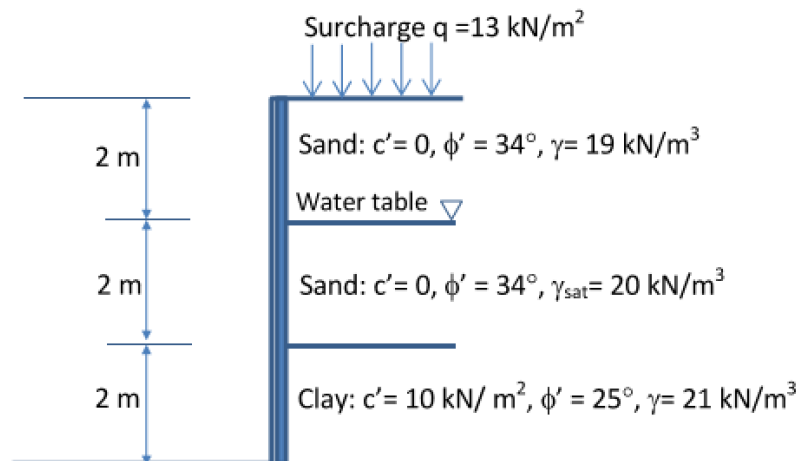**NOTE**: Use the Supplementary Geotechnical Data sheets provided.

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Question 4

A retaining wall is to retain 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 4.1).

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

(7 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).

(6 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)

Surcharge q =13 kN/m²

2 m — Sand: $c'= 0$, $\phi' = 34°$, $\gamma= 19$ kN/m³

Water table ▽

2 m — Sand: $c'= 0$, $\phi' = 34°$, $\gamma_{sat}= 20$ kN/m³

2 m — Clay: $c'= 10$ kN/m², $\phi' = 25°$, $\gamma= 21$ kN/m³

Q4 – Figure 4.1

Total 25 marks

NOTE: Use the Supplementary Geotechnical Data sheets provided.

END OF QUESTIONS

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Supplementary Geotechnical Information

Piled Foundations

$$Q = Q_b + Q_s$$

$$= \frac{\pi \times d^2}{4} q_b + \pi \times d \times \tau_s \times l$$
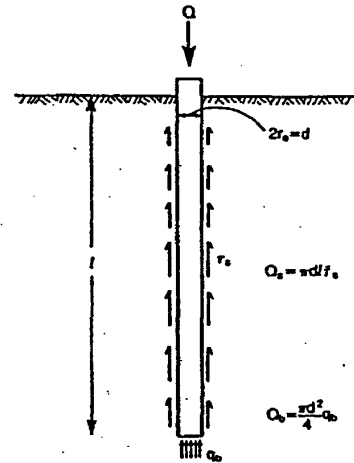
In clay:

$$q_b = N_c c_u \quad with \quad N_c = 9$$

$$\alpha - method: \quad \tau_s = \alpha c_u$$

$$\beta - method: \quad \tau_s = \beta \sigma_V' \quad with \quad \beta = K tan\delta$$

K relates to type of pile and past history of the soil.

Driven piles: use $K = 1.5 \times K_0$

Bored piles: use $K = (1 + K_0)/2$

- Undrained condition (Skempton's chart):
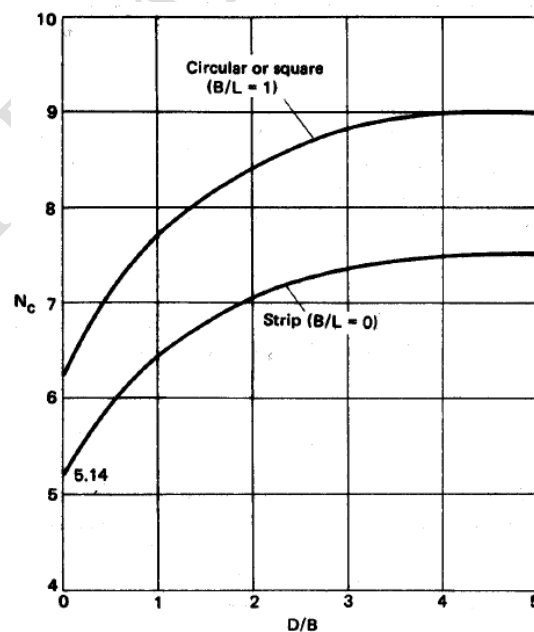
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Factor of Safety:

- *For straight shafted piles:*

    Without a pile test: $Q = (Q_s + Q_b)/2.5$

    With a pile test: $Q = (Q_s + Q_b)/2$

- *For underreamed piles without a pile test, use the lesser of:*

    With a pile test: $Q = (Q_s + Q_b)/2.5$ *and* $Q = Q_s + \frac{Q_b}{3}$

- *Negative skin friction:*

    With a pile test: $WL + NSF = Q_{ult}/F$ *where* $F = 2.5$

    Underreamed piles without a pile test, Working load (*WL*) is the lesser of the values given by the above and:
    $$WL + NSF = Q_s + Q_b/3$$

Pile Groups
- *Efficiency*

$$\eta = \frac{Q_{group}}{n \times Q_{single}}$$

- *Axial capacity in clay:*
$$Q_{block} = A_s \times c_u + A_b \times N_c \times s_c \times c_u$$

N_c: is the Skempton value of N_c for a buried strip footing
s_c: is the change factor for the block, $s_c = (1 + 0.2\, B/L)$
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

$$\frac{1}{Q_{group}^2} = \frac{1}{Q_{block}^2} + \frac{1}{(n \times Q_{single})^2}$$

- *Axial capacity in sand:*
Axial capacity not normally a problem. Efficiencies often > 1 due to compaction during driving. Typically:
$$Q_{group} \approx 2 - 3 \times nQ_{single}$$
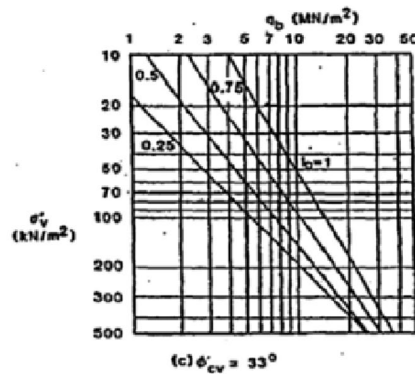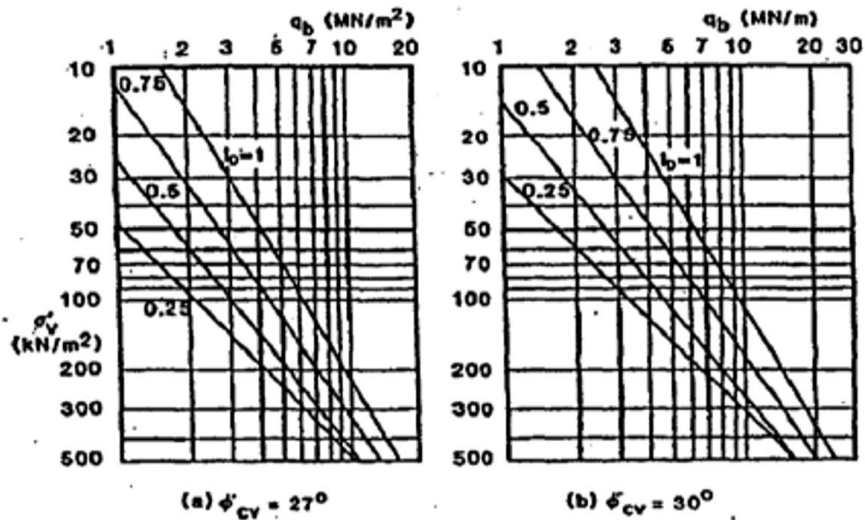
Usually settlement controls design.

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<u>In sand:</u>

$$q_b = N_q \sigma_V'$$

The design charts below (Fleming et al., 1997) can be used to estimate q_b if the initial relative density and critical state friction angle are known.

(a) $\phi_{cv}' = 27°$

(b) $\phi_{cv} = 30°$

(c) $\phi_{cv} = 33°$

$\tau_s = \beta \sigma_V'$,   with $\beta = K tan(\delta)$

Driven piles: $K \approx N_q /50$ which varies from ≈ 1.5 *at low* stress levels to ≈ 1.0 *at greater depths.*

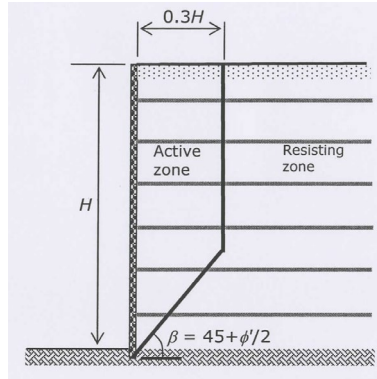Conventional bored piles: use $K = 0.7$

CFA piles: use $K = 0.9$

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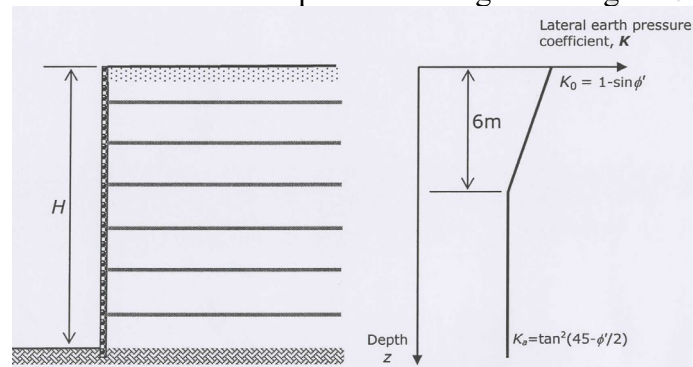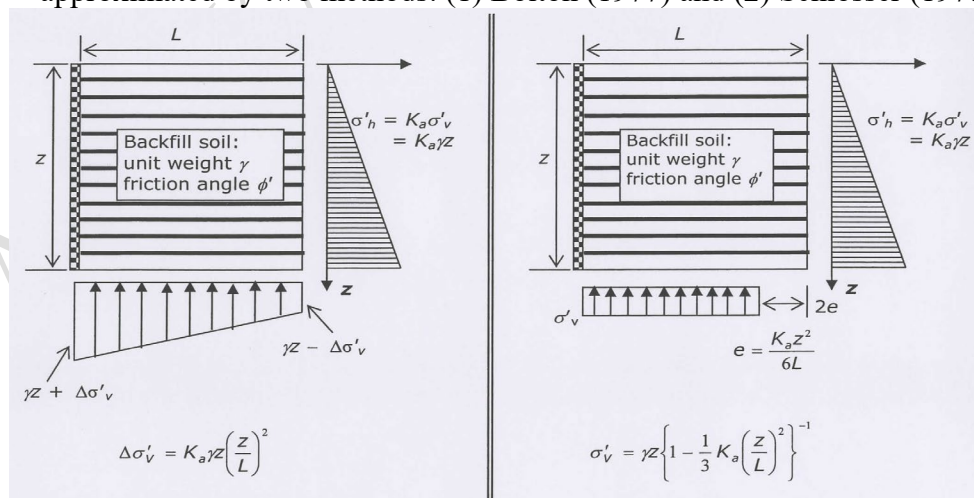Module No. CIE7001

Reinforced Soil Wall

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

- The coefficient of lateral earth pressure acting on facing.

- 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)

Bolton method

$$\Delta\sigma'_V = K_a \gamma z \left(\frac{z}{L}\right)^2$$

Schlosser method

$$e = \frac{K_a z^2}{6L}$$

$$\sigma'_V = \gamma z \left\{1 - \frac{1}{3} K_a \left(\frac{z}{L}\right)^2\right\}^{-1}$$

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- Factor of safety against tensile failure for strip reinforcement:

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

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

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

q_f = ultimate bearing capacity

q_n = net bearing capacity   = q_f - σ_o = q_f - γD (Total stresses)

                      = q_f - σ_o^1 = q_f - (γD - $\gamma_w h_w$)   (Effective stresses)

q_s = safe bearing capacity = $\dfrac{q_n}{F}$ and F = $\dfrac{q_f}{q_n}$ = 3.0 usually

q_a = allowable bearing capacity = $\dfrac{q_n}{F}$ + γD = $\dfrac{q_f - \gamma D}{F}$ + γD

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Shallow Foundations

c , ϕ soil

Terzaghi : $q_f = c \, N_c \, s_c + \gamma \, D \, N_q \, s_q + 0.5 \, B \, \gamma \, N_\gamma \, s_\gamma$

Where N_c ; N_q ; N_γ ; s_c ; s_q ; s_γ are bearing capacity and 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

- modified when Water Table present, γ_{sub} or $\gamma' = \gamma_{sat} - \gamma_w$

c_u soil ($\phi_u = 0$)

Skempton : $q_f = cN_c + \gamma D$ N_c from Skempton's graph

3-d Consolidation

$(1 - U) = (1 - U_v)(1 - U_r)$

$T_v = c_v \, t / d^2$ $T_r = c_h \, t / 4R^2$

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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)

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

(β is the angle of the slope, $\phi_m = \dfrac{\tan\phi}{F}$)

$$F = \frac{\sum(c'l + (W\cos\alpha - ul)\tan\phi')}{\sum W\sin\alpha}$$

$$F = \frac{\sum(c' \times R \times \theta_{rad}) + \sum(W \times \cos\alpha - u \times l)\tan\phi'}{\sum(W \times \sin\alpha)}$$

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

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

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

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

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

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

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

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

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

$(R$ *is the radius of the slip circle,* θ *is the included angle
and* d *is the eccentricity of the centre of mass*$)$

Retaining walls

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

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

$$\sigma_V' = \sigma_V - u$$

$$u = \gamma_w z$$

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

$$\sigma_h = \sigma_h' + u$$

$$\sigma_h' = K_a(\sigma_V') - 2c\sqrt{K_a}$$

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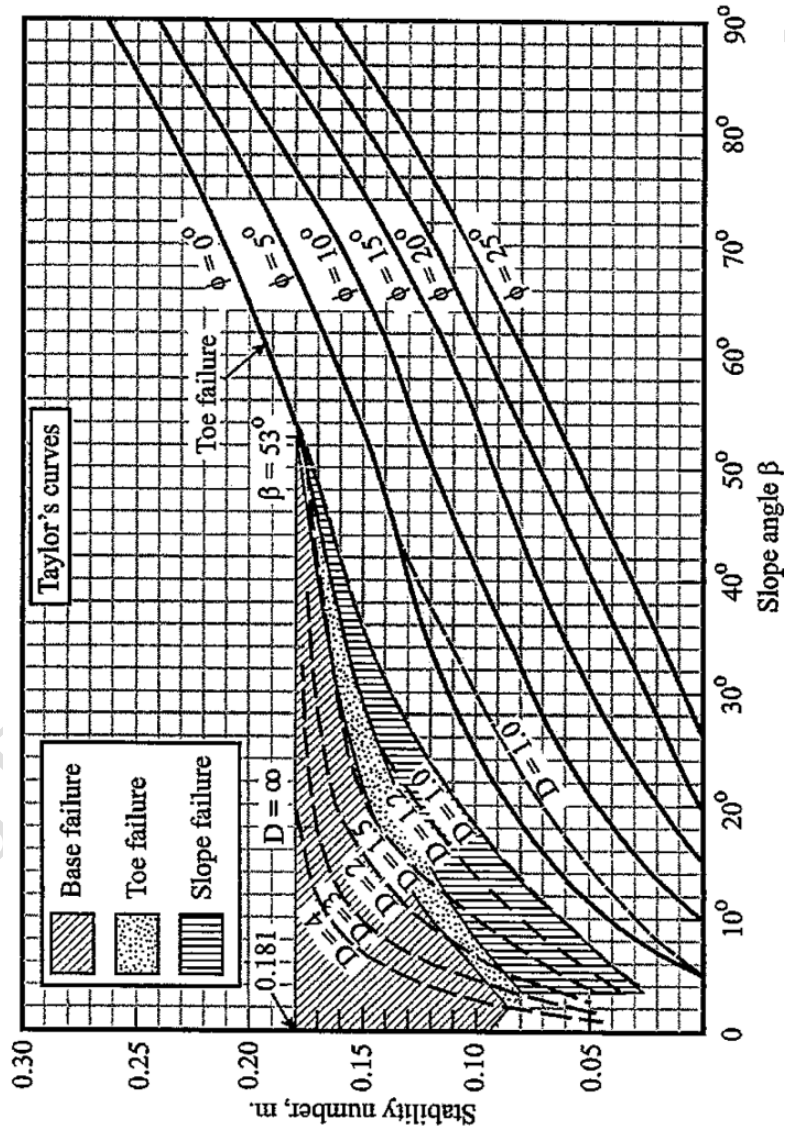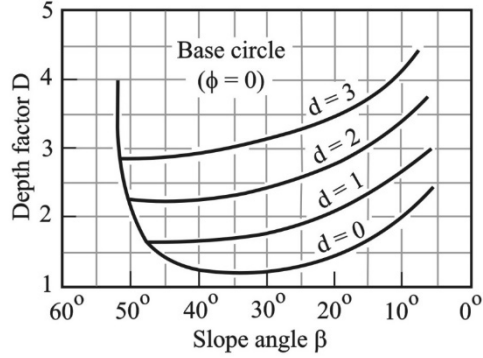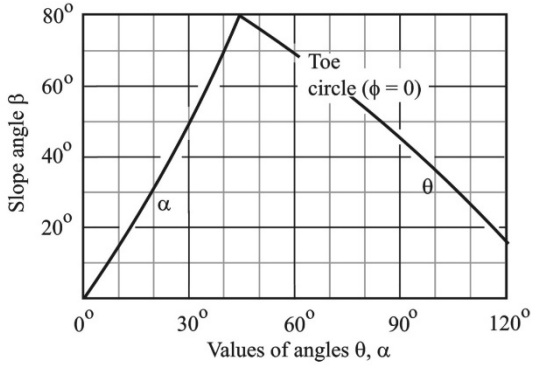
$$p_P = K_P(\gamma z + q) + 2c'\sqrt{K_P} \quad K_P = \frac{1 + sin\phi'}{1 - sin\phi'} = tan^2\left(45 + \frac{\phi'}{2}\right)$$

$(p_A, p_P, K_A$ *and* K_P *are the active and passive pressures and coeffecients
respectively,* z *is the depth,* γ *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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