[ENG34]

# UNIVERSITY OF BOLTON

# SCHOOL OF ENGINEERING

# BEng (HONS) CIVIL ENGINEERING

# SEMESTER 1 EXAMINATION 2021/2022

# GEOTECHNICAL ENGINEERING & GROUND IMPROVEMENT

# MODULE NO: CIE6003

**Date: Thursday 13th January 2022** **Time: 10.00am – 1.00pm**

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**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.**

**Supplementary Geotechnical Information is provided on page 11-14.**

**3hrs is provided for you to complete your answers.**

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**Question 1**

a) Produce a sketch to illustrate the relationship between the three different types of lateral earth pressure and the wall movement. With reference to your sketch, explain what happens when there is no movement of the wall, movement of the wall towards the soil and movement of the wall away from soil. In relation to strain, also explain when the minimum $P_a$ and maximum $P_p$ are achieved.

**(5 marks)**

b) A concrete cantilever wall with a sand backfill retains a layered geological sequence (Q1 - Figure 1.1). With depth the sequence includes: 0.5m of sandy topsoil, 2.5m of dense sand and 4.5m of stiff clay. All sections of the cantilever wall have a thickness of 0.5m, the base of the wall extends 1.5m backwards and 0.25m forwards. The properties of the materials are summarised in the table below:

| material | unit weight ($kNm^{-3}$) | angle of friction (°) | Cohesion ($kNm^{-2}$) |
|---|---|---|---|
| Concrete | 24 | - | - |
| Sand backfill | 14.5 | 15 | 0 |
| Sandy topsoil | 19 | 25 | 0 |
| Dense sand | 20.5 | 30 | 0 |
| Stiff clay | 18.5 | 10 | 22 |

i) Calculate and draw the distribution of the active and passive pressures applied to the wall and backfill along the lines marked AB and CD (Q1 - Figure 1.1 on page 3). **(10 marks)**

ii) Calculate the magnitudes and lines of action of the two thrusts produced by these pressures above the base of the wall. **(10 marks)**

**Total 25 marks**

**Q1 - Figure 1.1 over the page….**

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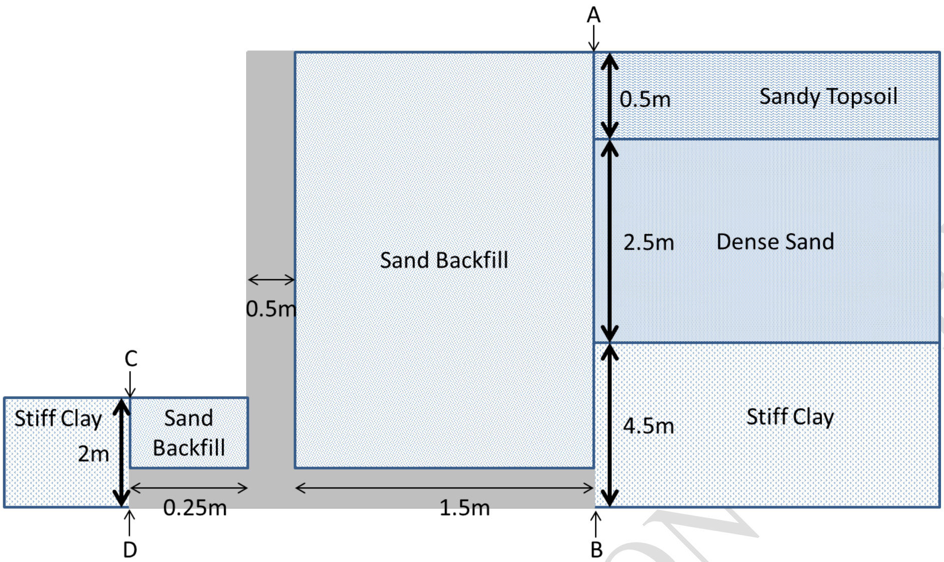
**Question 1 continued….**




**Question 1 - Figure 1.1**

**Question 2**

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. **(4 marks)**

b) In Q2 – Figure 2.1 (page 4), determine if the slope is stable or unstable. $L_{AB}$ = 8.64 m, R = 5.50 m. **(7 marks)**

c) An embankment made from clay is to be constructed upon the ground surface (See Q2 - Figure 2.2 page 4). 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 Table 2 (page 5). **(7 marks)**

d) A 7m excavation is required in a mudrock where a hard limestone is known to be 8.4m below ground level. The mudrock has a cohesion of 9kN/m$^2$ and a unit weight of 19kN/m$^3$. Using Taylor's curves in Q2 – Figure 2.3 (page 5), what is the angle of the critical slope. **(7 marks)**

**Total 25 marks**

**Q2 – Figure 2.1 & Q2 – Figure 2.2 over the page….**

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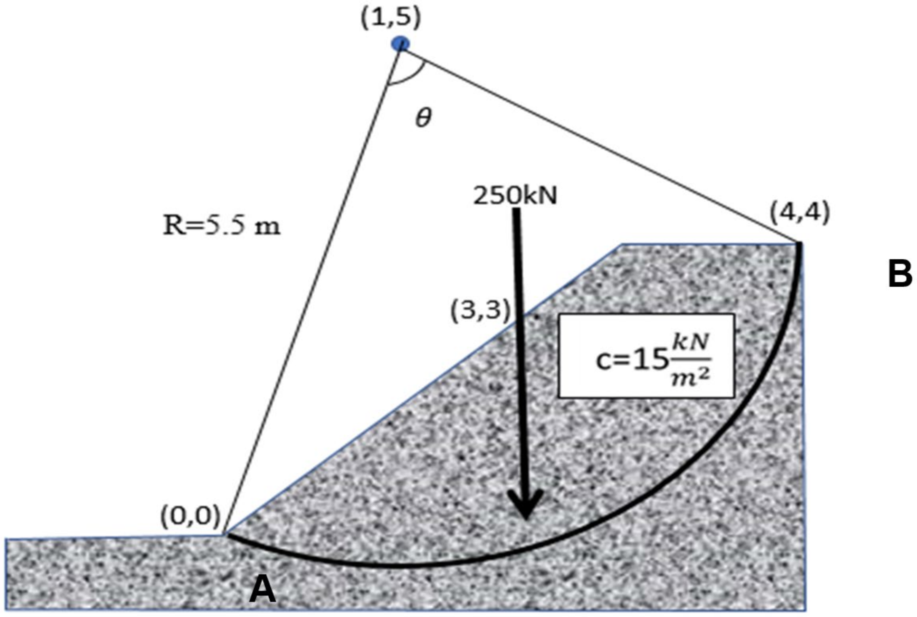
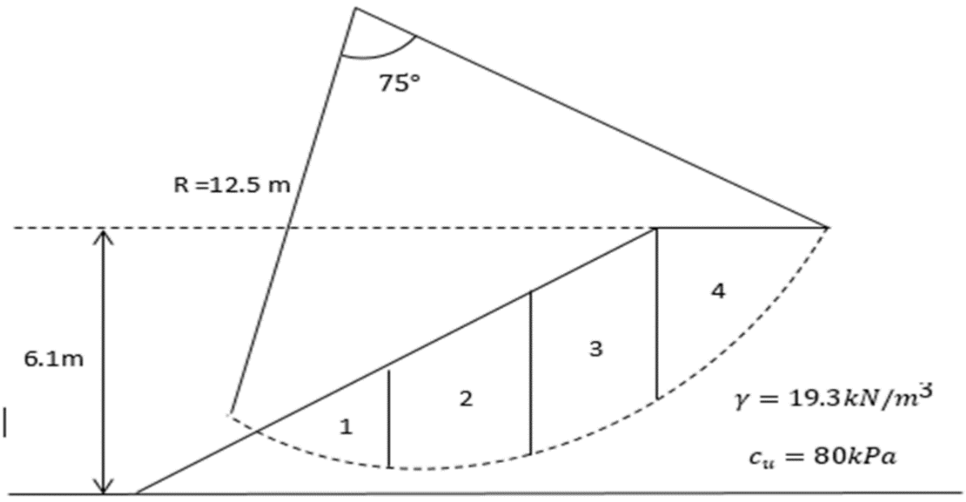
**Question 2 continued….**




**Q2 – Figure 2.1**




**Q2 – Figure 2.2**

**Q2 Table 2 & Q2 – Figure 2.3 over the page….**

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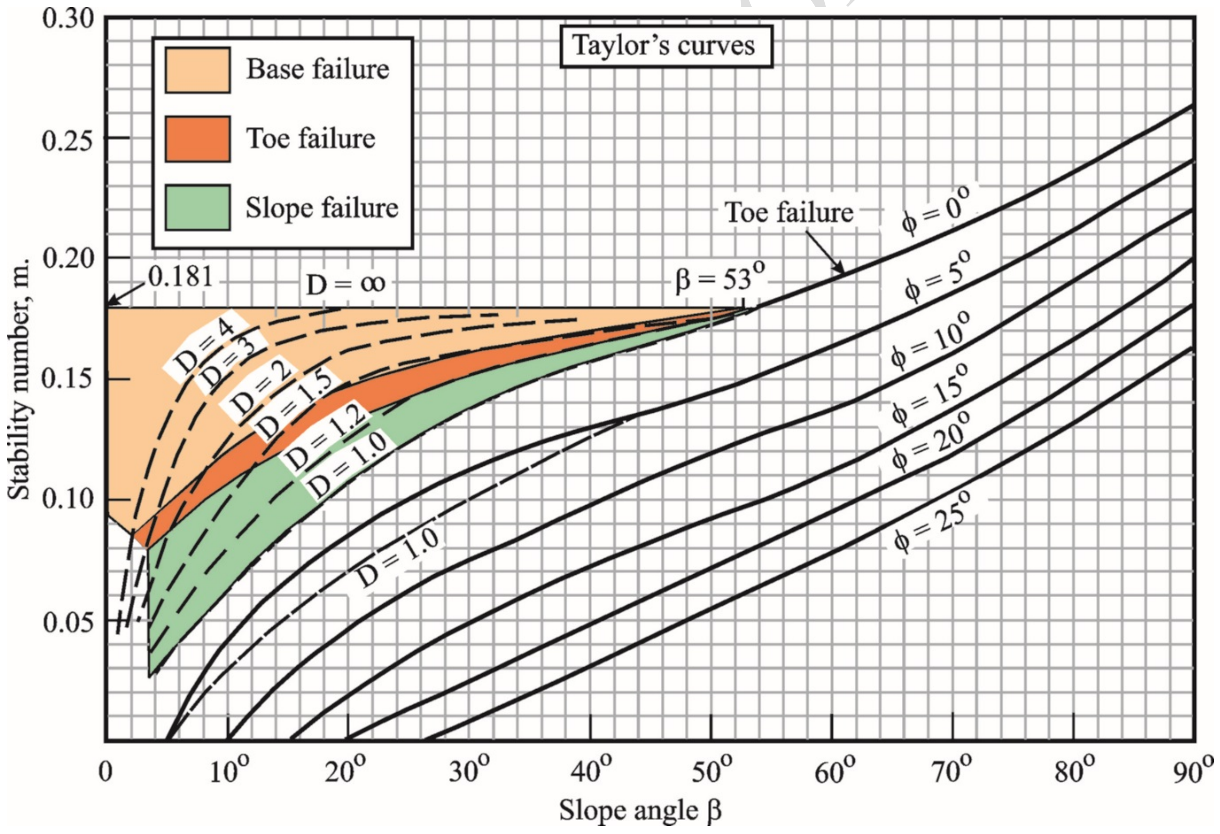
**Question 2 continued….**

| 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 |

**Q2 – Table 2**






**Q2 - Figure 2.3**

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**Question 3**

a) A wide embankment, 6m high, is to be constructed over a 10m thick layer of very soft to soft clay ($m_v$ = 0.5m$^2$/MN, $c_v$ = 6m$^2$/yr). This clay overlies a relatively impermeable layer of mudstone. The embankment is to be formed by compacting granular material to a bulk unit weight of 21kN/m$^3$.

i) Calculate the total consolidation settlement within the clay layer.

**(4 marks)**

ii) If "finishing works" can be commenced on top of the embankment as soon as less than 30mm of consolidation settlement of the clay layer remains to be achieved, then calculate the earliest time that "finishing works" can be commenced.

**(4 marks)**

b) If 250mm diameter vertical sand drains are available then determine the square grid spacing of such drains that would be required to achieve the same settlement restrictions as required in Q3 a) ii) within 3-months – ie. only 30mm of consolidation settlement remaining. NOTE: $c_h$ = 12m$^2$/yr and Q3 – Figure 3.1 and Q3 – Table 3 are provided (pages 7 and 8) for the solution of this question.

**(12 marks)**

c) Where 6m deep loose granular deposits occur along a section of proposed new high speed rail track, discuss <u>**FOUR**</u> ground improvement options that may be considered to ensure a stable platform is achieved. In geotechnical terms evaluate the advantages and limitations of each option you consider.

**(5 marks)**

**Total 25 marks**

**Q3 – Figure 3.1 over the page….**

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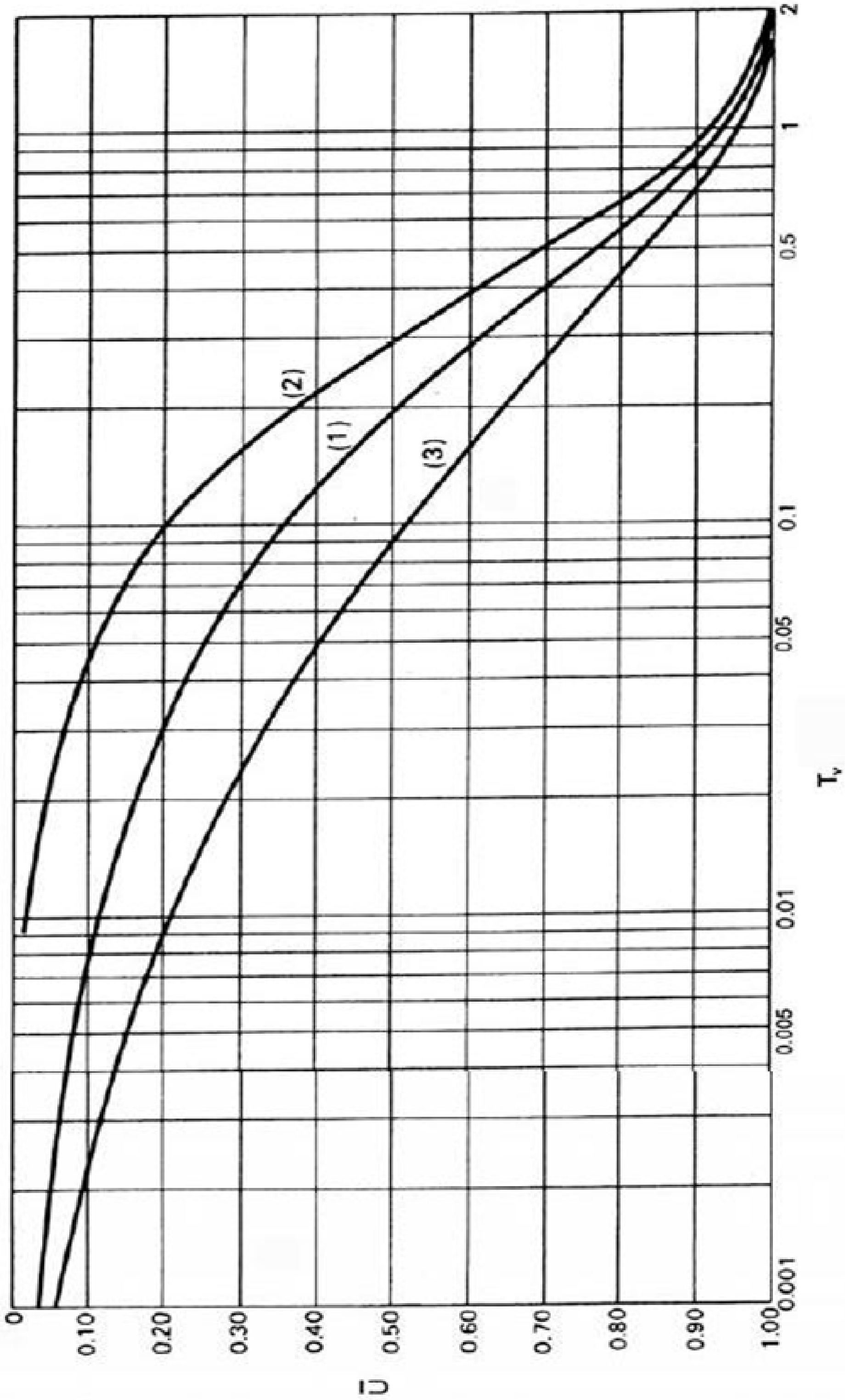
**Question 3 continued….**

**Q3 - Figure 3.1**




**Q3 – Table 3 over the page….**
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**Question 3 continued….**

**Q3 – Table 3**

| Degree of consolidation $U_r$ (%) | Dimensionless Time Factor, $T_r$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | n=5 | 10 | 15 | 20 | 25 | 30 | 40 | 50 | 60 | 80 | 100 |
| 10 | 0.012 | 0.021 | 0.026 | 0.030 | 0.032 | 0.035 | 0.039 | 0.042 | 0.044 | 0.048 | 0.051 |
| 20 | 0.026 | 0.044 | 0.055 | 0.063 | 0.069 | 0.074 | 0.082 | 0.088 | 0.092 | 0.101 | 0.107 |
| 30 | 0.042 | 0.070 | 0.088 | 0.101 | 0.110 | 0.118 | 0.131 | 0.141 | 0.149 | 0.162 | 0.172 |
| 40 | 0.060 | 0.101 | 0.125 | 0.144 | 0.158 | 0.170 | 0.188 | 0.202 | 0.214 | 0.232 | 0.246 |
| 50 | 0.081 | 0.137 | 0.170 | 0.195 | 0.214 | 0.230 | 0.255 | 0.274 | 0.290 | 0.315 | 0.334 |
| 55 | 0.094 | 0.157 | 0.197 | 0.225 | 0.247 | 0.265 | 0.294 | 0.316 | 0.334 | 0.363 | 0.385 |
| 60 | 0.107 | 0.180 | 0.226 | 0.258 | 0.283 | 0.304 | 0.337 | 0.362 | 0.383 | 0.416 | 0.441 |
| 65 | 0.123 | 0.207 | 0.259 | 0.296 | 0.325 | 0.348 | 0.386 | 0.415 | 0.439 | 0.477 | 0.506 |
| 70 | 0.137 | 0.231 | 0.289 | 0.330 | 0.362 | 0.389 | 0.431 | 0.463 | 0.490 | 0.532 | 0.564 |
| 75 | 0.162 | 0.273 | 0.342 | 0.391 | 0.429 | 0.460 | 0.510 | 0.548 | 0.579 | 0.629 | 0.668 |
| 80 | 0.188 | 0.317 | 0.397 | 0.453 | 0.498 | 0.534 | 0.592 | 0.636 | 0.673 | 0.730 | 0.775 |
| 85 | 0.222 | 0.373 | 0.467 | 0.534 | 0.587 | 0.629 | 0.697 | 0.750 | 0.793 | 0.861 | 0.914 |
| 90 | 0.270 | 0.455 | 0.567 | 0.649 | 0.712 | 0.764 | 0.847 | 0.911 | 0.963 | 1.046 | 1.110 |
| 95 | 0.351 | 0.590 | 0.738 | 0.844 | 0.926 | 0.994 | 1.102 | 1.185 | 1.253 | 1.360 | 1.444 |
| 99 | 0.539 | 0.907 | 1.135 | 1.298 | 1.423 | 1.528 | 1.693 | 1.821 | 1.925 | 2.091 | 2.219 |

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**Question 4**

a) Discuss when undrained <u>and</u> drained shear strength parameters would be used for the design of shallow foundations. Ensure that you highlight both testing and design aspects in your evaluation of shallow foundation design.

**(5 marks)**

b) A pad foundation, 2.0m square is to be located at a depth of 1.0m in a uniform bearing stratum of firm clay. The water table level is at an assumed depth of 1.0m below ground level (from a recent and reliable site investigation). The clay soil properties are as follows;

| | |
|---|---|
| Bulk unit weight | $\gamma = 20.0$ kN/m$^3$ |
| Saturated unit weight | $\gamma_{sat} = 21.5$ kN/m$^3$ |
| With respect to Total Stresses | $c_u = 50.0$ kN/m$^2$ |
| | $\Phi_u = 0^0$ |
| With respect to Effective Stresses | $c' = 8$ kN/m$^2$ |
| | $\Phi' = 30^0$ |

Determine the safe bearing load that the foundation can support in the <u>short term</u> (in kN). Use the formulae provided on page 11 and also Q4 – Figure 4.1 on page 10 (as appropriate). State any assumptions made in your calculations.

**(10 marks)**

c) A bored pile (14m long and 450mm in diameter) is to be installed into the following soil profile;

| Depth<br>m | Description | Unit Weight kN/m$^3$ | $c_u$<br>kN/m$^2$ | Adhesion Factor $\alpha$ |
|---|---|---|---|---|
| 0 – 5 | Soft CLAY | 21.0 | 35.0 | 0.55 |
| 5 – 10 | Firm to stiff CLAY | 22.0 | 80.0 | 0.5 |
| 10 - 30 | Stiff to very stiff CLAY | 22.5 | 130.0 | 0.45 |

The above clay strata are all taken to be fully saturated.

Determine the safe load carrying capacity of the pile (in kN). State any assumptions made in your calculations

**(10 marks)**
**Total 25 marks**

**Q4 – Figure 4.1 over the page….**
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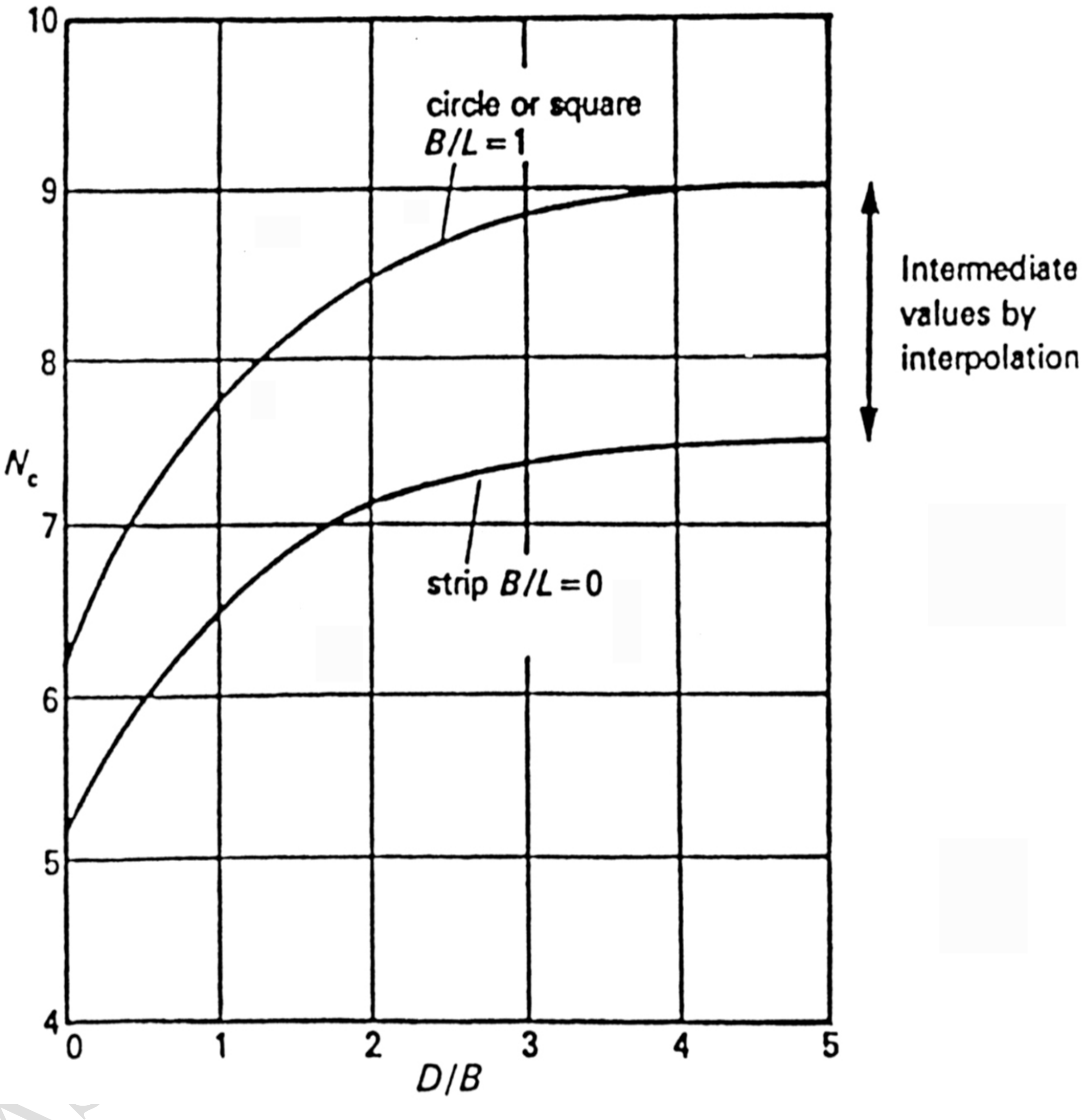
**Question 4 continued….**




**Q4 – Figure 4.1**

**END OF QUESTIONS**

**Please turn the page for Supplementary Geotechnical Information….**

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# Supplementary Geotechnical Information

$q_f$ = ultimate bearing capacity

$q_n$ = net bearing capacity $= q_f - \sigma_o = q_f - \gamma D$ (Total stresses)

$= q_f - \sigma_o^1 = q_f - (\gamma D - \gamma_w h_w)$ (Effective stresses)

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

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

## Shallow Foundations

c , $\phi$ soil

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

Where $N_c$ ; $N_q$ ; $N_\gamma$ ; $s_c$ ; $s_q$ ; $s_\gamma$ are bearing capacity and shape factors

| Shape of footing | $s_c$ | $s_q$ | $s_\gamma$ |
|---|---|---|---|
| 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, $\gamma_{sub}$ 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 (Figure 4.1 of Q4 for D/B values)

**3-d Consolidation**

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

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

**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,*** $\boldsymbol{\phi_m = \frac{tan\phi}{F}})$

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

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

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

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

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

$(\boldsymbol{W}$ ***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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**Retaining walls**

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

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

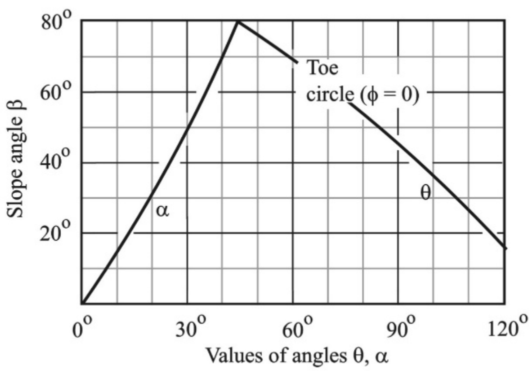
$p_A = K_A(\gamma z + q) - 2c'\sqrt{K_A}$ $K_A = \frac{1-sin\,\phi'}{1+sin\,\phi'} = tan^2\left(45 - \frac{\phi'}{2}\right)$

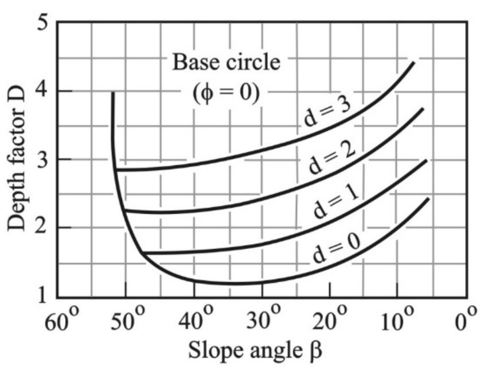
$p_P = K_P(\gamma z + q) + 2c'\sqrt{K_P}$ $K_P = \frac{1+sin\,\phi'}{1-sin\,\phi'} = tan^2\left(45 + \frac{\phi'}{2}\right)$

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



## Additional Data

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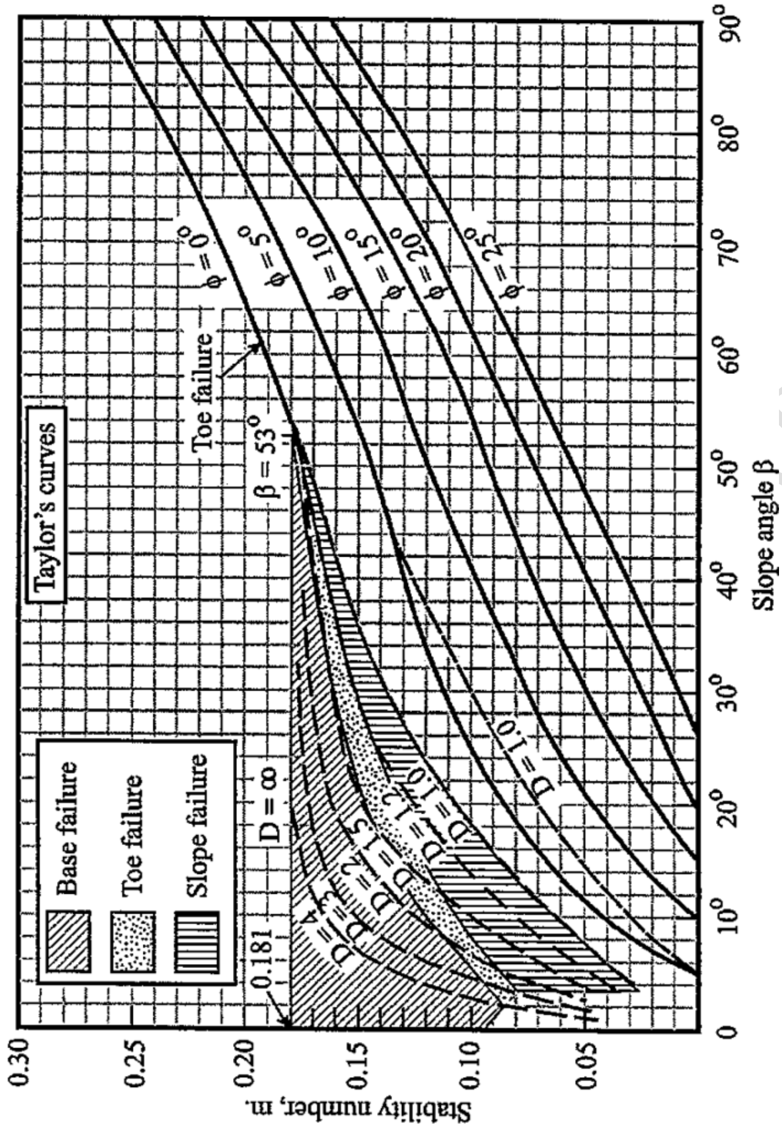


**Taylor and Fellenius charts for slopes in saturated clay**

**END OF PAPER**