UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BEng(HONS) IN CIVIL ENGINEERING

SEMESTER ONE EXAMINATION 2018/2019

GEOTECHNICAL ENGINEERING & GROUND IMPROVEMENT

MODULE NO: CIE6003

Date: Tuesday 15th January 2019 **Time: 10:00 – 13:00**

INSTRUCTIONS TO CANDIDATES:

There are FIVE questions.

Answer FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

Supplementary Geotechnical Information is provided on pages 11-13.

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

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Question 1

Figure Q1 shows a 4.0 m high gravity retaining wall which supports against its steeper face two soils with relevant material properties. It is assumed that the wall has a smooth back.

a) Sketch the earth pressure diagram for the retained soil, labelling all relevant values. You may assume the soil and the wall to be free-draining (so that there is no pore water), and that movement of the wall is sufficient for active conditions to develop in the soil.

(6 marks)

b) Determine the total force (F) and moment (M) acting about the level of the base of the wall due to earth pressure.

(5 marks)

c) Assuming that friction between the base of the wall and the soil is equal to δ=29° and the ultimate bearing capacity of Soil-2 is q_u=250 kN/m^2:

(i) calculate the factors of safety against sliding and overturning;

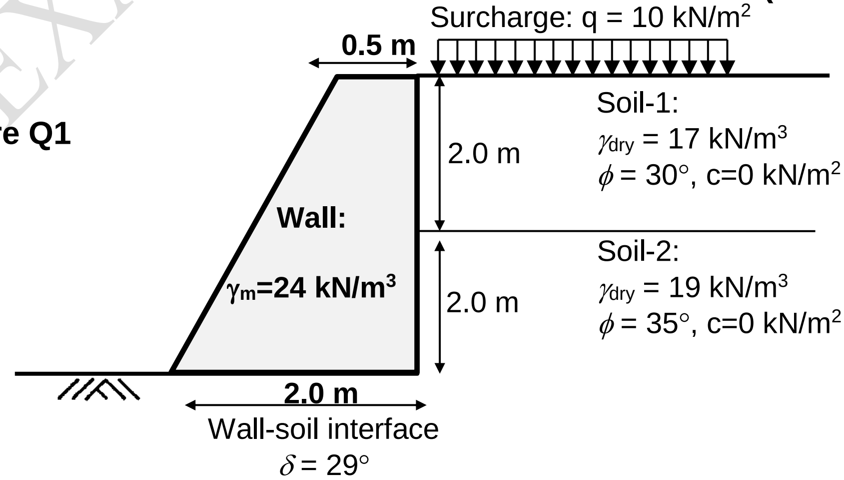
(ii) calculate the maximum ground pressures beneath the base assuming a rectangular and trapezoidal pressure distributions.

(10 marks)

d) Knowing that recommended factors of safety against sliding, overturning and bearing capacity are 1.5, 2.0 and 3 respectively, what design modifications should be introduced for the problem shown in Figure Q1 to increase the factors of safety to their minimum acceptable limits? Discuss and use sketches to illustrate your answer as appropriate.

(4 marks)

Figure Q1



Total 25 marks

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Question 2

(a) Given that the slope shown in Figure Q2 was initially submerged with water and that the water level has now dropped down to the level of the top of the sand, determine the short term stability factor using the rigorous approach. The soil mass limited by a trial slip line ABCD is divided into 8 slices all having identical width of b=1m whose average heights in sand (h_s) and clay (h_c), angle (α) and pore water pressure (u) are tabulated below:

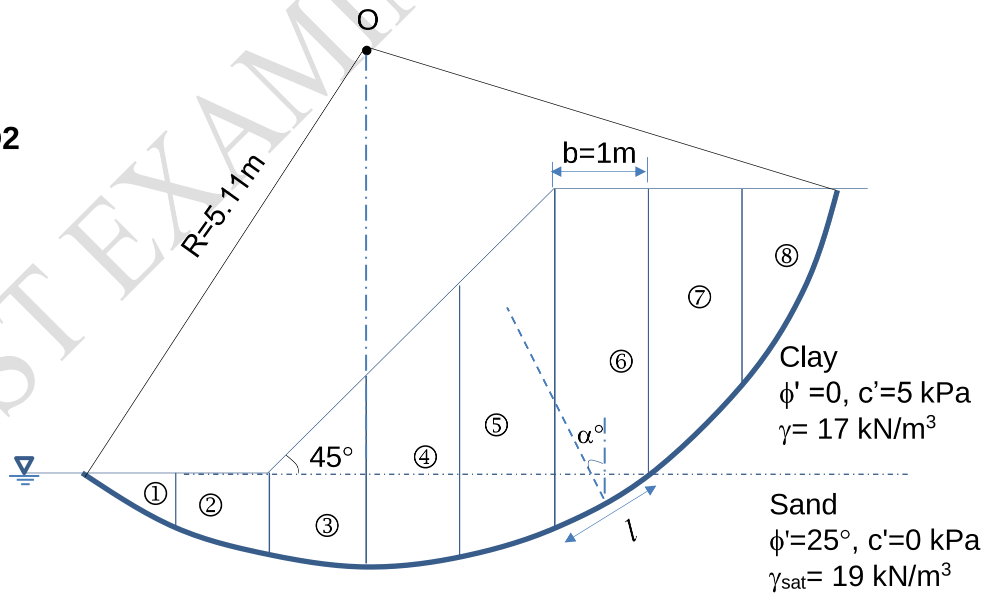
Slice No.	1	2	3	4	5	6	7	8
h_s (m)	0.32	0.75	0.96	0.96	0.76	0.33	0.00	0.00
h_c (m)	0.00	0.00	0.50	1.50	2.50	3.00	2.61	1.68
α (°)	-29.3	-17.1	-5.6	5.6	17.1	33.3	40.3	47.4
u (kPa)	3.14	7.36	9.42	9.42	7.46	3.24	0.00	0.00

The factor of safety according to the rigorous approach is given by:

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

(b) Comment on the obtained result.

Figure Q2



Total 25 marks

Question 3

Figure Q3 below shows a 5.0 m high cut slope in clay with a side slope angle 1.0 (vertical): 1.0 (horizontal). Relevant information is given for assumed circular and wedge slip and the unit weight of the clay (γ) is 18 kN/m^3.

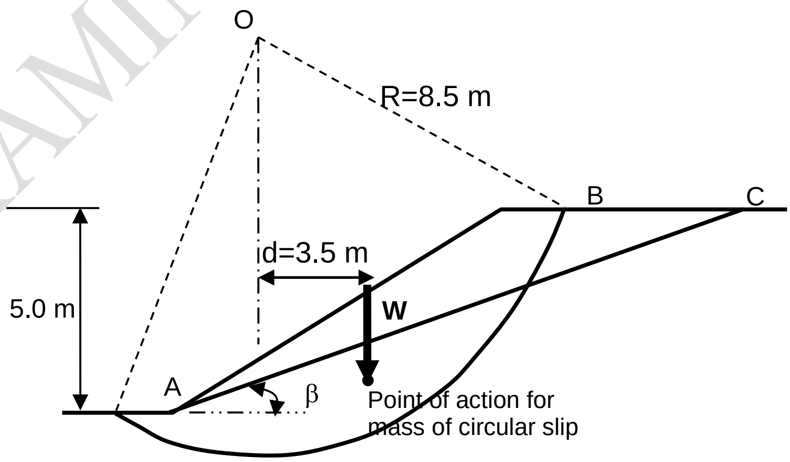
a) Assuming undrained behaviour with c_u=25 kN/m^2, calculate the factor of safety (FoS) against instability for each mechanism. **(8 marks)**

b) Use Taylor's chart provided on page 12 to calculate the factor of safety (FoS) assuming ϕ_u=0, D=1.2 and comment on the results. **(5 marks)**

c) Assuming generally favourable ground water conditions with r_u=0.5 assess the long-term stability of the slope based on a shallow translational slip or using Taylor's charts provided on page 13 for ϕ'=30 and c'=10. Comments on the results **(5 marks)**

d) What remedial actions you suggest to improve the stability of the slope shown in Figure Q3? Discuss and use sketches to illustrate your answer as appropriate. **(7 marks)**

Figure Q3



Circular slip : area =43 m^3/m, length (L) = 20 m^2/m.
Wedge slip ABC : area = 27 m^3/m, angle to horiz. β= 20°.

Total 25 marks

PLEASE TURN THE PAGE.....

Question 4

a) A pad foundation, 2m square is to be located at a depth of 1m in a uniform bearing stratum of firm to stiff clay. The water table level is at an assumed depth of 1.5m below ground level (from a recent and reliable site investigation). The clay soil properties are as follows;

Bulk unit weight	γ = 20.0 kN/m^3
Saturated unit weight	γ_{sat} = 22.0 kN/m^3
Quick undrained strength triaxial test parameters	c_u = 85.0 kN/m^2
	Φ_u = 0^0
Undrained strength triaxial test parameters	c^l = 12 kN/m^2
	Φ^l = 33^0

i) Determine the safe bearing load that the foundation can support in the short term (in kN). Use the formulae provided on the Formula Sheet as rear of this examination paper and Figure Q4 (as appropriate).

(9 marks)

ii) Evaluate why the above is an appropriate method to design a shallow foundation.

(4 marks)

NOTE: State any assumptions made in your calculations for Q4 a).

b) A bored pile (12m long and 600mm in diameter) is to be installed into the following fully saturated soil profile;

Depth m	Description	Unit Weight kN/m^3	c_u kN/m^2	Adhesion Factor α
0 – 4	Firm CLAY	21.0	45.0	0.50
4 – 7	Stiff CLAY	22.0	95.0	0.45
10 - 20	Very stiff CLAY	22.5	120.0 at 10m 180.0 at 20m	0.40

Determine the safe load carrying capacity of the pile (in KN).

NOTE: State any assumptions made in your calculations for Q4 b).

(12 marks)

Total 25 marks

Figure Q4a and Table Q4b are on the following page…..

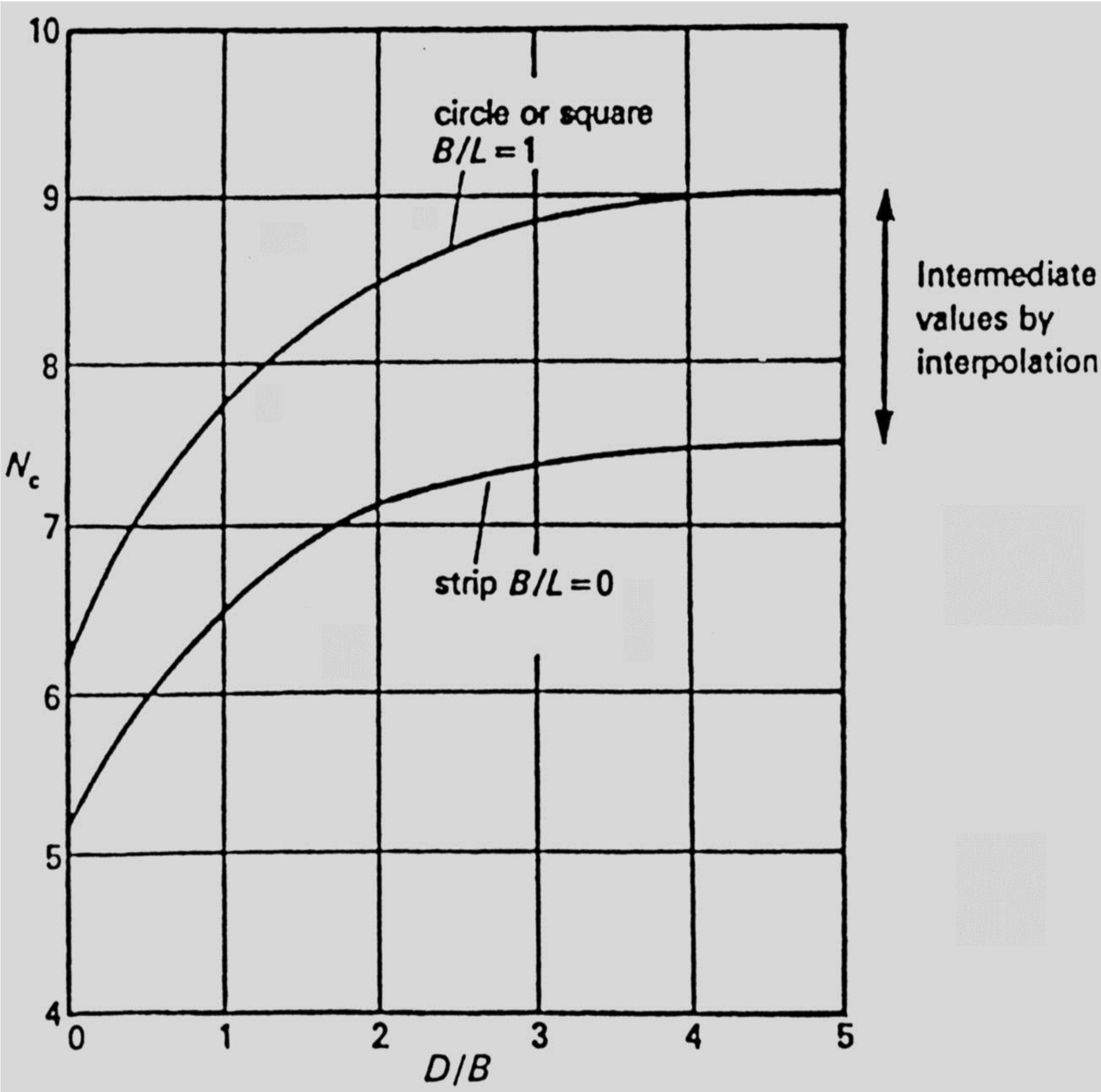

10
9
8
7
6
5
4
N_c
circle or square
B/L = 1
strip B/L = 0
Intermediate values by interpolation
0
1
2
3
4
5
D/B

Figure Q4a

ϕ	N_c	N_q	N_γ
0	5.14	1.0	0
1	5.4	1.1	0
2	5.6	1.2	0
3	5.9	1.3	0
4	6.2	1.4	0
5	6.5	1.6	0.1
6	6.8	1.7	0.1
7	7.2	1.9	0.2
8	7.5	2.1	0.2
9	7.9	2.3	0.3
10	8.4	2.5	0.4
11	8.8	2.7	0.5
12	9.3	3.0	0.6
13	9.8	3.3	0.8
14	10.4	3.6	1.0
15	11.0	3.9	1.2
16	11.6	4.3	1.4
17	12.3	4.8	1.7
18	13.1	5.3	2.1
19	13.9	5.8	2.5
20	14.8	6.4	3.0
21	15.8	7.1	3.5
22	16.9	7.8	4.1
23	18.1	8.7	4.9
24	19.3	9.6	5.7
25	20.7	10.7	6.8
26	22.3	11.9	7.9
27	23.9	13.2	9.3
28	25.8	14.7	10.9
29	27.9	16.4	12.8
30	30.1	18.4	15.1
31	32.7	20.6	17.7
32	35.5	23.2	20.8
33	38.6	26.1	24.4
34	42.2	29.4	28.8
35	46.1	33.3	33.9
36	50.6	37.8	40.0
37	55.6	42.9	47.4
38	61.4	48.9	56.2
39	67.9	56.0	66.8
40	75.3	64.2	79.5

Table Q4b

Question 5

a) A railway embankment, 7m high, is to be built on a 12m thick layer of very soft clay (m_v = 0.6m^2/MN, c_v = 8m^2/year), which overlies a relatively impermeable material that can be assumed to act as a rigid stratum.

The embankment is constructed using a sandy gravel (γ_b = 21kN/m^3).

i) calculate the total consolidation settlement expected within the very soft clay layer.

(4 marks)

ii) If the railway lines can tolerate a further uniform settlement of 50mm of the underlying soft clay after completion of the upper embankment layers, then calculate the earliest time after placement of the embankment material before the railway lines can be laid such that no more than 50mm of settlement occurs after that time.

(4 marks)

b) If 250mm diameter vertical sand drains can be installed down through the entire depth of soft clay prior to construction of the embankment, and these be connected to a granular surface drainage layer, then what square grid spacing would be required to achieve all but 50mm of the consolidation settlement of the soft clay layer within one month of completion of the embankment. The soft clay properties are as for Q5a) and also c_h = 12m^2/year.

(12 marks)

NOTE: Figure Q5a and Table Q5b are available for the solution to question 5a) and 5b)

c) If one part of the scheme passes over a zone with 6m of very loose to loose silty gravelly medium to coarse SAND then what ground improvement options would be available to provide a cost effective stable embankment solution. Ensure that your answer outlines a range of available options and evaluates the advantages and limitations of each.

(5 marks)

Total 25 marks

Figure Q5a and Table Q5b are on the following page….

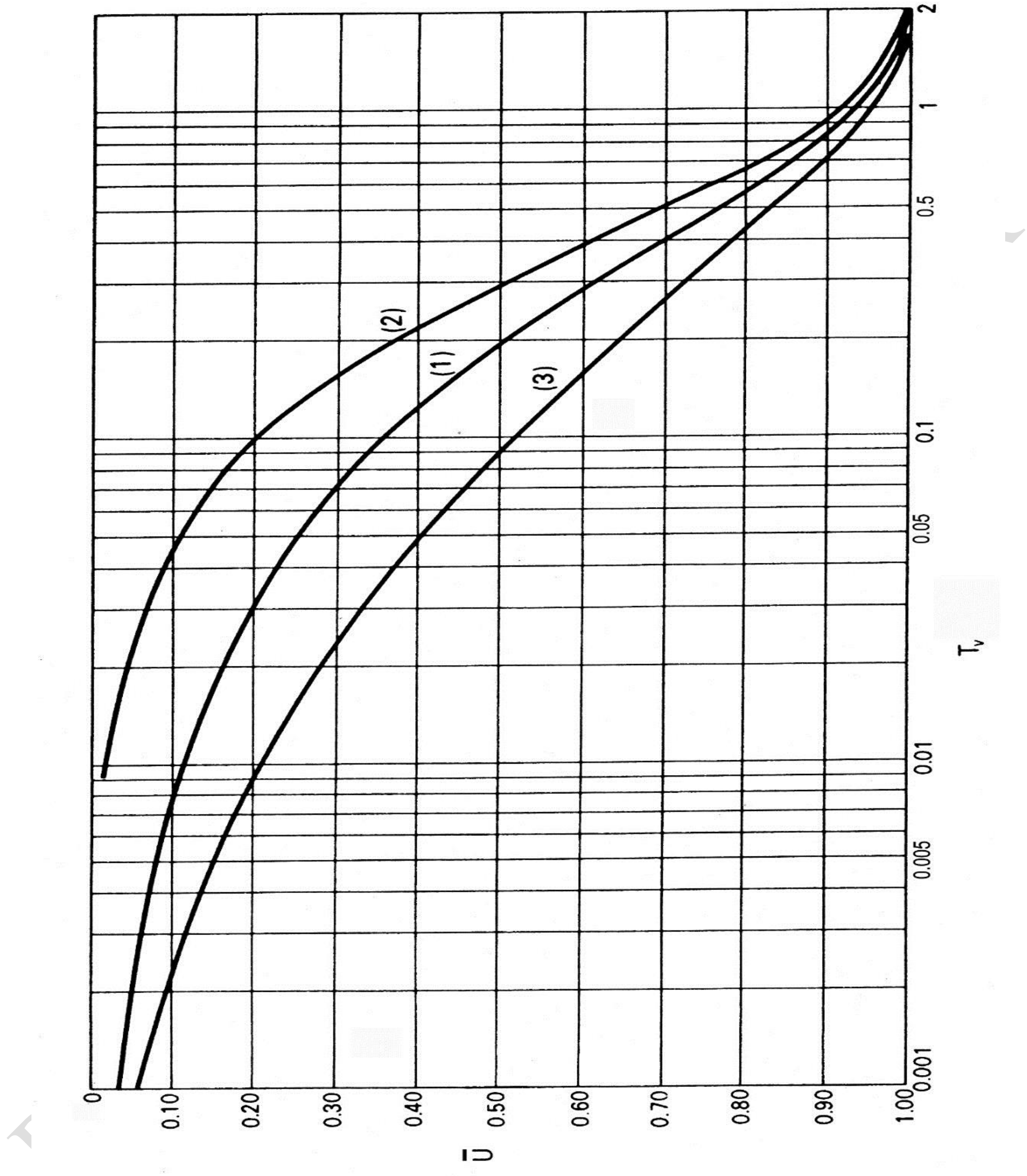

(1)
(2)
(3)
0
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Ū
0.001
0.005
0.01
0.05
0.1
0.5
1
2
T_v

Figure Q5a

Degree of Consolidation	Dimensionless Radial Time Factor T_r for varying values of 'n' (where $n = R / r_d$)										
U_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

Table Q5b

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 $F = \frac{q_f}{q_n} = 3.0$ (for original BS8004)

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

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 , $\phi_u = 0$ soil

Skempton : $q_f = cN_c + \gamma D$ N_c from Skempton's graph (Figure Q4 for D/B values)

Consolidation

$R = 0.564\ S$ (square grid)

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

$T_r = (c_h t) / (4 R^2)$

$T_v = (c_v t) / d^2$

Retaining walls

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

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

Ground pressure regular and trapezoidal distributions:

$$q = \frac{N}{B-2e}$$

$$q = \frac{N}{B} \pm \frac{6Ne}{B^2}$$

Slope stability

$F = c_u/(N_s \times \gamma \times H)$

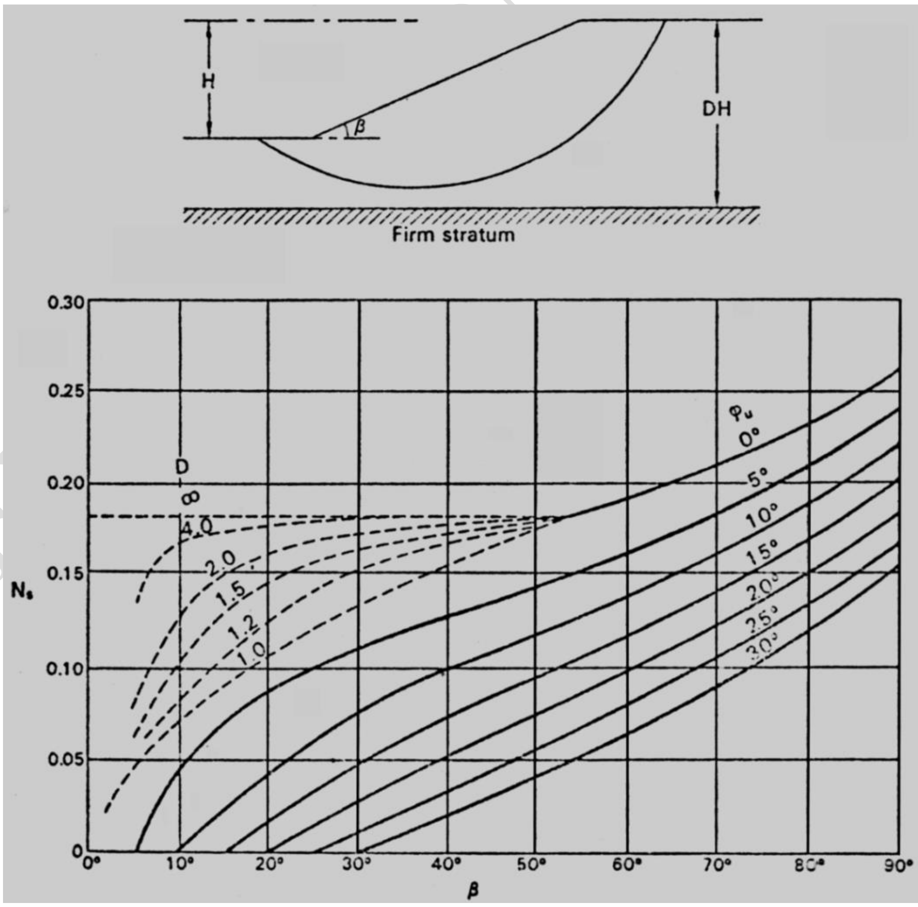

Figure A1: Taylor's chart for undrained slope stability.

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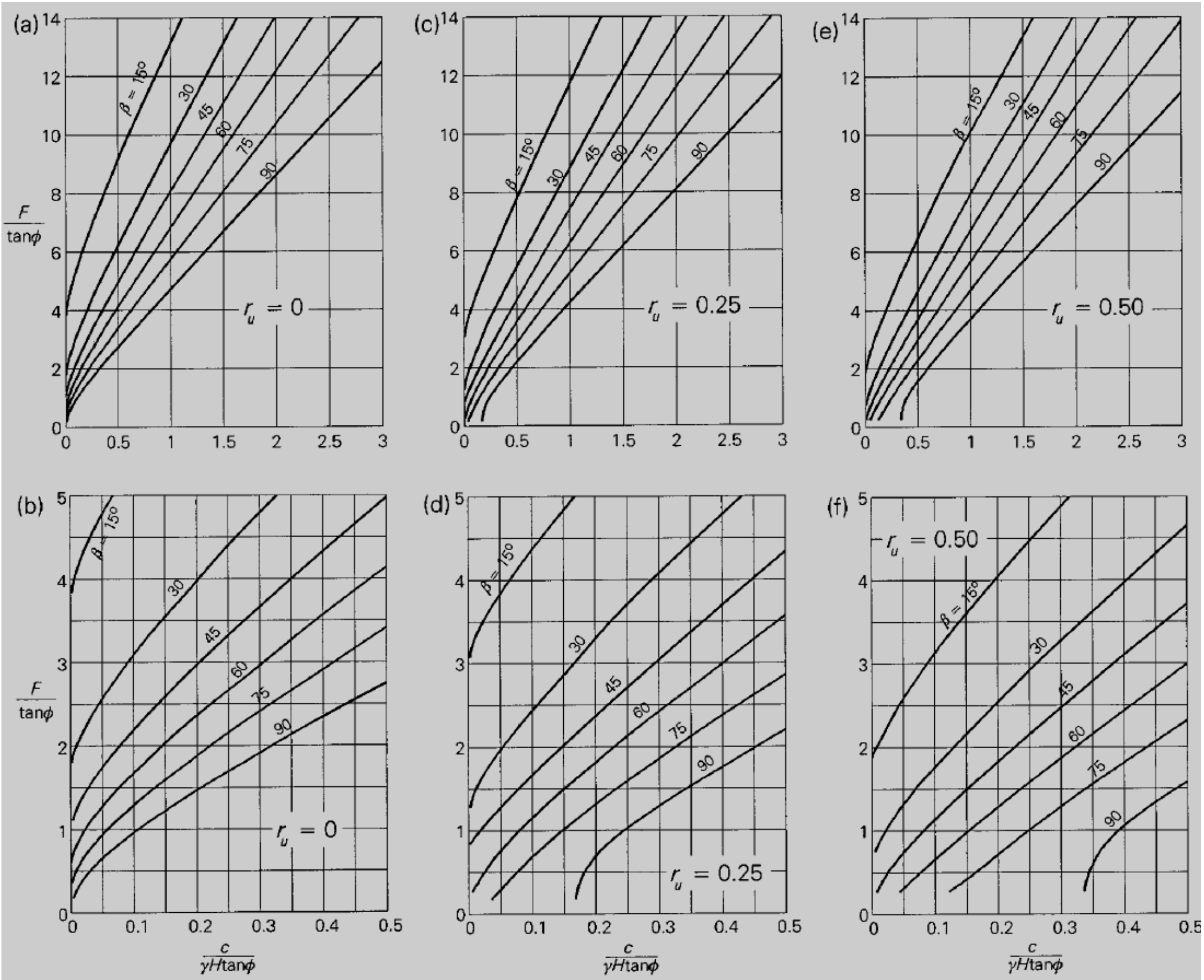

Figure A2: Stability charts for uniform slopes (R. L. Michalowski 2002).