Université d'Ottawa
Faculté de genie

Départment de
Génie civil

University of Ottawa
Faculty of Engineering

Department of
Civil Engineering

CVG 3109
SOIL MECHANICS - I
FINAL EXAMINATION

Length of Examination: 3hrs
Professor: Zhong Han

12th Dec, 2016 (14:00 to 17:00)

First Name: ____
Last Name: ____
Student Number: ___________
Signature ___________________________

i) This is a closed book exam. No textbooks are allowed
ii) **Formula sheet** is available on last pages of this question paper
iii) **If you do not understand a question, clearly state an assumption and proceed.**
iv) Non programmable calculators are permitted
v) Questions have the values shown next to the question.
vi) **Marks will be taken out for missing units and labels.**
vii) Answers should be succinct.

At the end of the exam, when time is up:

- Stop working and turn your exam upside down.
- Please remain silent.
- Do not move or speak until ALL exams have been picked up, and a TA or the Professor gives the go-ahead to leave.

Question	**Max Marks**	**Marks Awarded**
1	10	
2	10	
3	12	
4	16	
5	15	
6	12	
7	25	
Total	**100**	

Question 1 (1 x 10 = 10 Marks)

Please summarize your answers into this form (there may be more than one correct answer for each question)

1	2	3	4	5	6	7	8	9	10

1	The maximum size of clay particle is: (A) 2×10^{-6} m (B) 75×10^{-6} m (C) 100×10^{-6} m (D) 200×10^{-6} m
2	Optimum moisture content of a soil is close to the soil's: (A) Shrinkage limit (B) Plastic limit (C) Liquid limit (D) Plasticity index
3	Compaction (in terms of increasing soil's density) WILL NOT increase the soils (A) Strength (B) Permeability (C) Bearing capacity (D) Void ratio
4	To measure the coefficient of permeability for fine-grained soils, it is preferable to use: (A) Falling head test (B) Constant head test
5	The settlements in saturated clays are mainly attributed to (A) Deformation of soil grains (B) Compression of water within the voids (C) Expulsion of water from within the voids (D) Expulsion of soil grains
6	The stress versus strain behavior of an overconsolidated clay is similar to that of a dense sand. (A) True (B) False

7	The consolidated undrained triaxial test results with pore-water pressure measurements can only be used to estimate effective shear strength parameters. (A) True (B) False
8	Which of the following statements is / are <u>INCORRECT</u>: (A) Overconsolidated clay generally has an effective cohesion equals to 0 (B) Pore-water pressure can be negative during shearing for certain saturated clays (C) Volume reduction is expected during undrained triaxial shear tests (D) Consolidated drained triaxial test results can be used to analyze the long-term stability of an embankment
9	Which of the below is / are <u>NOT</u> the assumption(s) in the 1-D consolidation theory proposed by Terzaghi? (A) Homogeneous and 100% saturation (B) m_v and k vary with respect to the effective stress (C) Drainage at both the top and bottom of the compressible layer (D) Soil grains and water are incompressible (E) Unique relationship between the volume change and effective stress
10	Which one of the tests below has a different drainage condition than the others? (A) Consolidated drained triaxial test on a fully saturated clay (B) Vane shear test on a fully saturated clay (C) Unconfined compression test on a fully saturated clay

Question 2 (10 Marks)

a) Figure 1 shows typical compaction curves for five different soils. Fill the blanks using one of the following Unified Soil Classification System symbols; CL, CH, GW, SW. **(1.5 x 4 = 6 Marks)**

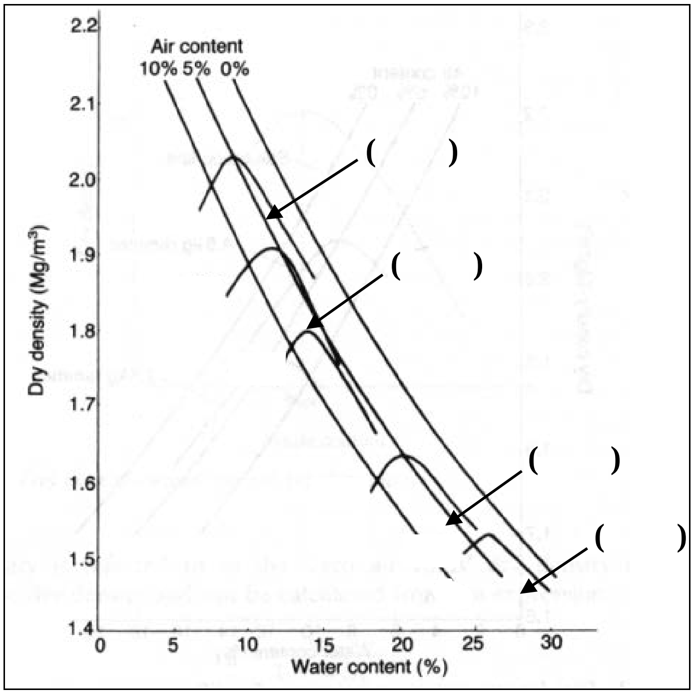


Figure 1

b) A saturated soil has a moisture content of 30% and a void ratio of 0.8. Determine the bulk unit weight (γ) and specific gravity (G_s) of soils using the phase diagram in Figure 2 (**Hint**: Assume that $V_s = 1$ m^3). **(4 Marks)**

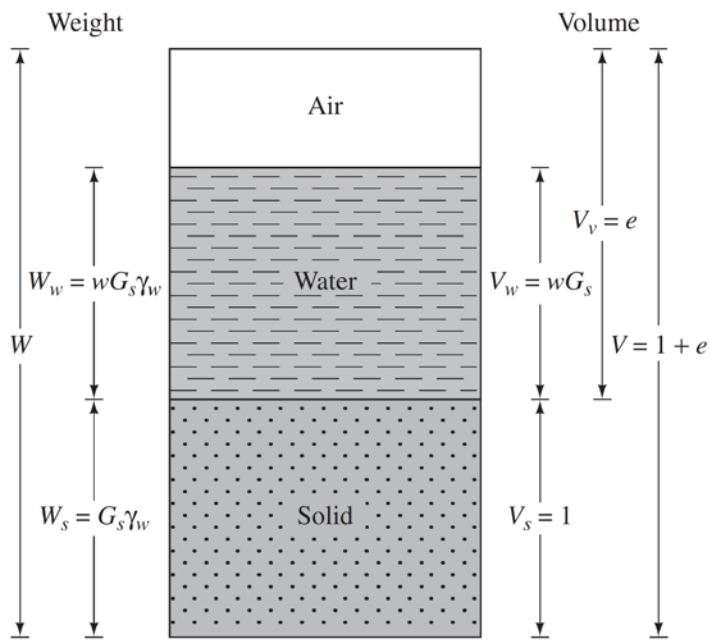


Figure 2

Answer:

Question 3 (12 Marks)

Determine the effective stress at points A and B for the section through a dam spillway as shown in Figure 3. Given that γ_{sat} = 21 kN/m^3. **(Use Table 1 in the next page for the calculations) (6 Marks for each point)**.

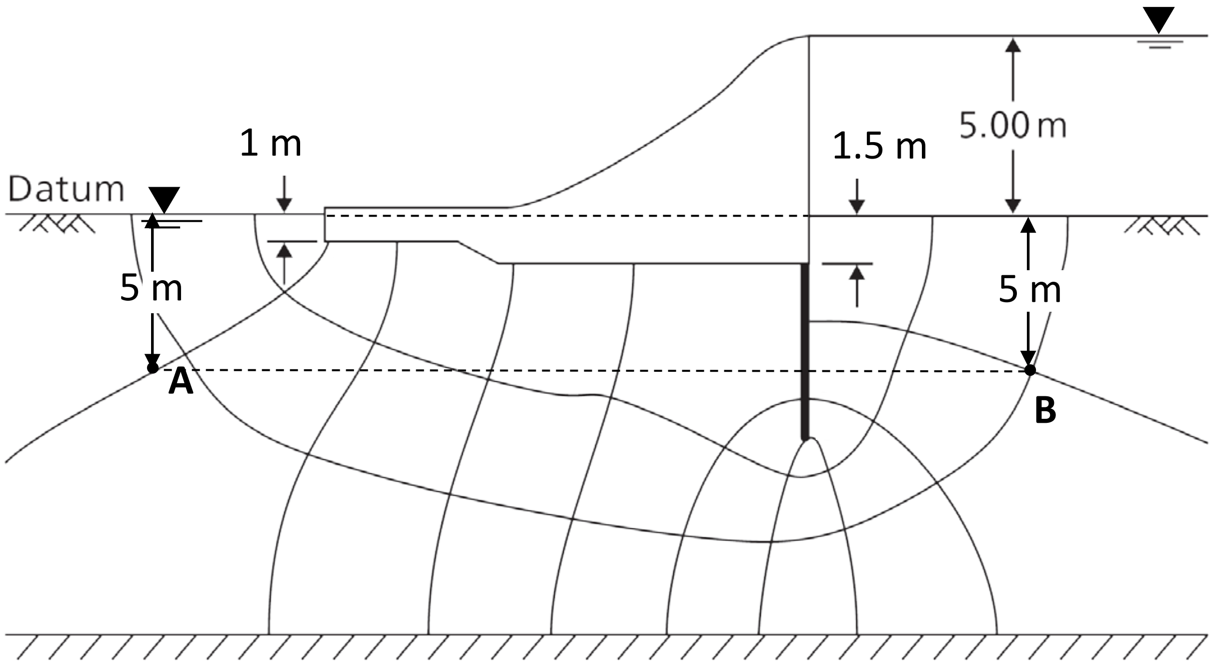


Figure 3

Answer:

Table 1

Point	Calculation
A	
B	

Question 4 (16 Marks)

See Figure 4, what will be the increase in the vertical stress ($\Delta\sigma_z$) at point A which is located in the middle of two foundations and is 2 meters deep from the ground surface? Calculation should be performed using two different methods. See below:

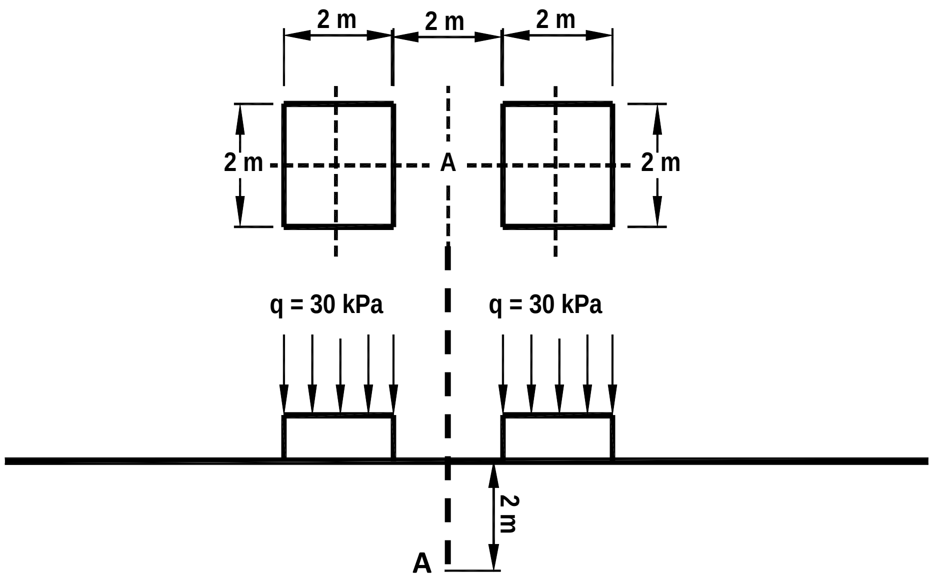
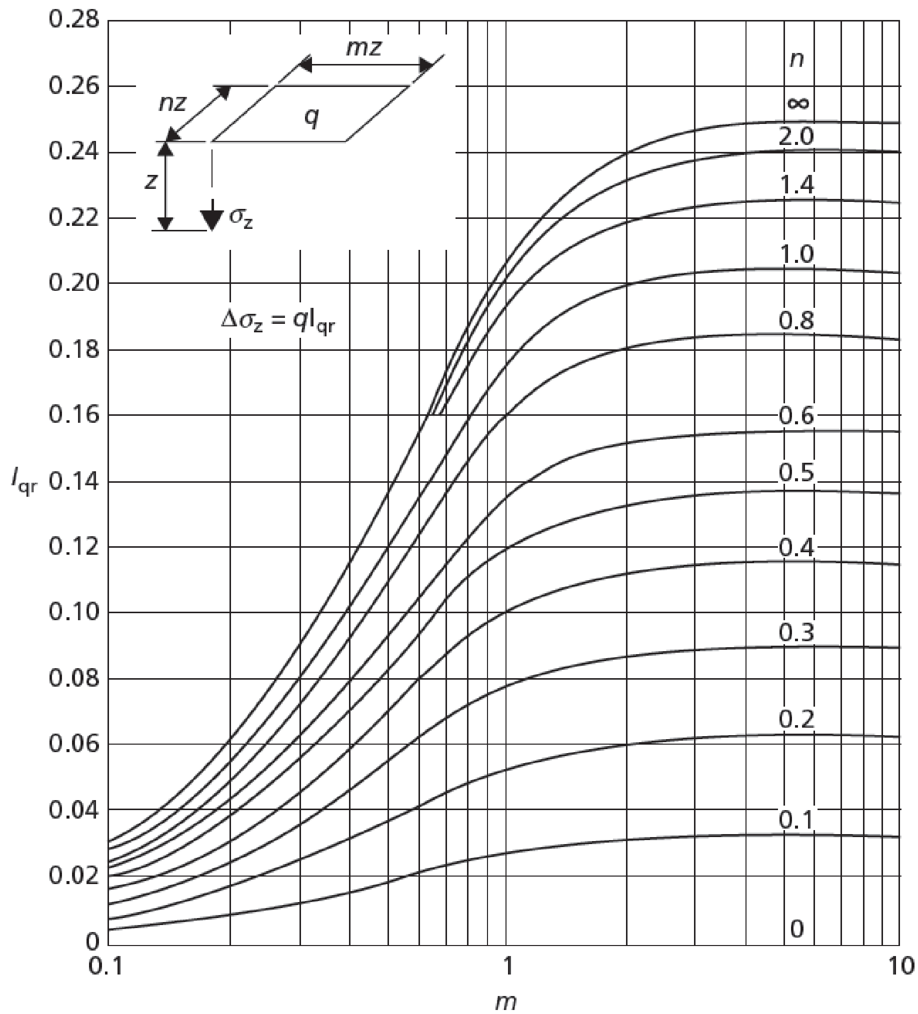


Figure 4

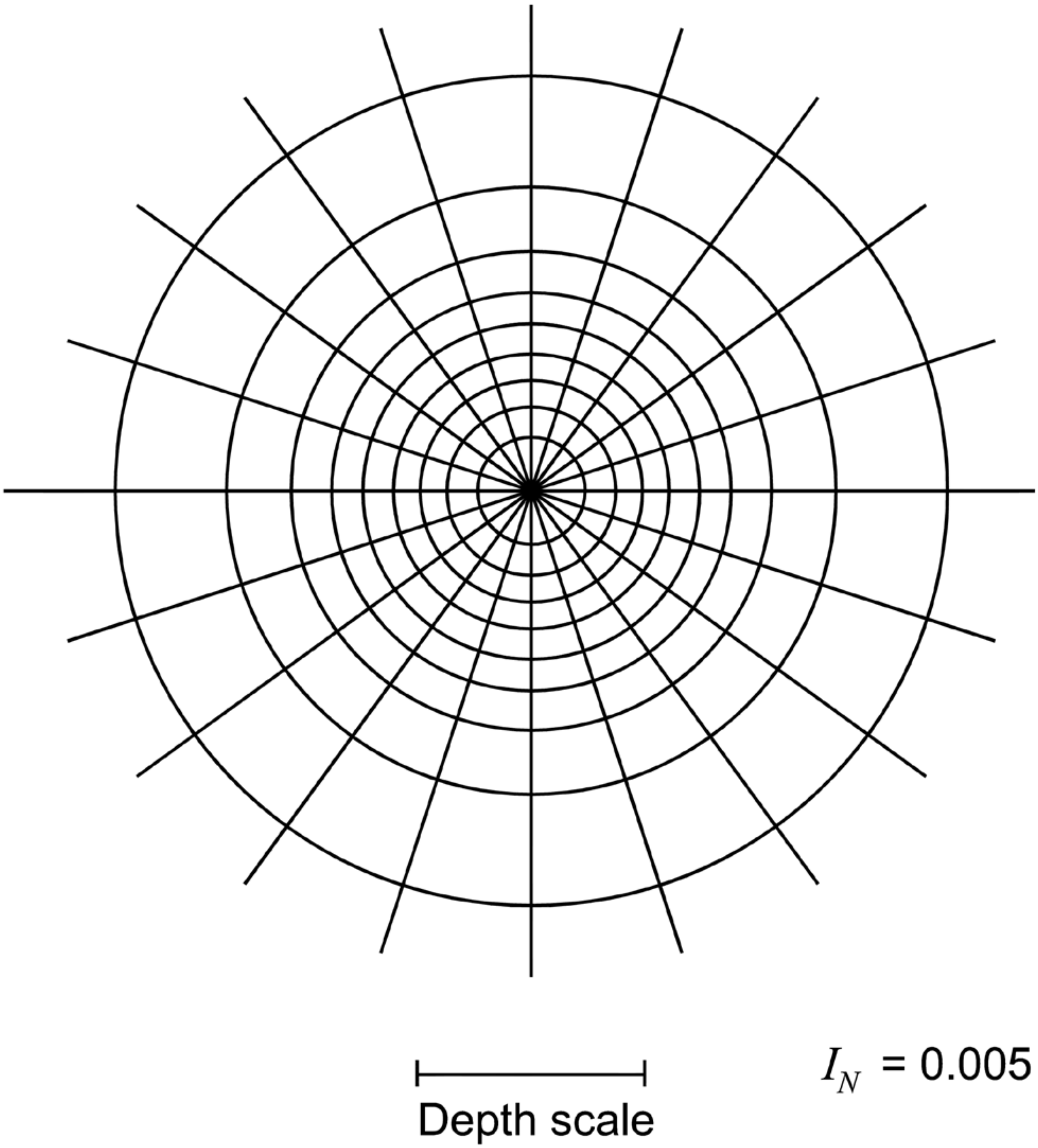
i) Use m and n chart in the next page for calculation **(8 Marks)**

Answer:


0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
I_{qr}
0.1
1
10
m
mz
nz
q
z
σ_z
$\Delta\sigma_z = qI_{qr}$
n
∞
2.0
1.4
1.0
0.8
0.6
0.5
0.4
0.3
0.2
0.1
0

m and n chart

ii) Use Newmark's chart for calculation **(8 Marks)**



Question 5 (15 Marks)

A series of oedometer tests were carried out on a specimen collected from the mid-depth of the soft clay layer (i.e. EL -2.25m) (see Figure 5). The initial thickness of the specimen and the water content at the (I have put some) of the test were 20mm and 46%, respectively. Given that G_s = 2.7 for both the sand and clay. (Make any other suitable assumptions if necessary for solving this question)

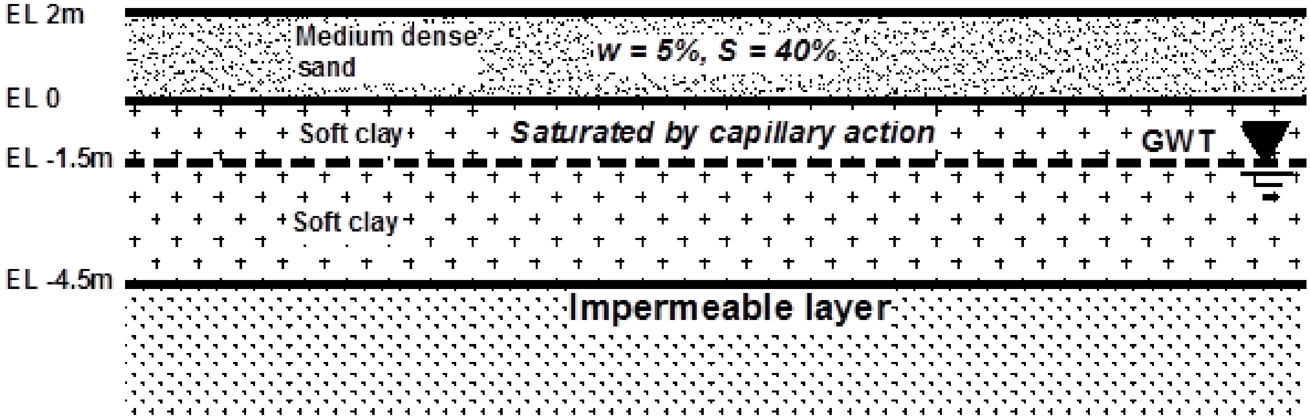


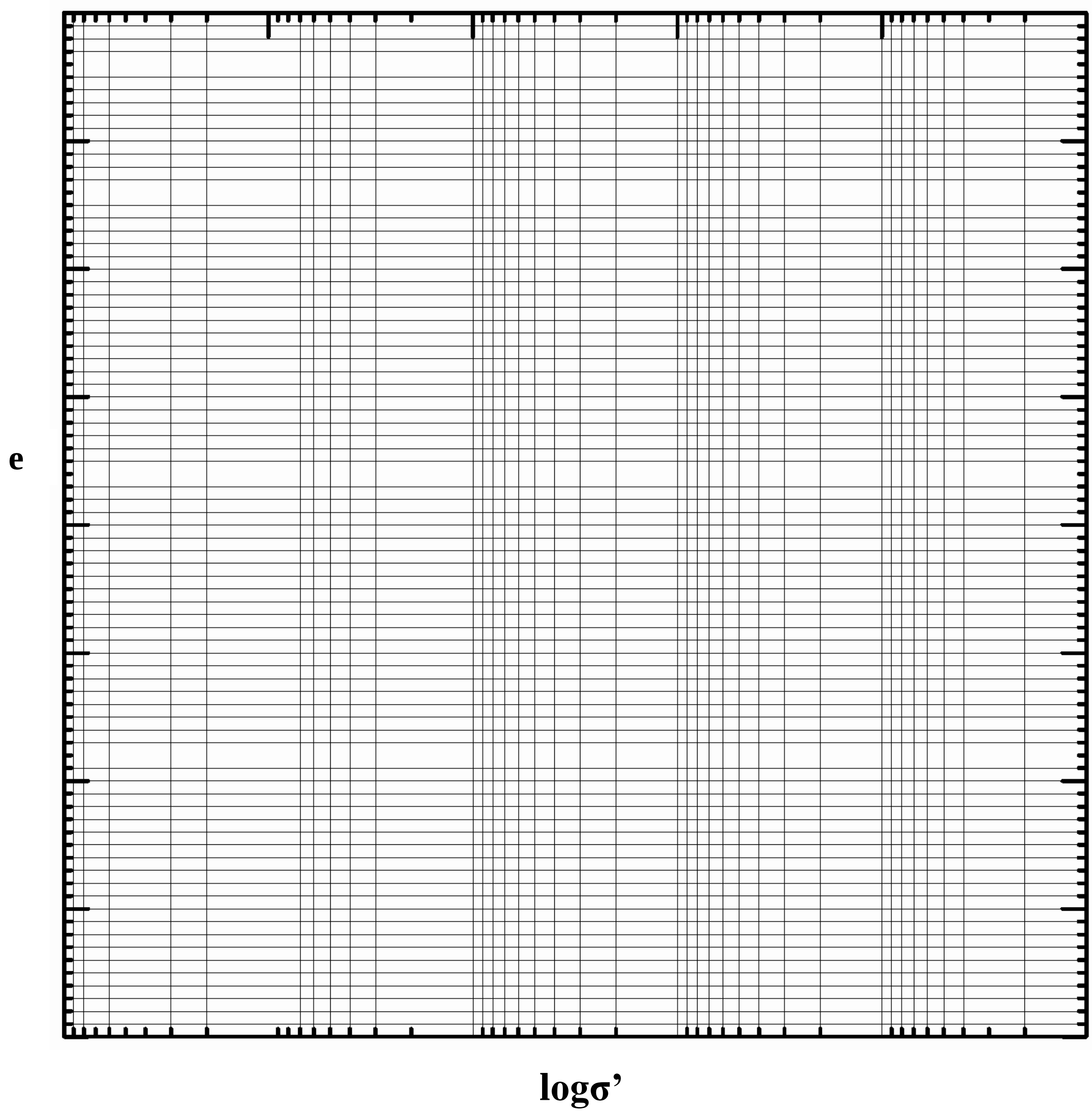
Figure 4

a) Plot e – log σ' curve and determine the compression index, C_c using the test results summarized in Table 2. **(Use the graph paper in the next page to plot the results) (10 Marks)**

Table 2. Compression readings from Oedometer tests

σ' (kPa)	0	15	30	60	120	240	480
ΔH (mm)	0	0.01	0.11	0.4	1.13	2.17	3.15

Answer:



e versus logσ’ relationship

b) Estimate the overconsolidation ratio, OCR. **(5 Marks)**

Answer:

Question 6 (12 Marks)

The results of a consolidated drained direct shear test over a normally consolidated clay are presented in Table 3:

• Dimension of the sample = B x L = 50 mm x 50 mm
• Hight of the sample = 40 mm

Table 3. Results of the CD direct shear test

Test No.	Normal Force (N)	Peak shear force reached (N)	Shear displacement at peak shear force (mm)
1	250	150	4

i) Draw the (i) Mohr circle **(5 Marks)** and (ii) the failure envelop for this soil **(5 Marks)**;
ii) Determine the effective friction angle ϕ' **(2 Marks)**

Question 7 (25 Marks)

The results in Table 4 given below were obtained at failure conditions in a series of Consolidated-Undrained triaxial tests with pore-water pressure measurements on fully saturated clay specimens.

Table 4

Specimen	Confining pressure σ_3 (kPa)	Deviator stress $(\sigma_1 - \sigma_3)$ kPa	Pore-water stress u (kPa)
A	150	103	82
B	300	202	169
C	450	305	252

i) Determine the effective shear strength parameters for the tested soil (i.e., c' and ϕ'). **(10 Marks)**

Answer:

ii) Calculate the Skempton's A_f value for this clay. Is the clay normally consolidated or over consolidated? Give reasons. Use Figure 6 for this question **(5 Marks)**

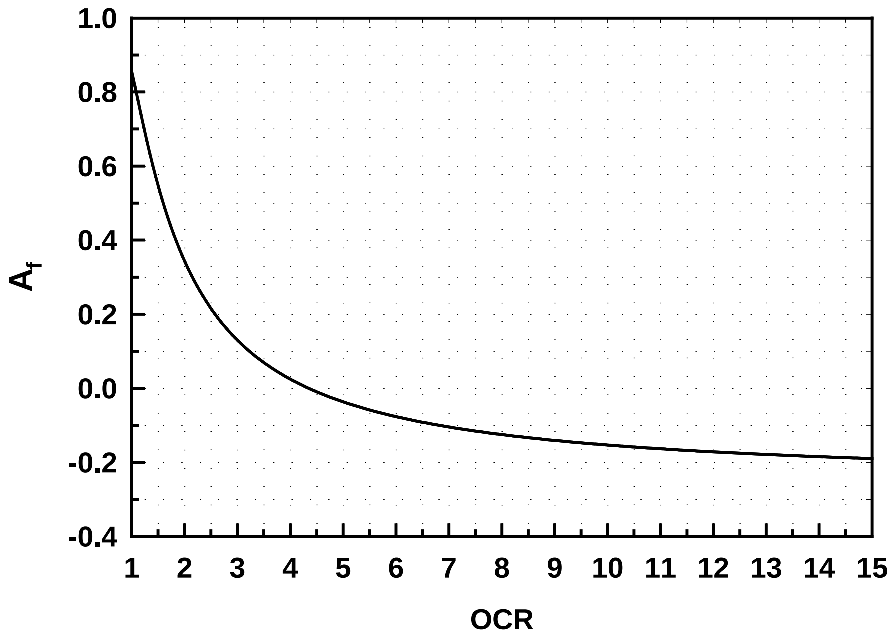


Figure 6. OCR versus A_f relationship

Answer:

b) In a series of Unconsolidated-Undrained triaxial tests on specimens of fully saturated clay, the following results (Table 5) were obtained at failure. Determine the shear strength parameters, c_u and ϕ_u. **(10 Marks)**

Table 5

Confining pressure, σ_3 (kPa)	200	400	600
Deviator stress, σ_d (kPa)	222	218	220

<u>Answer:</u>

Formulae Sheet

Phase relationships:

Unit weight of soil:

$$\gamma = \frac{W}{V} = \frac{(V_w + V_s G_S)\gamma_w}{1+e} = \frac{(Se + G_S)}{1+e}\gamma_w$$

Submerged unit weight: $\gamma_{sub} = \frac{(G_s - 1)}{1+e}\gamma_w$

Dry unit weight:

$$\gamma_d = \frac{W_s}{V} = \frac{G_s}{1+e}\gamma_w = \frac{\gamma}{1+w}$$

$$Se = wG_s$$

$$G_s = \gamma_s / \gamma_w$$

$$\gamma_s = W_s / V_s$$

$$w = W_w / W_s$$

$$e = V_v / V_s$$

$$S = V_w / V_v$$

Seepage:

Total head (h) = Pressure head (h_p)+ Elevation (z)

$$\Delta h = \frac{h_w}{N_d}$$

Seepage in a flow net:

$$q = k \cdot h_w \cdot \frac{N_f}{N_d}(width)$$

Total head: $h = \frac{n_d}{N_d} h_w$

Pore-water pressure (kPa):

$$u_w = \gamma_w (h - z)$$

Effective stress: $\sigma' = \sigma - u_w$

Stress Distribution Theory

m and n coefficient:

$$\Delta\sigma_z = q[I_1 + I_2 + I_3 + ...]$$

$$I = f(m,n)$$

$$m = \frac{L}{z}$$

$$n = \frac{B}{z}$$

Newmark's chart:

$$\Delta\sigma_z = q \cdot I_N \cdot N$$

Shear strength:

$$\tau_f = c' + (\sigma - u_w)\tan\phi'$$

$$\sigma_1' = \sigma_3' \tan^2\left(45° + \frac{\phi'}{2}\right) + 2c'\tan\left(45° + \frac{\phi'}{2}\right)$$

$$\tau_f = \frac{1}{2}(\sigma_1' - \sigma_3')\sin 2\theta$$

$$\sigma_f = \frac{1}{2}(\sigma_1' + \sigma_3') + \frac{1}{2}(\sigma_1' - \sigma_3')\cos 2\theta$$

$$B = \frac{\Delta u_{(Confining)}}{\Delta\sigma_3}$$

$$A = \frac{\Delta u_{(Deviator)}}{(\Delta\sigma_1 - \Delta\sigma_3)}$$

Consolidation:

Compression index

$$C_c = \frac{e_o - e_1}{\log\left(\frac{\sigma_1'}{\sigma_0'}\right)} \quad (\sigma_1' > \sigma_0')$$

$$C_c = 0.009[LL(\%) - 10] \text{ for undisturbed clay}$$

$$C_c = 0.007[LL(\%) - 10] \text{ for disturbed clay}$$

$$OCR = \frac{\sigma_p'}{\sigma_0'}$$

Swelling index, C_s *: Slope of swelling path*

$$m_v = \frac{\Delta e}{1+e_0}\left(\frac{1}{\Delta\sigma'}\right) = \frac{1}{1+e_o}\left(\frac{e_o - e_1}{\sigma_1' - \sigma_0'}\right)$$

$$s_c = \int_0^H \frac{e_o - e_1}{1+e_o} dz = \frac{\Delta e}{1+e_o} H$$

$$s_c = \int_0^H m_v \Delta\sigma' dz = m_v \Delta\sigma' H$$

$$s_c = \frac{C_c}{1+e_o} H \log\left(\frac{\sigma_0' + \Delta\sigma}{\sigma_0'}\right)$$

$$s_c = \frac{C_s}{1+e_o} H \log\left(\frac{\sigma_p'}{\sigma_0'}\right) + \frac{C_c}{1+e_o} H \log\left(\frac{\sigma_p' + \Delta\sigma}{\sigma_p'}\right)$$

$$T_v = \frac{c_v t}{H_{dr}^2}$$

$$U = \frac{e_1 - e}{e_1 - e_2}$$

$$U = \frac{u_i - u}{u_i} = 1 - \frac{u}{u_i}$$

$$U = \frac{\delta}{\delta_c}$$

for $U < 60\%$,

$$T_v = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2$$

for $U \geq 60\%$,

$$T_v = 1.781 - 0.933\log(100 - U\%)$$