# Addis Ababa University
# Addis Ababa Institute of Technology
# School of Civil and Environmental Engineering

## Fundamentals of Geotechnical Engineering III (CEng3143)
## Mid-term Examination Paper Set

| | |
|---|---|
| Name | |
| ID No. | |
| Signature | |
| Section | |
| Exam Date: | 27.05.2019 |

Instruction:

1) This examination is closed book and constitutes 40% of your final grade.
2) The time allowed for this exam is 3 hours.
3) Please read the questions carefully and make sure you understand the facts before you begin answering. Write as legibly and concisely as possible.
4) Use the provided space properly to present you answer.

| Question # | Weight [marks] | Score [marks] |
|---|---|---|
| 1 | 60 | |
| [redacted] | [redacted] | [redacted] |
| 2 | 40 | |
| | | |

Examination paper set checked by: Henok Fikre (Dr.-Ing.)

Signature:

……………………………………………………

# QUESTION 1: On Soil Compressibility & Settlement Analysis [60%]

## 1.1 Theoretical Background

1.1.1 List out the components of settlement and their corresponding causes. (3 marks)

| Settlement component | Corresponding cause |
|---|---|
| | |
| | |
| | |

1.1.2 With regard to the spring model put forward to simulate one-dimensional consolidation, draw a principal sketch and highlight the basic components and what they represent in actual soil.

Also explain each of the experiment's steps and results making parallel reference with that of actual soil consolidation phenomena.

Plot a rough sketch of stress vs time graph to complement your explanation. (12 marks)

| Principal sketch | Components |
|---|---|
| | |
| | |
| | |

| Spring model | Actual soil |
|---|---|
| | |
| | |
| | |
| | |

1.1.3 Lay out the assumptions, indicate their implications and derive the Terzaghi-Froelich 1D consolidation equation for time rate of settlement using an element of the soil sample of thickness $dz$ and cross-sectional area $dA=dx\ dy$. (10 marks)

| Assumption | Implication |
|---|---|
| ● .<br>● .<br>● . | |
| | |
| | |
| ● . | |
| ● . | |
| ● . | |

### 1.2 Oedometer Testing & Interpretation

A specimen of a fine-grained soil, 75 mm in diameter and 20 mm thick, was tested in an oedometer in a laboratory. The initial water content was 62% and Gs=2.7. The vertical stresses were applied incrementally—each increment remaining on the specimen until the porewater pressure change was negligible. The cumulative settlement values at the end of each loading step are as follows:

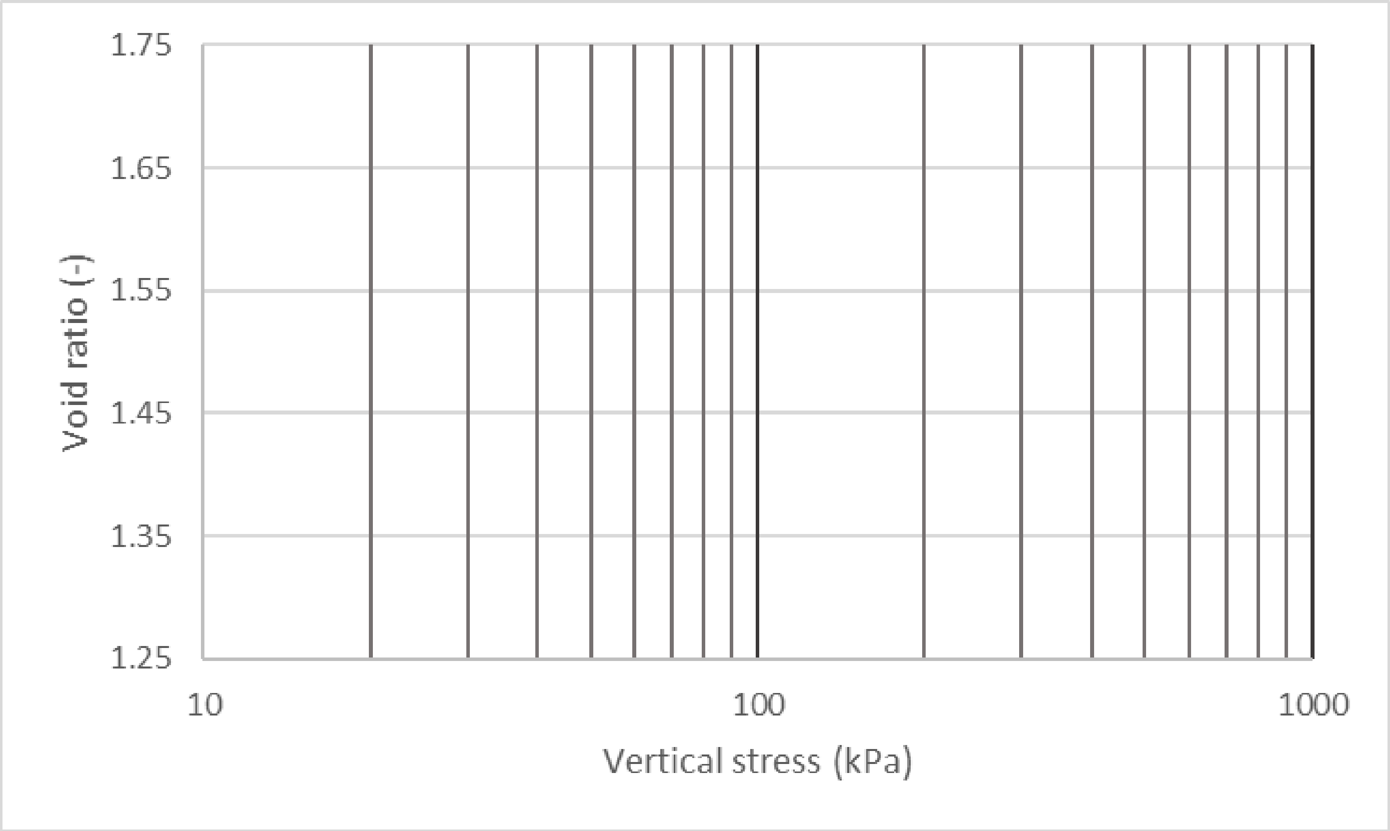
| Vertical stress (kPa) | 15 | 30 | 60 | 120 | 240 | 480 |
|---|---|---|---|---|---|---|
| Settlement (mm) | 0.10 | 0.11 | 0.21 | 1.13 | 2.17 | 3.15 |

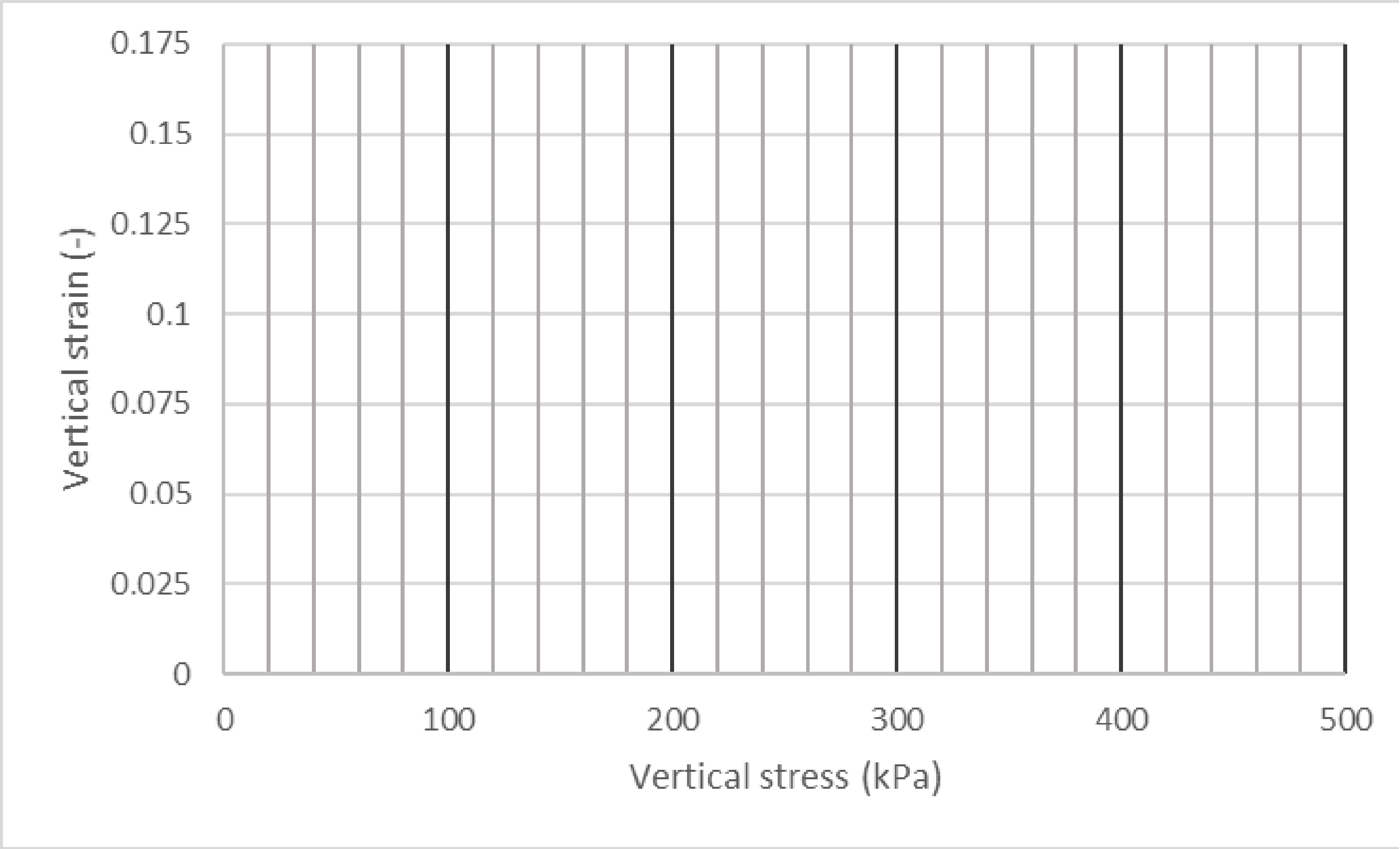
The time–settlement data when the vertical stress was 200 kPa are:

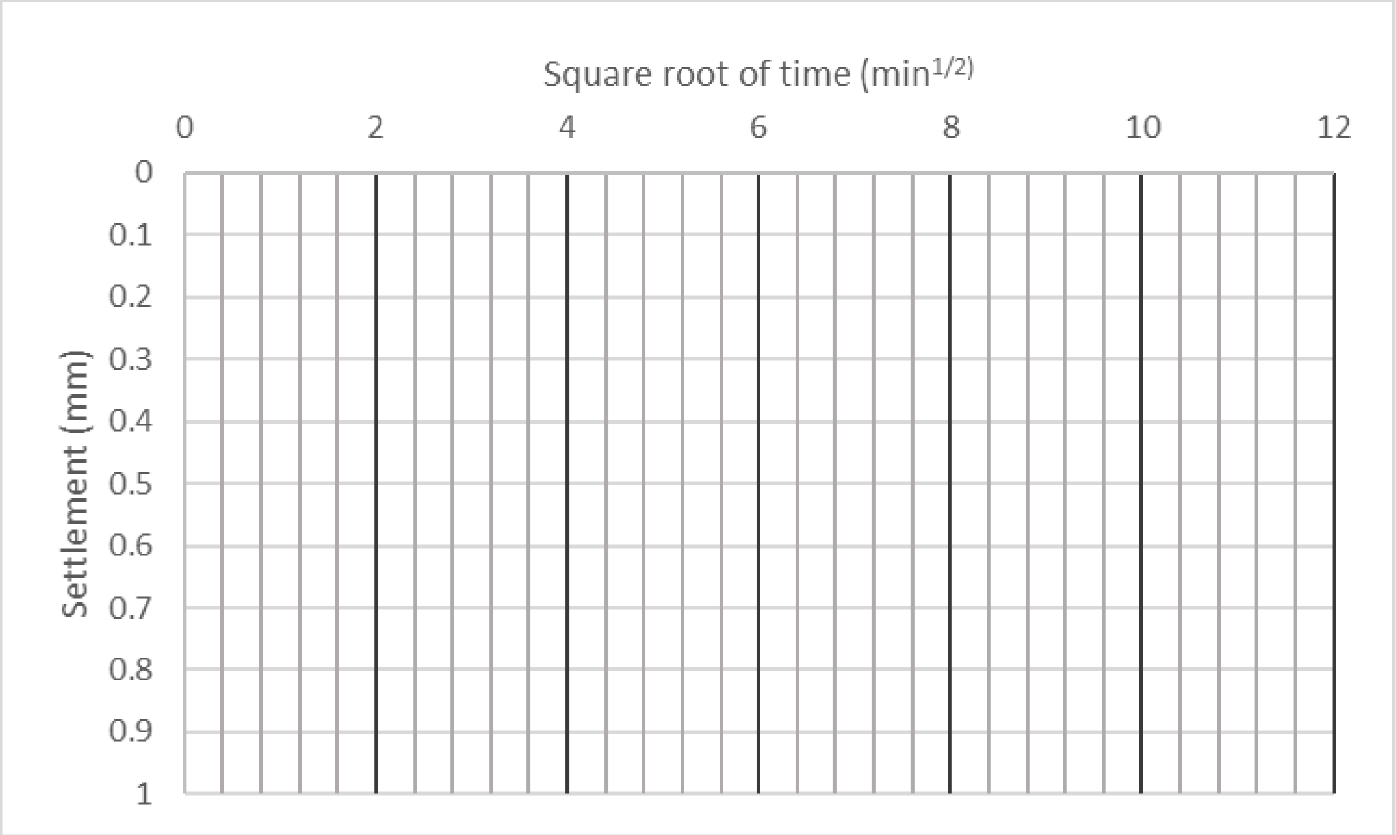
| Time (min) | 0 | 0.25 | 1 | 4 | 9 | 16 | 36 | 64 | 100 |
|---|---|---|---|---|---|---|---|---|---|
| Settlement (mm) | 0 | 0.22 | 0.42 | 0.6 | 0.71 | 0.79 | 0.86 | 0.91 | 0.93 |

1.2.1 Generate the appropriate graphs required to determine different parameters of settlement computation. (15 marks)

| Vertical stress (kPa) | 15 | 30 | 60 | 120 | 240 | 480 |
|---|---|---|---|---|---|---|
| Void ratio ( - ) | | | | | | |
| Vertical strain ( - ) | | | | | | |




Vertical strain (-)
0.175
0.15
0.125
0.1
0.075
0.05
0.025
0
0
100
200
300
400
500
Vertical stress (kPa)

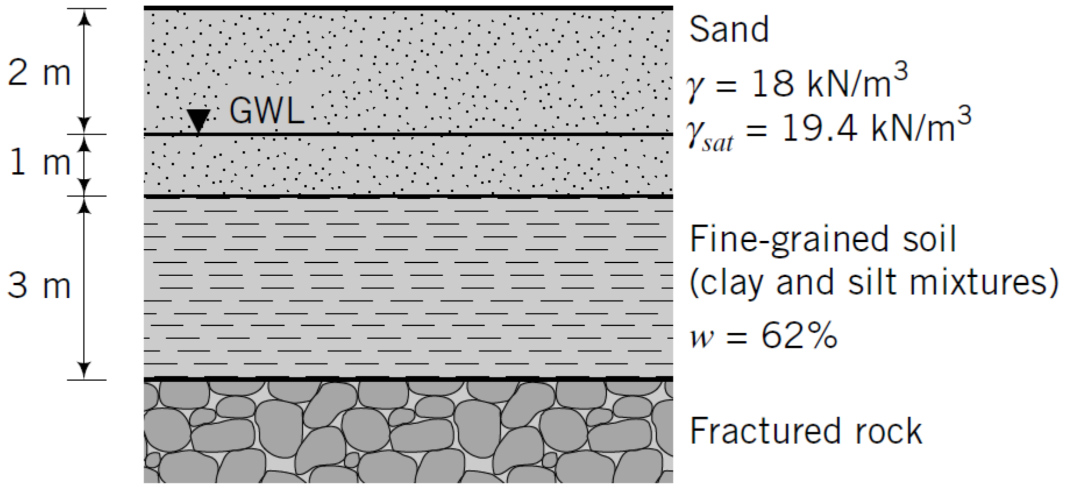

Square root of time (min^1/2)
0
2
4
6
8
10
12
Settlement (mm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

1.2.2 Determine the parameters required for calculation of elastic compression, primary consolidation and secondary consolidation (secondary compression). (10 marks)

| | |
|---|---|
| Elastic modulus | |
| Poisson's ratio | |
| Pre-consolidation pressure | |
| Over-consolidation ratio | |
| Coefficient of consolidation | |
| Compression index | |
| Modulus of volume Compressibility | |
| Recompression index | |
| Modulus of volume recompressibility | |
| Secondary compression index | |

### 1.3 Settlement Calculation

A foundation for circular, oil tank is proposed for a site with a soil profile as shown below.



The tank, when full, will impose vertical stresses of 90 kPa and 75 kPa at the top and bottom of the fine-grained soil layer, respectively. You may assume that the vertical stress is linearly distributed in this layer.

Use the parameters you determined in previous question (question 1.2) to perform the following tasks.

1.3.1 Calculate the immediate (elastic) settlement, primary consolidation, secondary compression (consolidation) and total settlement in the middle of the clay layer under the center of the footing. (6 marks)

Elastic compression

Primary Consolidation

Secondary Compression

Total settlement

1.3.2 Determine the time required for 90% consolidation to take place in the field.

(4 marks)

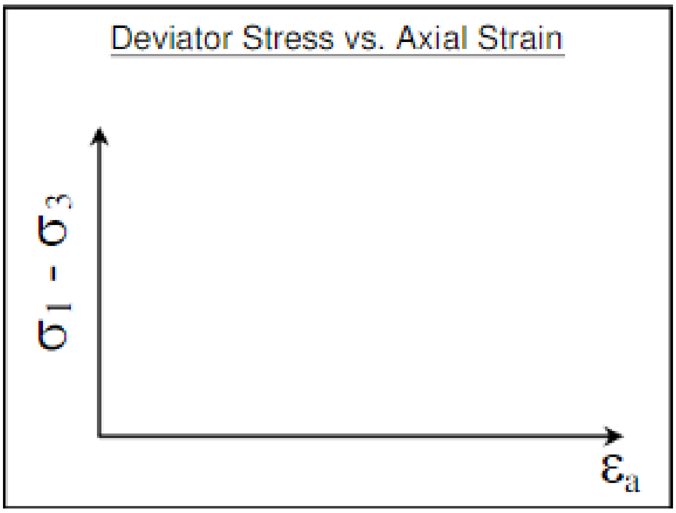
## QUESTION 2: On Shear Strength of Soils [40%]

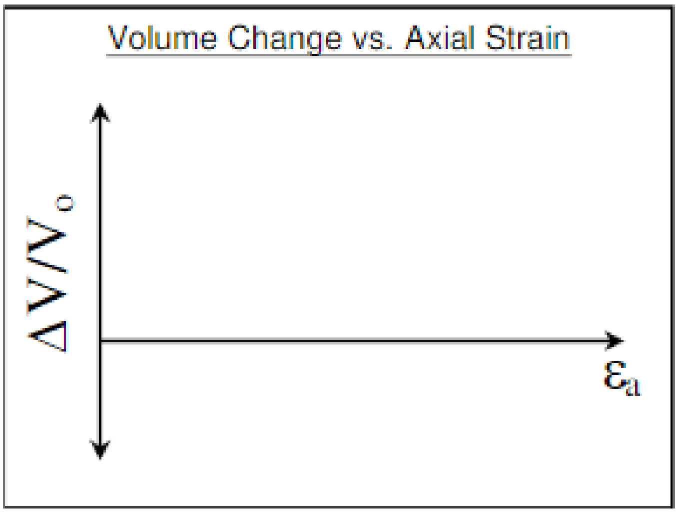
### 2.1 Theoretical Background

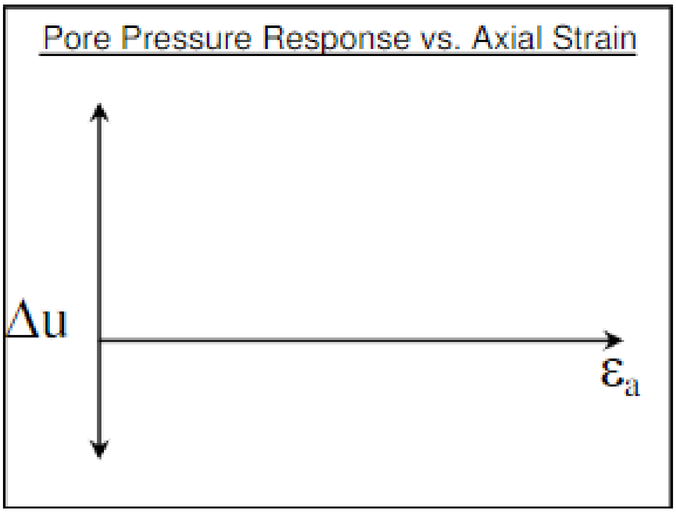
2.1.1 Mention three factors that control the strength of a mass of sand? Briefly outline the influence of each factor. (3 marks)

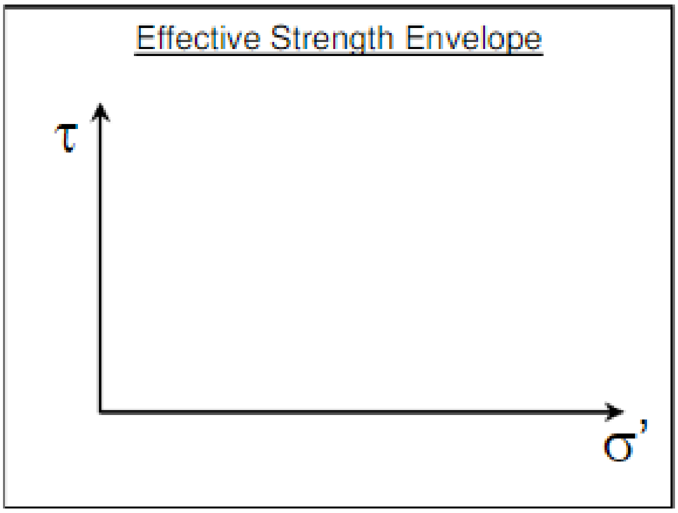
| | |
|---|---|
| | |
| | |
| | |

2.1.2 Indicate the behavior of normally consolidated and over-consolidated clays by showing on the following typical diagrams. (4 marks)









2.1.3 Compare and contrast Tresca and Mohr-Coulomb failure criteria (by means of equations and diagrams if need be). (6 marks)

| Tresca Failure Criterion | Mohr-Coulomb Failure Criterion |
|---|---|
| | |
| | |
| | |

2.1.4 What do undrained and drained loading conditions mean? How does each arise in a soil mass? How do we simulate these in triaxial tests? (6 marks)

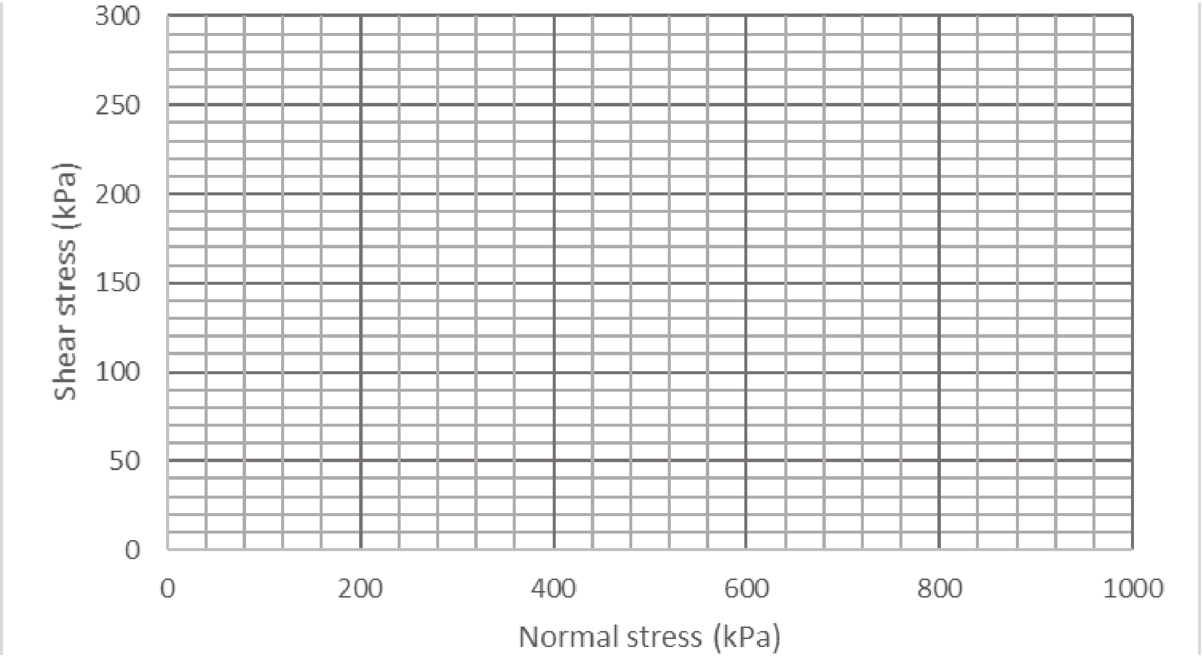
| Undrained loading condition | Drained loading condition |
|---|---|
| | |
| | |
| | |
| | |
| | |

### 2.2 Triaxial Testing and Interpretation

The failure stresses and excess porewater pressures for three samples of a loose sand in CU tests are given below.

| Sample no. | $(\sigma_3)_f$ $(kPa)$ | $(\sigma_1 - \sigma_3)_f$ $(kPa)$ | $(\Delta u)_f$ $(kPa)$ | $(\sigma_1)_f$ $(kPa)$ | $(\sigma_1)_f{}'$ $(kPa)$ | $(\sigma_3)_f{}'$ $(kPa)$ | $\phi = \sin^{-1}\frac{(\sigma_1)'_f - (\sigma_3)_f{}'}{(\sigma_1)'_f + (\sigma_3)_f{}'}$ |
|---|---|---|---|---|---|---|---|
| 1 | 210 | 123 | 112 | | | | |
| 2 | 360 | 252 | 162 | | | | |
| 3 | 685 | 448 | 323 | | | | |

2.2.1 Perform the necessary calculation and plot Mohr's circle of effective stress from the data. Also determine the friction angle for each test. (12 marks)



2.2.3 Determine the inclination of (a) the failure plane and (b) the plane of maximum shear stress to the horizontal plane for Test 2. (9 marks)

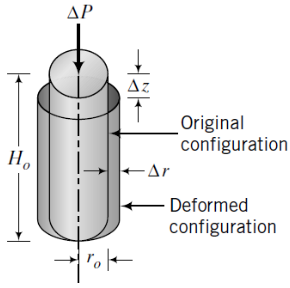
# Formula sheet

$$\Delta\sigma_z = \frac{\Delta P}{A}$$

$$\Delta\varepsilon_z = \frac{\Delta z}{H_o}$$

$$\Delta\varepsilon_r = \frac{\Delta r}{r_o}$$

$$v = \frac{-\Delta\varepsilon_r}{\Delta\varepsilon_z}$$



Constrained elastic modulus

$$E_c = \frac{E'(1+v')}{(1+v')(1-2v')}$$

$$E'_c = \frac{1}{m_{vr}}$$

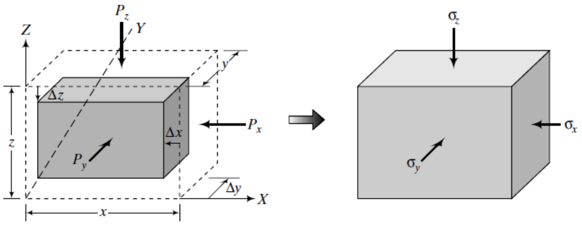
Undrained elastic modulus

$$E_u = \frac{1.5E'}{(1+v')}$$

$$\sigma_z = \frac{P_z}{xy},\ \sigma_x = \frac{P_x}{yz},\ \sigma_y = \frac{P_y}{xz}$$

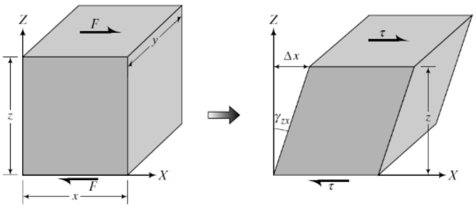
$$\varepsilon_z = \frac{\Delta z}{z},\ \varepsilon_x = \frac{\Delta x}{x},\ \varepsilon_y = \frac{\Delta y}{y}$$

$$\varepsilon_p = \varepsilon_x + \varepsilon_y + \varepsilon_z$$



$$\tau = \frac{F}{xy}$$

$$\gamma_{zx} = \tan^{-1}\frac{\Delta x}{z}$$



For rigid foundation

$$S_i = \frac{pB(1-v^2)}{E} I_p$$

| L/B | Circle | 1 | 2 | 5 | 10 |
|---|---|---|---|---|---|
| $I_p$ | 0.73 | 0.82 | 1.00 | 1.22 | 1.26 |

NC Clay

$$S_c = C_c \frac{H_o}{1+e_o} log \frac{\sigma'_{zo} + \Delta\sigma_z}{\sigma'_{zo}}$$

OC Clay

If $\sigma'_{zo} + \Delta\sigma_z < \sigma'_{zc}$ ,

$$S_c = C_r \frac{H_o}{1+e_o} log \frac{\sigma'_{zo} + \Delta\sigma_z}{\sigma'_{zo}}$$

If $\sigma'_{zo} + \Delta\sigma_z > \sigma'_{zc}$ ,

$$S_c = \frac{H_o}{1+e_o}\left(C_r\, log \frac{\sigma'_{zc}}{\sigma'_{zo}} + C_c\, log \frac{\sigma'_{zo} + \Delta\sigma_z}{\sigma'_{zc}}\right)$$

$$S_c = H_o m_v \Delta\sigma_z$$

$$C_c = -\frac{e_2 - e_1}{log \frac{(\sigma'_z)_2}{(\sigma'_z)_1}}$$

$$m_v = -\frac{(\varepsilon_z)_2 - (\varepsilon_z)_1}{(\sigma'_z)_2 - (\sigma'_z)_1}$$

$$C_r = -\frac{e_2 - e_1}{log \frac{(\sigma'_z)_2}{(\sigma'_z)_1}}$$

$$m_{vr} = -\frac{(\varepsilon_z)_2 - (\varepsilon_z)_1}{(\sigma'_z)_2 - (\sigma'_z)_1}$$

$$S_s = \frac{H_o}{1+e_o} C_\alpha \log\left(\frac{t}{t_p}\right)$$

$$C_\alpha = -\frac{(e_t - e_p)}{log(t/t_p)} = \frac{|\Delta e|}{log(t/t_p)};\ t > t_p$$

$$C_\alpha/C_c = 0.03\ to\ 0.08$$

$$T_v = \frac{\pi}{4}\left(\frac{U}{100}\right)^2\ for\ U < 60\%$$

$$T_v = 1.781 - 0.933\log(100 - U)\ for\ U \geq 60\%$$

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

$$C_v = \frac{k_z}{m_v \gamma_w}$$