Addis Ababa University
Addis Ababa Institute of Technology
School of Civil & Environmental Engineering

Fundamentals of Geotechnical Engineering III (CEng3143)
Test 1 Solution Set

Name	
ID No.	
Signature	
Section	
Exam Date:	04.11.2019

Instruction:

1) This test is closed book and constitutes 10% of your final grade.
2) The time allowed for this test is 1 hour.
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.
5) For all problems, assume Gs=2.7 unless otherwise stated.

Question #	Weight [marks]	Score [marks]
1	20	
2	40	
3	40	

Examination paper set checked by: Asrat Worku (Dr.-Ing.)

Signature:

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QUESTION 1: Theoretical Background [20%]

1.1 What is the difference between consolidation and compaction?

Both processes result in reduction in volume, but consolidation involves sustained loading as opposed to the instant load application in compaction. According to Karl von Terzaghi, consolidation is "any process which involves a decrease in water content of saturated soil without replacement of water by air" In simple words "Compaction is without saturation of soil whereas consolidation can only be achieved by saturation of soil" *(4 marks)*

1.2 A clay soil is 80% saturated. Would Terzaghi's consolidation theory be applicable to this soil? Justify your answer.

The equation is often presented simply as an almost self-evident expression of the deformation of saturated soils, consisting of incompressible solid particles and an incompressible fluid, in which the only possibility for a volume change is the expulsion of pore fluid. Degree of saturation of 80% implies that there is a significant portion of the void space occupied by air which leads to compression of soil through expulsion of air upon application of load – a mechanism outside the realm of consolidation. *(4 marks)*

1.3 In the development one-dimensional consolidation theory, small strains are assumed (i.e. the strains, change in length divided by original length in a given direction, are infinitesimal ≈ < 0.001% for practical applications). What is the implication of this assumption?

The assumption of one-dimensional consolidation leads to zero lateral strains, i.e. $\varepsilon_x = \varepsilon_y = 0$*.*

(4 marks)

1.4 The one-dimensional consolidation equation allows us to predict the changes in excess porewater pressure at various depths within the soil with time. What is excess pore pressure (in the context of oedometer testing) and why do we need to know it for the calculation of consolidation in soils?

The vertical load applied during oedometer testing causes an increase in pore water pressure within the sample that is greater than the static pore water pressure (u_s*) due to the water bath. The component of pore water pressure above the static pore water pressure is known as excess pore water pressure (*u_e*). Thus, excess pore water pressure is the pressure due to the applied load. Excess pore water pressure causes water to flow out of the sample towards the drainage boundaries (upper and lower porous stones). If the sample is considered to be 100 percent saturated and the soil grains are incompressible, settlement will occur only when water flows out of the sample voids and the soil particles rearrange to create a lower void ratio (tighter packing).*

We need to know the excess porewater pressure at a desired time because we want to determine the vertical effective stress to calculate the primary consolidation settlement.

(4 marks)

1.5 How much mass do you have to mount onto the consolidometer at AAiT geotechnical engineering laboratory if you want to apply a pressure of 100kpa on the specimen?

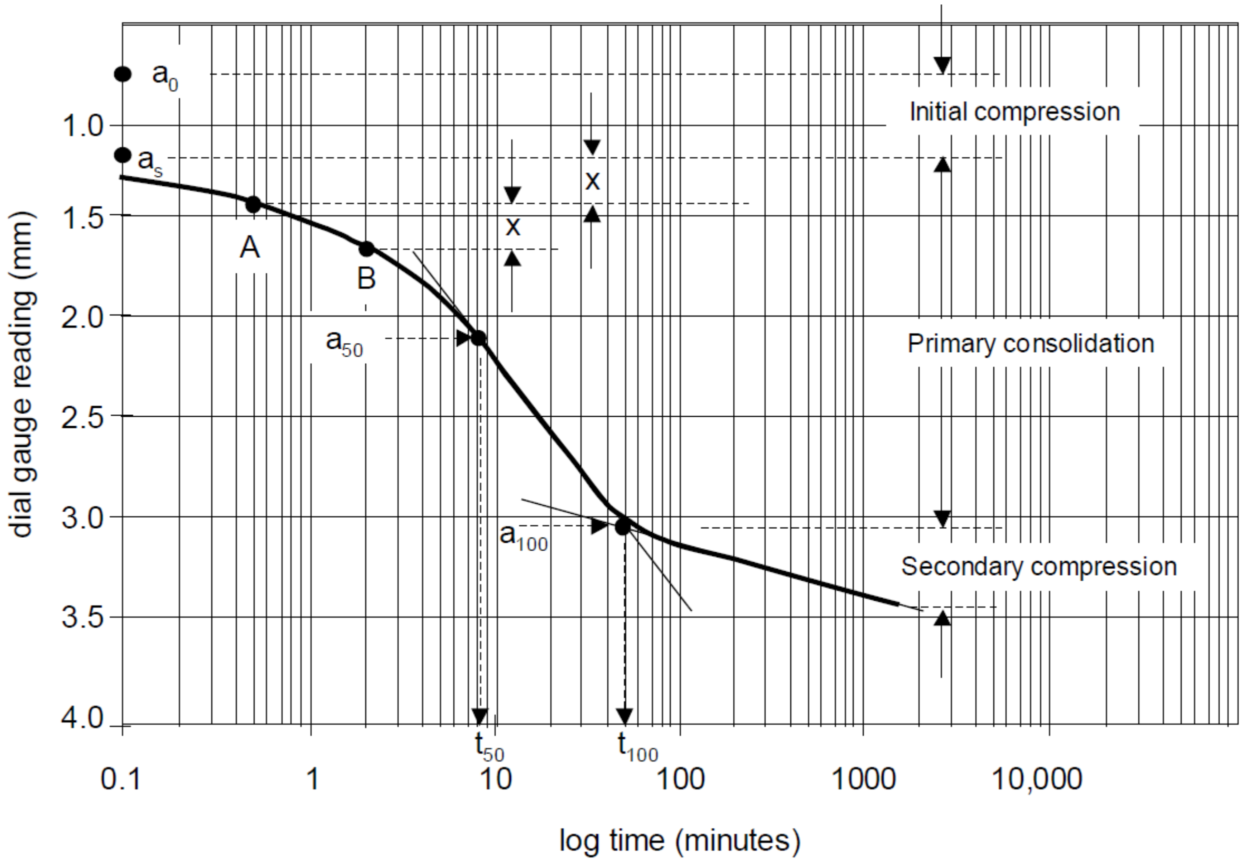
The AAiT lab utilizes an oedometer cell of 50 mm diameter and load ratio of 10:1.

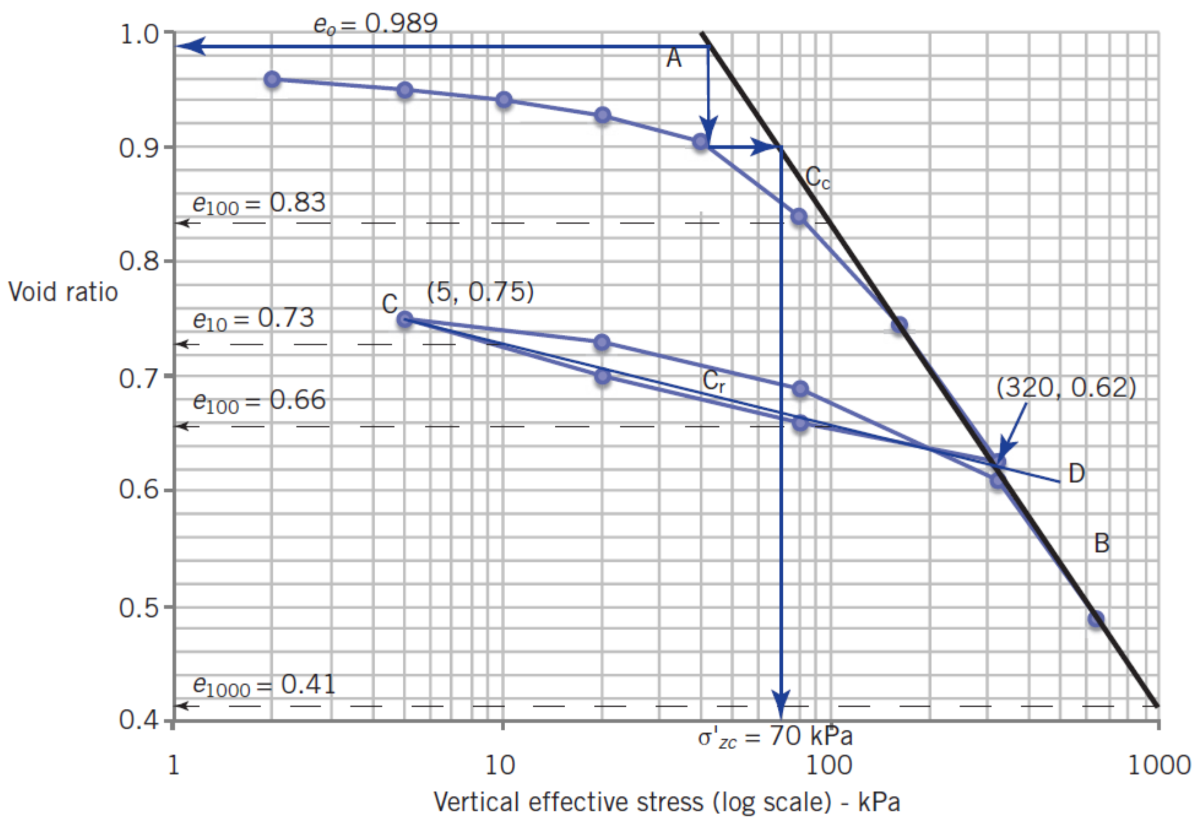
$$m_{actual} = \frac{1}{10} \times 100 \frac{N}{mm^2} \times \frac{\pi * 50mm^2}{4} \approx 2\ kgs$$

(4 marks)

QUESTION 2: Oedometer Testing & Interpretation [40%]

The results of a one-dimensional consolidation test on a clay taken from a depth of 4m are shown in Figure 2.1. The initial overburden (effective) pressure was 40kPa. The water content after the consolidation test was completed was 18.9%. The specific gravity of the solids was 2.65. The initial sample thickness was 20 mm. and the final thickness was 15.08mm.





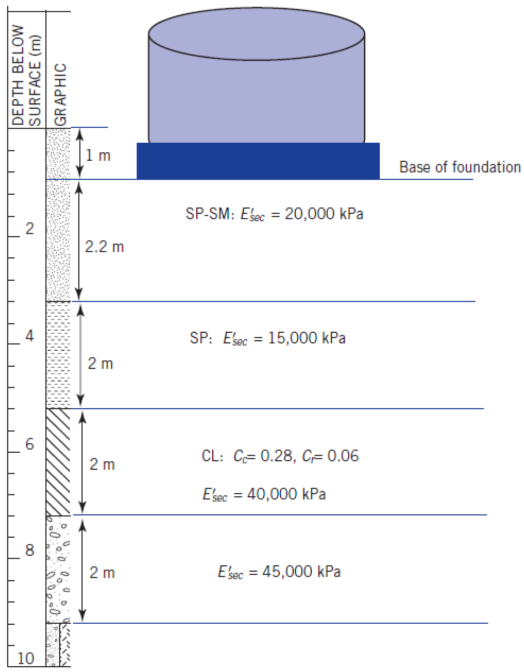
Determine the parameters required for calculation of elastic compression, primary consolidation and secondary consolidation (secondary compression).

Initial void ratio, e_o	$(\Delta H)_{fin} = H_o - H_{fin} = 20 - 15.08 = 4.92\ mm$ $e_{fin} = \omega G_s = 0.189 \times 2.65 = 0.5$ $e_o = \frac{e_{fin} + [(\Delta H)_{fin}/H_o]}{1 - [(\Delta H)_{fin}/H_o]} = \frac{0.5 + (4.92/20)}{1 - (4.92/20)} = 0.989$ *(4 marks)*
Compression index, C_c	*Cc is the slope AB* *Void ratio at 100 kPa on AB = e100 = 0.83* *Void ratio at 1000 kPa on AB = e1000 = 0.41* *(4 marks)*
Recompression index, C_r	*Cr is the slope of CD* *Void ratio at 10 kPa on CD = e_{10} = 0.73* *Void ratio at 100 kPa on CD= e_{100} = 0.66* *Cr = 0.73–0.66 = 0.07* *(4 marks)*
Pre-consolidation pressure, P_c	*The past maximum vertical effective stress is P_c = 70 kPa.* *(4 marks)*
Overconsolidation ratio, OCR	$OCR = \frac{P_c}{P_o} = \frac{70}{40} = 1.75 \approx 2$ *(4 marks)*
Coefficient of consolidation, C_v (in cm^2/sec) (Hint: use the Log Time Method)	$C_v = \frac{T_{50} H_{dr}^2}{t_{50}} = \frac{0.197 \times (0.1 \times 10)^2}{(8.25 \times 60)} = 3.98 \times 10^{-4}\ cm^2/sec$ *(4 marks)*
Modulus of volume re-compressibility	Void ratio at 5 kPa on CD = 0.75 Void ratio at 320 kPa on CD = 0.62 Δe = 0.75–0.62 = 0.13 $\Delta\varepsilon_{zr} = \frac{\Delta e}{1 + e_o} = \frac{0.13}{1 + 0.62} = 0.08$ $m_{vr} = \frac{\Delta\varepsilon_{zr}}{\Delta\sigma'_z} = \frac{0.08}{320 - 5} = 2.5 \times 10^{-4}\ m^2/kN$ *(4 marks)*
Constrained elastic modulus,	$E'_c = \frac{1}{m_{vr}} = \frac{1}{2.5 \times 10^{-4}} = 4 \times 10^3\ kPa$ *(4 marks)*
Time for primary consolidation, t_p	$t_p = t_{100}$ = 50 minutes *(4 marks)*
Secondary compression index, C_α	$C_\alpha = -\frac{(e_t - e_p)}{log(t/t_p)} = -\frac{(-)}{log(1500/50)}$ *Sufficient data has not been provided (4 marks)*

QUESTION 3: Settlement Computation [40%]

A representative stratigraphy at a site for a proposed grain storage tank, 4m in diameter and 15m high, is shown in Figure 3.1. The groundwater is at the top of the clay layer. The tank is located on a circular concrete slab 5m in diameter that serves as the foundation transmitting the loads to the soil. The weight of the tank full to capacity and of the concrete foundation is 3200kN. Local code regulations require that the minimum depth of embedment of the foundation be 1m from the finished surface elevation.

Soil Layer	Estimated Young's moduli E'_{sec}
Poorly graded sand with silt (SP-SM)	20,000kPa
Poorly graded sand (SP)	15,000kPa
Lean clay (CL)	40,000kPa
well-graded gravel with sand (GW)	45,000kPa



The specific gravity of clay is 2.65. Assume ν′= 0.35 and neglect the effects (e.g., uplift) of soil excavation.

One-dimensional consolidation test on the clay (CL) gave Cc = 0.28, Cr = 0.06, Cv =0.05 m^2/day and OCR = 8

3.1 Calculate the settlement due to the storage tank. (You may follow the following steps)

a) Estimate the elastic settlement of each layer except the GW soil layer.
b) Estimate the primary consolidation of the clay layer.
c) Compute the total settlement.

Initial void ratio of clay: $e_o = \omega G_s = 0.184 \times 2.7 = 0.5$

(2 marks)

Clay: $\gamma_{sat} = \frac{G_s+e_o}{1+e_o}\gamma_w = \left(\frac{2.7+0.5}{1+0.5}\right)9.81 = 20.9\ kN/m^3$

(2 marks)

Center of clay layer: $u_o = 1 \times 9.81 = 9.81 kPa$

$$\sigma_{zo} = [15 \times (1+1.2)] + (14.9 \times 2) + (20.9 \times 2/2) = 98.7\ kPa$$

$$\sigma'_{zo} = 98.7 - 9.81 \approx 89\ kPa$$

(3 marks)

Elastic settlements

SP-SM layer

$$q_s = \frac{3200}{(\pi \times 4^2)/4} = 255\ kPa$$

(2 marks)

$$S_i = \frac{q_s D(1-v^2)}{E'} I_d = S_i = \frac{255 \times 4 \times (1-0.35^2)}{20000} \times 1 = 0.04475\ m\ \approx\ 45mm$$

(2 marks)

SP layer

$$\Delta\sigma_v = q\left[1 - \frac{1}{\left[\left(\frac{R}{z}\right)^2 + 1\right]^{3/2}}\right] = 255\left[1 - \frac{1}{\left[\left(\frac{2}{2.2}\right)^2 + 1\right]^{3/2}}\right] = 158\ kPa$$

(2 marks)

$$S_i = \frac{158 \times 4 \times (1-0.35^2)}{15000} \times 1 = 0.03697\ m\ \approx\ 37mm$$

(2 marks)

CL layer

$$\Delta\sigma_v = 255\left[1 - \frac{1}{\left[\left(\frac{2}{4.2}\right)^2 + 1\right]^{3/2}}\right] = 107\ kPa$$

(2 marks)

$$S_i = \frac{107 \times 4 \times (1-0.35^2)}{8000} \times 1 = 0.009389\ m\ \approx\ 9mm$$

(2 marks)

Consolidation Settlement

$$OCR = \frac{\sigma'_{zc}}{\sigma'_{zo}} = 8\ ;\ \sigma'_{zc} = 8 \times 89 = 712\ kPa$$

(3 marks)

Vertical stress increase at the center of the clay

$$\Delta\sigma_v = 255\left[1 - \frac{1}{\left[\left(\frac{2}{5.2}\right)^2 + 1\right]^{3/2}}\right] = 99.5\ kPa \approx\ 100\ kpa$$

(2 marks)

$$\sigma'_{fin} = \sigma'_{zo} + \Delta\sigma'_z = 89 + 100 = 189\ kPa < 712\ kPa = \sigma'_{zc}$$

(2 marks)

$$S_c = C_r \frac{H_o}{1+e_o} log \frac{\sigma'_{zo} + \Delta\sigma_z}{\sigma'_{zo}} = 0.06 \times \frac{2}{1+0.5} log \frac{189}{89} = 26\ mm$$

(2 marks)

Total Settlement

$S_t = 45 + 37 + 9 + 26 = 117\ mm$ (2 marks)

3.2 Estimate how long it would take for 50%, 90% and 100% of primary consolidation settlement in the clay to occur.

Since the clay layer is sandwiched between coarse-grained soils, it is reasonable to assume double drainage.

For 50% consolidation, $T_v = 0.197$ (*1 mark*)

$$t = \frac{T_v H_{dr}^2}{C_v} = \frac{0.197 \times \left(\frac{2}{2}\right)^2}{0.05} = 3.94\ years \approx 4\ years$$

(*2 marks*)

For 90% consolidation, $T_v = 0.848$ (*1 mark*)

$$t = \frac{T_v H_{dr}^2}{C_v} = \frac{0.848 \times \left(\frac{2}{2}\right)^2}{0.05} = 16.96\ years \approx 17\ years$$

(*2 marks*)

For 100% consolidation,

$$t \approx \frac{H_o^2}{2C_v} = \frac{(2)^2}{2 \times 0.05} = 40\ years$$

(*4 marks*)

<table>
<tr><td colspan="2">$$S_i = \frac{q_s D(1-v^2)}{E'} I_d$$ Where q_s uniform surface stress, D is the diameter of the loaded area</td><td colspan="2">Center of the circular area: $I_d = 1$
Edge of circular area: $I_d = \frac{2}{\pi}$</td></tr>
<tr><td colspan="2">NC Clay $$S_c = C_c \frac{H_o}{1+e_o} log \frac{\sigma'_{zo} + \Delta\sigma_z}{\sigma'_{zo}}$$</td><td colspan="2" rowspan="2">$$C_c = -\frac{e_2 - e_1}{log \frac{(\sigma'_z)_2}{(\sigma'_z)_1}}$$ $$m_v = -\frac{(\varepsilon_z)_2 - (\varepsilon_z)_1}{(\sigma'_z)_2 - (\sigma'_z)_1}$$ $$C_r = -\frac{e_2 - e_1}{log \frac{(\sigma'_z)_2}{(\sigma'_z)_1}}$$ $$m_{vr} = -\frac{(\varepsilon_z)_2 - (\varepsilon_z)_1}{(\sigma'_z)_2 - (\sigma'_z)_1}$$</td></tr>
<tr><td colspan="2">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 $\sigma'_{zo} + \Delta\sigma_z > \sigma'_{zc}$, $$S_c = \frac{H_o}{1+e_o}\left(C_r\, log \frac{\sigma'_{zc}}{\sigma'_{zo}} + C_c\, log \frac{\sigma'_{zo} + \Delta\sigma_z}{\sigma'_{zc}}\right)$$</td></tr>
<tr><td>$$S_s = \frac{H_o}{1+e_o} C_\alpha \log\left(\frac{t}{t_p}\right)$$</td><td colspan="3">$$C_\alpha = -\frac{(e_t - e_p)}{log(t/t_p)} = \frac{|\Delta e|}{log(t/t_p)}; t > t_p$$ $$C_\alpha / C_c = 0.03\ to\ 0.08$$</td></tr>
<tr><td colspan="2">$$T_v = \frac{\pi}{4}\left(\frac{U}{100}\right)^2\ for\ U < 60\%$$ $$T_v = 1.781 - 0.933 \log(100 - U)\ for\ U \geq 60\%$$</td><td>$$T_v = \frac{C_v t}{H_{dr}^2}$$</td><td>$$C_v = \frac{k_z}{m_v \gamma_w}$$</td></tr>
<tr><td colspan="4">Stress increase under the center of circular loading $\Delta\sigma_v = q\left[1 - \frac{1}{\left[\left(\frac{R}{z}\right)^2 + 1\right]^{3/2}}\right]$</td></tr>
</table>