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ADDIS ABABA INSTITUTE OF TECHNOLOGY
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SCEE, Geotechnical Engineering Chair

Solution set for CEng2142 Fundamentals of Geotechnical Engineering - II

Examination date: 24th June 2019

Examination time (from-to): 13:30 - 17:30

Permitted exam support material: No printed or handwritten material

Number of pages enclosed: **14 including cover page**

Instruction:
- Write concise answers for theoretical questions.
- Show your steps clearly for problems involving calculations.
- The examination set shall be delivered with the answer sheet.

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

Date Signature

Question #	Weight [%]	Score [%]
1	5	
2	30	
3	10	
4	30	
5	5	
6	20	

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Question 1: On Genesis of Soils & Soil Mechanics [5%]

Below is a statement from the father of soil mechanics, Karl von Terzaghi.

> *"In engineering practice, difficulties with soils are almost exclusively due to not soils themselves but to water contained in the voids. On a planet without any water, there would be no need for soil mechanics."*

Why do you think Terzaghi made such a statement from the mechanics point of view? Mention few arguments in favor of and against the statement. Substantiate your arguments with examples.

Question 2: On Simple Soil Properties [30%]

2.1 Combined mechanical grain size analysis of a given sample of soil was carried out. The total weight of soil used in the analysis was 350 g. The sample was divided into coarser and finer fractions by washing it through a 75microns sieve. The fine fraction was 125 g. The coarser fraction was used for the sieve analysis and 50 g of the finer fraction was used for the hydrometer analysis. The test results were as given below:

Sieve Analysis	
Particle size	Mass retained (g)
4.75 mm	9.0
2.00 mm	15.5
1.40 mm	10.5
1.00 mm	10.5
500 µm	35.0
355 µm	24.5
180 µm	49.0
125 µm	28.0
75 µm	43.0

Hydrometer test correction		
T	K	C_T
25°C	0.0125	+1.30

Hydrometer Analysis (13%) [13 marks]							
Time (min)	Reading, R_a	R	L	D	Rc	P’	P
¼	50	*50.40*	*8.03*	*0.0708*	*49.80*	*97.45*	*34.80*
½	40	*40.40*	*9.67*	*0.0550*	*39.80*	*77.88*	*27.82*
1	31	*31.40*	*11.15*	*0.0417*	*30.80*	*60.27*	*21.53*
2	17.20	*17.60*	*13.41*	*0.0324*	*17.00*	*33.27*	*11.88*
4	12.00	*12.40*	*14.27*	*0.0236*	*11.80*	*23.09*	*8.25*
8	8.50	*8.90*	*14.84*	*0.0170*	*8.30*	*16.24*	*5.80*
15	6.21	*6.61*	*15.22*	*0.0126*	*6.01*	*11.76*	*4.20*
30	5.10	*5.50*	*15.40*	*0.0090*	*4.90*	*9.59*	*3.42*
60	4.25	*4.65*	*15.54*	*0.0064*	*4.05*	*7.93*	*2.83*
120	3.10	*3.50*	*15.73*	*0.0045*	*2.90*	*5.67*	*2.03*
240	2.30	*2.70*	*15.86*	*0.0032*	*2.10*	*4.11*	*1.47*
480	1.30	*1.70*	*16.02*	*0.0023*	*1.10*	*2.15*	*0.77*
1440	0.70	*1.10*	*16.12*	*0.0013*	*0.50*	*0.98*	*0.35*

A hydrometer (152 H type) was inserted into the suspension just a few seconds before readings were taken. It was next removed and introduced just before each of the subsequent readings. Temperature of suspension = 25°C. Temperature correction C_T=+1.3 Meniscus correction Cm = 0.4, zero correction Co = l.5, Gs = 2.75

(i)Complete the grain size distribution curve provided on the next page. (3%)

(ii)Determine the percentages of gravel, sand, and fine fractions present in the sample. (3%)

(iii) Compute the uniformity coefficient and the coefficient of curvature. (2%)

(iv) Comment on the basis of the test results whether the soil is well graded or not. (4%)

$D = K\sqrt{\frac{L}{t}}$ where $K = \sqrt{\frac{18\mu}{(G_s-1)\gamma_w}}$ (L is in cm, t is min, γ_w in in g/cm3, μ in (g-sec)/cm and D in mm.)

L=16.3-0.1641R for ASTM 152H hydrometer, also $R=R_a+C_m$, $R_c=R_a-C_o+C_T$,
$C_{sg} = 1.65G_s/2.65(G_s-1)$; $P' = \frac{C_{sg}R_c}{M_s} \times 100\%$; $P = P'\% \times \frac{M_p}{M}$ where P' is the percent finer with the correction factor C_{sg} , M_s is mass of soil used in the suspension in , P is percent finer(combined), M_p is the mass of soil particles passing through 75 micron sieve and M the total mass taken for the combined sieve and hydrometer analysis.

%Gravel=3%; %Sand=62 %; %Fines= 35%

$\boldsymbol{C_u = \frac{D_{60}}{D_{10}} = \frac{0.225}{0.03} = 8}$ [2 mark]; $\boldsymbol{C_c = \frac{(D_{30})^2}{D_{10}D_{60}} = \frac{0.06^2}{0.03*0.225} = 0.5}$ [2 mark]

$\boldsymbol{C_u > 4 \rightarrow Well\ graded}$; $\boldsymbol{C_c < 1 \rightarrow Gap\ graded}$; $\boldsymbol{FINAL\ VERDICT}$ =?[2 mark]

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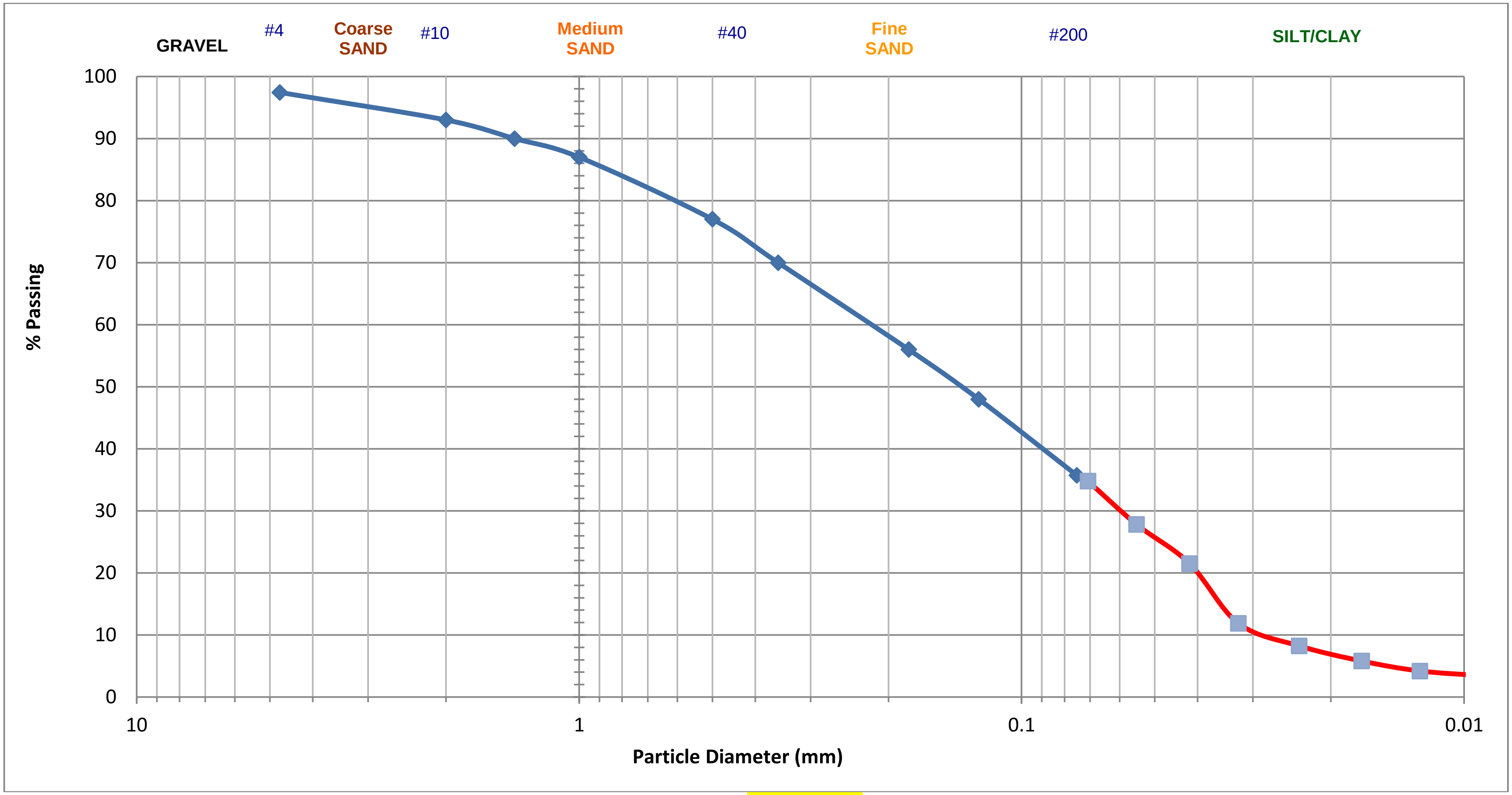
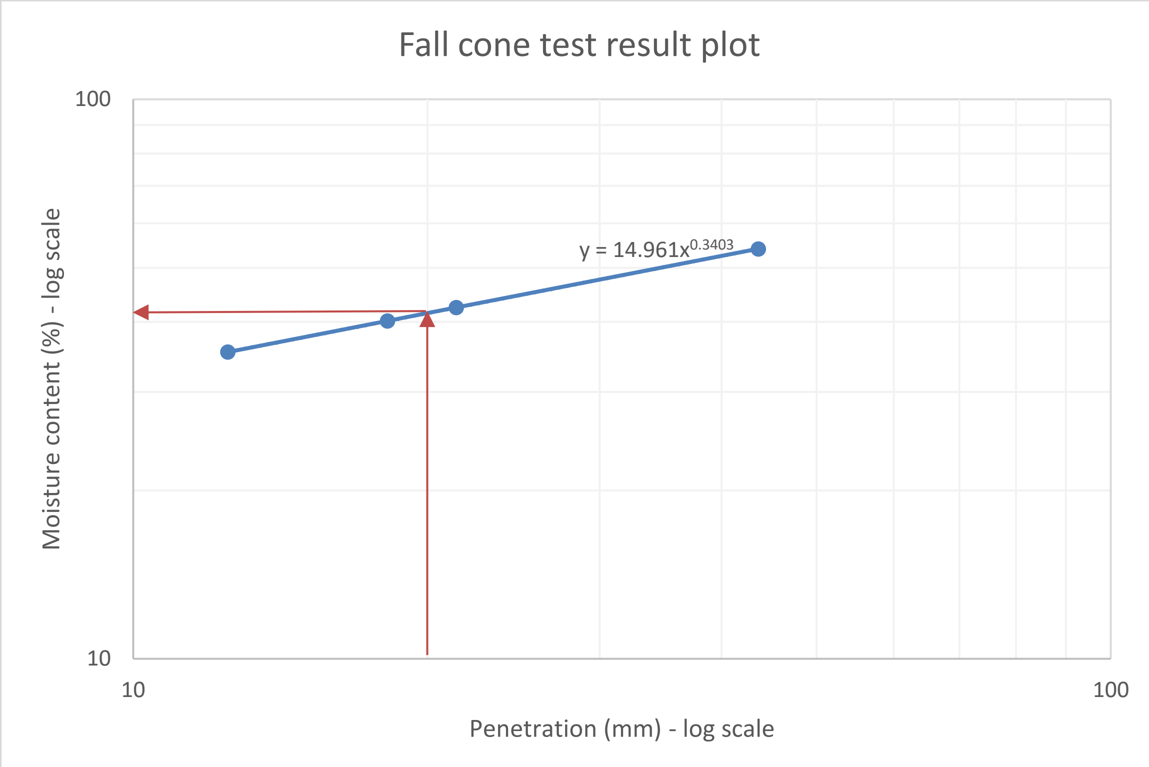


[6 marks]

2.2 A liquid limit test carried out on a sample of inorganic soil taken from below the water table gave the following results:

Fall cone penetration y (mm)	15.5	18.2	21.4	23.6
Moisture content, ω%	34.6	40.8	48.2	53.4

Determine the liquid limit, plastic limit, liquidity index and plasticity index of the soil. The natural moisture content has been determined to be 25%. Comment on the state of the soil. (5%)



LL=42%

[1 mark]

PL=C(2)^{m}=14.961(2)$^{0.34030}$=19%

[1 mark]

PI=LL-PL=23%

[1 mark]

LI= $LI = \frac{\omega - PL}{PI} = 0.09$

[1 mark]

State of soil → Very stiff plastic state

[1 mark]

Question 3: On Soil Classification & Field Identification [10%]

3.1 Which of the following statements is/are true regarding AASHTO soil classification. (2%)

- ❑ In AASHTO classification system, A-2 soil is better than A-3

  FALSE...... [1 mark] ....
- ❑ A group index of zero indicates a soil has a very poor quality in terms of subgrade material.

  FALSE...... [1 mark] ....

3.2 Describe potential assumptions made and associated uncertainties that a geotechnical engineer might face in trying to classify soils. (4%)

- Approximation in designating a soil mass (an unbounded, particulate material)
- Non-unique physical properties which could be achieved by manipulating different soil properties
- Lack of clear boundaries and the fact that is convention based.
- We are concerned with mechanical properties we deem are relevant to us. (we ignore other properties such as chemical ones)

[4 marks]

3.3 Mention at least two signs of the presence of organic matter in a soil mass? (2%)

The presence of an appreciable quantity of organic material can usually be recognized by the

- ➢ dark grey to black color and
- ➢ odor of decaying vegetation, which it lends to the soil

[2 marks]

3.3 Briefly discuss how you would identify clay soils from silt on field. (2%)

Feel: Clay can be molded readily into a shape or rod can be formed into long ribbons while silt does not feel and gritty has floury feel.
Dry strength test: A clay fragment can be broken only with a great effort, whereas a silt fragment crush easily.
Plasticity test : If a sample of moist soil can be manipulated between the palms of the hands and fingers and rolled into a long thread of about 3mm diameter, the soil then contains a significant amount of clay; whereas silt cannot be rolled into a thread of 3mm diameter without sever cracking.
Shaking test: Since clay soils contain much smaller voids than silts and are much less permeable, the appearance of the surface of pat does not change during the shaking test

[2 marks]

Question 4: On Soil Water, Permeability & Seepage [30%]

4.1 Determine the vertical hydraulic conductivity (k_V)of the soil in Question 2 using Hazen's empirical equation. Its horizontal permeability k_H is known to be approximately 500% of the k_V. If this soil makes the top 1m of a soil formation and below it is a red clay 3 meters thick with $k_V = k_H = 10^{-6}\, cm/sec$, what is the equivalent k_{Heq} for the upper 4 m of the soil mass? Note: Hazen's empirical formula is given as $k_V = C \cdot {D_{10}}^2$ where C ranges from 0.4 - 1.4. (5%)

$$k_{V1} = C{D_{10}}^2 = 1.4 * 0.03^2 = 0.00126\, cm/s \text{ [2 marks]}$$
$$k_{H1} = 5 * k_{V1} = 5 * 0.0384 = 0.0063\, cm/s \text{ [1 mark]}$$
$$k_{Heq} = \frac{k_1H_1 + k_2H_2}{H_1 + H_2} = \frac{0.0063*100 + 10^{-6}*300}{100+300} = 0.0016\, cm/s \text{ [2 marks]}$$

4.2 A canal, as shown in Figure 1 and Figure 2(not to scale), is excavated across a construction site in the clay of the previous question. The ground water level at the canal has a draw dawn of 2m. Determine the discharge per unit width of the slot (i.e. canal) (Hint: Assume the flow of water to be perpendicular to the canal) (10%)

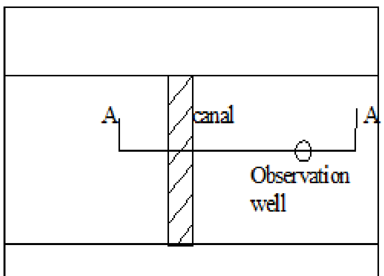


Fig 1:-Plan

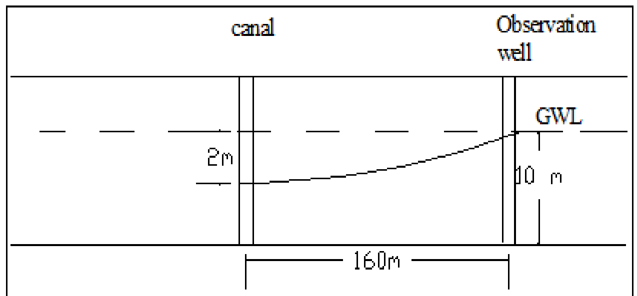


Fig 2:-section A-A

$$q = kiA \text{[1 mark]}$$

$$i = \frac{dh}{dr} \text{[1 mark]}$$

$$A = 1 \times h - Unit\ slot \text{ [1 mark]}$$

$$A = h\ (rectangular) \text{ [1 mark]}$$

$$q = k\frac{dh}{dr}h \text{[1 mark]}$$

$$\int_0^{160} q dr = \int_8^{10} khdh \text{[1 mark]}$$

$$qr|_0^{160} = k\frac{h^2}{2}\Big|_8^{10} \text{ [1 mark]}$$

$$q(160 - 0) = \frac{k}{2}(10^2 - 8^2) \text{ [1 mark]}$$

$$q = \frac{(1.0\times10^{-6})\times 36}{160\ m} = 3.3325 \times 10^{-6}\, {m^3}/{sec} \text{[2 marks]}$$

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4.3 Flow of water through soils (which is analogous to steady-state heat flow and flow of current in homogeneous conductors) is described by Laplace's equation.
Consider the physical model you produced as part of your course work to demonstrate groundwater flow.

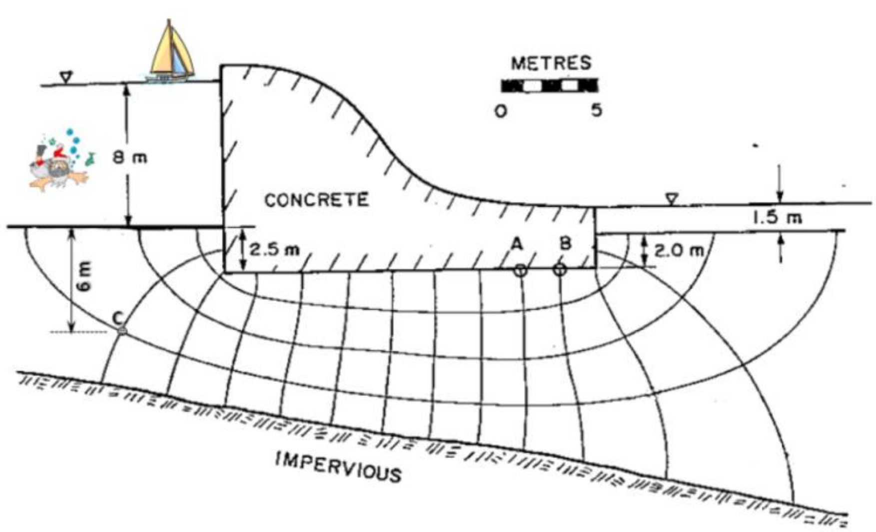
i) List out the assumptions in deriving Laplace's equation (for flow of water through soils)
ii) Label which of these assumptions are satisfied or not.
iii) Briefly explain why/how they are satisfied or not.

(5%)

Assumptions	Satisfied / Not satisfied	Explanation
Darcy's law is valid.		The flow is laminar.
There is inviscid flow.		This assumption means that the shear stresses are neglected.
The soil is homogeneous and saturated.		Physical properties of the soil does not change across the soil mass considered.
The soil and water are incompressible.		This assumption means that no volume change occurs.
Irrotational flow is negligible.		No vorticity

4.4 The flow net shown below is constructed for an isotropic sand which supports a concrete weir and having the following soil properties; permeability 1×10^{-3} cm/sec, an average void ratio of 0.6 and Gs = 2.65.
Determine the following:
a) The seepage loss in cubic meters per day per meter width of the dam perpendicular to the section shown.
b) The exit hydraulic gradient, the critical hydraulic gradient and the factor of safety against piping at the downstream toe of the dam.
c) How high would water rise in a standpipe situated at Point C?
d) What is the effective stress at Point C if γ_{sat}=20 kN/m³? Use $\gamma_w = 10\ \mathrm{kN/m^3}$
e) The uplift pressure under the dam.

(10%)



Answer 4.4 here ↓

a) $h_L = 8 - 1.5 = 6.5m = 650\ cm$; $N_f = 4$; $N_d = 13$ [1.5 marks]

$$==> q = kh_L \frac{N_f}{N_d} = 1 * 10^{-3} * 650 * \frac{4}{13} = 0.2\ cm^3/sec$$ [0.5 mark]

b)

$$i_{exit} = \frac{h_L/N_d}{L_{min}} = \frac{6.5/13}{2.0/2} = 0.5$$ [1 mark]

$$i_{crt} = \frac{G_s - 1}{1+e} = \frac{2.65-1}{1+0.61} = 1.03$$ [1 mark]

$$F_{piping} = \frac{i_{crt}}{i_{exit}} = \frac{1.03}{0.5} = 2.06$$ [1 mark]

c) Piezometric level for point C

$$H_c = 8 - \frac{6.5}{13} = 7.5m$$ [1 mark]

d) Effective stress = Total stress - Pore pressure

$$\sigma_v' = 8 * \gamma_w + 6 * \gamma_{sat} - (7.5 + 6) * \gamma_w = 8 * 10 + 6 * 20 - (7.5 + 6) * 10 = 65\ kPa$$
[1 mark]

e) Uplift pressure
Divide the base into a convenient number of equal intervals. Let us use 10 intervals. Determine the porewater pressure at each nodal point considering the elevation datum to be at the NGL.

Parameters	Under the base of the dam									
x (m)	0	2	4	6	8	10	12	14	16	18
N_d (m)	2	3	4	5	6	7	8	9	10	11
$N_d \Delta h$ (m)	1.15	1.73	2.31	2.88	3.46	4.04	4.62	5.19	5.77	6.35
h_z (m)	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
h_p (m) $= \Delta H - N_d \Delta h - h_z$	8.35	7.77	7.19	6.62	6.04	5.46	4.88	4.31	3.73	3.15
u (kPa) $= h_p * \gamma_w$	81.88	76.22	70.56	64.90	59.24	53.58	47.92	42.26	36.60	30.94

Using Simpson's rule, the uplift pressure becomes

$$P_w = \frac{\Delta x}{3}\left(u_1 + u_n + 2\sum_{\substack{i=3\\odd}} u_i + 4\sum_{\substack{i=2\\even}} u_i\right)$$

$$= \frac{2}{3}(81.88 + 30.94 + 2(70.56 + 59.24 + 47.92 + 36.60) + 4(76.22 + 64.90 + 53.58 + 42.26)) = 992.82\ kN$$

[3 marks]

Question 5: On Soil Compaction [5%]

5.1 Why is dry density/unit weight (from among the different density/unit weight types) used to indicate degree of compaction? (1%)

- It does not involve moisture content. And is not affected by moisture fluctuation in dry and wet seasons. As such it **better** represents the property of the soil grain.

[1 mark]

5.2 During compaction in the field, it is common practice to prefer the dry side of optimum moisture content than the wet one. Why do you think this is the case? (2%)

- For a given compactive effort, soils have a flocculated structure on the dry side (i.e. soil particles are oriented randomly), whereas they have a dispersed structure on the wet side (i.e. particles are more oriented in a parallel arrangement perpendicular to the direction of applied stress). This is due to the well-developed adsorbed water layer (water film) surrounding each particle on the wet side.
- The randomly oriented soil in the dry side exhibits the same permeability in all directions, whereas the dispersed soil in the wet side is more permeable along particle orientation than across particle orientation.
- At low applied stresses, the dry compacted soil is less compressible on account of its truss-like arrangement of particles whereas the wet compacted soil is more compressible.

[2 marks]

5.3 What is the fundamental reason for the development of modified Proctor test? (1%)

- Because of the benefits from compaction, contractors have built larger and heavier machines to increase the amount of compaction of the soil. It was found that the Standard Compaction test could not reproduce the densities measured in the field and this led to the development of the Modified Compaction test.

[1 mark]

5.4 Soil mass is compacted in layers called lifts in road construction. In the laboratory compaction tests, we also employ the use of layers. Why do you think is the reason? (1%)

- To ensure the compactive effort applied reaches all points with in the soil mass

[1 mark]

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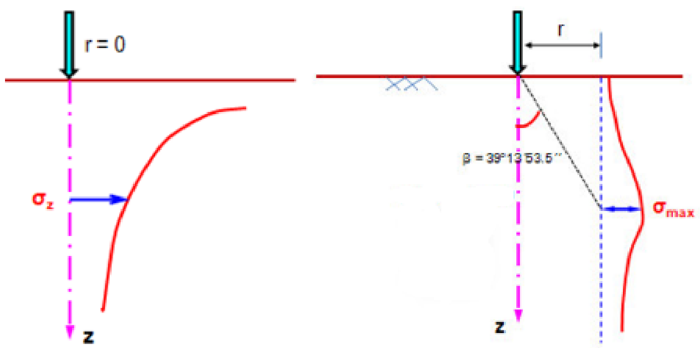
Question 6: On Stress in Soils [20%]

6.1 State at least four assumptions underlying Boussinesq's theory of stress distribution. Make a sketch of the distribution of vertical stresses due to a concentrated vertical load acting at the surface of a half-space (a) along vertical lines passing through the point of application and elsewhere, and (b) along a typical horizontal plane through the half-space other than the ground surface. (5%)

Assumptions: Elastic; isotropic; homogeneous; semi-infinite; weightless [2 marks]

a)

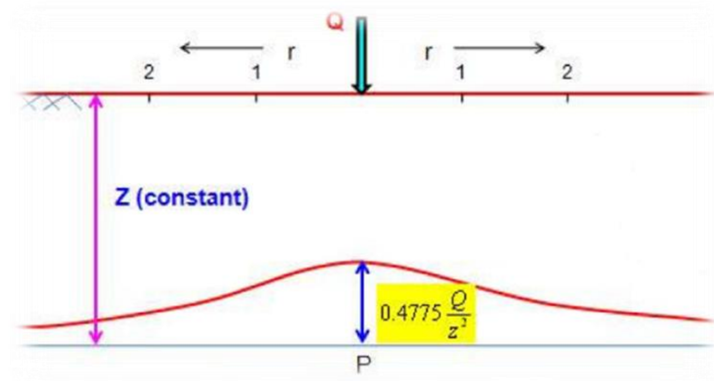
[2 marks]



directly under the point load

at a distance from point load

b)



[1 mark]

6.2 A wastewater treatment aeration tank of diameter 40m and gross weight 286.5 MN is to be constructed on one of the 40-60 Housing Project sites in Addis Ababa as shown below (left figure). To construct the tank, 6m of the top dense sand layer will be excavated, and the tank will be built as shown on the right-hand side.

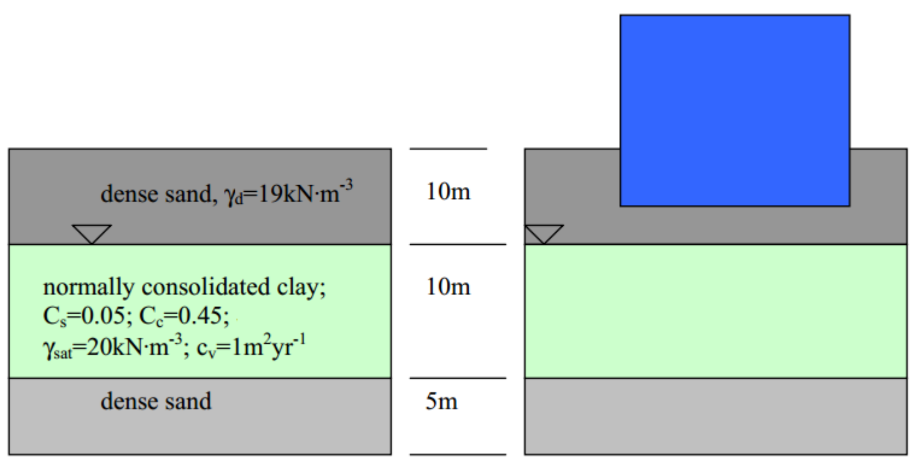
For the data provided in the figures:

i) Compute the geostatic stresses at the middle of the clay layer. Use $\gamma_w = 10\ kN/m^3$

ii) Compute the increase in vertical stress due to the construction of the tank at the middle of the clay layer directly beneath the center of the tank.

iii) If the nearest building imposes a total structural load of 900MN and is supported by 30X30m square mat foundation situated at a depth of 12m from the surface, at what minimum horizontal distance (edge clearance) should the tanker be constructed from the building to avoid stress overlap in the middle of the clay layer? Use 3V:1H method. (5%)

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



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Answer 6.2 here ↓

a) Geostatic stresses

Total stress: $\boldsymbol{\sigma = \gamma * z = 19 * 10 + 20 * 5 = 290\ kPa}$ [0.5 mark]

Pore pressure: $\boldsymbol{u = \gamma_w * z_w = 10 * 5 = 50}$ [0.5 mark]

Effective stress: $\boldsymbol{\sigma' = \sigma - u = 290 - 50 = 240\ kPa}$ [0.5 mark]

b) Additional stress

$$q = \frac{W}{A} = \frac{286.5 * 10^3}{\pi * \left(\frac{40}{2}\right)^2} = 228\ kPa \text{ [0.5 mark]}$$

Net bearing stress just below the tank

$$q = 228 - 19 * 6 = 114\ kPa \text{ [1 mark]}$$

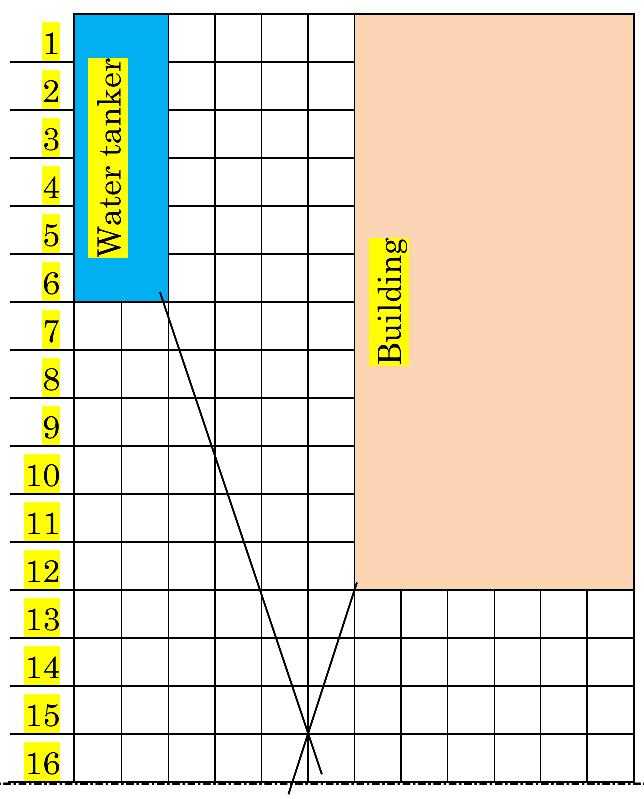
R=20m, z= 4+5=9m

$$\Delta\sigma_v = q\left[1 - \frac{1}{\left[\left(\frac{R}{z}\right)^2 + 1\right]^{3/2}}\right] = 228\left[1 - \frac{1}{\left[\left(\frac{20}{9}\right)^2 + 1\right]^{3/2}}\right] = 106\ kPa$$

[1 mark]

C) Stress overlap

4m [1 mark]



6.3 A square foundation (a slab of concrete), 4 m x 4 m, is required to support one of the column loads from a three story building. The foundation base is located at ground surface and weighs 160 kN. Each story applies a load of 720 kN. The soil is a stiff, saturated, over-consolidated clay with a saturated unit weight of 20 kN/m³ and Ko = 1. Groundwater is at 10 m below the surface. The building was to be constructed rapidly, but after the second story was nearly completed, work stopped for a period of 1 year. A transducer at a depth 5 m below the center of the foundation measured the porewater pressure. When work resumed after the 1-year hiatus, the excess porewater pressure developed during construction dissipated by 50%.

Assume the stiff clay behaves like an isotropic, linear elastic material.

For the soil element at 5 m:

(a) Plot the total and effective stress paths in (p, q) space before construction stopped.

(b) Predict the excess porewater pressures just before construction stopped.

(c) Plot the total and effective stress paths in (p, q) space after construction resumed.

(d) Predict the excess porewater pressures after construction resumed.

(10%)

Initial stresses

The soil element under the center of the foundation is under asymmetric condition. Groundwater is below the soil element at 5 m, so it has no effect. The initial total and effective stresses are the same because the porewater pressure is zero.

$$\sigma_z = \sigma_z' = 5 \times 20 = 100\ kPa\ (0.5\ mark)$$

$$\sigma_x = \sigma_x' = \sigma_y = \sigma_y' = K_o^{OC}\sigma_z' = 1 \times 100 = 100\ kPa\ (0.5\ mark)$$

$$p_o = p_o' = \frac{\sigma_x + \sigma_y + \sigma_z}{3} = \frac{100 + 100 + 100}{3} = 100\ kPa\ (0.5\ mark)$$

$$q_o = \sigma_z - \sigma_x = 100 - 100 = 0\ kPa\ (0.5\ mark)$$

Changes in stresses up to the end of construction of the second story

The total load at the completion of the second story is 160 + 720 + 720 = 1600 kN.

$$q_s = \frac{1600}{4 \times 4} = 100\ kPa\ (0.5\ mark)$$

$$\Delta\sigma_z = \frac{100 \times (4 \times 4)}{(4+5) \times (4+5)} = 19.75\ kPa\ (0.5\ mark)$$

$$\Delta\sigma_x = \Delta\sigma_y \approx 0\ kPa\ (since\ they\ are\ very\ small)(0.5\ mark)$$

$$\Delta p = \frac{\Delta\sigma_x + \Delta\sigma_y + \Delta\sigma_z}{3} = \frac{0 + 0 + 19.75}{3} = 6.6\ kPa\ (0.5\ mark)$$

$$\Delta q = \Delta\sigma_z - \Delta\sigma_x = 19.75 - 0 = 19.75\ kPa\ (0.5\ mark)$$

$$Slope = \frac{\Delta q}{\Delta p} = \frac{19.75}{6.6} = 3$$

Current stresses

$$p_1 = p_o + \Delta p = 100 + 6.6 = 106.6\ kPa\ (0.5\ mark)$$

$$q_1 = q_o + \Delta q = 0 + 19.75 = 19.75\ kPa\ (0.5\ mark)$$

$$p_1' = p_o' + \Delta p' = 100 + 0 = 100\ kPa\ (0.5\ mark)$$

Note: Since the soil is linearly elastic, the change in mean effective stress is zero. Also, the deviatoric (shear) stress is unaffected by changes in porewater pressures.

Excess porewater pressure

The excess porewater pressure is the mean stress difference between the total and effective stress paths.

$$\Delta u = \Delta p = 6.6\ kPa\ (0.5\ mark)$$

Excess porewater pressure just before construction resumes.

Amount of excess porewater pressure dissipated = 0.5 X 6.6 kPa = 3.3 kPa (0.5 *mark*)
Amount of excess porewater pressure present = 6.6 – 3.3 = 3.3 kPa (0.5 *mark*)
Because the excess porewater decreases, the mean effective stress will increase by a similar amount.
Current stresses:

$$p_2' = p_1' + \Delta u = 100 + 3.3 = 103.3\ kPa\ (0.5\ mark)$$
$$q_1 = q_o + \Delta q = 0 + 19.75 = 19.75\ kPa\ (0.5\ mark)$$

Changes in stresses due to the construction of the third story.
The additional load is 720 kN.

$$q_s = \frac{720}{4 \times 4} = 45\ kPa\ (0.5\ mark)$$

Because in the calculation of increase in soil stresses from surface stresses we are assuming an isotropic, elastic soil then we can simply use proportion to calculate the increase in stresses due to the additional surface stress.

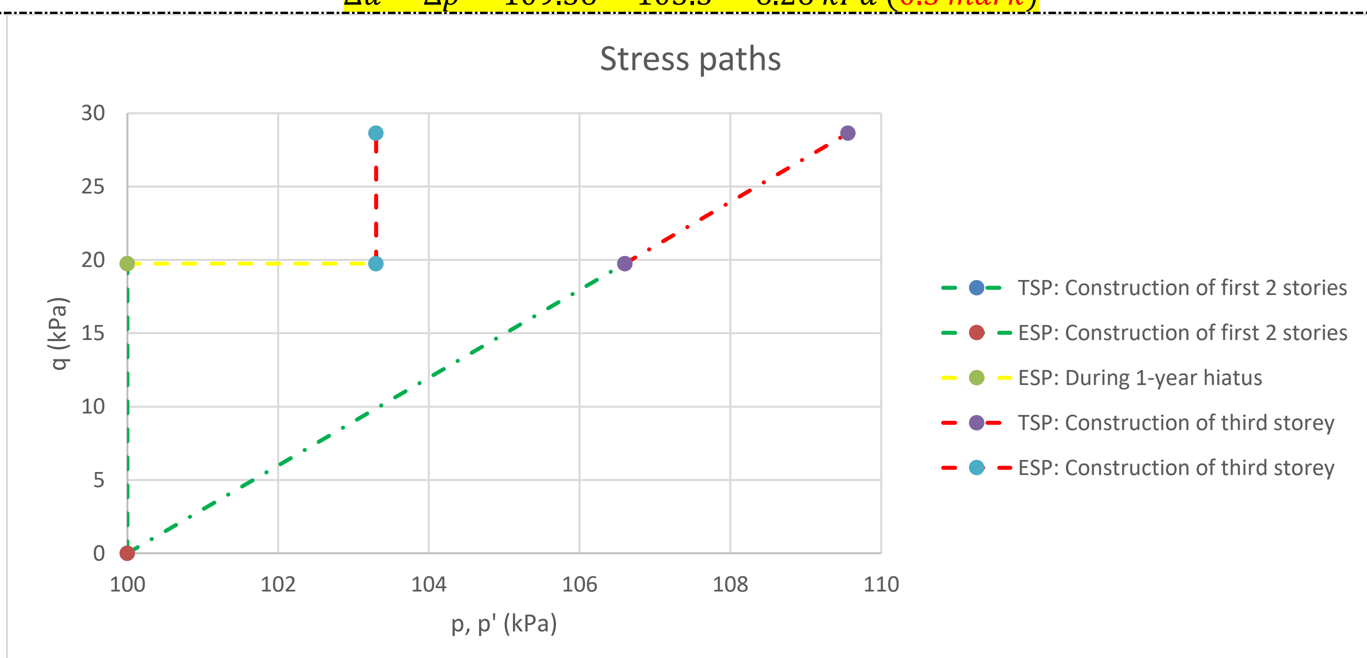
$$\Delta\sigma_z = 19.75 \times \frac{45}{100} = 8.89\ kPa\ (0.5\ mark)$$
$$\Delta p = \frac{\Delta\sigma_x + \Delta\sigma_y + \Delta\sigma_z}{3} = \frac{0 + 0 + 8.9}{3} = 2.96\ kPa\ (0.5\ mark)$$
$$\Delta q = \Delta\sigma_z - \Delta\sigma_x = 8.89 - 0 = 8.89\ kPa\ (0.5\ mark)$$
$$Slope = \frac{\Delta q}{\Delta p} = \frac{8.89}{2.96} = 3$$

Current stresses

$$p_3 = p_1 + \Delta p = 106.6 + 2.96 = 109.56\ kPa\ (0.5\ mark)$$
$$q_3 = q_1 + \Delta q = 19.75 + 8.89 = 28.64\ kPa\ (0.5\ mark)$$
$$p_3' = p_2' + \Delta p' = 103.3 + 0 = 103.3\ kPa\ (0.5\ mark)$$

Excess porewater pressure.
The excess porewater pressure is the mean stress difference between the total and effective stress paths.

$$\Delta u = \Delta p = 109.56 - 103.3 = 6.26\ kPa\ (0.5\ mark)$$



(2.5 *marks*)