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ESE 2024 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Civil Engineering

Test-1 : Geo-technical & Foundation Engineering [All Topics]
Environmental Engineering [All Topics]

Name :

Roll No

Test Centres			Student's Signature
Delhi ☑	Bhopal ☐	Jaipur ☐	
Pune ☐	Kolkata ☐	Hyderabad ☐	

Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	31
Q.2	50
Q.3	44
Q.4	—
Section-B	
Q.5	52
Q.6	
Q.7	
Q.8	55
Total Marks Obtained	232

Signature of Evaluator .... Cross Checked by ....

IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

Good, Keep it up.

(1) Improve, answer presentation & skills.
(2) practice more & more questions for increasing attempt.
(3) Numerical ability is good.
(4) Accuracy is also good.

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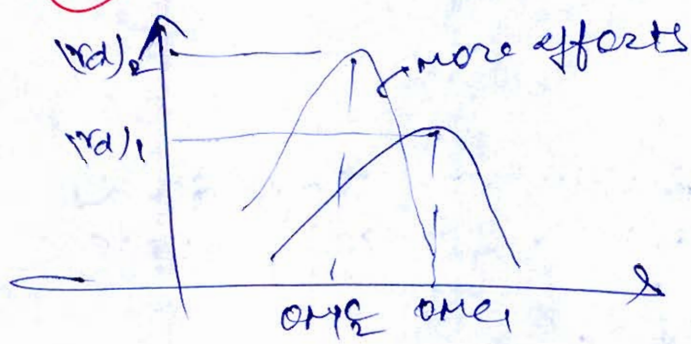
Section A : Geo-technical & Foundation Engineering

Q.1 (a) Explain the factors affecting compaction of a given type of soil.

[12 marks]

There are many factors effecting compaction of soil.

① compaction efforts:
it is observed as compaction energy is increased, γ_d is obtained more and OMC (optimum moisture content) decrease).



② water content:
At water content lower than OMC, soil is stiff and provided more resistant to the compaction efforts due to friction in between soil solids.
At OMC, water in soil induces lubrication effort as water film is coated to soil solids. this lubrication leads soil to obtain a large dry density.
At water content greater than OMC, water start occupying space that was initial for solids &

increases its volume of soil. Hence decrease γ_d.

(3) presence of lime

lime is lighter in weight than soil particles and if lime is mixed with soil, it will stablise the soil and increase strength, But it will reduce γ_d and increase OMC.

06

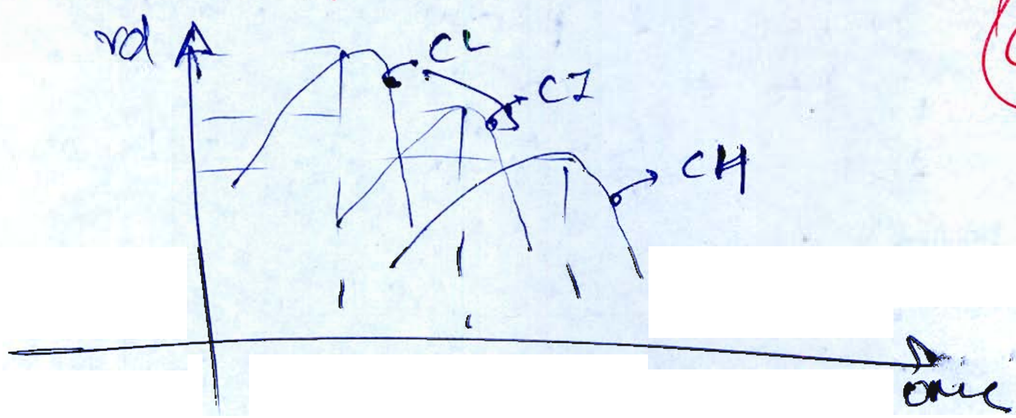
(4) plasticity:

plastic soil such as clay tends to Have low γ_d and High OMC.

(5) compressibility:

High compressible soil Have low γ_d & High OMC.

05



Q.1 (b) A natural deposit of loose, dry sand, 5 m thick with an in-situ unit weight of 14 kN/m^3 was compacted by vibro floatation technique and the surface settled by 0.5 m. The relative density of the sand after compaction was found to be 85%. If the dry unit weight of sand in the loosest state is 10.8 kN/m^3, then determine:

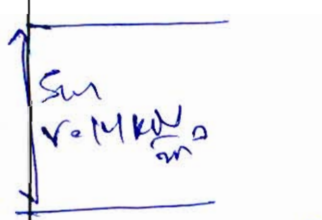
(i) the unit weight of the soil after vibro-floatation.

(ii) the dry unit weight in the densest state.

(iii) the maximum possible settlement of the surface under ideal compaction.

[12 marks]

$\Delta H = 0.5m$



$0.85 = \left[\frac{(\gamma_d)_{field}}{(\gamma_d)_{max}}\right]$

$(\gamma_d)_f = 0.85\,(\gamma_d)_{max}$

$\gamma_{d,min} = 10.8\ kN/m^3$

$\gamma_d = 14 = \frac{G\gamma_w}{1+e_0}$

Let, $G = 2.7$ (Assume)

$e_0 = 0.89$

$\frac{\Delta H}{H_0} = \frac{\Delta e}{1+e_0}$

$\Delta e = 0.19$

$e_f = 0.77$

$(\gamma_d)_{field} = \frac{2.7 \times 9.81}{1.77} = 14.88\ kN/m^3$

① $\gamma_d = 14.88\ kN/m^3$

② $(\gamma_d)_{max} = \frac{14.88}{0.85} = 17.51\ kN/m^3$

02

$(n_d)_{max} = \frac{G \gamma_w}{1+e}$

$e = 0.51$

$\frac{\Delta H}{H_0} = \frac{\Delta e}{1+e_0}$

$\Delta H = 5m \times \frac{(0.89 - 0.51)}{1.89}$

$\Delta H = 0.99 \simeq 1m$

$\Delta H_{reqd} = 1\,m$

Q.1 (c) A certain clay layer has a thickness of 5 m. After 1 year, when the clay was 50 percent consolidated, 8 cm of settlement has occurred. For similar clay and loading conditions, how much settlement would occur at the end of 1 year and 4 years respectively, if the thickness of this new layer was 25 m?

[12 marks]

$H_0 = 5m$
$U = .5$
$\Delta h = 8cm$

$T_v = \frac{C_v t}{d^2}$

$\frac{\pi}{4}(.5)^2 = C_v \times \frac{1}{(5)^2}$

$H_0' = 25m$

$H_0 = 5m$

Assume, single draining.

02

$\frac{\Delta h}{\Delta H} = U\%$

$\Delta H = 16cm$

for 25m

$\Delta H = 16 \times \frac{25}{5} = 75cm$

Calculation mistake

$T_u = C_u \frac{t}{d^2}$

$T_u = \frac{\pi}{4}(.5)^2 \times 25 \times \frac{(1)}{(25)^2}$

$T_u = 9.85 \times 10^{-3}$

$\frac{\pi}{4} U^2 = T_u$

$U = 0.1$

$(\Delta h) = 0.1 \times 75 = 7.5$ cm

$(\Delta h)_{1yr} = 7.5$ cm

$T_u = \frac{\pi}{4}(.5)^2 \times 25 \times \frac{4}{(25)^2}$

$T_u = 0.0314$

$\frac{\pi}{4} U^2 = 0.0314$

$U = 0.2$

$(\Delta h)_{4yr} = 15$ cm

Q.1 (d) (i) Determine the area ratios for the following soil samplers and comment on the nature of samples obtained in each of the samplers.

1.	Core cutter	160 mm OD	145 mm ID
2.	Split barrel	50 mm OD	34 mm ID
3.	Seamles tube	55 mm OD	52 mm ID

Here OD is outer diameter and ID is internal diameter of the soil sampler.

(ii) A canal having slopes 1 to 1 is proposed to be constructed in a cohesive soil to a depth of 6 m below ground surface. The soil properties are given below:

$\phi_u = 15°$, $C_u = 18\ kN/m^2$, $e = 0.75$, $G_s = 2.65$, $S_n = 0.08$

Find the factor of safety with respect to cohesion against failure of the bank slopes when the canal is full of water.

[6 + 6 = 12 marks]

(i). ① $A_r = \frac{D_o^2 - D_i^2}{D_i^2} \times 100$

$= \frac{160^2 - 145^2}{145^2} \times 100 = 21.75\%$

$A_r > 20$

It is not sensitive or soft soil

② $A_r = 116.26\%$

It is not sensitive or soft soil

③ $A_r = 11.87\% < 20$

it is a soft soil

04

(ii) $H = 6m$

$S_n = \frac{C}{\gamma H_c}$

$S_n = \frac{C}{\gamma\ FOS\ H_c}$

$FOS = \frac{C}{\gamma H_c S_n}$

$FOS = \frac{C}{\gamma' H_c (\sin\beta\cos\beta - \cos^2\beta \tan\phi)}$

$\beta = 45°$, $\phi = 15°$, $H = 6m$, $C = 18kPa$

$\gamma' = \left(\frac{G-1}{1+e}\right)\gamma_w =$

$\gamma' = \frac{(G-1)}{(1+e)}\gamma_w = \frac{1.65}{1.75} \times 9.81 = 9.25 kN/m^3$

06

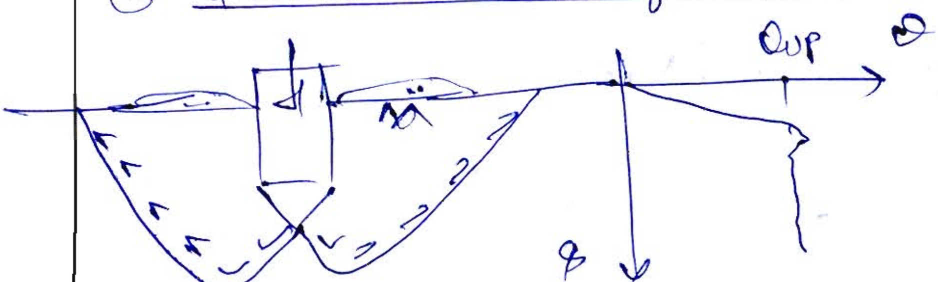
$FOS = \frac{18}{9.25 \times 6 \times 0.08}$

$FOS = 4.05$

Q.1 (e) What are the principal modes of soil failure based on the pattern of shearing zones? Explain with neat sketches along with load settlement curve of each of the modes.

[12 marks]

① General shear failure



→ Occurs in dense soil or over consolidated soils.

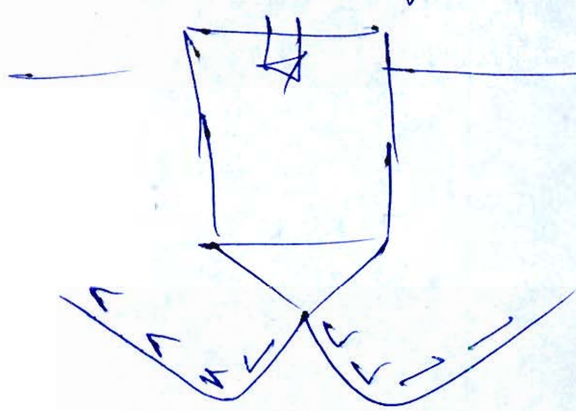
→ stress zone extends upto ground level

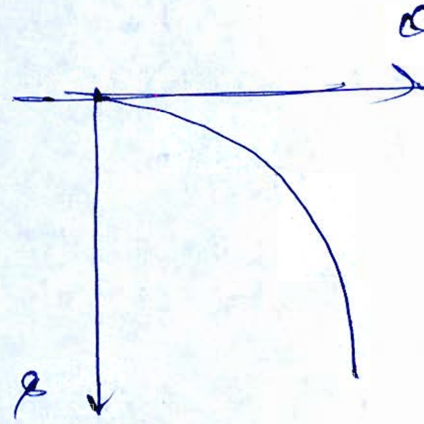
→ Heaving or tilting is observed at G.L

→ clear cut failure is observed in load vs settlement curve

→ Brittle failure

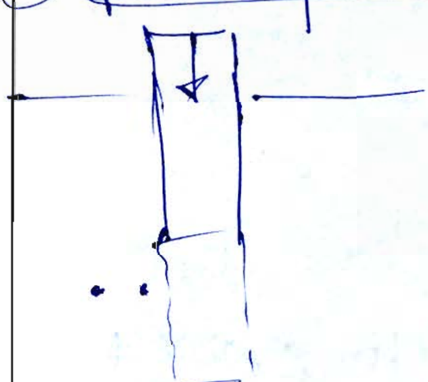
① Local shear failure

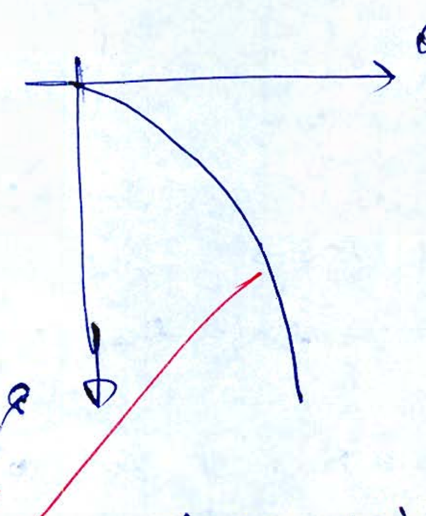




→ occurs in loose soil or Normal consolidated soil.
→ stress zone doesnot extend to G.L
→ Heaving & bulging is not observed
→ large settlement in initial phase of loading
→ No clear cut failure, progressive failure.

② punching shear failure





09

→ occurs in very loose soil
→ large settlement observed
→ adjacent soil solids to the footing are unstressed

Q.2 (a) **(i)** The results obtained from a series of $\overline{CU}$ tests on a soil are as below:

$C_{cu} = C'_{cu} = 0$

$\phi_{cu} = 20°, \phi'_{cu} = 45°$

A sample of this soil was tested in a $\overline{CU}$ test under a cell pressure of 120 kN/m^2.

σ_3

Determine

1. Deviator stress at failure.
2. Pore water pressure at failure
3. Minor principal effective stress at failure
4. Major principal effective stress at failure

(ii) Mention the advantages and limitations of triaxial test.

[16 + 4 = 20 marks]

(i) (1) $\sigma_1 = \sigma_3 \tan^2(45 + \frac{\phi}{2}) + 2c \tan(45 + \frac{\phi}{2})$, $c = 0$

$\sigma_3 = 120$ kPa

$\phi = 20°$

$\sigma_1 = 120 \tan^2(45 + \frac{20}{2})$

$\sigma_1 = 244.75$ kPa

$\sigma_d = \sigma_1 - \sigma_3 = 124.75$ kPa

(2) $\bar{\sigma}_1 = \bar{\sigma}_3 \tan^2(45 + \frac{\phi'}{2})$

$(\sigma_1 - u) = (\sigma_3 - u) \tan^2(45 + \frac{\phi'}{2})$

$(244.75 - u) = (120 - u) \tan^2(45 + \frac{45}{2})$

$u = 94.16$ kPa

16

(3) $\bar{\sigma}_3 = \sigma_3 - u = (120 - 94.16) = 25.84$ kPa

(4) $\bar{\sigma}_1 = (\sigma_1 - u) = 244.75 - 94.16 = 150.3$ kPa

(iii) Advantages

1. failure plane is the weakest plane.
2. Measurement of pore water pressure can be done practically
3. Effectively stimulates field condition of confining stresses
4. Suitable for any type of soil either cohesive or non cohesive.
5. Result could be obtained from any type of condition. (CU, CD, UU)

Limitations:

1. It is time taken process for condition of consolidation undrained test
2. At time, back up pressure valve blocks or does not work effectively
3. costly process
4. costly apparatus.
5. skilled supervision needed

03

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Q.2 (b) A retaining wall with a smooth vertical back retains sand backfill for a depth of 8 m. The backfill has a horizontal surface and has the following properties:

$C' = 0, \phi' = 30°; \gamma = 17\,kN/m^3, \gamma_{sat} = 21\,kN/m^3$

Calculate the magnitude of the total thrust against the wall for the conditions given below:

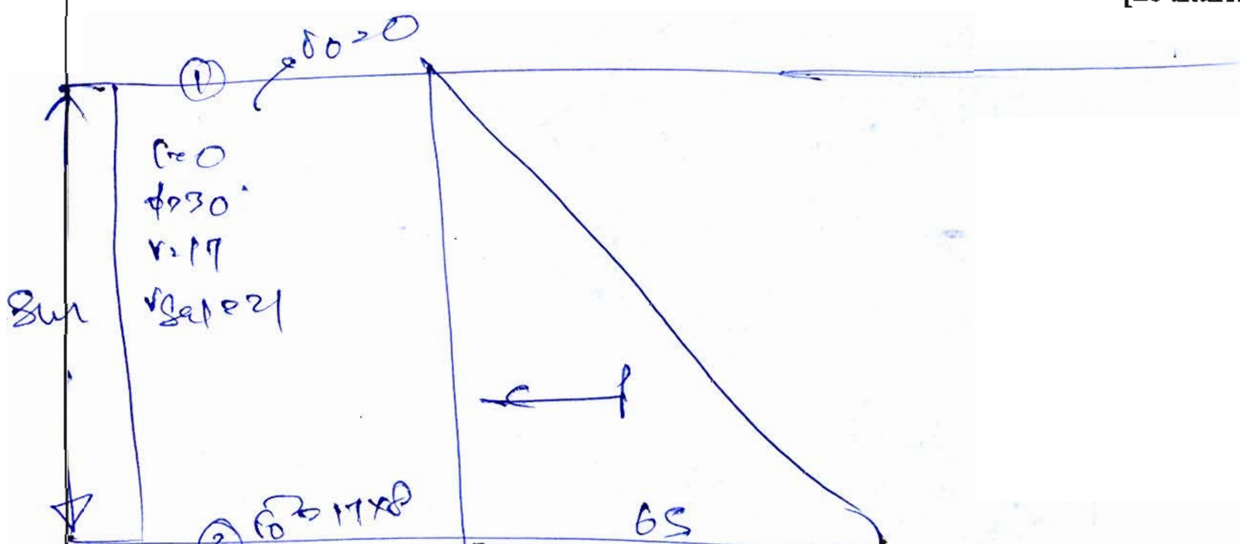
(i) Backfill fully drained but the top of the wall is restrained against yielding.

(ii) Backfill fully drained and the wall is free to yield.

(iii) Wall is free to yield, water table at 4 m depth and there is no drainage.

Also, determine the point of application of resultant thrust for case (iii).

[20 marks]



(i) Rest condition

$K_0 = (1 - \sin\phi) = 0.5$

$P_0 = K_0 \sigma_v$

at ①: $P_a = 0$

at ②: $P_0 = 0.5 \times 17 \times 8 = 68\,kPa$

$P = 0.5 \times 65 \times 8 = 260\,kN/m$

15

(ii) Active condition

$K_a = \frac{1 - \sin\phi}{1 + \sin\phi} = \frac{1}{3} = 0.33$

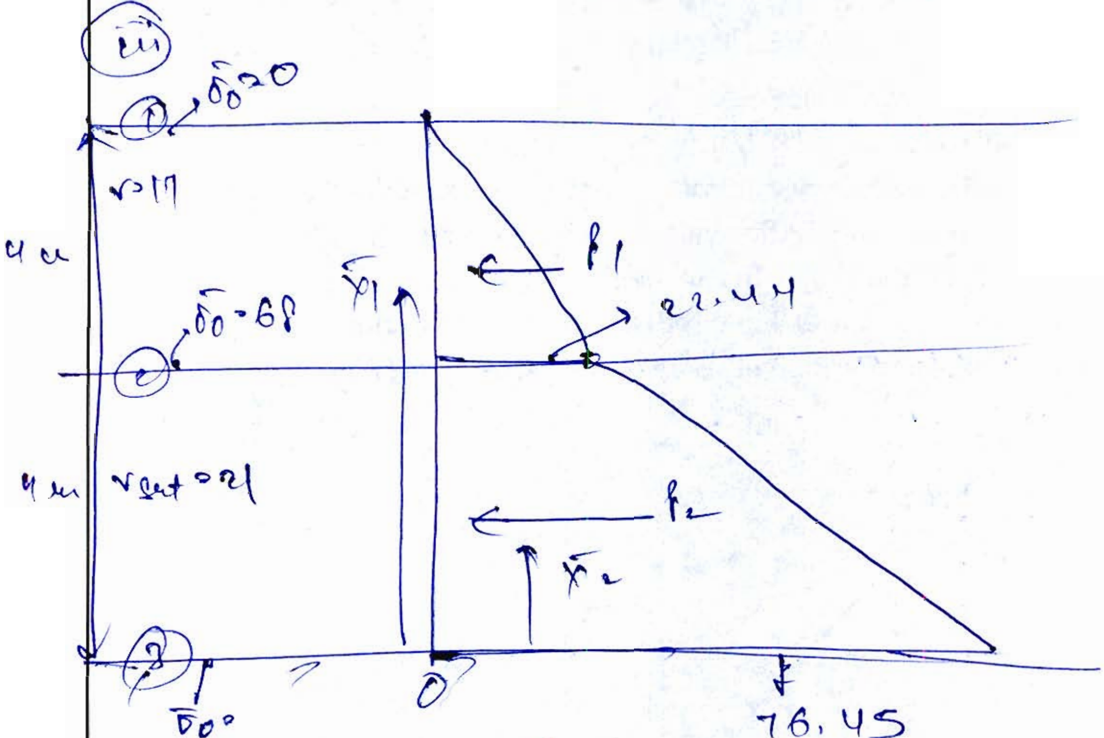
$P_a = K_a \sigma_v$

①: $P_a = 0$

②: $P_a = 0.33 \times 17 \times 8 = 45.33\,kPa$

$P = 0.5 \times 45.33 \times 8 = 181.32\,kN/m$

(iii)



$K_a = 0.33$

$P_a = K_a \bar{\sigma}_v - 2c\sqrt{K_a} + u$

at ①: $P_a = 0$

at ②: $P_a = 0.33 \times 68 = 22.44$ kPa

at ③: $P_a = K_a \bar{\sigma}_v + u$

$= 0.33(17 \times 4 + 4 \times 11.19) + 4 \times 9.81$

$= 76.45$ kPa

$P = P_1 + P_2$

$P_1 = 0.5 \times 22.44 \times 4 = 44.88$ kN/m

$P_2 = 0.5 \times (22.44 + 76.45) \times 4 = 197.78$ kN/m

$P = 242.66$ kN/m

point of application from O.

$$\bar{x} = \frac{P_1 \bar{x}_1 + P_2 \bar{x}_2}{P_1 + P_2}$$

$$\bar{x}_1 = 4 + \frac{4}{3} = 5.33$$

$$\bar{x}_2 = \left(\frac{76.45 + 2 \times 22.44}{76.45 + 22.44}\right) \frac{4}{3} = 1.63$$

$$\boxed{\bar{x} = 2.314\,m}$$

Q.2 (c) (i) What do you understand by permeability of soil? Explain the factors affecting permeability.

(ii) Explain the laboratory methods of determination of coefficient of permeability in coarse and fine grained soils with neat sketches. Derive the expression for coefficient of permeability in the both the cases.

[6 + 14 = 20 marks]

(i) permeability of soil is defined as the property of soil which allows flow of water through it.

Flow of water through soil is governed by Darcy's law which states velocity through soil medium is directly proportional to the hydraulic gradient.

$$v \propto i$$

$$v = ki$$

v → velocity through soil; k → coeff. of permeability; i → hydraulic gradient $\left(\frac{HL}{L}\right)$

04

As per Kozney Carman equation,

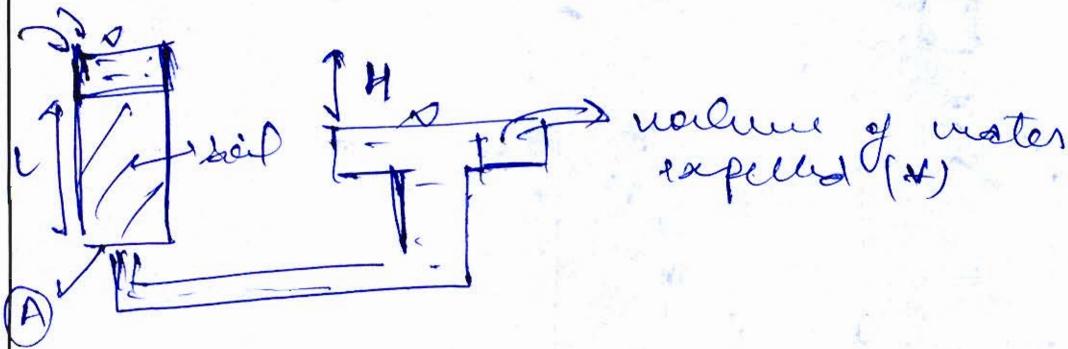
$$K = \frac{1}{K_K}\left\{\frac{e^3}{1+e}\cdot d^2\right\}_{medium}\left(\frac{\gamma}{\mu}\right)_{fluid}$$

permeability depends on fluid properties such as unit weight of liquid & viscosity of liquid.

permeability depends on medium properties such as void ratio & diameter of soil grain.

(ii) (1) constant Head permeability test

→ Done for coarse grained soil.



→ constant Head of water is maintained at every instant of test

→ volume of water expelled from lower elevation water funnel is collected and time period is noted.

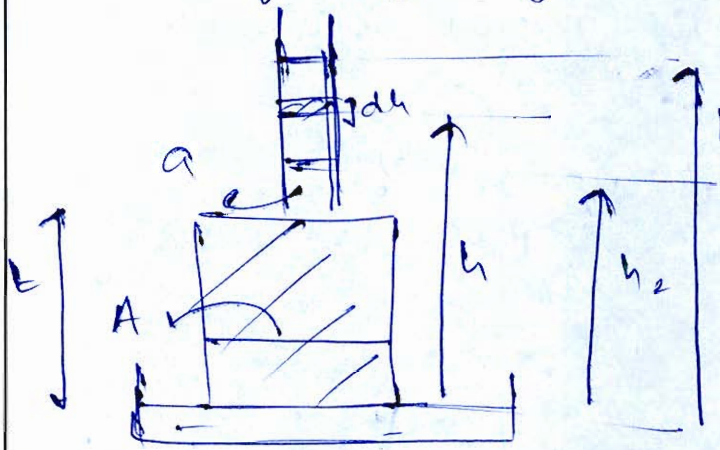
$$Q = kiA = \frac{V}{t}$$

$$k = \frac{V}{tiA} = \frac{VL}{tHA}$$

A = Area of C/S of soil
L = length of soil sample
k = coeff. of permeability
V = vol collected
H = Head given to soil.

Falling Head permeability test

→ Done for fine grained soil



Let in time dt, dh Head drop occurs.

By volume conservation

$Q \cdot dt = -a\,dh$

$kiA\,dt = -a\,dh$

$k\frac{h}{L}A\,dt = -a\,dh$

$\int_0^t dt = -\frac{aL}{AK}\int_{h_1}^{h_2}\frac{dh}{h}$

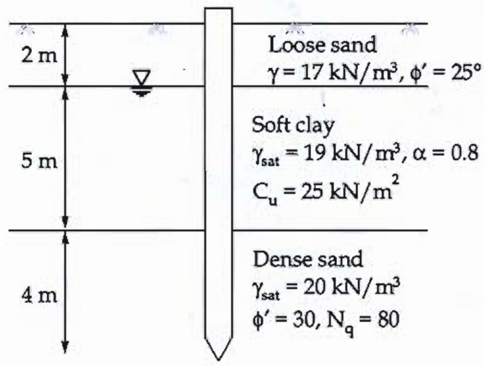
$t = \frac{aL}{AK}\ln\left(\frac{h_1}{h_2}\right)$

$k = \frac{aL}{At}\ln\left(\frac{h_1}{h_2}\right)$

$$k = 2.303\,\frac{aL}{At}\ln\left(\frac{h_1}{h_2}\right)$$

12

Q.3 (a) Determine the allowable load carrying capacity of a 50 cm diameter driven concrete pile as shown in figure.



(Assume, FOS = 2.5)

Given: Values of k and δ as in table below.

Pile material	δ	Values of k	
		Loose sand	Dense sand
Steel	20	0.5	1.0
Concrete	0.75φ	1.0	2.0
Timber	0.67φ	1.5	4.0

[20 marks]

0.5m, $\bar{\sigma}_0 = 0$

γ = 17, φ = 25°, (1) 2m, S, $\bar{\sigma}_0 = 34$

$Q_{sf} = K(\bar{\sigma}_v)_{av} \tan\delta \, A_s$ (18.75)

$= 1 \times \left(\frac{0+34}{2}\right) \times \tan 18.75 \times \pi \times .5 \times 2$

$= 18.12$ kN ✓

(C) $\gamma_{sat} = 19$, α = 0.8, $C_u = 25$, (2) 5m

$Q_{sf_2} = \alpha \bar{c} A_s$

$= 0.8 \times 25 \times \pi \times .5 \times 5$

$= 157.079$ kN

12

$\bar{\sigma}_0 = 79.95$

S, $\gamma_{sat} = 20$, φ = 30°, $N_q = 80$, (3) 4m

$Q_{sf_3} = 1 \times \left(\frac{79.95 + 120.71}{2}\right) \times \tan(22.5) \, \pi \times .5 \times 4$

$= 261.4$ kN

$\bar{\sigma}_0 = 120.71$

$Q_{eb} = \bar{\sigma}_v N_q A_b$

$= 120.71 \times 80 \times \frac{\pi}{4}(.5)^2$

$Q_{eb} = 1896.10$ kN

Q_{eb}

$Q_{eq,H}$ = Q_{eb} + Q_{sf_1} + Q_{sf_2} + Q_{sf_3}

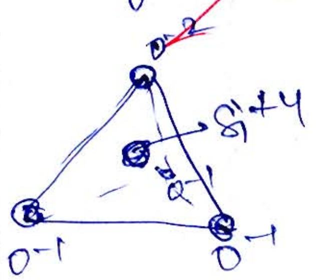
Q_{eq} = 933.079 kN

Q.3 (b) (i) With neat sketches, briefly explain the two fundamental crystal sheets of the clay minerals, viz. the tetrahedral and the octahedral sheet.

(ii) Describe different types of structure of clay mineral formed on the basis of arrangements of silica sheet and the octahedral sheet. **[8 + 12 = 20 marks]**

(i). Tetrahedral structure:

→ one silica ion is surrounded by 4 oxygen ions in tetrahedral geometry.



→ 3 atom of oxygen shares charges and 1 atom of oxygen donot share charge

→ Net charge is −1.

04

(ii). Octahedral structure

→ one trivalent ion (Al) is surrounded by 6 hydroxide ions.

→ Net charge is +1.

(ii) Kaolinite structure:

→ tetrahedral & octahedral unit are formed in 1:1 ratio.

→ Unit are combined with hydrogen Bond.

→ Net charge is 0 (Neutral)

→ large in size
→ Minimum swelling shrinkage
By of Hydrogen Bond
→ Eg. China clay.

(2). Monmorillonite structure

→ Tetrahedral & octahedral unit formed in 2:1 ratio.
→ Net charged structure (−1).
→ Units are combined By water Bonds.
→ Small in size
→ Shows High swelling and shrinkage, as water Bonds are weak Bonds.
→ Eg. Back cotton soil

(3) illite structure:
→ Structure formed By potassium Bonds
→ Size in Between monmorillonite and kaolinite
→ swelling shrinkage potential in Between as of monmorillonite and kaolinite
→ Eg. laterite

08

Q.3 (c) (i) The following test results were obtained on a soil sample:

Percentage passing through 4.75 mm IS sieve = 96%

Percentage passing through 75 μ IS sieve = 10%

D_{60} = 0.23 mm, D_{30} = 0.20 mm, D_{10} = 0.17 mm

Liquid limit = 27%; Plasticity limit = 18%

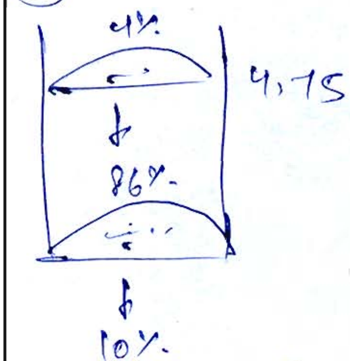
Classify the soil by IS classification.

(ii) A granular soil deposit is 6 m deep and lies over an impermeable layer. The ground water table is 3 m below the ground surface. The deposit has a zone of capillary rise of 1 m with a saturation of 60%. Plot the variation of total stress, pore water pressure and effective stress with the depth of deposit.

Given e = 0.5 and G_s = 2.65.

[8 + 12 = 20 marks]

(i)



① G < S
soil is sand

② fines (5–12%)

$C_u = \frac{D_{60}}{D_{10}} = \frac{0.23}{0.17} = 1.35 < 6$

$C_c = \frac{D_{30}^2}{D_{60} D_{10}} = \frac{0.2^2}{0.17 \times .23} = 1.02$ (1–3)

soil is poorly graded

② w_L = 27%

$(I_P)_{soil}$ = 18%

$(I_P)_{A\ line} = 0.73(27-20)$
$= 5.11\%$

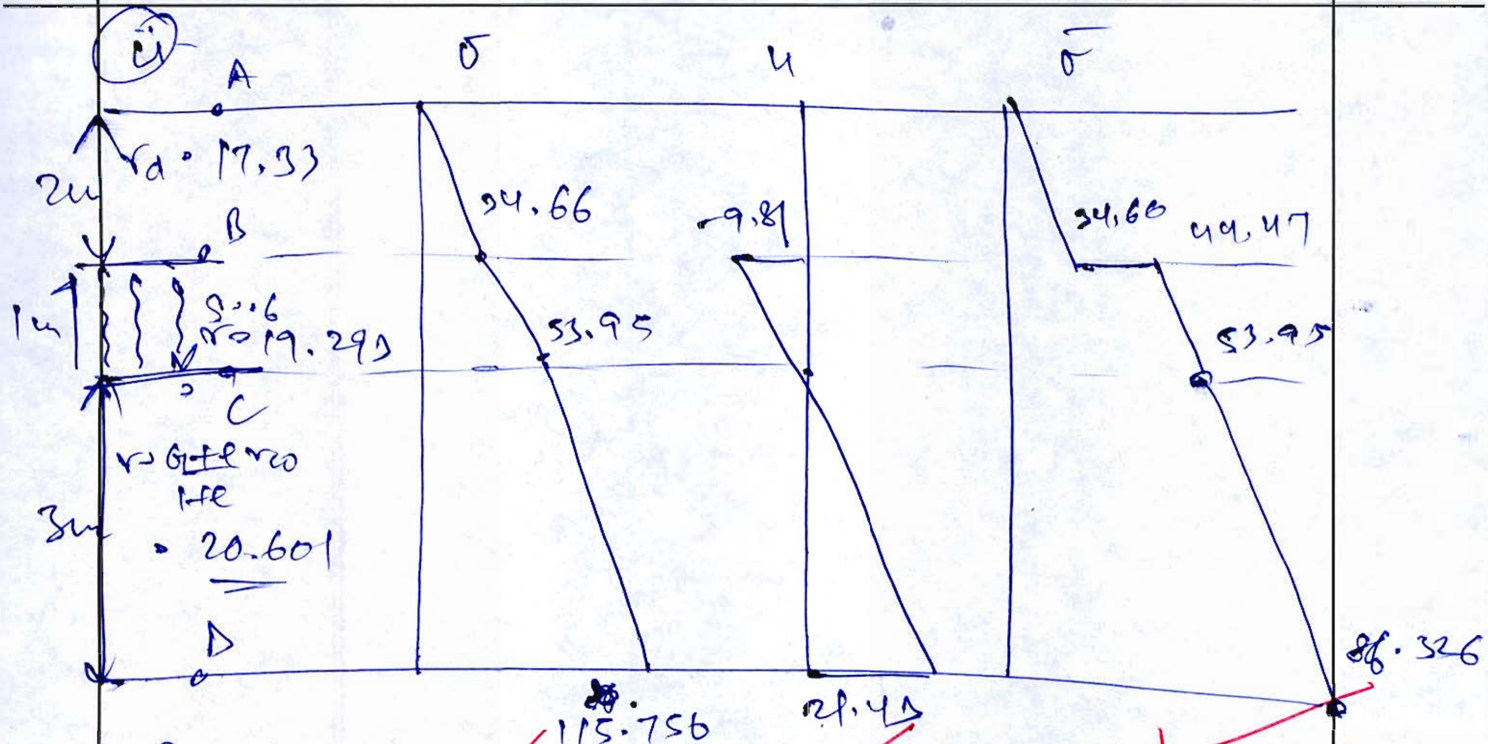
$(I_P)_{A\ line} < (I_P)_{soil}$

⇒ clay

⇒ **SP – SC**

08

(ii)



$\sigma_A = 0$

$u_A = 0$

$\bar{\sigma}_A = 0$

$\sigma_B = 17.33 \times 2 = 34.66$ kPa

$u_B = -9.81$

$\bar{\sigma}_B = \sigma_B - u_B = 44.47$ kPa

$\sigma_C = 17.33 \times 2 + 1 \times 19.293 = 53.95$ kPa

$u_C = 0$

$\bar{\sigma}_C = \sigma_C - u_C = 53.95$ kPa

$\sigma_D = 53.95 + 3 \times 20.601 = 115.756$ kPa

$u_D = 3 \times 9.81 = 29.43$ kPa

$\bar{\sigma}_D = 86.326$ kPa

12

Q.4 (a) (i) What are the assumptions involved in Boussinesq's and Westergaard's theory of stress distribution. Explain, which of the two theories is better suited for natural soil deposits.

(ii) A loading of 60 kN/m^2 is acting on an annular foundation of width 5 m and inside diameter of 8 m. Find the vertical stress intensity at a depth of 10 m below the centre of the foundation.

[10 + 10 = 20 marks]

Q.4 (b) A footing 2.5 m square, rests on a soft clay soil with its base at a depth of 2 m from ground surface. The stratum is 4 m thick and is underlain by a firm sand stratum. The clay soil has the following properties:

$w_L = 30\%$, $w_n = 40\%$, $G_s = 2.65$, $\phi_u = 0$, $C_u = 0.5 \text{ kg/cm}^2$.

It is known that the clay stratum is normally consolidated. Using Skempton's equation, determine the net safe bearing capacity of the soil (in t/m²). Compute the settlement that would result if this load intensity were allowed to act on the footing. Natural water table is at the ground surface. Assume the load spread of 2 V : 1 H and factor of safety of 3.

[20 marks]

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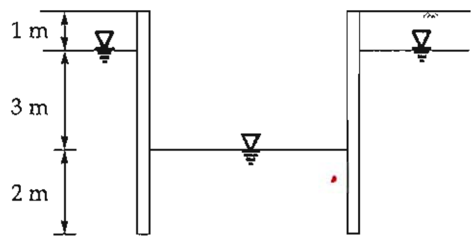
Q.4 (c) (i) What do you mean by consistency of clay? Explain 'ATTERBERG LIMITS' in detail.

(ii) A trench is excavated in fine sand for a building, up to depth of 4 m. The excavation was carried out by providing the necessary side supports for pumping water. The water levels at the sides and bottom of the trench are as given in figure. Examine wheather the bottom of the trench is subjected to a quick sand condition if $G = 2.64$ and $e = 0.7$. If so, suggest the remedies.



[10 + 10 = 20 marks]

Section B : Environmental Engineering

Q.5 (a) The population of a town as per the census records are given below for the years 1961 to 2021. Assume that the scheme of water supply will commence to function from 2026.

Year	Population
1961	42,560
1971	47,820
1981	63,500
1991	86,452
2001	1,11,230
2011	1,39,886
2021	1,82,800

Estimate the population of town after 30 years from the commencement of water supply scheme using geometric and incremental increase method.

[12 marks]

year	pop	% increase (%)	increase x	increase on increase y
1961	42560	–	–	
1971	47820	12.35	5260	
1981	63500	32.79	15680	10420
1991	86452	36.144	22952	7270
2001	111230	28.66	24778	1826
2011	139886	25.76	28656	3878
2021	182800	30.67	42914	14258

$\bar{r} = (r_1 r_2 \ldots r_6)^{1/6}$

$\bar{r} = 26.30\%$

$\bar{x} = \frac{x_1 + x_2 + \ldots + x_6}{6}$

$\bar{x} = 23373.33$

$\bar{y} = \frac{y_1 + \ldots + y_5}{5}$

$= 7530.4$

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$n = 3.5$

Pop^n By GIM = $182800\left(1+\frac{26.30}{100}\right)^{3.5}$

$= \underline{\underline{413893}}$

Pop^n By IIM = $P_0 + n\bar{x} + \frac{n(n+1)}{2}\bar{y}$

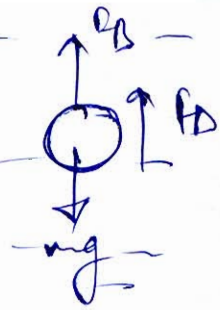
$= 182800 + 3.5 \times 23373.33 + \frac{3.5 \times 4.5}{2} \times 7530.4$

$= \underline{\underline{323909}}$

12

Q.5 (b) Derive governing equation for settling of discrete particles in laminar flow.

[12 marks]



Apply NSL,

$mg = F_B + F_D$

$\rho_B \forall g = \rho_w \forall g + F_D$

$F_D = \frac{1}{2} C_D \rho A V^2$

$(\rho_B - \rho_w) \forall g = \frac{1}{2} C_D \rho_w A (V_s)^2$

$(G_s - 1) \frac{4}{3} \pi \left(\frac{D}{2}\right)^3 g = \frac{1}{2} C_D \left[\frac{\pi}{4} D^2 \right] V_s^2$

$$V_s = \sqrt{\frac{4}{3} \frac{g D (G_s - 1)}{C_D}}$$

As per Stokes law, $C_D = \frac{24}{Re} = \frac{24 \mu}{\rho V D}$

$V_s = \sqrt{\frac{4}{3} \frac{g D (G_s - 1)}{24} \frac{\rho V_s D}{\mu}}$

$V_s^2 = \frac{4}{3} \frac{g D (G_s - 1) \rho V_s D}{24 \mu}$

$V_s = \frac{g}{18} \frac{(G_s - 1) D^2}{\mu / \rho}$

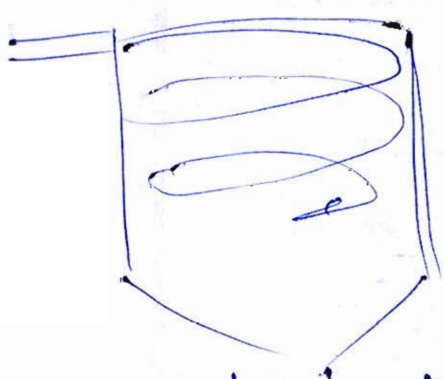
$$V_s = \frac{g}{18} \frac{(G_s - 1) D^2}{\nu}$$

10

Q.5 (c) Explain the following control devices for particles:
(i) Cyclone collectors. (ii) Electrostatic precipitators.
(iii) Fabric filters

[12 marks]

(i) cyclone collectors



→ used as a air pollution control device
→ principle behind using this is that, suspended particles entering this experiences a centrifugal force due to which they settles and hence air gets filtered
→ widely used, cheap,
→ No power consumption
→ Removes suspended particle, but not for removal of gases.

(ii) Electrostatic precipitator

→ used as a air control device in thermal plant and industries.

→ highest efficiency amongst all devices

→ works on the principle of electrostatics.

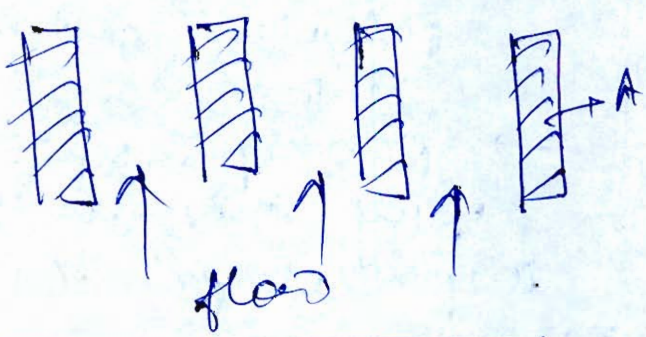
→ charged suspended particles are attracted toward the plates due to high voltage electrostatic forces.

→ costly process

→ high power consumption

→ can removal solids of even size < 2 mm.

→ not for gases removal



$$\eta = 100\left(1 - e^{-\frac{wA}{Q}}\right)$$

efficiency = η

ω = drift velocity

A = plate area

Q = Discharge through precipitator

(iii) fabric filters:

→ Air is passes through series of fabric Bags

→ Suspended solids of size greater than the voids created in Bags, gets trapped and removal from the system.

→ highly efficient

→ cheaper than electrostatic precipitator

→ No power consumption.

→ Not used for gases removal.

08

Q.5 (d) Design a septic tank for a colony of 250 people. The colony is supplied water at a rate of 135 litres/person/day. Assume a detention period of 24 hours and 80% of water becomes waste water. The tank is cleaned once in a year. The rate of deposition of sludge is 42 litres/person/year. Depth of tank is to be kept as 2.0 m. Provide a free board of 0.3 m. Length to breadth ratio may be kept as 3.5 : 1.

[12 marks]

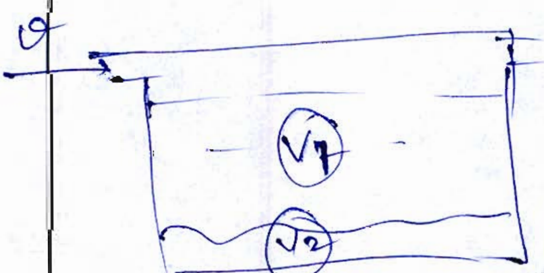
250c

q = 135 lpcd.

Dt = 24 Hours

flow through tank = $0.8 \times 135 \frac{l}{d\,c} \times 250\,c$

$= 270 \times 10^2\ l/d$



volume V_1 = (Weather Discharge)(Detention time)

= $270 \times 10^3 \times 10$

$V_1 = 270\ m^3$

volume V_2 = (Rate of Accumulation of Sewage)(Desludging interval)

= $42\ l/day \times 250 \times 1$

$V_2 = 10.5\ m^3$

Total vol. of tank = $37.5\ m^3$

At Height = 2m

Area of tank = $\frac{37.5}{2} = 18.75\ m^2$

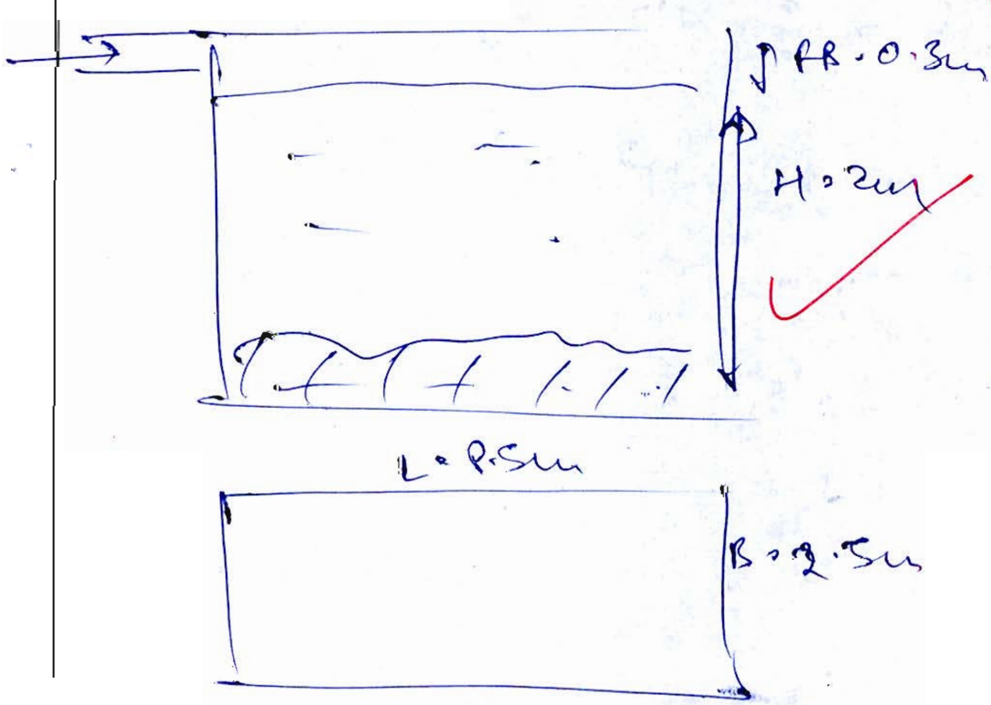
$\frac{L}{B} = \frac{2.5}{1}$

$B = 2.31\ m \simeq 2.5\ m$

$L = 8.1\ m \simeq 8.5\ m$

provide FB = 0.3m

(12)



Q.5 (e) The BOD_5 of waste water is 150 mg/lt at 20°C. The deoxygenation constant (base 10) is 0.1 per day. What would be $(BOD)_8$, if the test is performed at 15°C?

[12 marks]

$BOD_5 = 150 mg/L$ (20°C)

$BOD_5 = BOD_u(1 - 10^{-kt})$

$150 = L_0(1 - 10^{-0.1 \times 5})$

$L_0 = 219.37 mg/L$

$K_{15°C} = K_{20°C} \times (1.056)^{15-20}$

$= 0.076 d^{-1}$

$BOD_8 = L_0(1 - 10^{-K_{15} \times t})$

$= 219.37(1 - 10^{-0.076 \times 8})$

$BOD_8 = 165.27 mg/L$

10

Q.6 (a) Design a rapid sand filter unit with rate of filtration as 5000 lt/hr/m^2 for 4 million litres per day of supply with all its principal components.
[Assume 4% of filtered water is required for washing the filter with rate of washing as 60 cm rise/minute and 30 minutes is required for filter washing per day]

[20 marks]

$f_r = 5000$ l/Hr/m^2 $\quad V_B = 60$ cm/min

$Q = 4 \times 10^6$ l/d

Discharge after backwash Demand $= \dfrac{4\times10^6}{0.96}$ l/d

$Q = 4.167 \times 10^6$ l/d

$f_r = \dfrac{Q}{SA}$

$5000 \dfrac{l}{Hr\,m^2} = \dfrac{4.167\times10^6 \dfrac{l}{d} \times \dfrac{d}{23.5\,H}}{SA}$

SA = 35.46 m²

no. of filters req = 1.22 $\sqrt{Q}$

= 1.22 $\sqrt{4.167}$

= 2.49 ≃ 3

SA each filter = 11.82 m²

provide L : B = 1.5 : 1

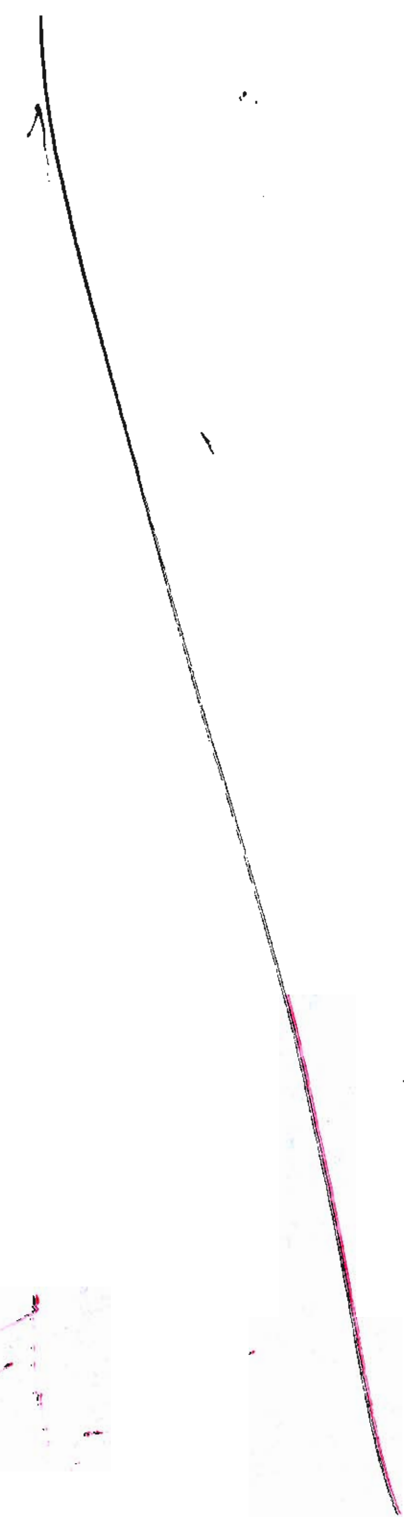
L = 6.3 m

B = 4.2 m

Q.6 (b) **(i)** Explain breakpoint chlorination along with its advantages.

(ii) What are the tests done for chlorine residuals? Explain.

[8 + 12 marks]



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Q.6 (c) A circular sanitary sewer is designed to carry the maximum flow of sewage while flowing 70% full at a velocity of 0.9 m/sec. If the ratio of $\frac{\text{Maximum}}{\text{Average}}$ and $\frac{\text{Average}}{\text{Minimum}}$ flow are 3 and 2.5 respectively, find out:

(i) The proportionate depth of flow.

(ii) The velocities of flow generated at the time of average flow and minimum flow.

(The variation of Manning's '*n*' with depth may be neglected).

[20 marks]

$v_0 = 0.79\ m/s$

$\frac{d}{D} = 0.7$

Q.7 (a) (i) Determine the size of a high rate trickling filter for the following data:

1. Sewage flow = 4.5 MLD
2. Recirculation ratio = 1.5
3. BOD of raw sewage = 250 mg/lt
4. BOD removal in primary tank = 30%
5. Final effluent BOD desired = 30 mg/lt.
6. Depth of filter = 1.5 m

(ii) What are different zones of pollution in a river stream?

[15 + 5 = 20 marks]

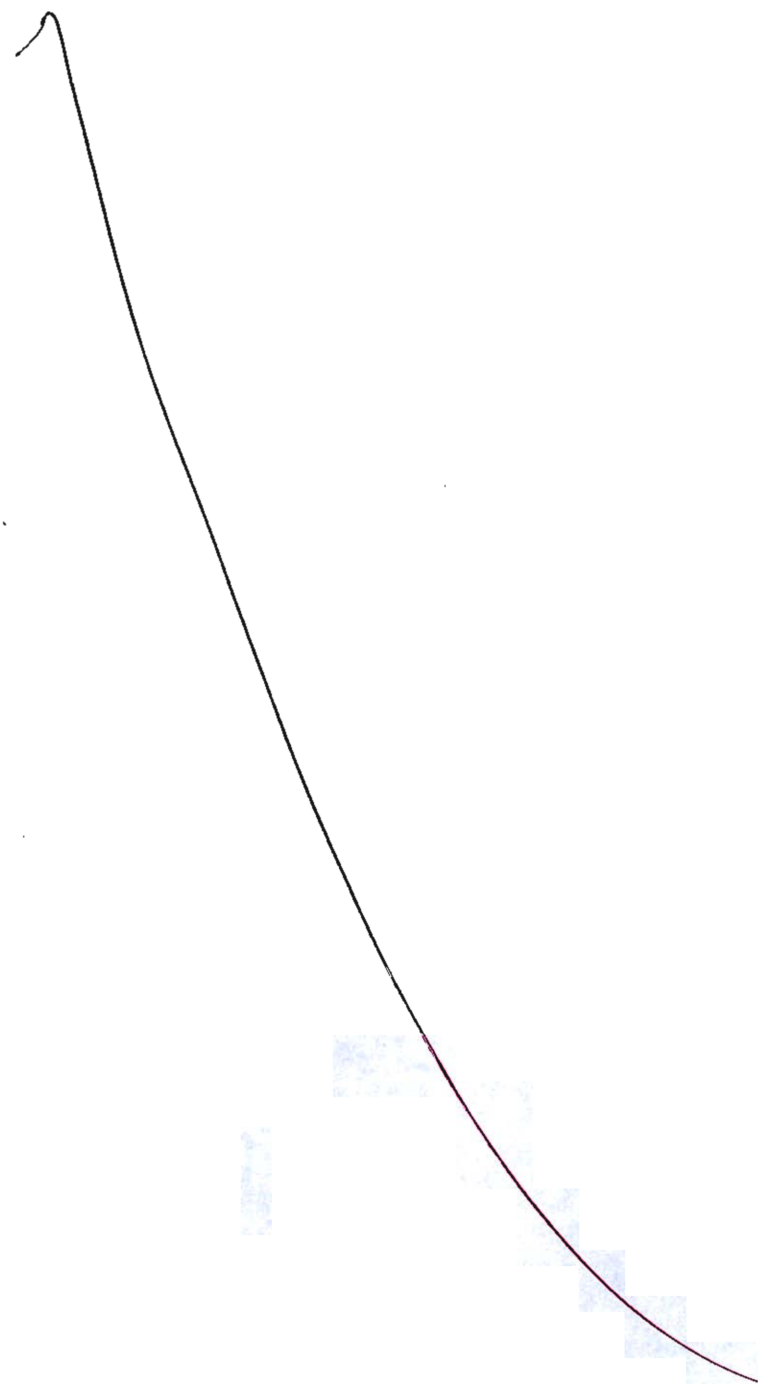
Q.7 (b) (i) Design a digestion tank of depth 6 m for the primary sludge with the help of following data:

1. Average flow = 20 MLD.
2. Total suspended solids in raw sewage = 300 mg/lt.
3. Moisture content of digested sludge = 85%.
4. Digestion period = 30 days.
5. 65% of solids are removed in primary settling tank.
6. Moisture content of fresh sludge = 95%
7. Moisture content of digested sludge = 85%
8. Specific gravity of wet sludge = 1.02

Assume any other suitable data if required.

(ii) Explain productivity of lake. Also explain the **types of lakes** based on increasing level of its productivity.

[12 + 8 = 20 marks]



.7 (c) A town with a population of 30,000 requires a sewage treatment plant to handle industrial as well as domestic wastewaters of the town. A sanitary survey revealed the following: Dairy wastes of 3 million litres per day with BOD of 1100 mg/lt and sugar mill waste of 2.4 million litres per day with BOD of 1500 mg/lt are produced. In addition, domestic sewage is produced at the rate of 240 litre per capita per day. The per capita BOD of domestic sewage being 72 gm/day. An overall expansion factor of 10% to be provided. The sewage effluents are to be discharged into a river stream with a minimum dry weather flow of 4500 lt/sec. and a saturation dissolved oxygen content of 9 mg/litre in the stream. Determine the degree of treatment required to be given to the sewage. Assume coefficient of deoxygenation and coefficient of deoxygenation as 0.1 and 0.3 day^{-1} (base 10) respectively. The dissolved oxygen content is not to fall below 4 mg/lt.

[20 marks]

Q.8 (a) (i) Explain different types of plumes along with their neat sketches.

(ii) Determine the effective height of a stack with the following given data:

(a) physical stack is 180 m tall with 0.95 m inside diameter.

(b) wind velocity is 2.75 m/sec.

(c) barometric pressure is 1000 millibars.

(d) stack gas velocity is 11.12 m/sec.

(e) stack gas temperature is 160°C.

[15 + 5 = 20 marks]

(ii) H = 180m

$$\Delta H = \frac{V_s D}{u}\left(1.5 + 2.68\times10^{-3} PD\left(\frac{T_s - T_a}{T_s}\right)\right)$$

$V_s = 11.12 m/s$

$u = 2.75 m/s$

$D = 0.95 m$

$P = 1000 mB$

$D = 0.95 m$

$T_s = (160 + 273) = 433 K$

$T_a = (25 + 273) = 293 K$

assumed (air temp)

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ΔH = 8.988m

effective height = ΔH + H
= 188.98
≃ 189 m

05

(ii) Different types of plume.

(1) Looping plume

→ occurs when environmental lapse rate (ELR) is greater than Adiabatic lapse rate (ALR)

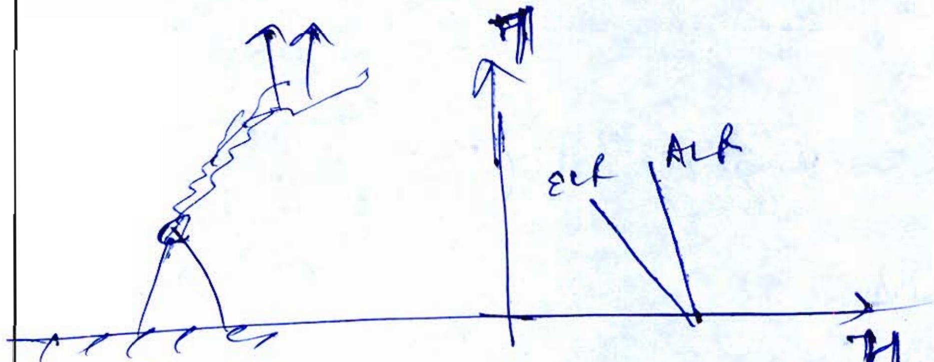
ELR > ALR

→ super Adiabatic condition.

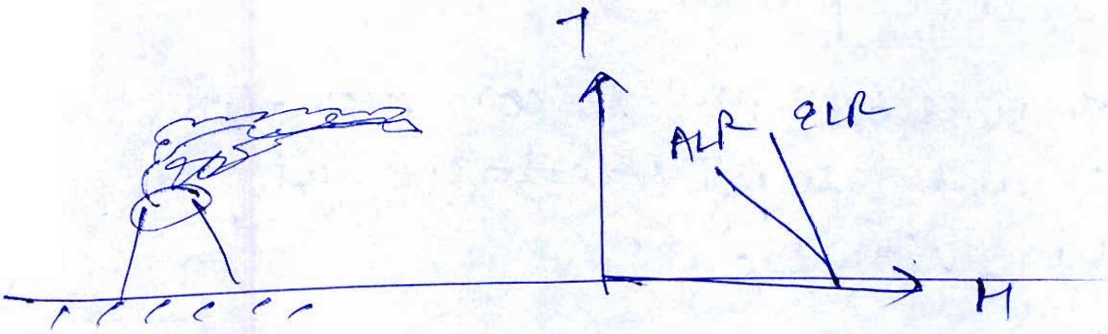
→ plume dispersion quickly

→ unstable plume

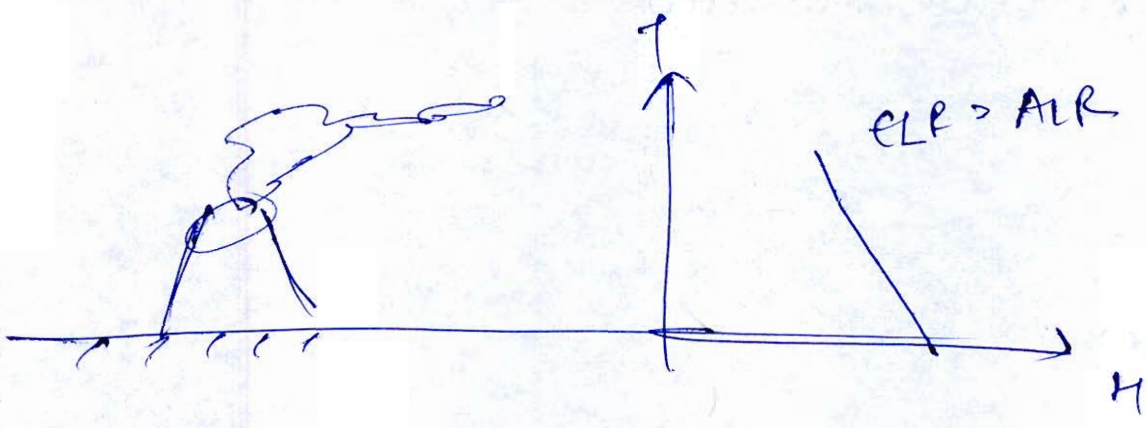
→ best condition.



② Coning plume
→ Occurs when ELR < ALR
→ SubAdiabatic condition
→ plume is stable and takes larger time to dissipate
→ Verst condition



③ Neutral plume
→ Occurs when ELR = ALR
→ Neutral condition
→ Better than subAdiabatic condition



④ Fanning plume
→ Occurs under complete inversion case.
→ when top to Bottom plume experience a raise in temperature as moving Away from ground.

(5) ~~Lofting~~ Fumigating plume

→ plume experiences a super-adiabatic condition (ELR > ALR) at closer to ground. And experiences inversion at Higher elevation.

(6) Lofting plume

→ Inversion at lower elevation level and super Adiabatic at Higher elevation.

(7) Trapped plume

→ inversion at lower & Higher level.

→ Super Adiabatic at middle / moderate elevation.

12

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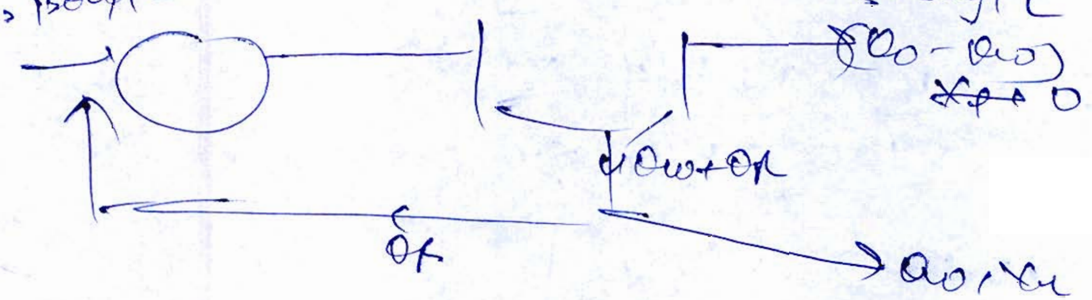
.8 (b) An activated-sludge system is to be used for secondary treatment of 10000 m^3/d of municipal wastewater. After primary classification, the BOD is 150 mg/lt and it is desired to have not more than 5 mg/lt of soluble BOD in the effluent. A completely mixed reactor is to be used, and pilot-plant analysis has established the following kinetic values: y = 0.5 kg/kg, k_d = 0.05d^{-1}. Assuming MLSS concentration of 3000 mg/lt and an underflow concentration of 10000 mg/lt from the secondary clarifier, determine:

1. The volume of the reactor.
2. The mass and volume of solids that must be wasted each day.
3. The recycle ratio.

[Assume sludge age = 10 days]

[20 marks]



Y = 0.5
Kd = 0.05d^{-1}
X = 3000mg/L
Xu = 10000 mg/L

θ_c = 10 day

(1) $VX = \frac{Q_0(S_0 - S)\theta_c Y}{1 + K_D \theta_c}$

$V \times 3000 \text{mg/L} = \frac{10000 \frac{m^3}{d} \times (145) \text{mg/L} \times 10d \times 0.5}{1 + 0.05 \times 10}$

V = 1611.11 m^3

(vi) $Q_e = \dfrac{4Y}{Q_0 X_{cl} + (Q_0 - Q_w) X_e}$ → 0 (Assume)

$10_d = \dfrac{1611.11\ m^3 \times 3000\ mg/L \times 10^3 / 10^6\ kg}{Q_0 \times 4}$

$Q_0 X_{cl} = 483.33\ kg/d$

$Q_w = \dfrac{483.33\ kg/d \times 10^{-3}}{10000\ mg/L \times 10^{-6}}$

$Q_w = 48.33\ m^3/d$

(7) $\dfrac{Q_R}{Q_0} = \dfrac{X}{X_u - X}$

$= \dfrac{3000}{10000 - 3000}$

$\dfrac{Q_R}{Q_0} = 0.42$

18

.8 (c) (i) Convert 150 mg/m³ of SO_2 concentration at 20°C into ppm.

(ii) A 0.6 m well is constructed in an unconfined aquifer of thickness 20 m. Assume that aquifer to be composed of sand with permeability of 50 m/day and storage coefficient $S_c = 0.22$. The original piezometric surface is 10 m below ground surface. After pumping the well for 1 day, the drawdown in the observation well 25 m away is 2.5 m. Calculate the pumping rate that caused this drawdown. Maintaining this pumping rate, what will be the drawdown in the observation well after 1 year?

[10 + 10 = 20 marks]

(i) $150\ mg/m^3 = 150 \times 10^{-3}\ mg/m^3$

$$\text{conc (in } \frac{mg}{m^3}) = (\text{conc in ppm}) \times \frac{\text{Molar mass} \times 10^{3}}{\text{vol of gas per mol.}}$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{1 \times 22.4\ l/mol}{273.15} = \frac{1 \times V_2}{(273.15 + 20)}$$

$V_2 = 24\ l/mol.$

$\Rightarrow 150 \times 10^{-3} = (\text{conc in ppm}) \times \frac{64 \times 10^{3}}{24}$

conc in ppm = 5.625×10^{-5}

10

(ii)

$r_w = 0.3m$

$H = 20m$

$K = 50m/d$

$S = 0.22$

1 day → $s = 2.5m$ $r = 25m$

(i) $s = \frac{Q}{4\pi T}\left\{\ln\left(\frac{4Tt}{r^2 S}\right) - 0.5772\right\}$

$2.5 = \frac{Q}{4\pi(50 m/d \times 20)}\left\{\ln\left(\frac{4\times1\times50\times20}{25^2\times0.22}\right) - 0.5772\right\}$

$Q = 11247.18\ m^3/d$

(ii)

$s = \frac{Q}{4\pi T}\left\{\ln\left(\frac{4Tt}{r^2 S}\right) - 0.5772\right\}$

$= \frac{11247.18}{4\pi\times50\times20}\left\{\ln\left(\frac{4\times50\times20\times365}{25^2\times0.22}\right) - 0.5772\right\}$

$= 7.78m$

10

■■■■

Space for Rough Work

Space for Rough Work