MADE EASY
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ESE 2026 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Civil Engineering

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

Name : .....

Roll No :

Test Centres	Student's Signature
Delhi ☑ Bhopal ☐ Jaipur ☐ Pune ☐ 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	54
Q.2	—
Q.3	—
Q.4	50
Section-B	
Q.5	60
Q.6	50
Q.7	48
Q.8	—
Total Marks Obtained	262

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

Good

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.

Section A : Geo-technical & Foundation Engineering

1 (a) A homogeneous clay layer, 9 m thick, is expected to have an ultimate settlement of 308 mm. After a time span of 2 years, the average settlement was measured to 108 mm. How much longer will it take for the average settlement to attain 220 mm?

[12 marks]

$H = 9m \rightarrow \Delta H = 308mm$

Assuming single drainage

$\Delta h = 108mm \rightarrow 2$ years

$\therefore d = H = 9m$

$\frac{\Delta h}{\Delta H} = 0.35 \rightarrow \frac{\pi}{4} \times (0.35)^2 = C_v \times \frac{2}{81}$

$\therefore C_v = 3.911\ m^2/year$

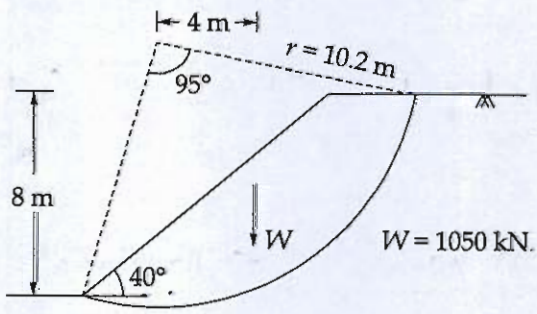
Now, $\frac{\Delta h}{\Delta H} = \frac{220}{308} = 0.7143 > 0.6$ (12)

$\therefore T_v = 1.781 - 0.933 \log(100 - 71.43) = \frac{C_v t}{d^2} = \frac{3.911 \times t}{81}$

$\therefore \boxed{t = 8.75 \text{ years}} \rightarrow$ Additional $= 8.75 - 2$

$= 6.75$ years

Q.1 (b) (i) A 40° slope is excavated to a depth of 8 m in a deep layer of saturated clay ($c = 50\ KN/m^2$ and $\phi = 0°, \gamma = 19\ KN/m^3$). Determine the factor of safety for the trial failure surface shown in Figure.



(ii) Explain the difference between soil liquefaction and quick sand condition.

[6 + 6 = 12 marks]

(i)

$$FOS = \frac{\bar{C} \times L_{arc} \times (1) \times R}{W \times 4}$$

$$= \frac{50 \times 95 \times 2\pi \times 10.2 \times 1 \times 10.2}{360 \times 1050 \times 4}$$

$$FOS = 2.0536$$

(ii) Soil liquefaction

→ It occurs in ~~loss~~ loose saturated sand due to dynamic loads (like during earthquake).

→ Due to dynamic load pore water pressure increases upto such extent that the ~~soil~~ effective stress becomes zero.

→ For sand, $C=0$ & if $\bar{\sigma}$ also becomes zero, then shear strength becomes zero & soil liquifies.

Quick sand condition

(2)

→ It occurs in fine saturated sand.

→ Due to upward ~~sp~~ seepage pressure, effective stress in soil becomes zero.

→ therefore, sand looses all its shear strength.

→ It occurs on downstream portion of dam.

.1 (c) A soil sample has a maximum dry density of 1.65 g/cc at an optimum moisture content (OMC) of 14.5%. The specific gravity of the soil solids is 2.70. Determine the degree of saturation and the percentage air voids at OMC. Also estimate the theoretical maximum dry density.

[12 marks]

Soln

$(\gamma_d)_{max} = 1.65\ gm/cm^3 \rightarrow w = 14.5\%$

$G = 2.7$

Now, $\gamma_d = \dfrac{G\gamma_w}{1 + \frac{wG}{S}} \Rightarrow 1.65 = \dfrac{2.7 \times 1}{1 + \left(\frac{0.145 \times 2.7}{S}\right)}$

$\therefore \boxed{S = 61.52\%}$ Ans

Now, $\gamma_d = \dfrac{(1 - n_a) G \gamma_w}{1 + wG}$

$\therefore 1.65 = \dfrac{(1 - n_a) \times 2.7 \times 1}{1 + (0.145 \times 2.7)}$

12

$\therefore \boxed{n_a = 14.96\%}$

$(\gamma_{d\,max})_{theoretical} = \dfrac{G\gamma_w}{(1 + wG)} = \dfrac{2.7 \times 1}{1 + (0.145 \times 2.7)}$

$= \boxed{1.94\ gm/cm^3}$ Ans

Q.1 (d) Two square footings with a contact pressure of 300 kPa under each are placed 6 m apart (center-to-center) on the ground surface.

Footing *A*: 2.5 m × 2.5 m

Footing *B*: 3.0 m × 3.0 m

Determine the increase in vertical stress at a depth of 3 m below the ground surface at the following locations:

(i) Vertically below the center of Footing *A*

(ii) Vertically below the center of Footing *B*

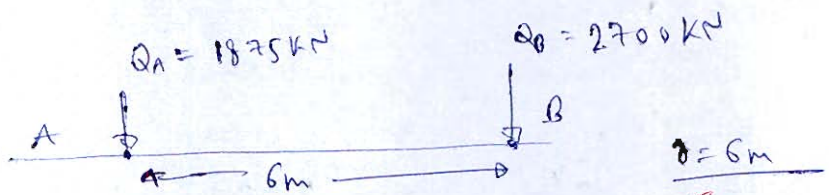
(iii) Vertically below the midpoint between the two footings.

Use Boussinesq's point load formula.

[12 marks]

Soln)

$q = 300\ kPa$



(i) $\sigma_z = \frac{Q}{z^2} \times \frac{3}{2\pi} \left[\frac{1}{1+\left(\frac{r}{z}\right)^2}\right]^{5/2}$

$= \frac{3}{9 \times 2\pi}\left[1875 + 2700 \times \left[\frac{1}{1+\left(\frac{6}{3}\right)^2}\right]^{5/2}\right]$

$\therefore \quad \sigma_z = 102.034\ kPa$

(i) $\sigma_z = \frac{3}{2\pi \times 9}\left[2700 + .1875\left\{\frac{1}{1+\left(\frac{6}{3}\right)^2}\right\}^{2.5}\right]$

$\therefore \boxed{\sigma_z = 145.02 \text{kPa}}$

(iii) $\sigma_z = \frac{3}{2\pi \times 9}\left[\frac{1}{1+1}\right]^{2.5} \times (1875 + 2700)$

$\therefore \boxed{\sigma_z = 42.906 \text{kPa}}$

12

Q.1 (e) An undisturbed soil in a borrow area has a water content of 16%, a void ratio of 0.55, and a specific gravity of solids of 2.7. This soil is used to construct an embankment with a finished volume of 60,000 m^3. The soil is excavated and transported via trucks with a 5 m^3 capacity. When loaded to capacity, these trucks contain a net weight of soil equal to 70 KN. During construction, water is added to bring the water content to 19%. The soil is then compacted to a dry unit weight of 18.0 KN/m^3. Using unit weight of water = 10 kN/m^3.

Calculate:

1. The degree of saturation, bulk unit weight, and dry unit weight of the undisturbed borrow material.
2. The number of truck loads required for construction.
3. The amount of water (in litres) to be added per truck load.

[6 + 3 + 3 = 12 marks]

vii)

Borrow	Embank.
$w = 0.16$, $e = 0.55$	$V = 60{,}000\ m^3$
$G = 2.7$	$\gamma_d = 18\ KN/m^3$
	$\gamma_w = 10\ KN/m^3$

(1)

$Se = wG$

$\therefore S = \left(\frac{0.16 \times 2.7}{0.55}\right) = 78.55\%$

6

$\gamma_b = \frac{(G + Se)\gamma_w}{(1+e)} = \left[\frac{2.7 + (0.785 \times 0.55)}{1.55}\right] \times 10$

$\therefore \gamma_b = 20.2\ KN/m^3$

$\gamma_d = \frac{\gamma_b}{1+w} = 17.414\ KN/m^3$

2)

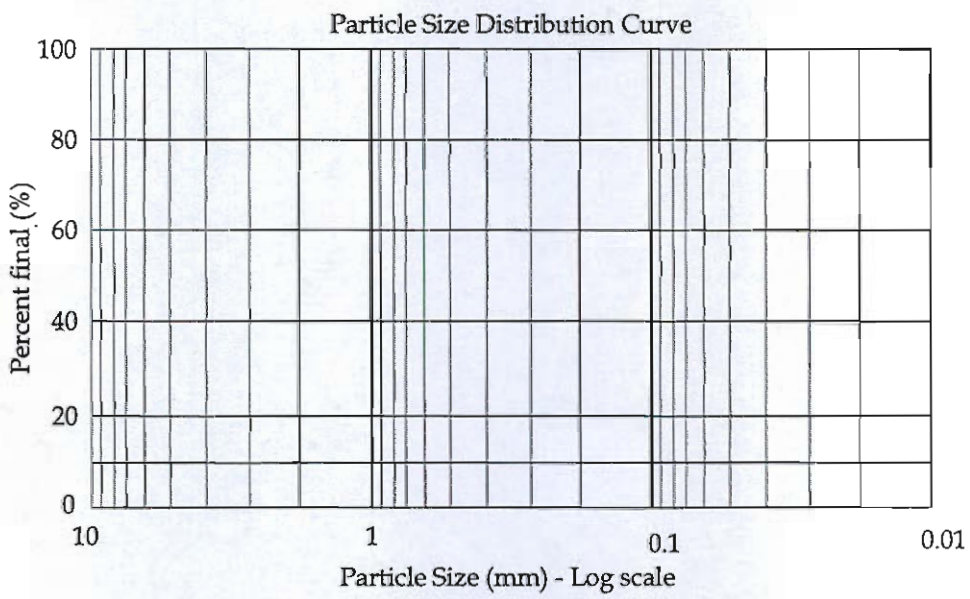
$W_s = 18 \times 60 \times 10^3 = 108 \times 10^4\ KN$

Truck

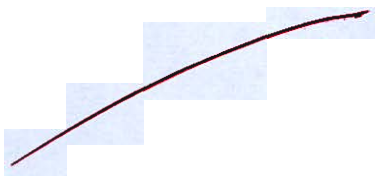
$V = 5\ m^3$

$W = 70\ KN$

Q.2 (a) A 500 g dry soil sample was subjected to a sieve analysis. The masses of soil retained on each sieve are as follows: 12 g on 4.75 mm sieve, 160 g on 2.00 mm sieve, 115 g on 1.00 mm sieve, 95 g on 425 μm sieve, 45 g on 212 μm sieve, 25 g on 150 μm sieve, 40 g on 75 μm sieve, and 8 g in the pan. Plot the Particle Size distribution curve on semi log graph given below. Determine the soil fractions and the gradation of the soil classify the soil also.



[20 marks]



.2 (b) Consolidated undrained triaxial tests were performed on two identical specimens of saturated clay with pore pressure measurements. The observations are as belows: Determine the shear strength parameters in terms of both total and effective stresses.

Specimen	Cell pressure (σ_3)	Deviator stress($\Delta\sigma_d$)	Pore Pressure (u)
1	$100kPa$	$160\ kPa$	$40\ kPa$
2	$300kPa$	$320\ kPa$	$120\ kPa$

[20 marks]

.2 (c) (i) A footing is constructed 2.0 m below the ground surface. The base is 3.0 m × 3.0 m and carries a total load of 2100 kN. The substrata consist of:

Sand & Gravel Layer: From ground to 5.0 m depth ($\gamma = 21.0$ kN/m^3).

Water Table: Located at 5.0 m below the ground surface.

Clay Layer: A 3.0 m thick normally consolidated clay layer exists below the sand ($e_0 = 1.1$, $C_c = 0.6$, $G_s = 2.72$).

Compute the probable ultimate consolidation settlement of footing.

(ii) Explain the criteria for design of protective filters in earthen dams.

[10 + 10 = 20 marks]

Q.3 (a) (i) At a proposed construction site, the soil profile consists of a 5 m thick layer of sand (G = 2.66, e = 0.70, D_{10} = 0.2 mm) underlain by a 4 m thick layer of clay (G = 2.72, w = 30%). Below the clay layer lies a dense, impermeable hardpan. The water table is located at a depth of 3 m below the ground surface. A uniform surcharge load of 20 kN/m^2 is applied over the entire ground surface. Assuming the capillary rise constant C = 0.5 cm^2 and that the clay layer is fully saturated, determine and plot the distribution of pore water pressure, total stress and effective stress.

(ii) Write short note over bulking of sand.

[15 + 5 = 20 marks]

Q.3 (b) (i) A pumping-out test was carried out in the field to determine the average coefficient of permeability of a 22 m thick sand layer. The ground water table was located at a depth of 3.5 m below the ground level. A steady state was reached when the discharge from the well was 25.0 lit/sec. At this stage, the drawdown in the test well was 3.10 m, while the drawdowns in two observation wells situated at 10 m and 25 m from the test well were found to be 2.15 m and 1.60 m respectively.

Determine:

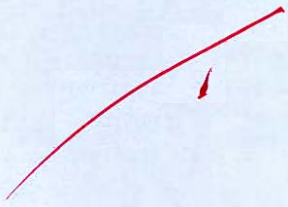
(a) Coefficient of permeability of the sand layer in m/day.

(b) Radius of influence of the test well.

(c) Effective size of the sand using Allen Hazen's formula (take $C = 110$).

[4 + 4 + 2 = 10 marks]

(ii) Discuss the type of foundations to be provided in Expansive soils. **[10 marks]**



Q.3 (c) A square group of 16 piles (arranged in a 4 × 4 formation), each 12 m long and 400 mm in diameter, supports a raft footing founded 1.5 m below the ground surface. The pile group is spaced at 1.2 m center-to-center. The foundation soil consists of a 19.5 m thick layer of normally consolidated clay underlain by dense sand, with the water table residing at the ground level.

The gross load carried by the pile group is 350 t. The properties of the clay are:

Water content (w): 32%

Specific Gravity (G): 2.67

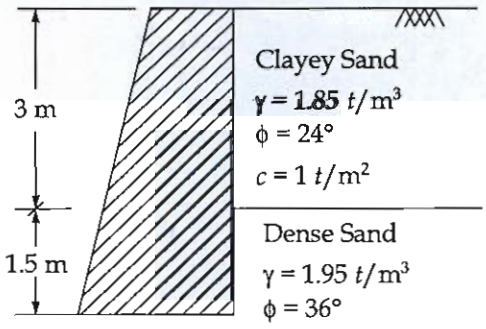
Liquid Limit (LL): 50%

Estimate the probable consolidation settlement of the pile group. Assume the load is distributed at an angle of 60 with the horizontal from an equivalent raft located at 2/3 of the pile length. For accuracy, divide the compressible clay layer into three sublayers of 3 m, 3 m, and 4 m thickness.

[20 marks]

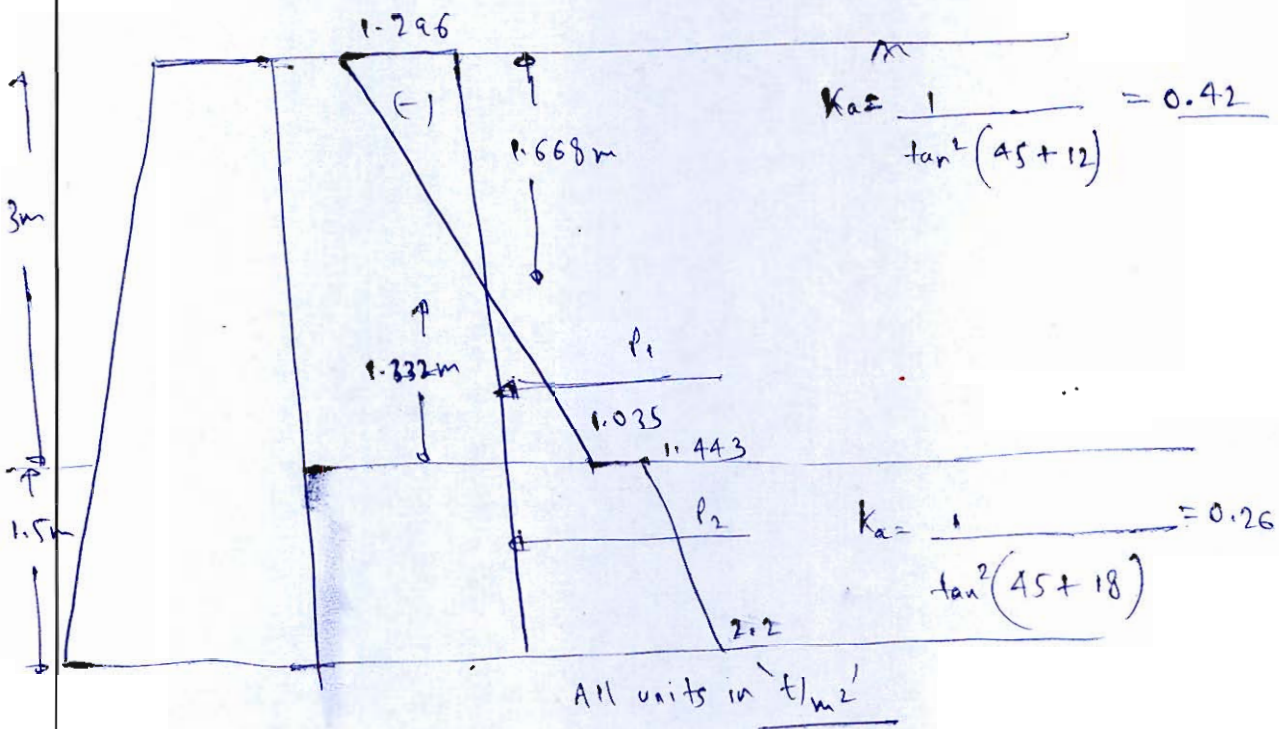
.4 (a) (i) Compute the total active thrust and its point of application for the retaining wall shown in Figure. The wall has a smooth back face.

Assume: Tension crack are developed



(ii) In a shrinkage limit test, a container of volume 9.6 cc was filled with soil slurry. The weight of the saturated soil was 17.46 g. The slurry was then gradually dried, first in atmosphere and then in an oven at a constant temperature of 110°C. The weight and volume of the dried soil were 11.58 g and 5.22 cc, respectively. Determine the shrinkage limit of the soil and the shrinkage ratio.

[12 + 8 = 20 marks]



$$\sigma_{h} = K_a \sigma_v \ominus 2c\sqrt{K_a}$$

$$\therefore \sigma_{h\,top} = -2\times 1\times\sqrt{0.42} = -1.296\ t/m^2$$

$$z_c = \frac{2c}{\gamma\sqrt{K_a}} = \frac{2\times 1}{1.85\times\sqrt{0.42}} = 1.668\ m$$

$$\sigma_h\big|_{3m}\big|_{above} = (1.85\times 3)\times 0.42 - (1.296) = 1.035\ t/m^2$$

$$\sigma_h\big|_{3m}\big|_{below} = (1.85\times 3)\times 0.26 = 1.443\ t/m^2$$

$$\sigma_h\big|_{4.5m} = \left((1.85\times 3)+(1.95\times 1.5)\right)\times 0.26 = 2.2\ t/m^2$$

$P_1 = \left(\frac{1}{2} \times 1.035 \times 1.332\right) = 0.69\,t$

$\bar{x}_1 = 1.5 + \left(\frac{1.332}{3}\right) = 1.944\,m$

$P_2 = \frac{1}{2}(1.443 + 2.2) \times 1.5 \times 1 = 2.73\,t$

$\bar{x}_2 = \left[\frac{(2 \times 1.443) + 2.2}{(1.443 + 2.2)}\right] \times \frac{1.5}{3} = 0.698\,m.$

$P_a = P_1 + P_2 = 3.42\,t/m$ Ans

2

Location from base

$\bar{x} = \frac{(0.69 \times 1.944) + (2.73 \times 0.698)}{3.42}$

$= 0.949\,m$ Ans

(ii) $V_1 = 9.6 cm^3$

$W_1 = 17.46 gm$

$W_d = 11.58 gm$

$V_d = 5.22 cm^3$

$$W_s = w_1 - \frac{(V_1 - V_d)\rho_w}{W_d}$$

$$= \frac{(17.46 - 11.58) - (9.6 - 5.22) \times 1}{11.58}$$

$\therefore \boxed{W_s = 12.95\%}$

8

~~SR~~ $w_1 = 0.508$

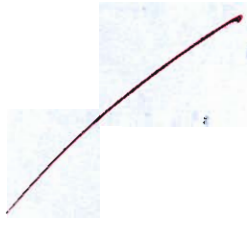
$$SR = \frac{(V_1 - V_d)}{\frac{V_d}{(w_1 - w_s)}} = \frac{(9.6 - 5.22)}{5.22 \times (0.508 - 0.129)}$$

$\therefore \boxed{SR = 2.215}$

4 (b) (i) A raft foundation is supported by a group of 12 concrete piles, each with a diameter of 400 mm and a length of 12 m, arranged in a rectangular formation of 3 rows and 4 columns. The piles are spaced at 1.0 m center-to-center in both directions and are embedded in a deep layer of clay having an undrained cohesion of 4.5 t/m^2 and a unit weight of 1.8 t/m^3. Assuming an adhesion factor of 0.9 and using a Factor of Safety of 2, determine the allowable net capacity of the pile group.

(ii) What factors should be considered while determining the appropriate depth of footing for a civil structure?

[12 + 8 = 20 marks]



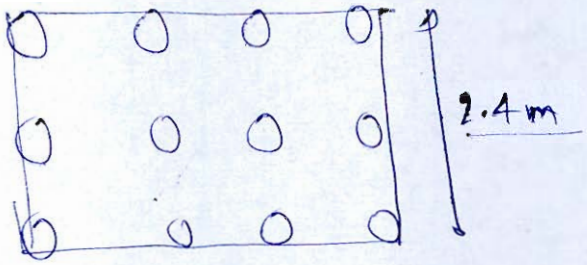
(i) $d = 0.4\,m$, $L = 12\,m$ $S = 1\,m$

$C_u = 4.5\ t/m^2$

$\gamma = 1.8\ t/m^3$

$\alpha = 0.9$

$FOS = 2$



~~4~~ $3 + 0.4 = 3.4\,m$ —①

⇒ Considering single pile

$$Q_{up} = (\alpha C \pi d L) + \left(9c \times \frac{\pi}{4} \times d^2\right)$$

$$= (0.9 \times 4.5 \times \pi \times 0.4 \times 12) + \left\{9 \times 4.5 \times \frac{\pi}{4} \times (0.4)^2\right\}$$

$$= 66.16 \text{ ~~kN~~ } t$$

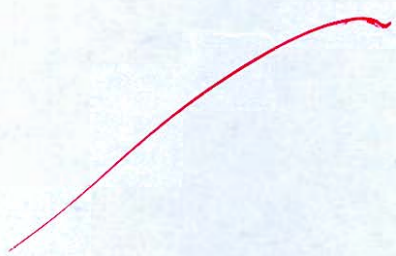
$\therefore$ $Q_u = 12 Q_{up} =$ ~~793.94 kN~~ $793.94\ t$ ①

⇒ Considering group action

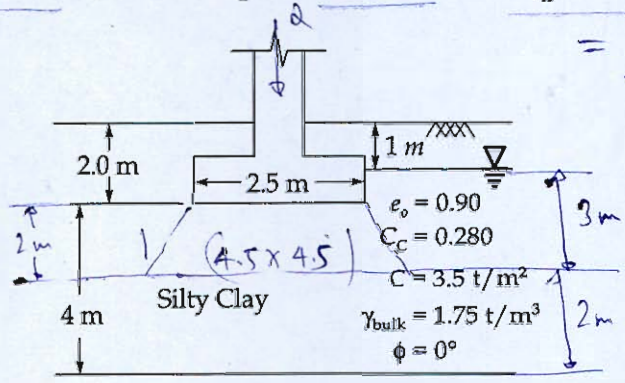
$$Q_{ug} = \{4.5 \times (3.4 + 2.4) \times 2 \times 12\} + (4.5 \times 9 \times 3.4 \times 4.2)$$

$$= 1204.74\ t$$

$$Q_{allowable} = \text{min of} \begin{cases} \frac{793.94}{FOS} \longrightarrow \text{~~36~~ } 396.97\ ton \\ \text{~~tot~~ } \frac{1204.74}{FOS} \end{cases}$$ Ans.



Q.4 (c) A square footing of dimensions 2.5 m × 2.5 m is proposed to be constructed at a depth of 2.0 m below ground level in a deep, uniform deposit of soft silty clay. The foundation soil has an undrained cohesion of 3.5 t/m^2, a bulk unit weight of 1.75 t/m^3, and an angle of internal friction equal to 0°. Laboratory consolidation tests on the clay indicate a compression index $C_C = 0.280$ and an initial void ratio $e_0 = 0.90$. The groundwater table is located at a depth of 1.0 m below the ground surface. Determine the allowable net bearing capacity of the footing such that a factor of safety of 3 is ensured against shear failure and the total consolidation settlement is limited to a maximum of 5.0 cm. For the analysis of shear failure, use Skempton's method. Take $\gamma_w = 10$ kN/m³.



[20 marks]

$$q_{nu} = CN_c = C \times 6\left(1 + 0.2\frac{D_f}{B}\right)$$

$$\therefore q_{nu} = 3.5 \times 6\left[1 + \left(0.2 \times \frac{2}{2.5}\right)\right] = 24.36\ t/m^2$$

$$q_{n\,safe} = \frac{24.36}{3} = 8.12\ t/m^2 \rightarrow \text{shear criteria}$$

Now, settlement criteria, $\Delta H = 50$ mm

$$\bar{\sigma_0} = (1.75 \times 4) - (1 \times 3) = 4\ t/m^2$$

$$\Delta H = \frac{C_c \times H}{1 + e_0} \times \log_{10}\left(\frac{\bar{\sigma_0} + \Delta\bar{\sigma}}{\bar{\sigma_0}}\right)$$

$$\therefore 50 = \frac{0.28 \times 4000}{1.9} \times \log_{10}\left(\frac{4 + \Delta\bar{\sigma}}{4}\right)$$

$$\Rightarrow \Delta\bar{\sigma} = 0.8627\ t/m^2$$

Now, $Q = \theta \Delta\bar{\sigma} \times (4.5)^2$

$\therefore \quad q_{allowable} = \dfrac{0.8627 \times (4.5)^2}{(2.5)^2} = 2.795\ t/m^2$

As for settlement.

$q_{n\,allow} = \min \begin{cases} 8.12\ t/m^2 \\ 2.795\ t/m^2 \end{cases} \therefore q_{net\,allow} = 2.795\ t/m^2$

Ans

23

Section B : Environmental Engineering [All Topics]

Q.5 (a) (i) A water supply scheme is under preparation for a city. Data shows the population of the city has grown from 40,000 to 1,60,000 and then to 4,00,000 in the last two successive periods of each of 20 years. Using the logistic curve method, determine

(a) The saturation population of the city.

(b) The expected population of the city after next 50 years.

(ii) Explain the following terms in relation to the aquifers a) Specific Capacity; b) Specific yield.

[8 + 4 = 12 marks]

(i) (a) $P_0 = 40K$ $(t_2 - t_1) = (t_1 - t_0) = 20$ years

$P_1 = 160K$

$P_2 = 400K$

$$P_S = \frac{2P_0P_1P_2 - P_1^2(P_0+P_2)}{P_0P_2 - P_1^2} = \frac{(2\times 40\times 160\times 400) - 160^2(440)}{(400\times 40) - (160)^2}$$

$\therefore \boxed{P_S = 640,000}$

(b) $t = 90$ years

$$m = \frac{P_S - P_0}{P_0} = \left(\frac{640}{40} - 1\right) = 15$$

$$n = \frac{1}{t}\ln\left[\frac{P_0(P_S - P_1)}{P_1(P_S - P_0)}\right] = \frac{1}{20}\times\ln\left[\frac{40\times(640-160)}{160\times(600)}\right]$$

$\therefore n = -0.08047$

$$P_{90\text{ years}} = \frac{P_S}{1+me^{nt}}$$

$$= \frac{640,000}{1+15\times e^{(-0.08047\times 90)}} = \boxed{633,204}$$

Ans.

i) (a) Specific capacity

→ It is defined as the discharge from the well for unit drawdown.

(b) Specific yield

→ It is the volume of water that can be taken out for unit volume of soil.

i.e $S_y = \frac{V_w}{V}$

→ because some water is bound to remain in soil. (Specific retention).

Q.5 (b) (i) A fully penetrating well is constructed in a confined sandy aquifer that is bounded above and below by impervious clay strata. The well has a maximum discharge capacity of 900 L/min. The thickness of the aquifer is 15 m. Determine the required length of the well screen, assuming that the available strainer has 13% open area and the borehole diameter is 15 cm. The maximum permissible velocity through the strainer is 2 cm/sec.

(ii) Draw the neat sketches of the different types of plume behaviour observed for emissions from a chimney. Also illustrate the corresponding atmospheric lapse rate conditions under which each type of plume behaviour occurs.

[4 + 8 = 12 marks]

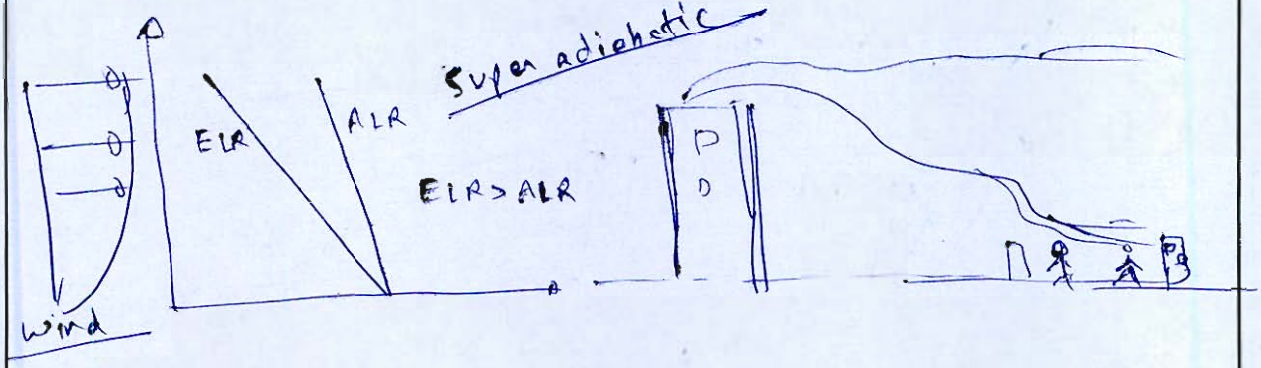
(i) $Q_{max} = 900\ l/min$, ~~$B = 15\ m$~~,

Now, $\frac{0.9}{60} = (0.13 \times \pi \times 0.15 \times L) \times 0.02$

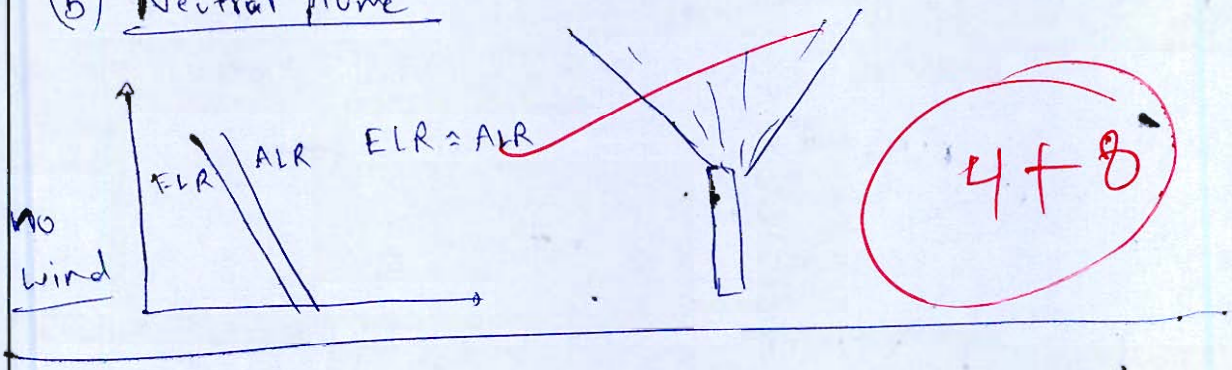
$\therefore L = 12.243\ m$ ($B = 15\ m$)

(OK)

i) (a) Looping plume

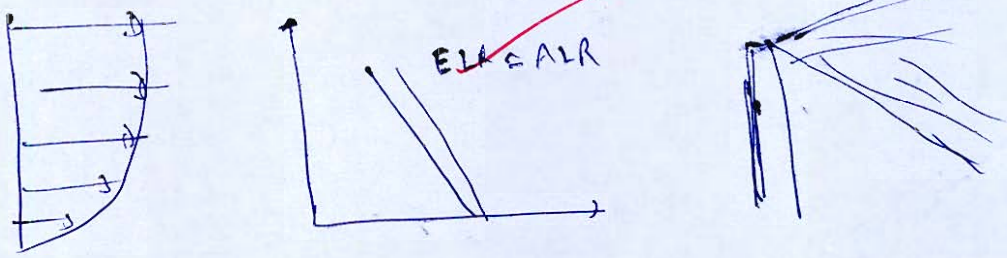


(b) Neutral plume



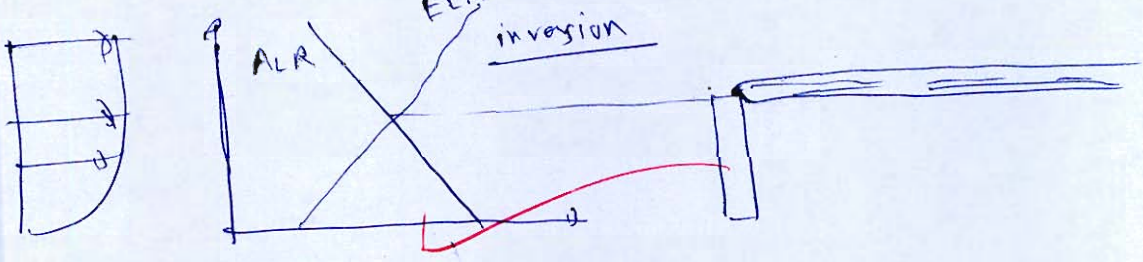
4 + 8

(c) Coning plume

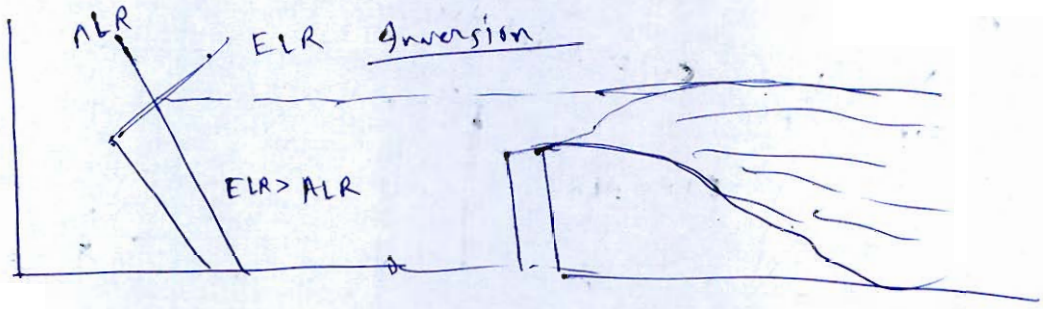


V > 32 km/hr

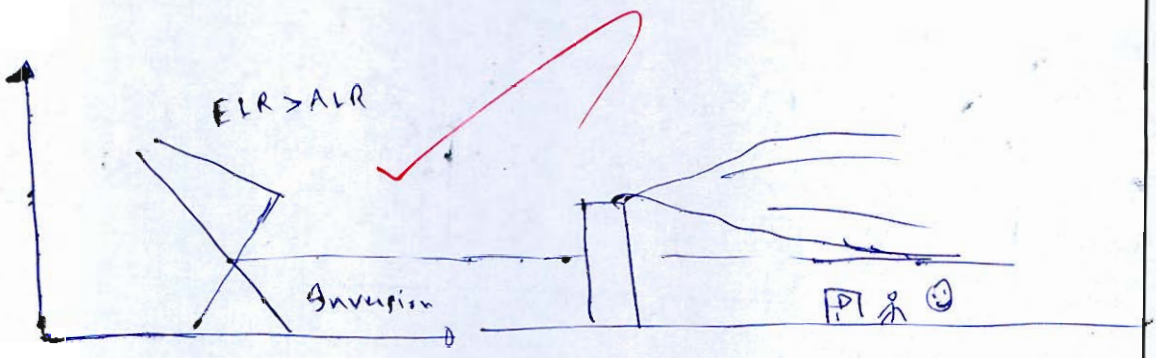
(d) Fanning plume



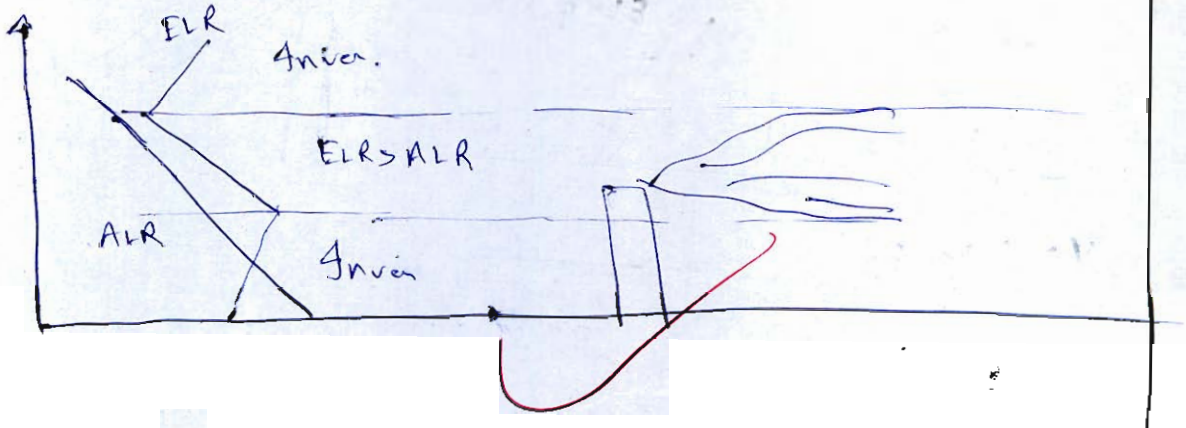
(e) Fumigating plume (worst)



(f) Lofting plume (good)



(g) Trapping plume



(c) To determine the pollution level in the river, the BOD_5 test was performed. The river water sample was diluted 10 % with distilled water. The dissolved oxygen of river water sample was measured as 2.5 mg/*l* and that of diluted water as 6 mg/*l* before incubation. After incubation of 5 days at 20°C, the DO of the sample was recorded as 1.2 mg/*l*. Calculate the 5 day standard BOD of the river water and also calculate 3-day BOD at 27°C. Given deoxygenation constant at 20°C = 0.23 per day.

[12 marks]

~~Assume 300 ml (size of BOD bottle)~~

$$DO_i = \frac{(2.5 \times 0.1) + (6 \times 0.9)}{1} = 5.65 \text{ mg/l}$$

$$DO_f = 1.2 \text{ mg/l}$$

$$BOD_5 (20°C) = (5.65 - 1.2) \times \frac{1}{0.1} = \boxed{44.5 \text{ mg/l}}$$

Ans

$$K_{d(27°C)} = 0.23 \times 1.047^{(7)} = 0.317 \text{ d}^{-1}$$

12

Now,

$$\frac{44.5}{1 - e^{-(0.23 \times 5)}} = \frac{BOD_3 (27°C)}{1 - e^{-(0.317 \times 3)}}$$

$$\therefore \boxed{BOD_3 (27°C) = 39.976 \text{ mg/l}}$$ Ans

Q.5 (d) Two primary settling basins, each of 25 m diameter and having a side water depth of 2.0 m, are provided with single effluent weirs located along the periphery of the tanks. For a total wastewater flow of 25,000 m^3 per day, calculate:

1. The surface area and volume of the settling basins,
2. The surface overflow rate (in m^3/m^2 day),
3. The detention time (in hours), and
4. The weir loading (in m^3/m day).

[12 marks]

Sol:) $H = 2\,m$ $\quad Q_{each} = 12500\,m^3/day$

(1) 1. $SA_{each} = \frac{\pi}{4} * (25)^2 = 490.874\,m^2$

$D = 25\,m, \quad H = 2\,m.$

$\therefore V = D^2 (0.785H + 0.011D)$

$= (25)^2 [(0.785 \times 2) + (0.011 \times 25)]$

$= 1153.125\,m^3$

$$SOR = \frac{Q}{SA} = \frac{12500}{490.874} = 25.465\ m^3/m^2\ day$$

$$\theta_t = \frac{V}{Q} = \left(\frac{1153.125 \times 24}{12500}\right) = 2.214\ hrs$$

$$WLR = \frac{Q}{\pi D} = \left(\frac{12500}{\pi \times 25}\right) = 159.155\ m^3/m\ day$$

12

Q.5 (e) A factory is consuming 2 ML of fuel every month. Determine the safe height of chimney from which the flue gases emitted contains following pollutants per ML per year.
Particulate Matter = 2.5 tonnes
SO_2 = 15 tonnes
Oxides of Nitrogen = 4 tonnes
HC, CO and other = 2 tonnes **[12 marks]**

Soln)

For SO_2,

1 ML → 15 tonnes/year

24 ML → (15 × 24) = 360 t/year.

$\therefore Q = \dfrac{360 \times 1000}{365 \times 24} = 41.096$ kg/hr

12

$\therefore H = 14 \times Q^{0.3} = 1.4 \times (41.096)^{0.3} = \boxed{42.68\ m}$

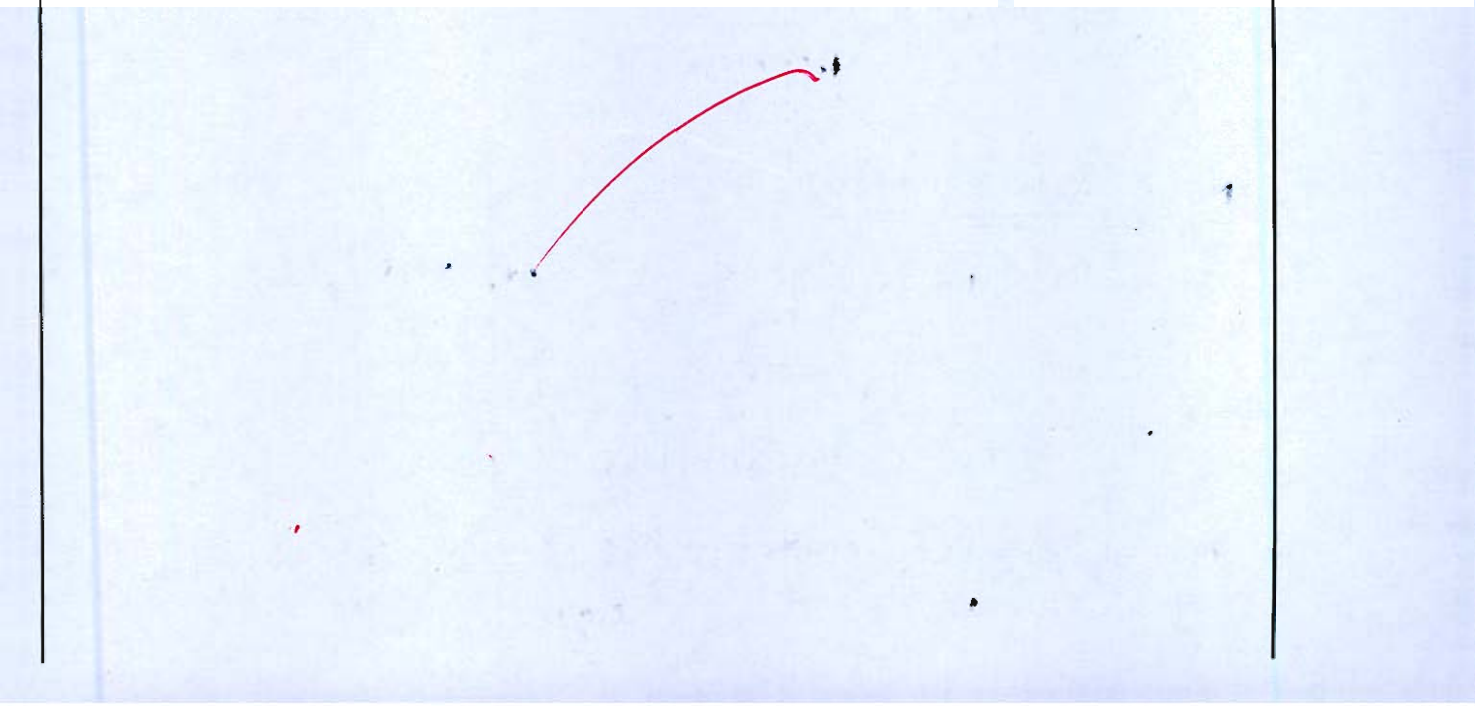
For PM,

$Q = \dfrac{2.5 \times 24}{365 \times 24} = 6.85 \times 10^{-3}$ t/hr

$\therefore H = 74 \times Q^{0.27} = \boxed{19.27\ m}$

Consider max^m of → (42.68m, 19.27m & 30m)

∴ Safe height = 42.68 m Ans



Q.6 (a) Given the following data, obtain the required size of an anaerobic digestion tank.

Domestic sewage treated in plant = 4.5 MLD

Suspended solids in incoming flow = 220 mg/L

Solids removal efficiency of primary clarifier = 65%

Moisture content of influent sludge = 95%

Volatile solid content in influent sludge = 70%

After digestion, volatile solids in the digested sludge are reduced by 35 % of that in influent sludge.

Digested sludge moisture content = 92%

Consider, the detention time as 20 days and specific gravity of primary sludge & digested sludge as 1.03 and 1.04 respectively.

[20 marks]

Soln)

Total solids entering in digestion tank $= 4.5 \times 220 \times 0.65$

$\therefore = 643.5 \text{ Kg/day}$

$VS = 450.45 \text{ Kg/d}$

$NVS = 193.05 \text{ Kg/day}$

Mass of water in incoming sludge $= \left(\frac{643.5 \times 95}{5}\right)$

$= 12226.5 \text{ Kg/day}$

Total mass of sludge $= 12870 \text{ Kg/day}$

Volm of inc. sludge,

$\therefore V_1 = \frac{12870}{1.03 \times 1000} = 12.495 \text{ m}^3/\text{day} = V_1$

Now, After digestion,

$VS = (1 - 0.35) \times 450.45 = 292.7925 \text{ Kg/day}$

$NVS = 193.05 \text{ Kg/day}$

$TS = 485.84 \text{ Kg/day}$

Mass of digested sludge $= \frac{485.84}{0.08} = 6073.03 \text{ Kg/day}$

Vol^m of digested sludge (V_2) = $\frac{6073.03}{1.04 \times 1000}$

$= 5.839\ m^3/day$

$$V = \left[V_1 - \frac{2}{3}(V_1 - V_2)\right] \times D_t$$

$$= \left[12.495 - \frac{2}{3}(12.495 - 5.839)\right] \times 20$$

$V = 161.16\ m^3$ → Vol^m of tank

Assuming $(H = 3m)$

$\therefore$ Dia $\Rightarrow$ $\frac{161.16}{3} = \frac{\pi}{4} \times (D)^2$

$\therefore D = 8.27\ m$

20

Q.6 (b) (i) A low lying area is to be identified for the municipal solid waste disposal using landfill method for a design life of 35 years. Estimate the volume of landfill site required for a city of having population as four persons per household generating the 2.5 kg of solid waste per capita per day. Survey shows the compacted density of MSW may be assumed as 900 kg/m^3 for design. Assuming the ratio of solid waste to cover as 4:1, what volume of cover soil is needed on yearly basis. Total number of households in the city are 5000.

(ii) Explain the different methods used for land filling in dry areas. Also explain the ways to control the gas and leachate movement in landfills.

[12 + 8 = 20 marks]

Soln) (i) $n = 35$ years $\quad V = ?$

Population $= 4 \times 5000 = 20,000$ C

Total MSW generated $= (2.5 \times 20,000) = 50,000$ Kg/day

" " " in one year $= 1825 \times 10^4$ Kg/year.

$\therefore$ Vol^m of MSW (1 year) $= 2027.78$ m^3/year.

Vol^m of cover on yearly basis $= 5069.44$ m^3/year

Vol^{n} of landfill for 1 year = 20277.78 + 5069.44

= 25347.22 m^3/year.

Vol^{m} of site for 35 years = 0.88715 Mm^3

(or)

88.715 ha-m

10

Ans.

Determine the dimensions of a high-rate trickling filter using the following data: the sewage flow is 3.5 MLD, the recirculation ratio is 1.5, and the BOD of raw sewage is 220 mg/*l*. The primary settling tank removes 25% of the BOD, and the desired final effluent BOD concentration is 30 mg/*l*. Take depth of filter as 1.5 m.

Further, determine by what percentage the diameter of the filter would need to be modified if the filter were designed instead as a standard-rate trickling filter to meet the same treatment requirements.

[15 + 5 = 20 marks]

$Q_0 = 3.5$ MLD , $R = 1.5$, $F = \frac{1+R}{(1+0.1R)^2} = 1.89$

$BOD_0 = 0.75 \times 220 = 165$ mg/l

$BOD_e = 30$ mg/l

$\eta = \left(\frac{165 - 30}{165}\right) \times 100 = 81.82\%$

$\eta = \frac{100}{1 + 0.44\sqrt{\frac{OLR}{1.89}}} = 81.82$ (20)

$\Rightarrow OLR = 0.482$ kg/m3/day

$\therefore OLR = \frac{Q_0 \times BOD_0}{V} \Rightarrow V = \left(\frac{3.5 \times 165}{0.482}\right) = 1197.9 m^3$

As $H = 1.5$ m $\rightarrow \left(SA = \frac{V}{H}\right)$

$\therefore SA = 798.6 m^2 = \frac{\pi}{4} \times D^2$

$\therefore D = 31.89 \simeq 32$m

overall depth = $1.5 + 0.3 = 1.8$ m

FB

For SRTF,

$$\eta = \frac{100}{1 + 0.44 \times \sqrt{OLR}}$$

$$\therefore \quad 1 + 0.44 \times \sqrt{OLR} = \frac{100}{81.82}$$

$$OLR = 0.255 = \frac{3.5 \times 165}{V}$$

$$\therefore V = 2264.58\ m^3$$

$$\therefore \quad SA = \frac{V}{H} = 1509.723\ m^2 = \frac{\pi \times D^2}{4}$$

$$\therefore \boxed{D = 43.843\ m}$$

$$\%\ \text{increase} = \left(\frac{43.843 - 31.89}{31.89}\right) \times 100 = \boxed{37.483\ \%}$$

(i) A coagulation-sedimentation water treatment plant treats 45 million litres of water per day. The dosage of filter alum required at the plant is 16 mg/*l*. The raw water has an alkalinity equivalent to 5 mg/*l* as $CaCO_3$. Determine the annual quantity of filter alum required and the annual quantity of quicklime (containing 85% CaO) required for the plant. The molecular weights of the elements are given as: Al = 27, S = 32, O = 16, H = 1, Ca = 40, and C = 12.

(ii) Explain the mechanism in brief occurring in slow sand filtration process.

[12 + 8 = 20 marks]

Q = 45 MLD

Alum dose = 16 mg/l

12

Total alkalinity req^d = (0.45 × 16) = 7.2 mg/l as $CaCO_3$

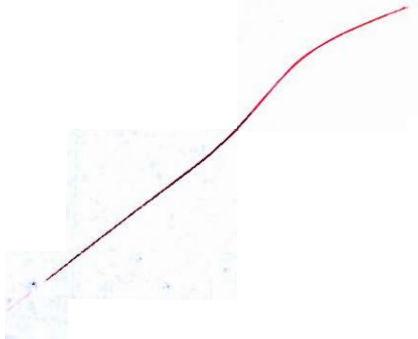
∴ Additional alkalinity = (7.2 − 5) = 2.2 mg/l as $CaCO_3$

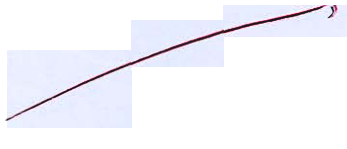
Annual quantity of alum = $\frac{45 \times 16 \times 365}{1000}$ = 262.8 tonnes/year

Quick lime as (CaO) = $\frac{2.2 \times 28}{50}$ = 1.232 mg/l

Annual quantity of quick lime = $\frac{1.232 \times 45 \times 365}{1000 \times 0.85}$

= 23.806 tonnes/year





Q.7 (b) A wastewater treatment plant discharges its treated effluent into a stream at a point designated as A. The characteristics of the stream at a location sufficiently upstream of point A, as well as those of the effluent being discharged, are given below.

		Effluent	Stream
Flow	m^3/s	0.30	0.65
DO	mg/l	1.5	8.00
temperature	°C	27	23
$BOD_{5/20°C}$	mg/l	50	2

For the combined mixture of effluent and stream water, assume that the deoxygenation constant K_D at 20°C (base 10) is 0.087 day^{-1} and the reoxygenation constant K_R at 20°C (base 10) is 0.174 day^{-1}. The equilibrium concentration of dissolved oxygen (C_s) for fresh water at different temperatures is provided below:

Temperature °C	18	20	22	23	24	25	26
C_s (mg/l)	9.54	9.17	8.99	8.83	8.53	8.38	8.22

The average velocity of the stream downstream of the discharge point *A* is 0.3 m/s. For temperature correction, use coefficients of 1.04 for the deoxygenation constant θ_D and 1.02 for the reoxygenation constant θ_R. Determine:

1. The critical oxygen deficit in the stream, and
2. The location downstream of point A at which this critical deficit occurs.

[20 marks]

Sol^n)

$$DO|_{mix} = \frac{(0.3\times1.5)+(0.65\times8)}{0.95} = 5.947 \text{ mg/l}$$

$$(BOD_5|(20°C))_{mix} = \frac{(50\times0.3)+(2\times0.65)}{0.95} = 17.158 \text{ mg/l}$$

$$T_{mix} = \frac{(27\times0.3)+(23\times0.65)}{0.95} = 24.263°C$$

$$L_0 = 17.158$$

$$17.158 = L_0\times\left[1-10^{-(0.087\times5)}\right]$$

$$\therefore L_0 = 27.118 \text{ mg/l}$$

$$K_d(24.263°C) = 0.087\times(1.04)^{4.263} = 0.103\ d^{-1}$$

$$K_R(24.263) = 0.174\times(1.02)^{4.263} = 0.189\ d^{-1}$$

$$\left(\frac{L_0}{D_c \times f}\right)^{f-1} = f\left[1 - \frac{(f-1)D_0}{L_0}\right]$$

$$\therefore \quad f = \frac{K_R}{K_d} = 1.838$$

$$C_s = 8.53 - \frac{(8.53 - 8.38)}{1} \times (0.263) = 8.49 \text{ mg/l}$$

$$D_0 = 8.49 - 5.947 = 2.54 \text{ mg/l}$$

$$\therefore \quad \left(\frac{27.118}{D_c \times 1.838}\right)^{0.838} = 1.838\left[1 - \left(\frac{0.838 \times 2.54}{27.118}\right)\right]$$

$$\therefore \quad D_c = 7.868 \text{ mg/l}$$

20

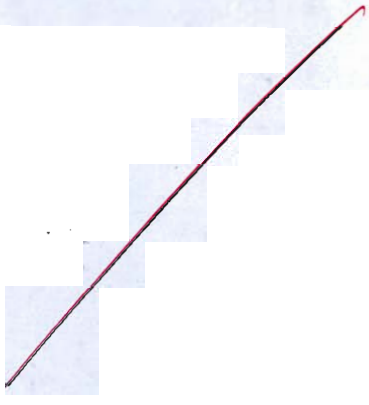
$$D_c = \frac{K_d}{K_R} \times L_0 \times 10^{-(K_d \times t_c)}$$

$$\therefore \quad 7.868 = \left(\frac{0.103}{0.189}\right) \times 27.118 \times 10^{-(0.103 \times t_c)}$$

$$\therefore \quad t_c = 2.658 \text{ days}$$

$$\therefore \quad \text{Distance } (L) = \frac{0.3 \times 2.658 \times 86400}{1000}$$

$$= 68.888 \text{ Km}$$ Ans



(i) Explain the different type of settling observed in settling tanks of water / Sewage treatment plant.

(ii) In a rectangular primary settling tank of size 4 m deep and 55 m long, if the horizontal flow velocity is 1.20 cm per sec. What would be the minimum size of particle to be removed effectively. Assume kinematic viscosity of water as 0.01 cm^2/sec. Specific gravity of the concerned particle is 2.65.

[10 + 10 = 20 marks]

$L = 55m \quad H = 4m$

$V_H = 0.012 m/s \quad d = ?$

$$\frac{L}{V_H} = \frac{H}{V_s} \Rightarrow V_s = \frac{4 \times 0.012}{55} = 8.73 \times 10^{-4} m/s$$

$$\therefore 8.73 \times 10^{-4} = \frac{1.65 \times 9.81 \times d^2 \times 10^4}{18 \times 0.01} \quad \left(V_s = \frac{(G-1) g d^2}{18 \vartheta} \right)$$

$$\therefore d = 31.153 \mu m$$

10+6

(a) Type - 1 (Discrete settling)

→ stoke's law is valid

→ During settling, there is no interference from other particles.

(b) Type - 2 (Flocculent settling)

→ Particles coalesce as they settle.

→ stoke's law not valid.

→ settling column analysis is done.

(c) Type-3 (Zone or hindered settling)

→ Not a ~~sig~~ single particle settles individually.

→ During setting particles forms a group.

(d) Type-4 (Compression setting)

→ High density of solids with voids ~~in~~ filled with water.

→ Water comes out as particles settles.

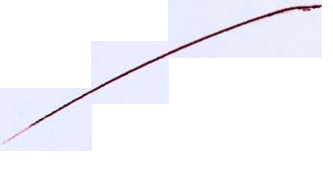
→ Settling column analysis is used ~~to~~ to determine settling behaviour.

There is a thermal power plant of total capacity 915 MW with a load factor of 72.5 percent and an efficiency of 40 percent. Determine the amount of particulates, CO_2 and SO_2 that are generated annually if oil is the fuel source. The ultimate analysis of fuel are give below:

Moisture	Ash	Carbon	Hydrogen	Nitrogen+Oxygen	Sulphur
0.3%	0.04%	85.2%	11.3%	0.36%	2.8%

[Assume 80% of ash is particulate, Calorific value of fuel = 40.5MJ/kg]

[20 marks]



(i) An average operating data for a conventional activated sludge wastewater treatment plant are as follows. The wastewater flow rate is 40,000 m^3 per day and the volume of the aeration tank is 9,500 m^3. The influent BOD concentration is 240 mg/L, while the effluent BOD concentration is 18 mg/L. The mixed liquor suspended solids (MLSS) concentration in the aeration tank is 2480 mg/L. The effluent suspended solids concentration is 30 mg/L. The waste sludge has a suspended solids concentration of 9,700 mg/L, and the quantity of waste sludge withdrawn is 220 m^3 per day. Based on the above information, determine

(a) Aeration period in hours,

(b) F/M ratio expressed as kg BOD per day per kg MLSS,

(c) Sludge age in days.

(d) Percentage efficiency of BOD removal

(ii) Discuss the advantage and disadvantages of Activated Sludge treatment.

[12 + 8 = 20 marks]

Q.8 (c) (i) Calculate the storage capacity required to meet the water demand given below, assuming that the inflow to the service reservoir is maintained at a uniform rate throughout the 24-hour period.

Time	00 – 04	04 – 08	08 – 12	12 – 16	16 – 20	20 – 24
Demand in million litres	0.36	0.86	1.70	1.36	0.74	0.42

(ii) Write a short note over Water distribution network and it's type.

[12 + 8 = 20 marks]

Space for Rough Work

Space for Rough Work