MADE EASY

Leading Institute for ESE, GATE & PSUs

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	45
Q.2	—
Q.3	—
Q.4	46
Section-B	
Q.5	48
Q.6	50
Q.7	54
Q.8	—
Total Marks Obtained	243

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

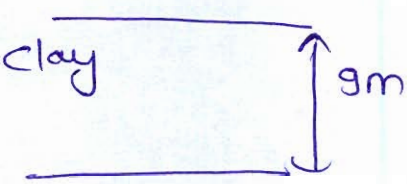
1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough 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

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]

⇒ Given, Ultimate settlement of clay layer = 308mm



After t = 2 years → avg settlement = 108mm

t = ? → avg. settlement = 220mm

(A) degree of consolidation for 220 mm settlement

$$U = \frac{\Delta h}{\Delta H} \times 100 = \frac{220mm}{308mm} \times 100 = 71.429\% > 60\%$$

∴ Tv (time factor) = 1.781 − 0.933 log (100 − U%)

= 1.781 − 0.933 log (100 − 71.429)

= 0.4226

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

t = time

Cv = degree of consolidation

$$0.4226 = \frac{C_v}{d^2} \times t \quad \text{— (I)}$$

(12)

Also → $U = \frac{108}{308} \times 100 = 35.065\% < 60\%$

$$T_v = \frac{\pi}{4} U^2 = \frac{\pi}{4}[0.35065]^2$$

$$\frac{\pi}{4}[0.35065]^2 = \left[\frac{C_v}{d^2}\right] \times 2 \text{ years} \quad \text{— (II)}$$

from (I)st & (II)nd

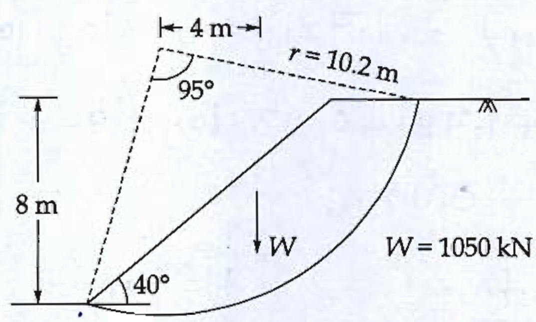
$$t = \frac{\frac{\pi}{4}(0.35065)^2}{0.4226} = \frac{\left(\frac{C_v}{d^2}\right) \times 2 \text{ years}}{\left(\frac{C_v}{d^2}\right) \times t}$$

t = 8.75 years (Ans)

Time required to attain settlement of 220mm is $= 8.75 - 2$

$= 6.75$ years (Ans)

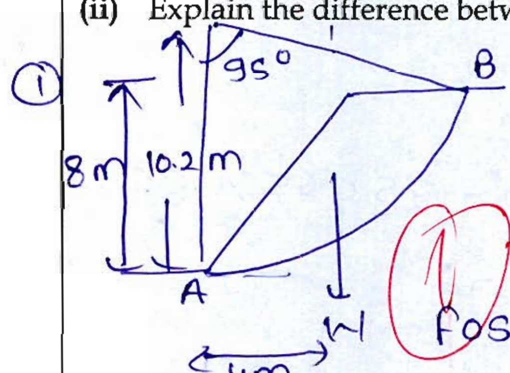
Q.1 (b) (i) A 40° slope is excavated to a depth of 8 m in a deep layer of saturated clay ($c = 50\ \text{KN/m}^2$ and $\phi = 0°$, $\gamma = 19\ \text{KN/m}^3$). Determine the factor of safety for the trial failure surface shown in Figure.



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

[6 + 6 = 12 marks]

(i)



Given, $W = 1050\ \text{kN}$

$c = 50\ \text{kN/m}^2$

$\phi = 0°$, $\gamma = 19\ \text{kN/m}^3$

$R = 10.2\text{m}$

$$FOS = \frac{M_{Resisting}}{M_{overturning}}$$

$\frac{(cL)R}{W\bar{x}}$

$$FOS = \frac{W \times 4m}{c[L_{AB} \times 1m] \times R}, \quad L_{AB} = R\theta$$

$$FOS = \frac{1050\,\text{kN} \times 4\text{m}}{50\frac{\text{kN}}{\text{m}^2}\left(10.2\text{m} \times \frac{95 \times \pi}{180} \times 1\right) \times 10.2} = \underline{0.487}$$

(Ans)

(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]

Given, maximum dry density, $\gamma_d = 1.65 g/cc$

Optimum moisture content, $\omega = 14.5\%$

$G = 2.7$

$S = ?$

$\eta = ?$

$\gamma_{d_{th}} = ?$

a) $\because \gamma_d = \frac{(1-\eta_a)G\gamma_w}{1+\omega G}$ $\eta_a = \%$ air voids

$$1.65\, g/cc = \frac{(1-\eta_a)\,2.7 \times 1\, g/cc}{1+0.145 \times 2.7}$$

$\eta_a = 0.1496 = 14.96\%$ (Ans)

also $\gamma_d = \frac{G\gamma_w}{1+e}$

12

$$1.6 = \frac{2.7 \times 1}{1+e}$$

$\Rightarrow e = 0.6875$

from $Se = \omega G$

$$S = \frac{\omega G}{e} = \frac{0.145 \times 2.7}{0.6875} = 0.5694 = 56.94\%$$

$S = 56.94\%$ (Ans)

$\Rightarrow$ γ_d theoretical at zero air content & 100% saturated soil

$$\gamma_{d_{th}} = \frac{G\gamma_w}{1+\omega G} = \frac{2.7 \times 1}{1+0.145 \times 2.7} = 1.94\, g/cc$$ (Ans)

$\gamma_{d_{th}} = 1.94\, g/cc$ (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:

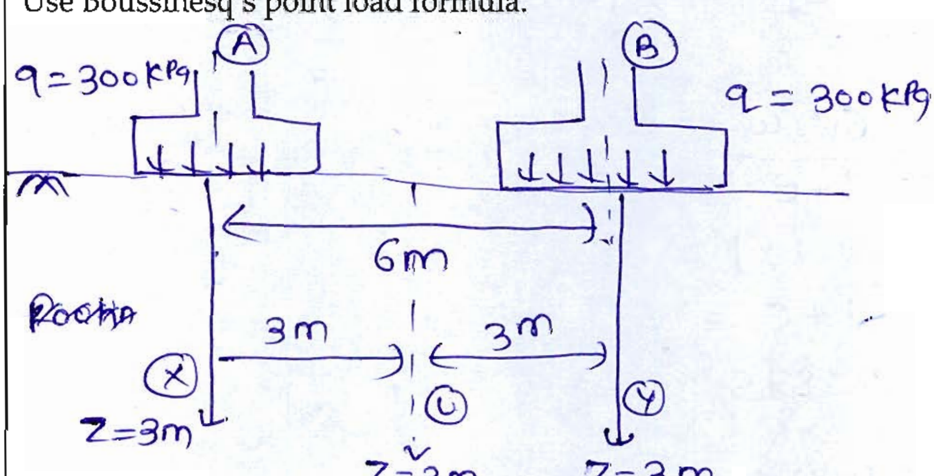
(i) Vertically below the center of Footing *A*

(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]



Footing A → 2.5m × 2.5m

Footing B = 3m × 3m

→ Boussinesq's point load formula

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

Case① Vertical below the centre of footing A

$r_A = 0, z = 3m, r_B = 6m$

$\sigma_z = \sigma_{zA} + \sigma_{zB}$

$$\sigma_{zA} = \frac{3}{2\pi}\left[\frac{300\times(2.5\times2.5)}{3^2}\right]\left[\frac{1}{1+\left[\frac{0}{3}\right]^2}\right]^{5/2}$$

$= 99.472\ kN/m^2$

$$\sigma_{zB} = \frac{3}{2\pi}\left[\frac{300\times(3\times3)}{3^2}\right]\left[\frac{1}{1+\left[\frac{6}{3}\right]^2}\right]^{5/2}$$

$= 2.56\ kN/m^2$

$\sigma_z = 99.472 + 2.56 = 102.032\ kN/m^2$ (Ans)

Case 2 Vertically below the centre of footing B

$r_A = 6m, z = 3m, r_B = 0$

$\sigma_z = \sigma_{zA} + \sigma_{zB}$

$$\sigma_{zA} = \frac{3}{2\pi}\left[\frac{300\times2.5\times2.5}{3^2}\right]\left[\frac{1}{1+\left[\frac{6}{3}\right]^2}\right]^{5/2}$$

$= 1.78\ kN/m^2$

$$\sigma_{zB} = \frac{3}{2\pi}\left[\frac{300\times3\times3}{3^2}\right]\left[\frac{1}{1+\left(\frac{0}{3}\right)^2}\right]^{5/2}$$

$= 143.239\ kN/m^2$

$\sigma_z = 1.78 + 143.239 = 145.019\ kN/m^2$ (Ans)

Case 3 Vertically below mid point between the two footing

$r_A = 3m, r_B = 3m, z = 3m$

$\sigma_z = \sigma_{zA} + \sigma_{zB}$

$$\sigma_{zA} = \frac{3}{2\pi}\left[\frac{300\times2.5\times2.5}{3^2}\right]\left[\frac{1}{1+\left[\frac{3}{3}\right]^2}\right]^{5/2}$$

$= 17.584\ kN/m^2$

$$\sigma_{zB} = \frac{3}{2\pi}\left[\frac{300 \times 3 \times 3}{3^2}\right]\left[\frac{1}{1+\left(\frac{3}{3}\right)^2}\right]^{5/2}$$

$= 25.321 \text{ kN/m}^2$

$\sigma_z = 17.584 + 25.321 = 42.905 \text{ kN/m}^2$ (Ans)

(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]

Undisturbed soil in borrow area

→ water content, $w = 16\%$

$e = 0.55$

$G = 2.7$

→ Embankment → $V_{soil} = 60{,}000 \text{ m}^3$

Case (A)

S = ? saturation

$\because Se = wG$

$S = \frac{wG}{e} = \frac{0.16 \times 2.7}{0.55} = 0.7854$

$S = 78.54\%$ (Ans)

Bulk unit wt

$\gamma_b = \left(\frac{G+Se}{1+e}\right)\gamma_w = \left[\frac{2.7 + 0.7854 \times 0.55}{1+0.55}\right] \times ~~9.81~~ 10$

$\gamma_b =$ ~~19.822 kN/m³ (Ans)~~ 20.206 kN/m³ (Ans)

8

~~γ_d~~ = dry unit weight

$\gamma_d = \frac{\gamma_b}{1+w} = \frac{~~19.822~~\ 20.206}{1+0.16} =$ ~~17.088 kN/m³ (Ans)~~ 17.42 kN/m³ (Ans)

b) ∴ Assuming, during ~~trans~~ excavation and transportation volume of solids remain same & hence weight of solids also remain same. $(W_s)_{Emb} = (W_s)_{B.A.}$

→ Embankment → $\gamma_d = 18$ kN/m³

$V_{soil} = 60,000 m^3$

Mass of dry soil, $W_d = W_s = \gamma_d \times V_{soil}$

$= 18 \times 60,000$

$W_s =$ ~~256,000 kN~~ 1080,000 — (1)

In Borrow area

$\gamma_d = 17.42$ kN/m³ $= \frac{W_s}{V_{B.S}}$ ⇒

$W_s = 17.42 \times V_{BS}$

$\because (W_s)_{BA} = (W_s)_{em} \Rightarrow 17.42 V_{BS} =$ ~~256000~~ 1080,000

~~$V_{BS} = 14695.7$~~

$V_{BS} = 61997.704 m^3$ (Volume of Borrow soil)

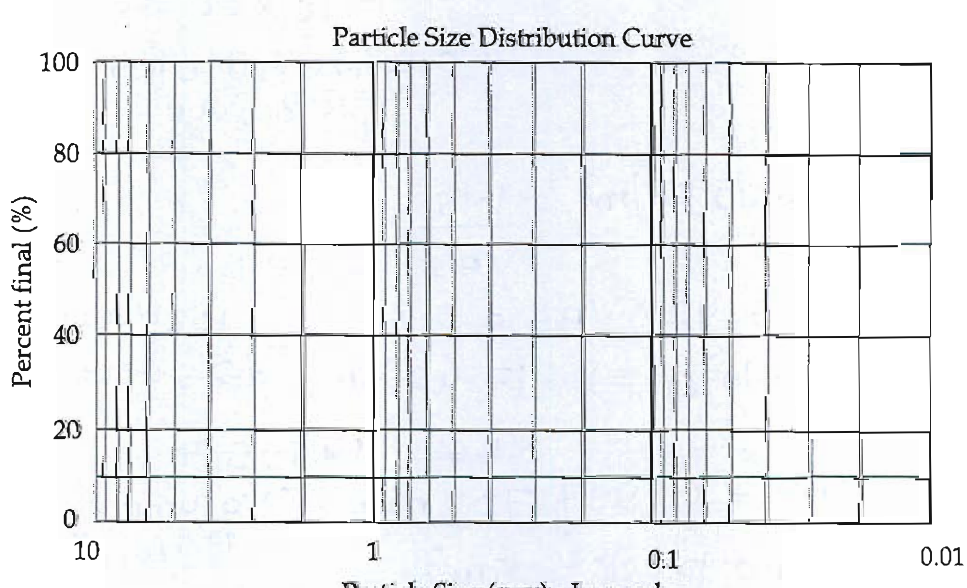
Capacity of one truck = 5 m³

No. of trucks $= \frac{V_{BS}}{Capacity} = \frac{61997.704 m^3}{5 m^3}$

= 12339.54 ≈ 12340 trucks (Ans)

Do not write in this

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]

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]

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(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 (γ = 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]

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Do not write in this margin

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]

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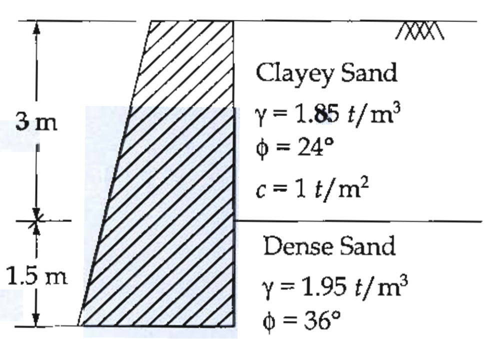
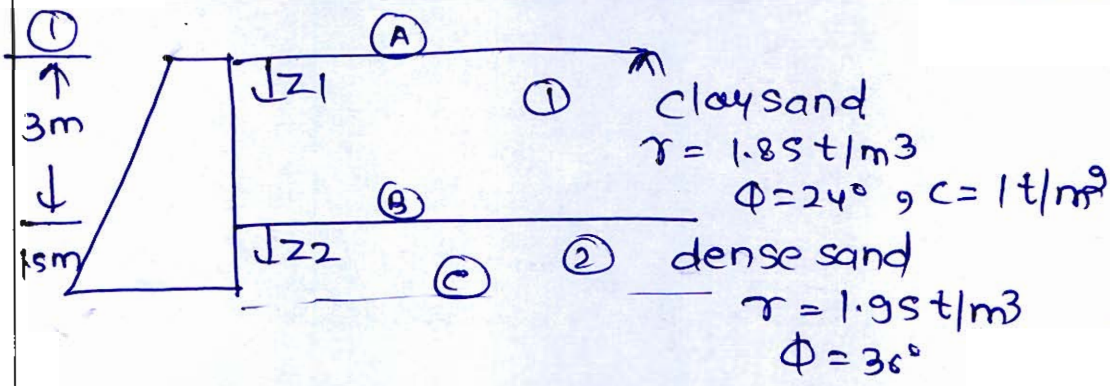
1 (a) (i) Compute the total active thrust and its point of application for the retaining wall shown in Figure. The wall has a smooth back face.

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]



As the wall has a smooth back, using Rankine earth pressure theory

→ Computing active earth pressure coefficient

Layer ① → $K_{a_1} = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin 24°}{1+\sin 24°}$

$= 0.4217$

$K_{a_2} = \frac{1-\sin 36°}{1+\sin 36°} = 0.3905$

⇒ Vertical pressure computation

At [A] $\bar{\sigma_v} = 0 \times 1.85 = 0$

At [B] $\bar{\sigma_v} = 3 \times 1.85 = 5.55\ t/m^2$

at [C] $\bar{\sigma_v} = 5.55 + 1.5 \times 1.95 = 8.475\ t/m^2$

⇒ Active earth pressure computation

at (A) $P_a = K_{a_1}\bar{\sigma_v} - 2c\sqrt{K_{a_1}}$

$= 0.4217 \times 0 - 2 \times 1\sqrt{0.4217} =$

$= -1.2988\ t/m^2$

6

at [B] Just above

$P_a = 0.4217 \times 5.55 - 2 \times 1\sqrt{0.4217}$

$= 1.0417\ t/m^2$

at [B] Just below

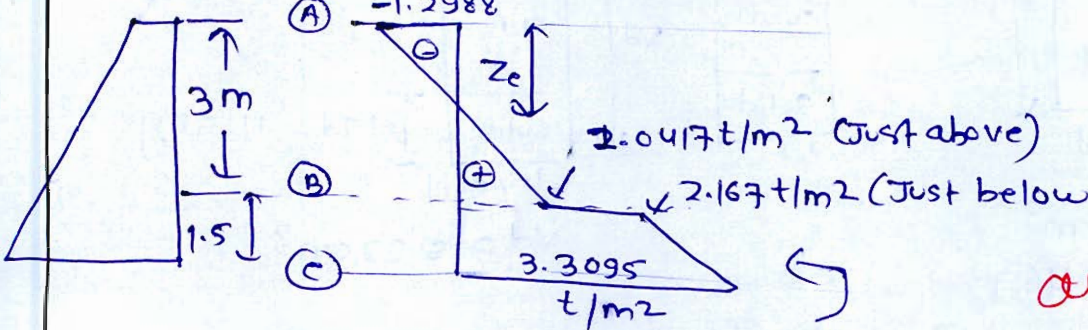
$P_a = K_{a_2}\bar{\sigma_v} - 2 \times c_2\sqrt{K_{a_2}}$

$= 0.3905 \times 5.55 - 2 \times 0\sqrt{0.3905}$

$= 2.167\ t/m^2$

at (C) $P_a = 0.3905 \times 8.475$

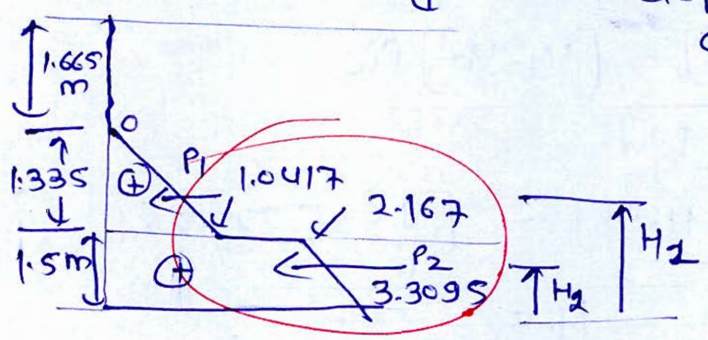
$= 3.3095\ t/m^2$



Before tension crack

avoid silly mistakes and Calculation Error

After tension crack]



depth of tension crack

$Z_c = \frac{2C_1}{\gamma\sqrt{K_{a1}}}$

$= \frac{2 \times 1}{1.85\sqrt{0.4217}}$

$= 1.665\ m$

Active thrust

$P_{total} = P_1 + P_2$

$P_1 = \frac{1}{2}(0 + 1.0417) \times 1.335 \times 1$ | $H_1 = 1.5 + \frac{1}{3} \times 1.335$

$= 0.695\ t/m$ length | $= 1.945\ m$

$P_2 = \frac{1}{2}[2.167 + 3.3095] \times 1.5 \times 1$

$= 4.1074\ t/m$ length of wall

$H_2 = \left(\frac{2 \times 2.167 + 3.3095}{2.167 + 3.3095}\right) \times \frac{1.5}{3}$

$H_2 = 0.698\ m$

$P_{total} = 0.695 + 4.1074$

$= 4.8024\ t/m$ length of wall (Ans)

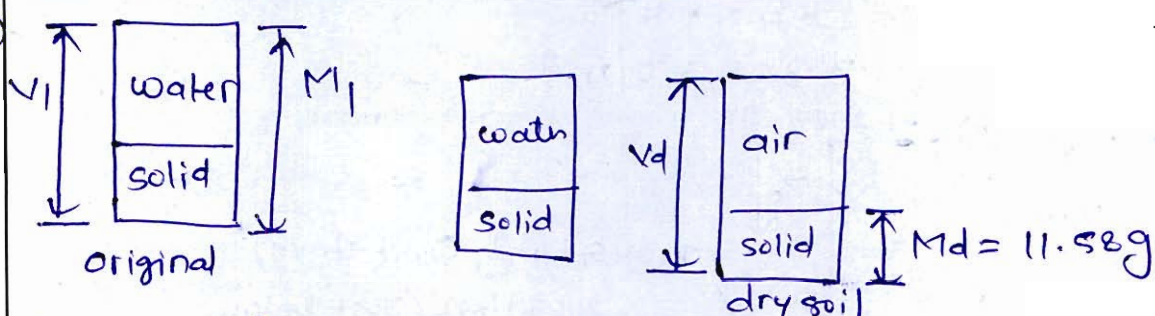
Point of application

$\bar{z} = \frac{P_1 H_1 + P_2 H_2}{P_{total}}$

$= \frac{0.695 \times 1.945 + 4.1074 \times 0.698}{4.8024}$

$\bar{z} = 0.878\ m$ from base of wall (Ans

(11)



$V_1 = 9.6 cm^3$

$M_1 = 17.46g$

$V_d = 5.22 cm^3$

① Shrinkage limit (ω_s)

$$\omega_s = \frac{[M_1 - M_d] - [V_1 - V_d]\rho_w}{M_d}$$

$$= \frac{[17.46 - 11.58] - [9.6 - 5.22] 1 \times 1}{11.58}$$

$$= 0.1295$$

$\boxed{\omega_s = 12.95\%}$ Ans)

(6)

Shrinkage Ratio, R

$$R = \frac{V_1 - V_d}{V_d[\omega_1 - \omega_d]}$$

$$\omega_1 = \frac{M_1 - M_d}{M_d} = \frac{17.46 - 11.58}{11.58} = 0.5078$$

$$R = \frac{[9.6 - 5.22]}{5.22 \times [0.5078 - 0.1295)}$$

$\boxed{R = 2.218}$ Ans

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]

Given, no. of piles = 12 Concrete

dia of pile, $d = 0.4m$

length of pile, $L = 12m$

spacing, $S = 1m$

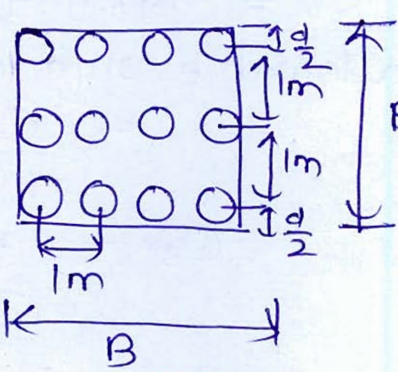
$C_u = 4.5\ t/m^2$

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

$\alpha = 0.9$

$FOS = 2$

$Q_{allowable} = ?$



12

$B' = \sout{2s+d}\; 2s+d = 2\times1+0.4 = 2.4m$

$B = 3s+d = 3\times1+0.4 = 3.4m$

Ultimate capacity of group of piles

$= \min \begin{cases} \text{Group action} = Q_{ug} \\ \text{Individual pile action} = NQ_{up} \end{cases}$

(i) Individual pile action

$NQ_{up} = N[Q_{eb}+Q_{sf}]$

$= N[9cA_b + \alpha\bar{c}A_s]$

$= N[9c.\frac{\pi}{4}d^2 + \alpha\bar{c}.\pi dL]$

$= 12[9\times4.5\times\frac{\pi}{4}\times0.4^2 + 0.9\times4.5\times\pi\times0.4\times12]$

$NQ_{up} = 793.94\ t/m^2$

(ii) Group action of piles

$Q_{ug} = 9c[B\times B'] + \bar{c}[2(B+B')\times L]$

$= 9\times4.5\times[2.4\times3.4] + 4.5\times2[2.4+3.4]\times12$

$= 956.88\ t/m^2$

$\Rightarrow Q_u = \min\{793.94, 956.88\}$

$Q_u = 793.94\ t/m^2$

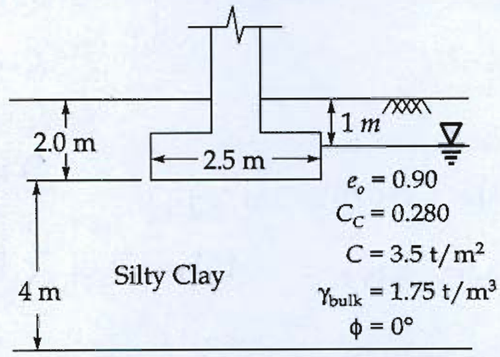
allowable safe load capacity

$= \frac{Q_u}{FOS} = \frac{793.94}{2}$

$Q_s = 396.97\ t/m^2$ (Ans)

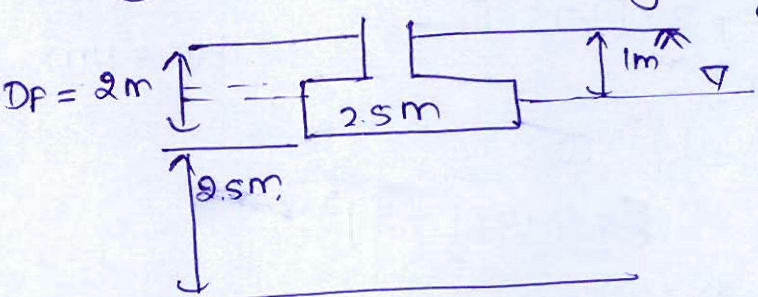
Do not write in this margin

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/m^3.



[20 marks]

Case (A) $q_{ns} = ?$ ⟶ Checking shear failure criteria.



Footing = square

As per Skempton's method, for square footing

$$\frac{D_f}{B} = \frac{2}{2.5} = 0.8 < 2.5$$

$q_{nu} = C N_c$ where

$$N_c = 6\left[1 + 0.2\frac{D_f}{B}\right] = 6\left[1 + 0.2 \times 0.8\right] = 6.96$$

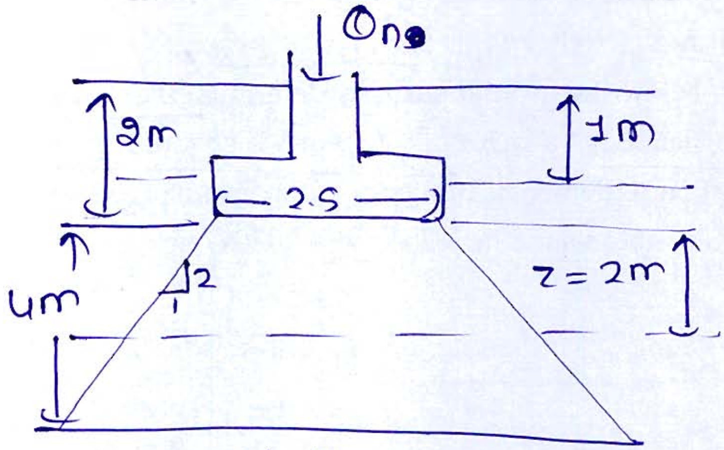
$q_{nu} = 3.5 \times 6.96$
$= 24.36$ t/m^2

FOS = 3

$$q_{ns} = \frac{q_{nu}}{FOS} = \frac{24.36}{3} = 8.12 \text{ t/m}^2$$

(ii) Settlement Criteria

Total consolidation settlement is limited = 50mm = 5cm



$\gamma_b = 1.75 t/m^3$

$e = 0.9$

$C_c = 0.280$

$\phi = 0°$

$\gamma_w = 10 kN/m^3 = 1 t/m^3$

Assuming load dispersion 2V : 1H

Initial effective stress at mid of clay layer.

$\overline{\sigma_0} = \gamma_b \times 1m + 3 \times \gamma_{sub}$

$= 1.75 \times 1 + 3 \times (1.75 - 1)$

$= 4 t/m^2$

assuming $\gamma_w = 1 t/m^3$

$H_0 = 4m$

$$\Delta\overline{\sigma} = \frac{Q}{(B + 2nz)^2} = \frac{Q}{(2.5 + 2 \times \frac{1}{2} + 2)^2}$$

$$= \frac{Q}{20.25} t/m^2$$

$$\because S = \Delta H = \frac{H_0}{1+e_0} C_c \log\left[\frac{\overline{\sigma_0} + \Delta\overline{\sigma}}{\overline{\sigma_0}}\right]$$

$$50 mm \times 10^{-3} \frac{m}{mm} = \frac{4m}{1+0.9} \times 0.28 \log\left[1 + \frac{\Delta\overline{\sigma}}{4}\right]$$

$$\Delta\overline{\sigma} = 0.8627 t/m^2 = \frac{Q}{20.25}$$

$$Q = 17.47 \text{ tonn}$$

$$q_{allowable} = \frac{Q}{2.5^2} = \frac{17.47}{2.5^2} = 2.795 t/m^2$$

~~$q_{nS} = \frac{2.795}{FOS} = 2.795$~~

allowable net bearing capacity of footing

$= \min[2.795\ t/m^2,\ 8.12\ t/m^2]$

$= 2.795\ t/m^2$

20

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]

(1)

(yr) Time	Population
t=0	40,000 ← P_o
t=20	160,000 ← P_1
t=40	400,000 ← P_2

$\Delta t = 20$ years

Using logistic curve method,

a) Saturation population of city

$$P_s = \frac{2P_oP_1P_2 - P_1^2(P_o+P_2)}{P_oP_2 - P_1^2}$$

$P_s = 640{,}000$ (Ans)

b) Population after 50 years from present

t = 40 + 50 = 90 years from t=0

$$P_t = \frac{P_s}{1+me^{nt}}$$

where $m = \frac{P_s - P_o}{P_o}$

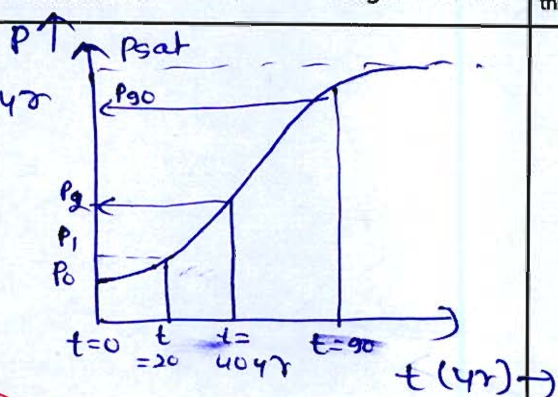
$$n = \frac{1}{\Delta t}\ln\left[\frac{P_o}{P_1}\left[\frac{P_s-P_1}{P_s-P_o}\right]\right]$$

$m = \frac{640{,}000 - 40{,}000}{40{,}000} = 15$, $n = -0.0804792$

$$P_{90} = \frac{640{,}000}{1 + 15\, e^{-0.08047\, yr^{-1} \times 90\, yr}}$$

$$= 633202.597$$

$$\simeq 633203$$



8

11)

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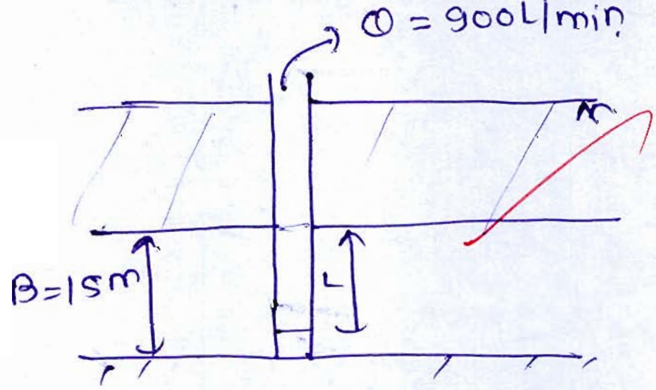
Q.5 (b) (i) A fully penetrating well is constructed in a confined sandy aquifer that is bounded above and below by impervious clay strata. The well has a maximum discharge capacity of 900 L/min. The thickness of the aquifer is 15 m. Determine the required length of the well screen, assuming that the 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]

(1)



Confined Aquifer.

let length of well screen is 'L'

Area of holes = 0.13 × A total

borehole diameter = 15cm = d

Velocity (max) = 2 cm/s through strainer.

∴ Q = Area of holes × Velocity through strainer

$$900\frac{L}{min}\times10^{-3}\frac{m^3}{L}\times\frac{1min}{60sec} = 0.13\times[\pi d L]\times2\times10^{-2}\frac{m}{s}$$

Do not write in this margin

$$\frac{9\,60 \times 10^{-3}}{60} \cdot \frac{m^3}{s} = 0.13 \times \pi \times 0.15 \times L \times 2 \times 10^{-2} \, \frac{m}{m}/s$$

$L = 12.243\,m$ (Ans)

4

(11)

Do not write in this margin

(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]

Given

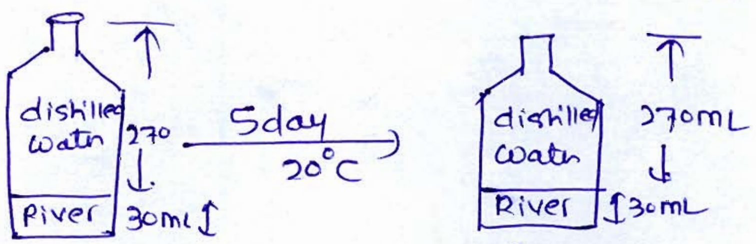
→ ~~Dilution Ratio~~

dilution factor of River sample = 10%

Dissolved oxygen in River, DO_R = 2.5 mg/L

Dissolved oxygen of distilled water, DO_w = 6 mg/L

$K_{d\,(20^\circ C)} = 0.23\ day^{-1}$ (assume base e)



$(DO_i)_{mix} = 5.65\ mg/L$ $(DO_F)_{mix} = 1.2\ mg/L$

$(DO_F)_{mix} = 1.2\ mg/L$

⇒ Step ① $(DO_i)_{mix} = \dfrac{[DO_w]\,V_w + (DO)_R \times V_R}{V_w + V_R}$

$= \dfrac{6\ mg/L \times 270\ mL + 2.5\ mg/L \times 30\ mL}{300\ mL}$

$= 5.65\ mg/L$

$BOD_5(20^\circ C) = \left[(DO_i)_{mix} - (DO_F)_{mix}\right] \times \dfrac{300\ mL}{30\ mL}$

$= \left[5.65\ \dfrac{mg}{L} - 1.2\ \dfrac{mg}{L}\right] \times \dfrac{300}{30}$

$= 44.5\ mg/L$ (Ans)

∵ BOD Ultimate

$BOD_U = \dfrac{BOD_t}{1 - e^{-K_D t}} = \dfrac{BOD_5}{1 - e^{-K_D \times 5}} = \dfrac{44.5\ mg/L}{1 - e^{-0.23 \times 5}}$

$BOD_U = 66.12\ mg/L$

$K_{27°C} = K_{20°C} [1.047]^{27-20}$ $T > 20°C$

$(K_{D(T)} = K_{D20} [1.047]^{T-20°C})$

$= 0.23 [1.047]^7$

$= 0.317 \text{ day}^{-1}$

$BOD_3 (27°C) = BOD_U [1 - e^{-K_{D(27°)} \times 3}]$

$= 66.12 \text{ mg/L} [1 - e^{-0.317 \times 3}]$

$= 40.574 \text{ mg/L}$ (Ans)

12

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:

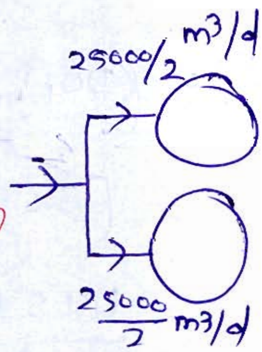
1. The surface area and volume of the settling basins,
2. The surface overflow rate (in m^3/m^2 day),
3. The detention time (in hours), and
4. The weir loading (in m^3/m day).

[12 marks]

→ Diameter of each basin, D = 25 m

Sidewater depth, H = 2 m

$Q_{Total} = 25,000 \text{ m}^3/d$



discharge entering ~~per bas~~ in each basin, $Q = \frac{25000}{2} = 12,500 \text{ m}^3/d$

[a] Surface area & Volume of settling basin

Surface area $= \frac{\pi}{4} D^2 = \frac{\pi}{4} \times 25^2$

$= 490.874 \text{ m}^2$ (Ans)

Volume, $V = D^2[0.785H + 0.011D]$

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

$V = 1153.125 m^3$ (Ans)

(ii) Surface overflow rate

$SOR = \frac{\text{discharge}}{\text{Surface area}}$

$= \frac{12500 \, m^3/d}{490.874 \, m^2}$

$SOR (V_0) = 25.465 \, m^3/m^2/d$ (Ans)

(iii) Detention time

$D_t = \frac{\text{Volume}}{\text{discharge}}$

$= \frac{1153.125 \, m^3}{12500 \, \frac{m^3}{d}} \times \frac{24 hr}{d}$

$D_t = 2.214 \, hr$ (Ans)

12

(iv) Weir loading Rate

$= \frac{\text{discharge}}{\text{Perimeter}}$

$= \frac{12500 m^3/d}{\pi \times 25 \, m}$

$= 159.155 \, m^3/m/d$ (Ans)

Do not write in this margin

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]

⇒ Fuel consumption per month = 2 ML

Annual fuel consumption = $12 \times 2 \frac{ML}{month}$

$= 24$ ML/year

∵ From 1 ML of fuel per year

PM = 2.5 tonnes

SO_2 = 15 tonnes

→ From 24 ML of fuel per year

$PM = 2.5 \frac{tonnes}{ML} \times 24 = 60$ tonnes/year

$= \frac{60 \text{ tonnes}}{365 \times 24 \text{ hr}} = 6.849 \times 10^{-3}$ tonne/hr

→ $SO_2 = 15 \frac{tonne}{ML} \times 24 ML = 360$ tonne/year

$= \frac{360 \times 1000 \text{ kg}}{365 \times 24 \text{ hr}} = 41.096$ kg/hr

Safe height of chimney (max of below criteria)

(I) Absolute min. height = 30m

(II) Based on PM

$$H = 74[Q]^{0.27} \quad (Q \rightarrow \text{tonne/hr})$$

$$= 74[6.849 \times 10^{-3}]^{0.27}$$

$$= 19.268\ m$$

(III) Based on SO_2

$$H = 14[Q]^{0.3} \quad (Q \rightarrow \text{kg/hr})$$

$$= 14[41.096]^{0.3}$$

$$= 42.68\ m$$

12

Safe height of chimney = max [30m, 19.268m, 42.68m]

= 42.68m (Ans)

Do not write this margin

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%

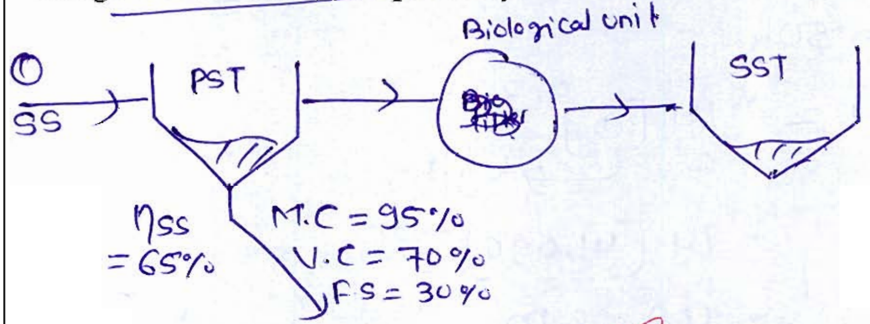
Volatile solid content in influent sludge = 70%

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]



wastewater discharge, Q = 4.5 MLD

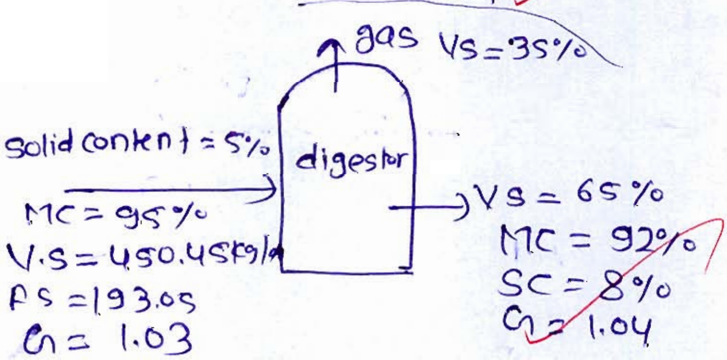
Suspended solid in incoming = 220 mg/L

SS removed in PST = 0.65 × 220

= 143 mg/L

Solids removed per day from PST = $143 \times 10^{-6} \frac{kg}{L} \times 4.5 \times 10^{6} \frac{L}{d}$

= 643.5 kg/d



volatile solids in influent sludge = 0.7 × 643.5

= 450.45 kg/d

Fixed solid = 643.5 − 450.45

= 193.05 kg/d

∵ Solid content of influent sludge = 5%

Weight of influent sludge = $643.5 \text{ kg/d} \times \frac{100}{5}$

$= 12870 \text{ kg/d}$

Volume of influent sludge

$$V_1 = \frac{12870 \text{ kg/d}}{1.03 \times 1000 \text{ kg/m}^3} \qquad \left[V = \frac{M}{G \rho_w}\right]$$

$= \underline{12.495 \text{ m}^3/\text{d}}$

→ After digestion

Volatile solids = 0.65×450.45
(35% destroyed in digestor) = 292.793 kg/d

Fixed solids = 193.05 kg/d
(as original)

Solids present in digested sludge = $292.793 + 193.05$
= 485.843 kg/d

∴ Solid content of digested sludge = 8%

Total weight of digested sludge = $485.843 \text{ kg/d} \times \frac{100}{8}$

$= 6073.04 \text{ kg/d}$

Volume of digested sludge

$$V_2 = \frac{M_{DS}}{G_{DS} \times \rho_w} = \frac{6073.04 \text{ kg/d}}{1.04 \times 1000 \text{ kg/d}}$$

$\underline{V_2 = 5.84 \text{ m}^3/\text{d}}$

→ Detention time = 20 days = D_t

Size of Anaerobic digestion tank

$$V = \left[V_1 - \frac{2}{3}\left[V_1 - V_2\right]\right] D_t \qquad \text{(FAIR ET AL formula)}$$

$= \left[12.495 - \frac{2}{3}\left[12.495 - 5.84\right]\right] \times 20$

$$\boxed{V = 161.167 \text{ m}^3}$$ (Ans)

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]

(i) ⇒ Design life of landfill = 35 years

Persons in household = 4

Per capita waste generation = 2.5 kg/day

Compacted density of waste = 900 kg/m^3

$\frac{\text{Solid waste}}{\text{Cover}} = \frac{4}{1}$

Total no. of households = 5000

(A) Total population of city = 5000 × 4
= 20,000 person

Total waste generated per day, M_w = 20,000 person × $\frac{2.5 \text{ kg}}{\text{person} \times \text{d}}$

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$M_w = 50{,}000$ kg/d

Volume of waste generated per day $= \frac{M_w}{\rho_{waste}}$

$= \frac{50{,}000 \text{ kg/d}}{900 \text{ kg/m}^3}$

$= 55.56 \text{ m}^3/\text{d}$

→ Total volume of waste generated per year $= 55.56 \frac{\text{m}^3}{\text{d}} \times 365 \frac{\text{d}}{\text{yr}}$

$= 20279.4 \text{ m}^3/\text{yr}$

→ Volume of cover soil required per year $= \frac{1}{4} \times 20279.4$

$= 5069.85 \text{ m}^3/\text{yr}$ (Ans)

→ Total volume of landfill site required for design life of 35 years

$= 20279.4 \frac{\text{m}^3}{\text{year}} \times 35$ year

Volume of landfill $= 709779 \text{ m}^3$ (Ans)

(ii) The methods of land filling in dry areas are

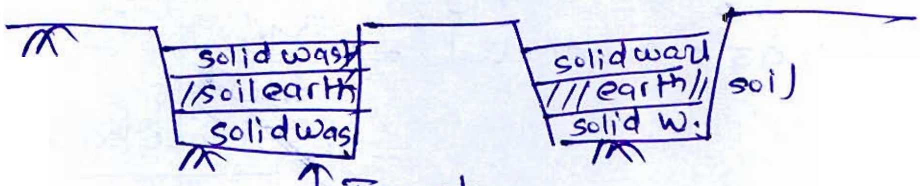
(i) Trench method

(ii) Area Method

(iii) Depression Method

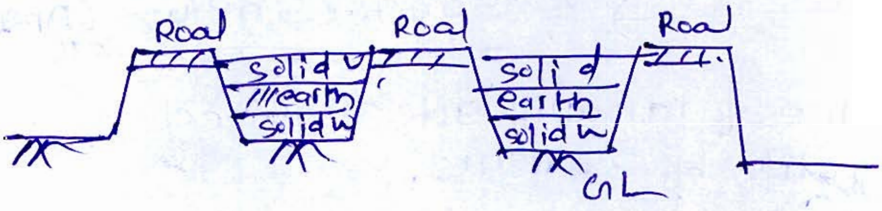
→ (i) Trench method

This method is suitable when adequate earth cover soil is available and water table is at greater depths. Trenches are excavated in area and ~~soil~~ solid wastes are disposed in layers by ~~layer~~ layer and seperated by soil earth.



Area Method

→ This method is adopted when terrain is not suitable for trench excavation and water table is high. The whole area is divided into no. of subareas called cell by embankment and Road.



12+6

Depression Method

This is adopted when natural or artificial depressions are available for landfill. It can be in form of canyons, quarries, borrow pit etc. The techniques used for waste disposal depend on geometry of area, characteristic of waste, hydrology & geology of waste.

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(c) 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]

⇒ Sewage flow = 3.5 MLD

$= 3.5 \times 10^6 \frac{L}{d} = 3500 \frac{m^3}{d}$

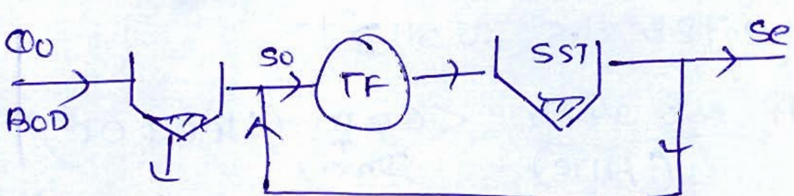
Recirculation Ratio, R = 1.5

BOD of Raw sewage = 220 mg/L

BOD removed in PST (Primary settling Tank) = 25%

BOD in effluent = 30 mg/L

Depth of filter, H = 1.5 m



$\eta_{BOD} = 25\%$

→ BOD applied to HRTF = 0.75 × 220 mg/L

So = 165 mg/L

BOD of effluent = 30 mg/L = Se

efficiency of TF ⇒ $\eta = \frac{So - Se}{So} \times 100$

$= \frac{165 - 30}{165} \times 100 = 81.82\%$

From NRC formula

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

where OLR = organic loading Rate (kg/m³/d)

F = Recirculation factor.

$F = \frac{1+R}{(1+(1-f)R)^2}$, f = treatability factor = 0.9 assume

$= \frac{1+1.5}{(1+0.1 \times 1.5)^2} = 1.89$

$81.82 = \frac{100}{1+0.44\sqrt{\frac{OLR}{1.89}}}$

$OLR = 0.482\ kg/m^3/d$

$OLR = \frac{\text{kg of BOD applied to filter}}{\text{Volume of filter}} = \frac{Q_0 S_0}{V}$

$0.482 \frac{kg}{m^3 \times d} = \frac{3.5\times10^6 \frac{L}{d} \times 165 \frac{mg}{L} \times 10^{-6} \frac{kg}{mg}}{V}$

12

$V = 1198.133\ m^3$

depth of filter given, $H = 1.5m$, let 'D' is dia of filter

$\because V = D^2[0.785H + 0.11D]$

$1198.133 = D^2[0.785 \times 1.5 + 0.011D]$

$D =$ ~~28.36m~~ $28.362m < 60m$ (Hence ok)
(Ans) $\quad D_{max}$

Dimensions of HRTF

→ Dia = 28.362m

Depth = 1.5 + 0.3 (FB) = 1.8m

(b) If the filter is designed as SRTF

$\rightarrow \eta = \frac{100}{1+0.44\sqrt{OLR}}$ as $F = \frac{1+R}{(1+0.1R)^2}$

R = 0 for SRTF

$81.82 = \frac{100}{1+0.44\sqrt{OLR}}$ $\Rightarrow F = 1$

$OLR = 0.255\ kg/m^3/d$

$OLR = \frac{Q_0 S_0}{V'}$

$0.255\ kg/m^3/d = \frac{3.5\times10^6 \frac{L}{d} \times 165\times10^{-6} \frac{kg}{L}}{V'}$

$V' = 2264.706 m^3$ (modified volume)

$2264.706 = D'^2 [0.785 \times 1.5 + 0.011 D']$ D' = dia of SPTF

$D' = 37.713 m < 60 m$ ok

% Change $= \frac{D' - D}{D} = \frac{37.713 - 28.362}{28.362} \times 100$

$= 32.97\%$ (Ans)

Dia of HRTF has to be increased by 32.97% if filter is designed as SRTF

(a) (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]

(1) Water treated per day, Q = 45MLD

Dosage of filter alum = 16mg/L

Raw water alkinity = 5mg/L as $CaCO_3$

a) Annual quantity of filter alum

$= 16 \frac{mg}{L} \times 10^{-6} \frac{kg}{mg} \times 45 \times 10^6 \frac{L}{d} \times 365 \frac{d}{yr}$

$= 262800 \frac{kg}{year} = 262.8$ tonne/year (Ans)

(b) ∵ 1 g of alum required 0.45 g of alkalinity as $CaCO_3$ to treat water by gram equivalence concept.

⇒ 16mg/L of alum required alkalinity = $0.45 \times 16 = 7.2$ mg/L as $CaCO_3$

Additional alkalinity to be added in water = 7.2 − 5 = 2.2 mg/L as $CaCO_3$

→ Amount of quick lime (purity 85% CaO) required for alkalinity

$$= \frac{2.2\ mg/L}{\text{equivalent wt of } CaCO_3} \times \frac{\text{equivalent wt of } CaO}{0.85}$$

$$= \frac{2.2\ mg/L \times 28g}{50g} \times \frac{1}{0.85}$$

= 1.45 mg/L

annual quantity of quick lime

$$= 1.45 \frac{mg}{L} \times 10^{-9} \frac{tonne}{mg} \times 45 \times 10^6 \frac{L}{d} \times 365 \frac{d}{yr}$$

= 23.816 tonne/yr (Ans)

(ii) Mechanism of slow sand filter.

→ Slow sand filter consisting fine gradation of sand for filtering media. The size of grains is approx 0.25–0.35 mm.

Slow sand filters provide high efficiency of removal of solids & aims to produce turbidity nearly zero in effluent. When water after ~~flocculation tank~~ ~~is applied~~ PST treatment applied with turbidity less than 20 mg/L → majority of impurities are blocked on surface of filter and form schmutzdecke layer and very less amount of impurity able to penetrate whole filter media. The cleaning of slow sand filter required only scraping of top sand layer of about 1.5 to 3 cm thickness and for better efficiency in 2–3 month cleaning is done.

Slow sand filters provide very low discharge rates with rate of filteration about 100-300 l/hr/m².

They are not able to handle shock loading ie. variation in discharge rates.

They are suitable for rural areas where discharge flow rate requirement is less & no other treatment is available

12+6

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:

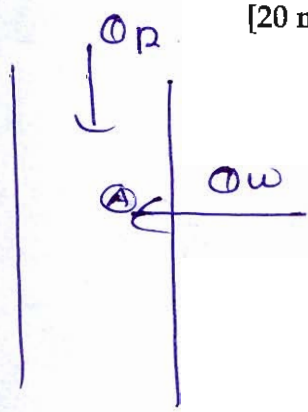
Temperature °C	18	20	22	23	24	25	26
C_s (mg/l)	9.54	9.17	8.99	8.83	8.53	8.38	8.22

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]

	Effluent	Stream
Q (m^3/s)	0.3	0.65
DO	1.5 mg/L	8 mg/L
T(°C)	27	23
BOD_5(20°C)	50 mg/L	2 mg/L



$K_D(20°C) = 0.087\ day^{-1}$ (base 10)

$K_R(10°C) = 0.174\ day^{-1}$ (base 10)

(A) Dissolved oxygen in River water after mixing

$$(DO)_{mix} = \frac{Q_W \times DO_W + Q_R \times DO_R}{Q_W + Q_R}$$

$$= \frac{0.3\ m^3/s \times 1.5\ mg/L + 0.65\ m^3/s \times 8\ mg/L}{0.3 + 0.65}$$

$$= 5.947\ mg/L$$

$$(\text{Temp})_{mix} = \frac{Q_w T_w + Q_R T_R}{Q_w + Q_R}$$

$$= \frac{0.3\,m^3/s \times 27^\circ C + 0.65\,\frac{mg}{L} \times 23}{0.3 + 0.65}$$

$$= 24.263^\circ C$$

$DO_{sat} = ?$

T°C	DOsat (mg/L)
24	8.53
25	8.38

$$DO_{sat}\,(T = 24.263^\circ C) = 8.53 - \frac{(24.263 - 24)}{(25 - 24)}(8.53 - 8.38)$$

$$= 8.4906\ mg/L$$

$$\simeq 8.49\ mg/L$$

→ Initial oxygen deficit

$$D_0 = DO_{sat} - (DO)_{mix}$$

$$= 8.49 - 5.947$$

$$D_0 = 2.543\ mg/L$$

→ $K_D(T^\circ C) = K_D(20)\,[1.047]^{T-20} \quad T > 20$

$K_R(T^\circ C) = K_R(20^\circ)\,[1.02]^{T-20} \quad T > 20$

$$K_D(23^\circ C) = 0.087\,[1.04]^{23-20}$$

$$= 0.0979\ day^{-1}$$

$$K_D[27^\circ C) = 0.087\,(1.048)^{27-20}$$

$$= 0.1145\ day^{-1}$$

$$K_D(24.263^\circ C) = 0.087\,[1.04]^{24.263-20}$$

$$= 0.1028\ day^{-1}$$

$$K_R(24.263^\circ C) = 0.174\,[1.02]^{24.263-20}$$

$$= 0.189\ day^{-1}$$

(i) $[BOD_u]$ Ultimate BOD of waste & River

$$[BOD_u]_w = \frac{(BOD_5)_{20°C}}{1-10^{-K_{D20}\times 5}} = \frac{50 mg/L}{1-10^{-0.087\times 5}}$$

$$= 79.024 mg/L$$

$$[BOD_u]_R = \frac{2 mg/L}{1-10^{-0.087\times 5}} = 3.161 mg/L$$

Ultimate BOD of River after mixing

$$L_0 = \frac{Q_w.(BOD_u)_w + Q_R(BOD_u)_R}{Q_w + Q_R}$$

$$= \frac{0.3\times 79.024 + 0.65\times 3.161}{0.3+0.65}$$

$$L_0 = 27.118 mg/L$$

16

(A) Critical oxygen deficit

$$f = \frac{K_R}{K_D} = \frac{0.189}{0.1028} = 1.838$$

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

$$= \left[\frac{27.118}{D_c\times 1.838}\right]^{1.838-1} = 1.838\left[1-(1.838-1)\times\frac{2.543}{27.118}\right]$$

$$D_c = 7.868 mg/L \text{ (Ans)}$$

(B) Critical location = ?

$$\because D_c = \frac{K_D L_0}{K_R} e^{-K_D t_c} \Rightarrow 7.868 = \frac{0.1028}{0.189}\times 27.118\, e^{-0.1028\times t_c}$$

t_c (days) = 6.113 days

Velocity = 0.3 m/s

Location of critical deficit beyond point A in downstream = $V\times t_c$

$$l = 0.3\frac{m}{s}\times\frac{6.113\times 24\times 3600 \text{ sec}}{10^3 \frac{m}{km}}$$

$$l_c = 158.449 \text{ km (Ans)}$$

(c) (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]

⇒ (1) Based on the concentration of suspended matter and characteristics of particles, settling of Particles are classified into four categories :-

I) Type 1 settling

In this settling, particles have little or no tendency to interact with each other or flocculate in dilute suspension. Such particles are called discrete particles. They settle as an individual entities and there is no significant interaction betn them.

Ex. settling in Grit chamber

II) Type 2 settling

In the 2nd type, flocculent particles settle in dilute suspension. Particles agglomerate during settling which causes increase in size, shape and density results in settlement at a faster rate.

Ex. settling primary sedimentation of wastewater treatment.

III) Type 3 settling

In the 3rd type, flocculent particles settle in intermediate concentration of particles. Due to proximity of particles with each other, they tend to remain at their fixed position with eachother and settle as a whole mass rather than individual. This settling is known as Zone settling or hindered settling.

Ex. Setting of sludge in secondard sedimentation tank after ASP.

(iv) Type IV settling

This settling is also known as Compression Settling.

→ In Compression settling, ~~compre~~ concentration of particles becomes very high such that particles are in direct contact with each other and form a structured mass. lower layers support weight of upper layers and any further settling results due to compression of whole mass.

It results in expulsion of water from voids between particles.

Ex. This type of settling generally occur at bottom of SST. ~~Ex~~ like deep bottom of sludge settlement in SST after ASP.

(ii) Given, depth, $H = 4m$

length, $L = 55m$

Horizontal flow velocity, $V_H = 1.2$ cm/sec

size of particle $d = ?$

Kinematic viscosity $\nu = 0.01 cm^2/s = 0.01 \times 10^{-4} m^2/s$

$G = 2.65$

$\because Dt = \frac{H}{V_0} = \frac{L}{V_H} = \frac{V}{Q}$ where V_0 = Surface overflow rate

$V_0 = \frac{H \times V_H}{L} = \frac{4}{55} \times 1.2 = 0.0873$ cm/s

assuming the design particle is 'd' and which is to be removed 100% ⇒ surface ~~rate~~ overflow rate is equal to settling velocity to remove this particle.

$V_S = 0.0873$ cm/s

Do not write in this margin

assuming Stokes law valid

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

$0.0873 \times 10^{-2} \frac{m}{s} = \frac{9.81\, m s^{-2}}{18} \frac{(2.65-1) d^2}{10^{-6} m^2/s}$

20

$d = 3.116 \times 10^{-5} m = 0.03116 mm < 0.1 mm$

$+ Re (\text{Reynold no.}) = \frac{V_s d}{\nu} = \frac{0.0873 \times 10^{-2} \times 0.03116 \times 10^{-3}}{10^{-6}}$

$= 0.027 < 1$ ← Stokes law valid

dia of particle

$= 0.03116 mm$ (Ans)

-a) 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]

ɔ) (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]

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Space for Rough Work

Space for Rough Work