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	42
Q.2	— 53
Q.3	~~50~~ —
Q.4	32
Section-B	
Q.5	58
Q.6	48
Q.7	—
Q.8	—
Total Marks Obtained	233

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.

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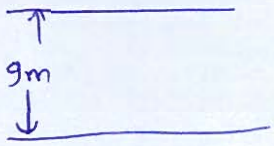
Section A : Geo-technical & Foundation Engineering

(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]



$\Delta H = 308\,mm$

$(\Delta h)_{2\,years} = 108\,mm$

$U\% = \frac{\Delta h}{\Delta H} = \frac{108}{308} = 0.351 < 0.60$

6

$T_v = \frac{C_v t}{d^2} \Rightarrow \frac{\pi}{4}(0.351)^2 = \frac{C_v \times 2\,year}{(9)^2}$

{ Assuming single way drainage allowed }

$C_v = 3.919\ m^2/year$

%U for 220 mm settlement $= \frac{220}{308} \times 100 = 71.43\% > 60\%$

$T_v = 1.781 - 0.933(\log(100 - U\%))$

$T_v = 0.546$

avoid silly mistakes

$0.546 = \frac{3.919\,\frac{m^2}{year} \times t}{(9)^2} \Rightarrow t = 11.285\,years$

$\therefore$ To attain a total of 220 mm settlement, time reqd from the start $= 11.285\,years$

Ans –

Note – Additional time reqd $= 11.285 - 2 = 9.285\,yrs$

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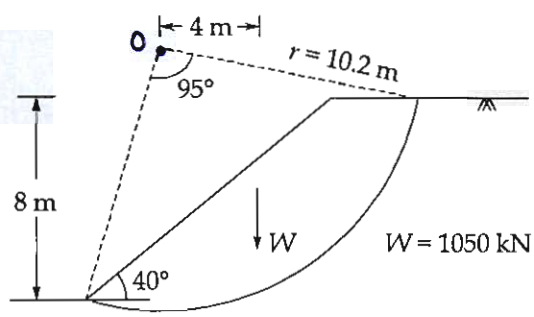
Q.1 (b) (i) A 40° slope is excavated to a depth of 8 m in a deep layer of saturated clay ($c = 50$ KN/m^2 and $\phi = 0°$, $\gamma = 19$ KN/m^3). Determine the factor of safety for the trial failure surface shown in Figure.



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

[6 + 6 = 12 marks]

Sol^n - (i) By swedish circle method —

$$FoS = \frac{\text{resisting moment}}{\text{overturn moment}} = \frac{C \cdot r \cdot (r \times \theta)}{W \cdot \bar{x}}$$

where $\bar{x}$ = lever arm from center 'O'

$$FoS = \left[\frac{50 \times 10.2^2 \times \left(95 \times \frac{\pi}{180}\right)}{1050 \times 4}\right]$$

$$\boxed{FoS = 2.054}$$ Ans.

Note - Here 'θ' is taken in radians,
So, $95^\circ \rightarrow \left(95 \times \frac{\pi}{180}\right)$ radians

) Quick sand condⁿ - In an upward flow condⁿ of water, the seepage pressure acts upward, thus the effective stress of the soil keeps on decreasing. The moment when the seepage pressure becomes equal to submerged wt. of soil, the eff. stress becomes zero, and the sandy soil starts flowing like a liquid. This condⁿ is called quick sand condⁿ.

Liquefaction - The phenomenon that occurs during sudden loading on the soil due to earthquake, explosions etc; where due to increase in load, the soil particles come closer to each other. But as water can't escape due to sudden increase, excess pore water develops, which decrease the effective stress of soil to zero. This is called liquefaction of soil

4

Major differences b/w both phenomenon-

D) In both phenomenon, the eff. stress of non-cohesive soil is getting zero. But quick sand condⁿ occurs due to upward seepage movement that reduces eff. stress and liquefaction occurs due to excess pore pressure development.

) Quick sand condⁿ can occur in normal cases due to upward seepage flow. But for liquefaction to occur, there should be a sudden and cyclic loading / vibrations like earthquakes, pile driving, explosion.

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(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]

Ans. $(\gamma_d)_{max} = 1.65\ g/cc$ @ OMC = 14.5% $G_s = 2.70$

$$\gamma_d = \frac{G\gamma_w}{1+e} \Rightarrow 1.65 = \frac{2.70 \times 1}{1 + \frac{0.145 \times 2.70}{S}} \quad \{\because Se = wG\}$$

$S = 0.6152$ or 61.52% Ans -

12

Also,

$$(\gamma_d)_{max} = \frac{(1-\eta_a)G\gamma_w}{1+wG}$$

$$\Rightarrow 1.65\ g/cc = \frac{(1-\eta_a) \times 2.70 \times 1}{1+(0.145 \times 2.7)} \Rightarrow \eta_a = 0.1496$$

or 14.96% Ans.

Theoretical max^m dry density occurs where there is no air voids left in the soil; i.e at $S = 1$

$$((\gamma_d)_{max})_{theo.} = \frac{G\gamma_w}{1+wG} = \frac{2.7 \times 1.0}{1+(0.145 \times 2.70)}$$

$(\gamma_d)_{max\,|theo.} = 1.94\ g/cc$ 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]

Soln

(i) vertically below center of A -

$$\sigma_A = 0.4775 \frac{Q}{z^2} \quad \left\{\because \frac{r}{z} = 0\right\}$$

$$\sigma_A = 0.4775 \times \frac{300 \times 2.5^2}{3^2} = 99.48 \text{ kN/m}^2$$

$\{\because Q = A \times q\}$

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

$$\frac{r}{z} = \frac{6}{3} = 2.0$$

$$\sigma_B = \frac{3}{2\pi} \times \frac{(300 \times 3^2)}{3^2} \left[\frac{1}{1+2^2}\right]^{5/2} = 2.56 \text{ kN/m}^2$$

$\therefore$ Inc. in vertical stress $= \sigma_A + \sigma_B$

$= 102.04 \dfrac{\text{kN}}{\text{m}^2}$ Ans.

(ii) vertically below footing B –

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

$$\left(\frac{r}{z}\right) = \frac{6}{3} = 2.0$$

$$\sigma_A = \frac{3}{2\pi} \times \frac{300 \times 2.5^2}{3^2} \left[\frac{1}{1+2^2} \right]^{2.5} = 1.78 \text{ Kpa}$$

12

$$\sigma_B = 0.4775 \frac{Q}{z^2} \qquad \left\{ \because \frac{r}{z} = 0 \right\}$$

$$\sigma_B = 0.4775 \times \frac{300 \times 3^2}{3^2} = 143.25 \text{ Kpa}$$

$\therefore$ Inc in vertical stress $= \sigma_A + \sigma_B = 145.03 \text{ kN/m}^2$ Ans

(iii) vertically below midpoint b/w A & B –

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

$$\frac{r}{z} = \frac{3}{3} = 1.0$$

$$\sigma_A = \frac{3}{2\pi} \times \frac{300 \times 2.5^2}{3^2} \left[\frac{1}{1+1} \right]^{5/2} = 17.584 \frac{\text{kN}}{\text{m}^2}$$

Similarly, $\left(\frac{r}{z}\right) = 1.0$ for footing B also

$$\sigma_B = \frac{3}{2\pi} \times \frac{300 \times 3^2}{3^2} \left[\frac{1}{1+1} \right]^{5/2} = 25.32 \frac{\text{kN}}{\text{m}^2}$$

$\therefore$ Inc. in vertical stress $= \sigma_A + \sigma_B$

$= 42.905 \frac{\text{kN}}{\text{m}^2}$ Ans –

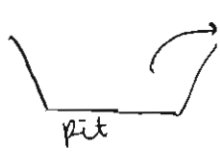
Q.1 (e) An undisturbed soil in a borrow area has a water content of 16%, a void ratio of 0.55, and a specific gravity of solids of 2.7. This soil is used to construct an embankment with a finished volume of 60,000 m^3. The soil is excavated and transported via trucks with a 5 m^3 capacity. When loaded 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:

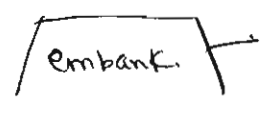
1. The degree of saturation, bulk unit weight, and dry unit weight of the undisturbed borrow material.
2. The number of truck loads required for construction.
3. The amount of water (in litres) to be added per truck load.

[6 + 3 + 3 = 12 marks]

Sol^n.



$G_s = 2.55$, $w = 0.16$, $e = 0.55$



$V_T = 60{,}000\ m^3$

d) For undisturbed borrow pit;

$e S = w G$

$S = \frac{16 \times 2.70}{0.55} = 78.545\%$

$\gamma_b = \frac{G(1+w)\gamma_w}{1+e} = \frac{2.7(1+0.16) \times 10}{1+0.55} = 20.206 \frac{kN}{m^3}$

$\gamma_d = \frac{G\gamma_w}{1+e} = \frac{2.7 \times 9.81}{1.55} = 17.42 \frac{kN}{m^3}$ Ans-

4

e) Vol^m of soil solids in pit = Vol^m of soil solids in embankment

for embankment; $\gamma_d = 18\ kN/m^3 = \left(\frac{G\gamma_w}{1+e}\right)$

$18 = \frac{2.7 \times 10}{1+e_2} \Rightarrow e_2 = 0.50$

$\left(\frac{V_T}{1+0.55}\right) = \frac{60 \times 10^3}{1+0.50} \rightarrow (V_T)_{pit} = 62000\ m^3$

No. of truck loads reqd $= \frac{62000\ m^3}{5\ m^3} = 12400$ trucks Ans-

f) $\left(\frac{70}{5}\right) = \frac{2.7(1+w) \times 10}{1+0.50} \Rightarrow w_1 =$

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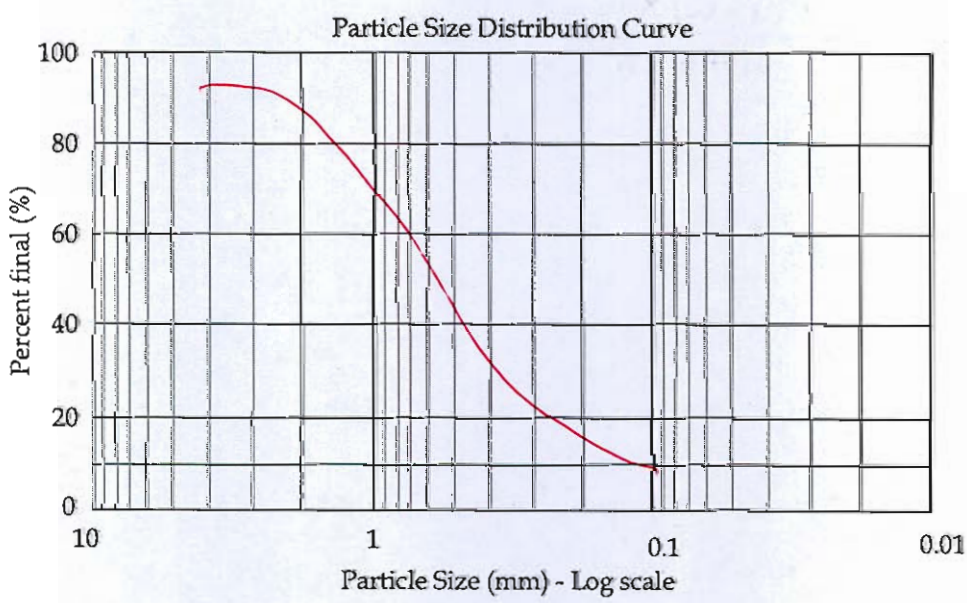
Q.2 (a) A 500 g dry soil sample was subjected to a sieve analysis. The masses of soil retained on each sieve are as follows: 12 g on 4.75 mm sieve, 160 g on 2.00 mm sieve, 115 g on 1.00 mm sieve, 95 g on 425 μm sieve, 45 g on 212 μm sieve, 25 g on 150 μm sieve, 40 g on 75 μm sieve, and 8 g in the pan. 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]

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sieve size	mass retained	cum. mass retained (g)	% cum. mass ret.	% cum passing
4.75 mm	12 gm	12	2.4	97.6
2 mm	160 gm	172	34.4	65.6
1 mm	115 gm	287	57.4	42.6
425 μm	95 gm	382	76.4	23.6
212 μm	45 gm	427	85.4	14.6
150 μm	25 gm	452	90.4	9.6
75 μm	40 gm	492	98.4	1.6
pan	8 gm	500	100	0
	Σ = 500 gm			

15

% fines = 1.6%
sand > gravel

D_{60} of soil –

65.6 → 2 mm
42.6 → 1 mm

$$\frac{65.6-60}{65.6-42.6} = \frac{2-D_{60}}{2-1}$$

$$D_{60} = 1.756 \text{ mm}$$

D_{10} of soil –

$$\frac{14.6-10}{14.6-9.6} = \frac{212-D_{10}}{210-150}$$

$$D_{10} = 156.8 \ \mu m$$

D_{30} of soil –

$$\frac{42.6-30}{42.6-23.6} = \frac{1-D_{30}}{1-0.425}$$

$$D_{30} = 618.7 \ \mu m$$

$$C_u = \frac{D_{60}}{D_{10}} = \frac{1.756}{0.1568} = 11.20 > 6$$

$$C_c = \frac{D_{30}^2}{D_{10} \times D_{60}} = \frac{0.6187^2}{1.756 \times 0.1568} = 1.39 \text{ (b/w 1 \& 3)}$$

Given soil is – SW – well graded sand

Ans –

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(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]

Total stress parameters (undrained).

(S1)

$\sigma_3 = 100\,kPa$ $\sigma_d = 160\,kPa$

$\sigma_1 = (\sigma_3 + \sigma_d) = 260\,kPa$

$\sigma_1 = \sigma_3 \tan^2\left(45 + \frac{\phi}{2}\right) + 2c\tan\left(45 + \frac{\phi}{2}\right)$

$260 = 100\tan^2(\theta_f) + 2c\tan(\theta_f)$ — (1)

(S2)

$\sigma_3 = 300\,kPa$, $\sigma_d = 320\,kPa \Rightarrow \sigma_1 = 620\,kPa$

$620 = 300\tan^2\theta_f + 2c\tan\theta_f$ — (2)

From (1) and (2);

$\tan^2(\theta_f) = 1.8 \Rightarrow \tan\theta_f = 1.34$

$\boxed{\phi = 16.601^\circ}$

From eqn (1);

$260 = 100(1.8) + 2c(1.34) \Rightarrow \boxed{c = 29.85\,kPa}$

for Total stress parameters, $\boxed{\phi = 16.601^\circ,\ c = 29.85\,kPa}$

Ans.

Eff. stress parameters - (drained)

(S1)

$\sigma_3 = 100\,kPa$; $\sigma_d = 160\,kPa$, $\sigma_1 = 260\,kPa$

$\bar{\sigma}_1 = \bar{\sigma}_3 \tan^2\theta_f' + 2c'\tan\theta_f'$

$(260 - 40) = (100 - 40)\tan^2\theta_f' + 2c'\tan\theta_f'$

$220 = 60\tan^2\theta_f' + 2c\tan\theta_f'$ — (iii)

(S2)

$\sigma_3 = 300\,kPa$, $\sigma_d = 320\,kPa$, $\sigma_1 = 620\,kPa$

$(620 - 120) = (300 - 120)\tan^2\theta_f' + 2c'\tan\theta_f'$

$500 = 180 \tan^2\theta_f' + 2c' \tan^2\theta_f'$ —— (IV)

from eq^n (III) + (IV),

$\tan^2\theta_f' = 2.333 \Rightarrow \tan\theta_f' = 1.527$

$\boxed{\phi' = 23.58^\circ}$

from eq^n (4)

$500 = 180(2.333) + 2c'(1.527) \Rightarrow c' = 26.21$ kPa

for eff. stress parameters,

$\boxed{\begin{array}{l}\phi' = 23.58^\circ \\ c' = 26.21 \text{ kPa}\end{array}}$

Ans -

20

(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]

(ii) Terzaghi criteria for design of protective filters –

a) For stability of protective material – The protective filter should have such small voids, such that the protected / base material's should not be able to pass the filter, otherwise the base material will keep on decreasing in size.

$$\boxed{\frac{(D_{15})\ \text{filter mat.}}{(D_{85})\ \text{protected material}} < 5}$$

b) for efficient filtration – for efficient filteration from the filter, the filter's particle size should be such that it can be able to filter most of the impurities, thus protecting the base material from accumulation of impurities and choking the material. For such cond,

$$\boxed{\frac{(D_{15})\ \text{filter material}}{(D_{15})\ \text{base material}} < 25}$$

c) Terzaghi also give the third criteria for ease of determination of size and material for the filter. The material should be capable of trapping most of impurities

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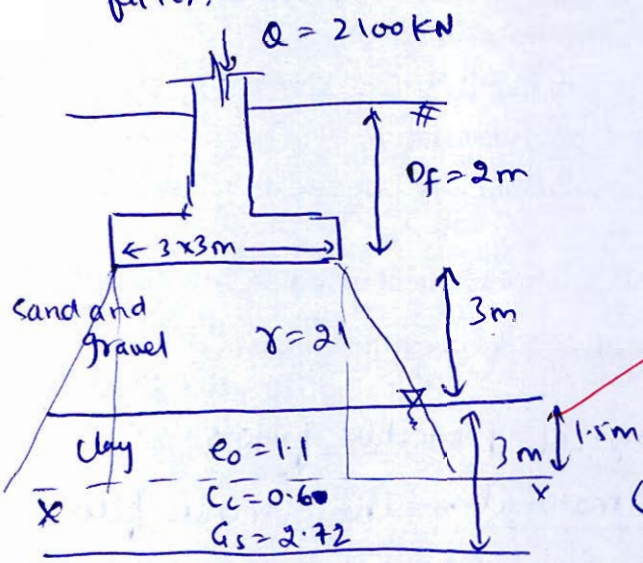
without getting clogged in small time

$$\boxed{4 < \frac{(D_{50})\ \text{filter material}}{(D_{50})\ \text{base material}} < 20}$$

By using these 3 mentioned criteria, we can determine the material & size of the particles to be utilised to make the filter.

(i)



Δh = probable settlement

$$= \frac{H_0 C_c}{1+e_0} \log\left(\frac{\bar{\sigma}_0 + \Delta\bar{\sigma}}{\bar{\sigma}_0}\right)$$

$\bar{\sigma}_0$ = eff. stress at the center of clay layer

$$(\bar{\sigma}_0)_{x-x} = (5 \times 21) + 1.5(\gamma_{clay})$$

for clay; $\gamma_{sub} = \left(\frac{G-1}{1+e}\right)\gamma_w = 8.035\ kN/m^3$

$$(\bar{\sigma}_0)_{x-x} = (5 \times 21) + (8.035 \times 1.5) = 117.05\ kN/m^2$$

Assuming 2:1 load distribution (2V:1H)

$$(\Delta\bar{\sigma}_0) = \frac{2100}{(3+4.5)^2} = 37.33\ kN/m^2$$

10 + 8

$$\Delta h = \frac{3 \times 1000 \times 0.6}{1+1.1} \log\left(\frac{117.05 + 37.33}{117.05}\right)$$

$$\boxed{\Delta h = 103.05\ mm}$$ Ans –

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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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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]**

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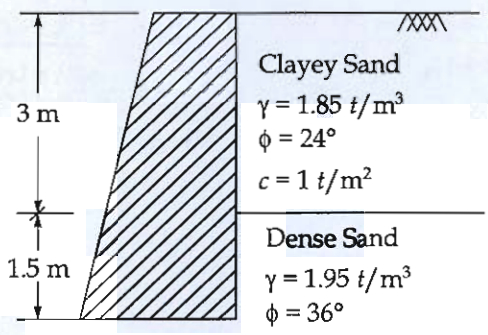
(a) (i) Compute the total active thrust and its point of application for the retaining wall shown in Figure. The wall has a smooth back face.

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]

Soln –

(ii) Volm of soil slurry $(V_1) = 9.6cc$

weight of saturated soil $(m_1) = 17.46gm$

dried mass of slurry $(m_d) = 11.58gm$

dry. volm of slurry $(V_d) = 5.22cc$

$$SR = \frac{\left(\frac{V_1 - V_d}{V_d}\right)}{(w_1 - w_s)} \text{ or } \left(\frac{\gamma_d}{\gamma_w}\right)$$

Shrinkage limit can be calculated as–

$$w_s = \frac{(M_1 - M_d) - (V_1 - V_d)\rho_w}{M_d}$$

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

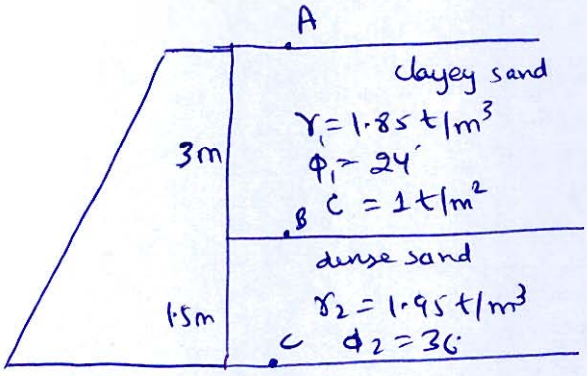
$w_s = 0.1295$ or 12.95% Ans –

Shrinkage Ratio can be calculated as –

$$SR = \left(\frac{\rho_d}{\rho_w}\right) = \frac{\left(\frac{11.58gm}{5.22cc}\right)}{1g/cc}$$

$\boxed{SR = 2.218}$ Ans –

(i)



$$K_{a_1} = \frac{1 - \sin 24°}{1 + \sin 24°} = 0.422$$

$$K_{a_2} = \frac{1 - \sin 36°}{1 + \sin 36°} = 0.260$$

$\sigma_A = 0 kPa$; $p_A = K_a \sigma_A - 2C\sqrt{K_a}$

$= 0 - 2 \times 1 \times \sqrt{0.422} = -1.3 t/m^2$

Depth of tension crack $= \frac{2C}{\gamma\sqrt{K_a}} = \frac{2 \times 1}{1.85\sqrt{0.422}} = 1.66m$

Given, Tension crack has developed

$\sigma_B = 1.85 \times 3 = 5.55 t/m^2$

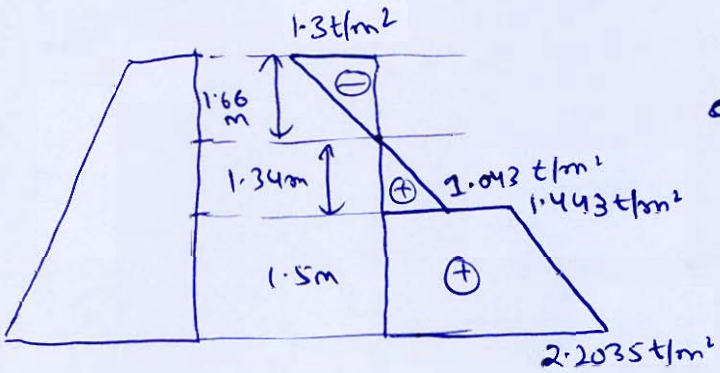
$p_B = (0.422 \times 5.55) - (2 \times 1 \times \sqrt{0.422}) = 1.043 t/m^2$

σ_B (in sand layer) $= 5.55 t/m^2$

$(p_B)_{sand} = K_{a_2} \gamma z = 0.26 \times 5.55 = 1.443 t/m^2$

$\sigma_C = (1.85 \times 3) + (1.95 \times 1.5) = 8.475 t/m^2$

$(p_C) = K_{a_2} \sigma_C = 8.475 \times 0.260 = 2.2035 t/m^2$



As tension crack has already developed, we will neglect the negative earth pressure effect

Total active Earth thrust –

$P_A = \left(\frac{1}{2} \times 1.34 \times 1.043\right) + \left[\frac{1}{2}(1.443 + 2.2035) \times 1.5\right]$

$= 3.434$ t/m length of wall Ans–

Point of application –

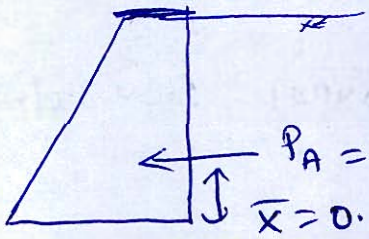
$$\bar{x} = \frac{P_{A_1}\bar{x}_1 + P_{A_2}\bar{x}_2}{P_{A_1} + P_{A_2}}$$

$\bar{x}_1 = 1.5 + \left(\frac{1.34}{3}\right) = 1.95$ m from base of wall

$\bar{x}_2 = \left(\frac{2(1.443) + 2.2035}{1.443 + 2.2035}\right) \times \frac{1.5}{3} = 0.698 \simeq 0.7$ m from base

$$\bar{x} = \frac{\left(\frac{1}{2} \times 1.34 \times 1.043 \times 1.95\right) + \left[\left(\frac{1}{2} \times 1.5 (2.2035 + 1.443)\right) \times 0.7\right]}{3.434}$$

$\bar{x} = 0.954$ m from base of wall Ans–



$P_A = 3.434\ t/m$ length

$\bar{x} = 0.954\ m$

Ans –

12

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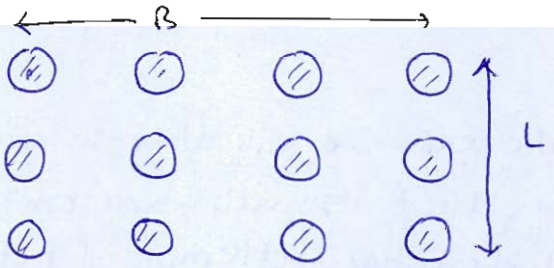
(b) (i) A raft foundation is supported by a group of 12 concrete piles, each with a diameter of 400 mm and a length of 12 m, arranged in a rectangular formation of 3 rows and 4 columns. The piles are spaced at 1.0 m center-to-center in both directions and are embedded in a deep layer of clay having an 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]



dia. of pile = 0.4m

Length (l) = 12m

$B = (3s + d) = 3 \times 1 + 0.4$
$= 3.4m$

$L = (2s + d) = 2 \times 1 + 0.4$
$= 2.4m$

a) Ultimate load capacity as per Individual pile –

Total $Q_{up} = n \cdot Q_{up} = 12 \times [(9 \times 4.5 \times \frac{\pi}{4}(0.4)^2) + (0.9 \times 4.5 \times \pi \times 0.4 \times 12)]$

$\boxed{nQ_{up} = 793.94 \text{ tkN}}$

b) Ultimate load capacity of pile group (Qug)

$$Q_{ug} = 9 \times 4.5 \times (BL) + \overset{1.0}{\cancel{\alpha}}\, \bar{C} \times 2(L+B) \times l$$

{∵ for pile group $\alpha = 1$}

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

$$\boxed{Q_{ug} = 956.88\ tN}$$

Allowable load capacity of pile group

$$\text{min.} \begin{cases} Q_{all.} = \dfrac{Q_{ug}}{FOS} = \dfrac{956.88}{2.0} = 478.44\ tN \\ = \dfrac{Q_{up}}{FOS} = \dfrac{793.94}{2.0} = 396.97\ tN \end{cases}$$

∴ Allowable load capacity of pile group ≃ 397 tN

(ii) Factors considered while determining the appropriate depth of footing –

① Ground water depth is a major concern for footing placement, because presence of GWT can decrease the bearing capacity of soil.

② Stratification of soil, i.e. presence of layers of soil during soil exploration is also a concern due to change in soil properties and behaviour

③ Encounter with highly plastic expansive soils along the soil depth is generally not suited, due to its swelling and shrinkage properties, that can lead to differential settlement of footing

④ The loading of the superstr. / building plays a vital role in determining the depth of footing, because of the amount of load acting on the footing. Generally, depth of footing is high for heavy superstructures.

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5) Type of soil over which the super str. is to be constructed is also a factor to be observed. Generally, clayey soils have tendancy to show large settlements as compared to granular soils, and get more affected by moisture.

The position of the nearby str. also affects the choice of footing and depth of placement of footing.

Presence of organic matter or loose fill at depth also inc. the depth of footing.

The gradation of the soil always place a major role in estimating the depth of footing. Well graded sand has more angle of internal friction, so more load can be bear by the soil easily as compared to poorly graded soil.

12 + 6

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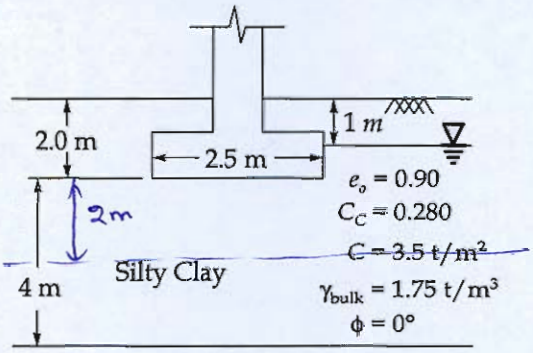
.4 (c) A square footing of dimensions 2.5 m × 2.5 m is proposed to be constructed at a depth of 2.0 m below ground level in a deep, uniform deposit of soft silty clay. The foundation soil has an undrained cohesion of 3.5 t/m^2, a bulk unit weight of 1.75 t/m^3, and an angle of internal friction equal 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]

$$\gamma_{sat} = \frac{(G+e)\gamma_w}{1+e} = 1.75\ t/m^3$$

$$\Delta h = \frac{H_0 C_c}{1+e_0} \log\left(\frac{\bar{\sigma}_0 + \Delta\bar{\sigma}}{\bar{\sigma}_0}\right)$$

2

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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]

Sol^n

Year	Population
T	40,000 — P_0
(T+20)	1,60,000 — P_1
T+40	4,00,000 — P_2

$\boxed{t_1 = 20 \text{ yrs}}$

a) Saturation population $(P_s) = \left[\dfrac{2P_0P_1P_2 - P_1^2(P_0+P_2)}{P_0P_2 - P_1^2}\right]$

$$P_s = \frac{(2\times 40\times 160\times 400\times 10^9) - (160^2(40+400)\times 10^9)}{[(40\times 400)\times 10^6] - (160^2\times 10^6)}$$

$$P_s = 640\times 10^3 = 640{,}000 \quad \text{Ans-}$$

b) Expected population after next 50 years

$t = 90$ yrs (from the start)

$$m = \frac{P_s - P_0}{P_0} = 15$$

$$n = \frac{1}{t_1}\ln\left(\frac{P_0}{P_1}\left(\frac{P_s-P_1}{P_s-P_0}\right)\right)$$

$$n = \frac{1}{20\text{ yr}}\ln\left[\frac{40}{160}\left(\frac{640-160}{640-40}\right)\right]$$

$$n = -0.0805 \text{ yr}^{-1}$$

Population after 50 yrs (P_n -

$$P_n = \frac{P_s}{1+me^{nt}} = \frac{640\,000}{1+15e^{-0.0805\times 90}}$$

$P_n = 633220.73$

$\boxed{P_n \simeq 633221}$ Ans.

ii) Specific Capacity – Specific capacity of a well is defined as the yield per unit drawdown of the well. In short, it is the discharge of water from the well for unit drawdown.

$$S_c = \frac{Q}{S} \quad m^3/s/m \text{ drawdown}$$

12

Specific capacity is a parameter which is used to measure the efficiency of an aquifer. If a well has high specific capacity, it means that a large discharge of water can be easily taken out from the well.

Specific Capacity depends on various factors – permeability of well, particle size of well & type of soil particles, cone of depression etc

Specific Yield – Specific yield is the vol^m of water that can be taken out (discharged out from the vol^m of aquifer, at the time of pumping.

Specific Yield of coarse grained soils is more as compared to that of fine grained soils, due to high permeability.

Specific yield is an important parameter, alongside with sp. retention during the working cond^n of a well.

$$\boxed{S_y = \eta - S_r}$$

where η = porosity
S_r = sp. retention

$$S_y = \frac{\text{vol}^m \text{ of water discharged out}}{\text{vol}^m \text{ of water in aquifer}} \times 100\%$$

Specific yield depends on various factors – like permeability of soil, presence of impurities or adsorbed layer, rate of discharge etc.

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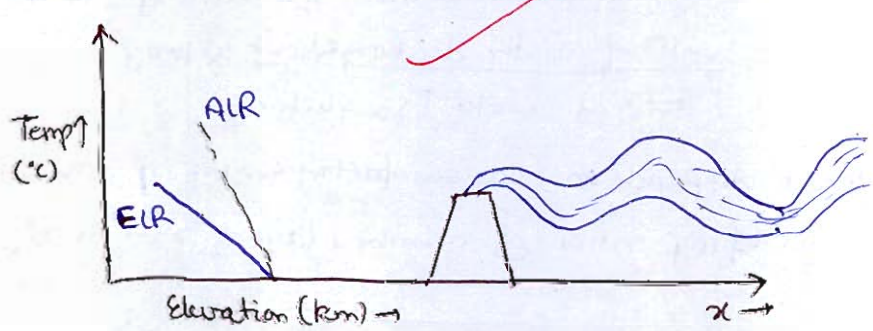
Q.5 (b) (i) A fully penetrating well is constructed in a confined sandy aquifer that is bounded above and below by impervious clay strata. The well has a maximum discharge capacity of 900 L/min. The thickness of the aquifer is 15 m. Determine the required length of the well screen, assuming that the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

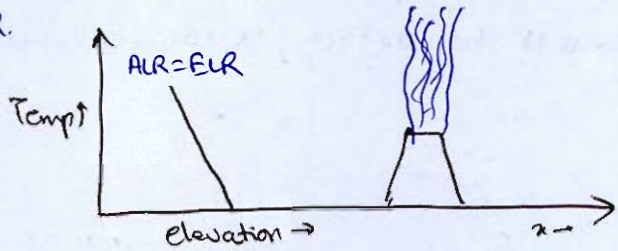
[4 + 8 = 12 marks]

Sol^n (ii) Various types of plume behaviours are –

① Looping Plume – Formed when the ELR > ALR, or superadiabatic cond^{n}s prevail in the atmosphere (unstable cond^n). The plume moves in a zig-zag (S-pattern).

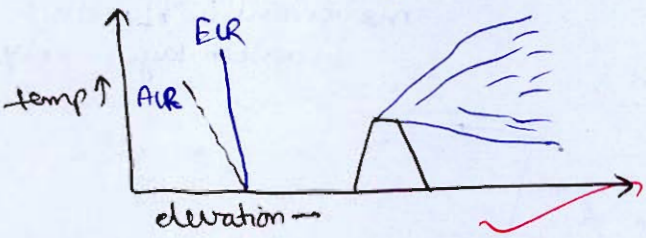


2) Neutral plume – It occurs when the ALR = ELR, and is characterised by the vertical movement of pollutants from the stack.

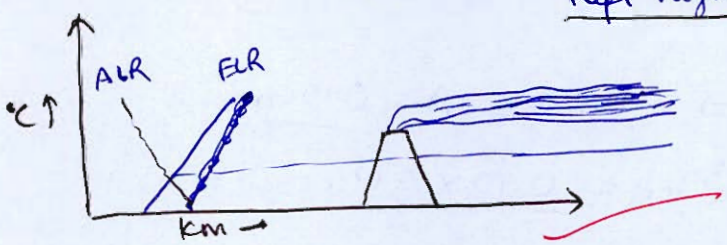


) Coning plume – It occurs under subadiabatic condⁿ (ALR > ELR) or stable condⁿ.

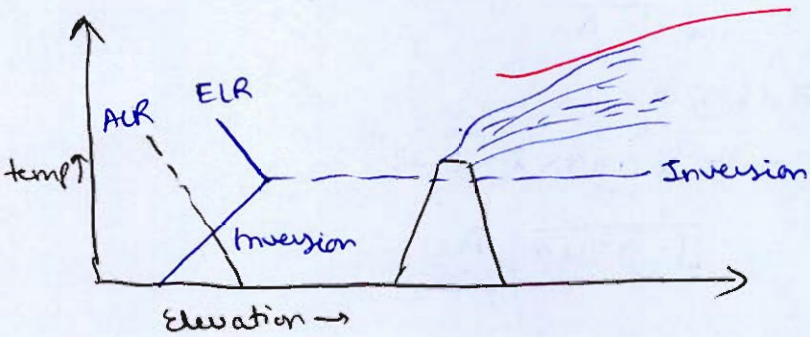
It is characterised by cone shaped pollutant movement and high wind velocity (> 32 Kmph)



Fanning plume – It occurs when the condⁿ of atmosphere is of extreme inversion. Characterized by vertical as well as horizontal mixing of pollutants. The stack ht. is generally kept higher in such case



) Lofting plume – occurs when superadiabatic condⁿ prevails above the inversion condⁿ (which occurs below stack ht). It is the best plume condⁿ because the smoke doesn't move towards the surface due to inversion layer



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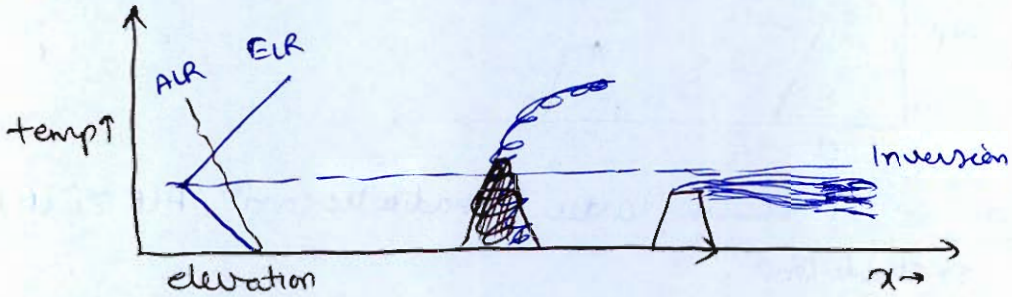
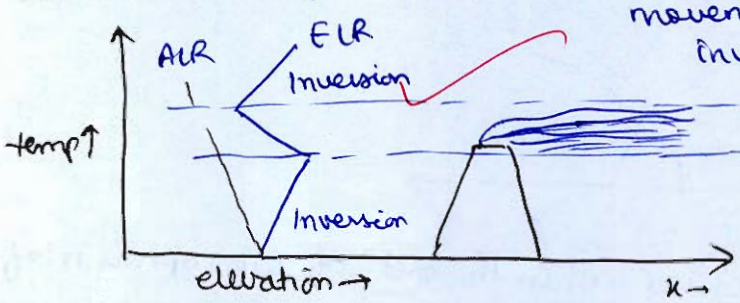
(6) Fumigating plume – Observed when inversion layer occurs above superadiabatic condⁿ. Worst possible plume because the pollutants moves towards the surface, leading to health hazards



(7) Trapped plume – observed when superadiabatic condⁿ occurs b/w two inversion layers (trapped in b/w). The pollutants movement is b/w two inversion layers only.



(i) $Q_{max} = \frac{900\,L}{60\,sec} = \frac{0.9\,m^3}{60\,sec}$

2+8

$B = 15\,m$

$d_w = 15\,cm \Rightarrow 0.15\,m \Rightarrow A = 0.196\,m^2$

open area in stainer $= 0.13 \times 0.196 = 0.0255\,m^2$

Velocity through stainer = 2 cm/sec

$Q = A_s V$

$A_s = \frac{0.9}{60}\frac{m^3}{sec} \times \frac{sec}{2\times10^{-2}\,m} = 0.75\,m^2$

diameter $= \sqrt{\frac{0.75\times4}{\pi}} = 0.98\,m$

$Q = \pi d l \times v$

$\left(\frac{0.9}{60}\right) = \pi \times 0.98 \times l \times 0.02$

$\boxed{l = 0.24\,m}$ Ans –

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5 (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]

$(DO)_{initial} = DO_{mix} = \frac{10(2.5) + 90(6)}{90+10}$

{∵ Assuming 90 mL of diluted water is added to 10 mL of sample to make 10% dilution}

$(DO)_{mix} = 5.65 \text{ mg/l} = (DO)_i$

$(DO)_f$ after incubation $= 1.2 \text{ mg/l}$

$(BOD)_5\ 20°C = [(DO)_i - (DO)_f] \times DF$

$= (5.65 - 1.2) \times 10 = 44.5 \text{ mg/l}$

$(BOD)_5\ 20°C = (BOD)_u (1 - e^{-K_D t})$

$(BOD)_u = \frac{44.5}{1 - e^{-0.23 \times 5}} = 65.12 \text{ mg/l}$

(∵) For same water sample, ult. BOD remains same.

$(K_D)_{27°C} = (K_D)_{20} (1.047)^{T-20}$

$= 0.23 (1.047)^7 = 0.317 \text{ d}^{-1}$

$(BOD)_5\ 27°C = (BOD)_u (1 - e^{-K_D t})$

$= 65.12 (1 - e^{-0.317 \times 5})$

12

∴ $(BOD)_5\ 27°C = 51.77 \text{ mg/l}$ Ans –

Also,

$(BOD)_3\ 27°C = BOD_u (1 - e^{-K_D t})$

$= 65.12 (1 - e^{-0.317 \times 3})$

$(BOD)_3\ 27°C = 39.96 \text{ mg/l}$ Ans –

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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^n –

diameter of each settling basin = 25 m

Discharge through each basin = $\frac{25000}{2}$ = 12500 m^3/d

a) Vol^m of settling basin –

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

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

$\boxed{V = 1153.125\ m^3}$ Ans –

S. Area of basin = $\frac{\text{vol}^m \text{ of basin}}{\text{depth}} = \frac{1153.125}{2.0} = 576.56\ m^2$ Ans –

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SOR –

$$V_s = \frac{Q}{A} = \frac{25000 (m^3/d)}{2 \times 576.56 m^2} = 21.68 \ m^3/m^2/d$$

Ans –

Detention time – $(D_t) = \frac{\text{Vol}^m \text{ of basin}}{Q}$

$$D_t = \frac{1153.125 \ m^3}{12500 \ \frac{m^3}{d}} = 2.214 \text{ hrs}$$

Ans –

weir loading –

$$V_w = \frac{Q}{\pi D} = \frac{12500 (m^3/d)}{(\pi \times 25) m}$$

$$V_w = 159.15 \ m^3/m/d$$ Ans.

12

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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]**

Sol^n

Safe ht = max $\{30m, H_1, H_2\}$

where $H_1 = 74 (Q_p)^{0.27}$ Q_p = Conc of SPM in t/hr

$H_2 = 14 (Q_s)^{0.30}$ Q_s = Conc of SO_2 in kg/hr

~~Conc of PM~~

~~$Q_p = \frac{2.5 \text{ tonne}}{\text{ML} \times \text{year}} \times \frac{2 \text{ ML}}{\text{month}} \times 12 \text{ month} \times \frac{1000 \text{ kg}}{1 \text{ tonne}} \times \frac{1 \text{ year}}{(365 \times 24) \text{ hr}}$~~

~~$Q_p = 6.849$ kg/hr~~

~~$H_1 = 74 (6.849)^{0.27} = 124.409$ m~~

~~Conc of SO_2 –~~

~~$Q_s = \frac{2.5 \text{ tonne}}{\text{ML} \times \text{year}} \times$~~

Conc. of Particulate matter –

$$Q_p = \frac{2.5\ t}{MC \times year} \times \frac{2\ MC}{month} \times 12\ month \times \frac{1\ year}{(365 \times 24)\ hr}$$

$$= 6.849 \times 10^{-3}\ t/hr$$

$$H_1 = 74 (Q_p)^{0.27} = 19.27\ m$$

Conc. of SO_2 –

$$Q_s = \frac{1.5\ t}{MC \times year} \times \frac{2\ MC}{month} \times 12\ month \times \frac{1000\ kg}{1\ t} \times \frac{1\ year}{(365 \times 24)\ hr}$$

(kg/hr)

$$Q_s = 41.096\ kg/hr$$

12

$$H_2 = 14 (41.096)^{0.3} = 42.68\ m$$

$\therefore$ max^m ht. of chimney $= \max\{30\ m, 19.27\ m, 42.68\ m\}$
$= 42.68\ m$

$\therefore$ Provide chimney of ht. 45 m Ans –

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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]

Sol^n –

SS conc. in the sewage $= 220\times10^{-6}\,\frac{kg}{l}\times 4.5\times10^{6}\,\frac{l}{d}$

$= 990$ kg/d

Efficiency of PST = 65%

SS removed / settled in PST $= 0.65\times990 = 643.5$ kg/d

Volatile solids conc. in the sludge each day $= (0.7\times643.5)$
$= 450.45$ kg

non-volatile solids each day $= 0.3\times643.5 = 193.05$ kg

moisture content = 95%

It means that 5% of total sludge mass → 643.5 kg

mass of total sludge (raw) $= \frac{643.5}{0.05} = 12870$ kg

mass of water in sludge $= 0.95\times12870 = 12226.5$ kg

Vol^m of raw sludge –

$V_1 = \frac{\text{mass of raw sludge}}{\text{Density of sludge}} = \frac{12870\text{ kg}}{1.03\times10^3\text{ kg/m}^3}$

$\boxed{V_1 = 12.495\text{ m}^3}$

After digestion;

mass of volatile solids remaining $= (1-0.35)\times450.45$
$= 292.8$ kg

mass of non-volatile solids = 193.05 kg

Total SS mass in digested sludge = 485.84 kg

moisture content of digested sludge = 92%

It means that 8% of the digested sludge mass → 485.84 kg

∴ mass of digested sludge = $\frac{485.84}{0.08}$ = 6073.03 kg

Vol^m of digested sludge (V_2) = $\frac{6073.03}{1.04 \times 10^3}$ = 5.84 m^3

Vol^m of digestion tank –

By FAIR Et-al formula –

20

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

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

$$V = 161.2 \text{ m}^3$$

Adopting depth of tank = 5 m

∴ S. Area of tank = $\frac{161.2}{5}$ = 32.24 m^2

diameter of digestion tank (d) = $\sqrt{\frac{32.24 \times 4}{\pi}}$

$$d = 6.4 \text{ m}$$

∴ Provide digestion tank of dia – 6.4 m and depth = 5 m; along with 1:1 slope at the bottom hopper for the collection of sludge.

Do not write in this mar

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]

Sol^n – (ii) Various methods of landfilling in dry area –

(1) AREA METHOD – This method is useful when the GWT is very near to the surface, (or) the terrain is rocky and not suitable for deep excavation.

→ In area method, the MSW is distributed in large areas, in thin layers, compacted with bulldozers and at the day end, covered with dry earth (daily cover).

→ This method is less time consuming, less labourious than trench method, but daily cover has to be arranged seperately after each day's work.

TRENCH METHOD – It is generally adopted where deep excavations can be done to create trenches for sewage disposal.

→ The major advantage of this method is that the excavated soil acts as daily cover at the day end, so there is no problem of cover.

→ It is suitable for plain lands, where GWT is deep and the soil is clayey for easy excavations

DEPRESSION METHOD – It is a subtype of area method of landfilling where natural or man-made depressions are utilised as sewage disposal site.

→ Various depressions such as ravines, isolated quarries, borrow pits, canyons etc. are utilised as disposal site

→ The general rule of disposal is to start at bottom and then end at face of depression, so as to minimise the accumulation of water behind solid waste

→ The major disadvantage with this method is that such natural & man-made depressions are not easily available.

Various ways to control leachate and gas movement –

The clay liners (bentonite clay + geotextile) are generally used for lining the landfill bottom and sides, so as to make it impervious and leachate movement can be minimised.

Leachate collection system and gas vents are provided in the landfill to collect the dirty liquid and gases

The gases collected by air vents and pipes are then used to make renewable energy, electrical power etc

By giving primary treatment to the MSW before disposal in landfill, thus reducing the production of foul gases and leachate.

Use of hydrophobic | liquid polymers at the bottom, which are corrosive resistant and not react with leachate, making impervious

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(i) Total solid waste generated each day

$$= \frac{2.5\ kg}{c} \times 5000\ h \times \frac{4c}{h} = 5\times10^4\ kg$$

Total waste generated in 35 yrs

$$= \frac{5\times10^4\ kg}{day} \times (35\times365)\,d = 6.3875\times10^8\ kg$$

Density of compacted MSW = 900 kg/m³

Volᵐ of compacted MSW = $\frac{6.3875\times10^8}{900} = 709722.22\ m^3$

$$\frac{\text{Solid waste vol}^m}{\text{cover vol}^m} = \frac{4}{1} = \frac{709722.22}{\text{vol}^m \text{ of cover}}$$

18

∴ volᵐ of cover = $\frac{709722.22}{4} = 177430.56\ m^3$

volᵐ of cover reqd (in yearly basis) = $\frac{177430.56}{35} = \boxed{5069.44\ m^3}$ Ans –

Now,

$$\frac{4}{5} \times \text{vol}^m \text{ of landfill} = 709722.22\ m^3$$

∴ volᵐ of landfill = $709722.22 \times \frac{5}{4}$

$= \boxed{887152.775\ m^3}$ Ans

(or)

88.715 Ha-m

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5(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]

BOD of raw sewage = 220 mg/l

BOD entering the TF (BOD) = $(1-0.25) \times 220$
$= 165$ mg/l

BOD conc. entering $= 165 \times 10^{-6} \frac{kg}{l} \times 3.5 \times 10^{6} \frac{l}{d} = 577.5 \frac{kg}{d}$

$(BOD)_e = 30$ mg/l

efficiency of TF $(\eta) = \frac{\text{BOD removal}}{\text{influent BOD}} \times 100$

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

recirculation factor $(F) = \frac{1+R}{(1+(1-f)R)^2}$

for Indian condⁿ, $f = 0.9$ (say purification factor)

$F = \frac{1+1.5}{(1+(0.1 \times 1.5))^2} = 1.890$

20

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

$\therefore$ OLR $= 0.482$ kg/m³/d

OLR = $\frac{\text{Kg of BOD entering each day}}{\text{volᵐ of T. Filter}}$

0.482 kg/m³/d $= \frac{577.5 \text{ kg/d}}{\text{volᵐ } (m^3)} \Rightarrow$ volᵐ $= 1198.13$ m³

volᵐ $\simeq 1200$ m³

Taking depth of filter = 1.5m

Surface area = $\frac{1200}{1.5} = 800 m^2$

∴ diameter of T. Filter = $\sqrt{\frac{800 \times 4}{\pi}} = 31.9 \simeq 32m$ < 60m (OK)

So, provide TF of dia. 32m and depth 1.5m

Case 2. If SRTF is used

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

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

$$0.255 = \frac{577.5 \, kg/d}{vol^m} \Rightarrow vol^m = 2264.6 m^3$$

Surface area of SRTF = $\frac{2264.6}{1.5} = 1509.7 m^2$

∴ dia. of SRTF = $\sqrt{\frac{1509.7 \times 4}{\pi}} = 43.84 m \simeq 44m$

% inc in diameter = $\frac{44-32}{32} \times 100 = 37.5\%$

Ans –

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(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]

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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]

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(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]

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-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]

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(b) (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]

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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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OOOO

Space for Rough Work

Space for Rough Work

$\frac{D_{15}}{D_{85}} < 4$

$\frac{D_{15}}{D_{15}} < 25$

$5 < \frac{D_{50}}{D_{50}} < 20$