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ESE-2019 : MAINS TEST SERIES

UPSC ENGINEERING SERVICES EXAMINATION

CIVIL ENGINEERING | Test No. 1

Section A : Geo-technical & Foundation Engineering [All Topics]

Section B : Environmental Engineering [All Topics]

Time Allowed : 3 hrs. | Maximum Marks: 300

Question Paper Specific Instructions

Please read each of the following instructions carefully before attempting questions:

- Answers must be written only in **ENGLISH**.
- There are **EIGHT** questions divided in **TWO** sections.
- Candidate has to attempt **FIVE** questions in all.
- 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.
- The number of marks carried by a question/part is indicated against it.
- Wherever any assumptions are made for answering a question, they must be clearly indicated. Diagrams/figures, wherever required, shall be drawn in the space provided for answering the question itself.
- Unless otherwise mentioned, symbols and notations carry their usual standard meanings. Attempt of questions shall be counted in sequential order. Unless struck off, attempt of a question shall be counted even if attempted partly. Any page or portion of the page left blank in the Question-cum-Answer Booklet must be clearly struck off.

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE ASKED TO DO SO

For any query write to us, at: **info@madeeasy.in**

Section A : Geo-technical & Foundation Engineering

Q.1 (a) A core-cutter of diameter 100 mm and height 130 mm having weight 1.5 kg was pushed into embankment under construction and mass of core cutter with soil was found to be 3.865 kg. The soil has water content of 11% and specific gravity of soil is 2.67. Determine the bulk unit weight, dry unit weight and void ratio of soil sample. The unit weight of water is 9.81 kN/m^3.

[12 marks]

(b) $\overline{CU}$ tests carried out on a saturated normally consolidated clay showed that $C_u = 0$ and $\phi_u = 15°$. If the pore pressure coefficient A at failure was 0.92, what are the values of c' and ϕ' for the soil?

[12 marks]

(c) Compare the salient features of Standard Penetration Test and Plate Load Test.

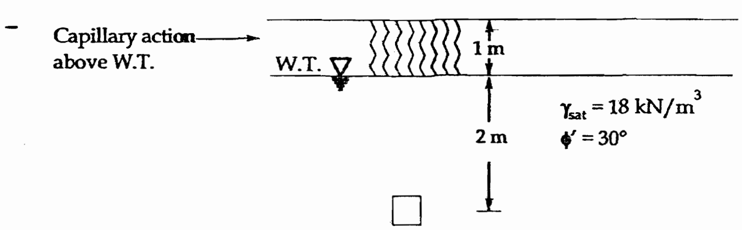
[12 marks]

(d) (i) What quantity of cement per m^3 of soil is required for permeation grouting in soil, having void ratio of 0.6, if the grout mix has a water cement ratio of 6 : 1 by weight? Assume that 50% of the void space gets filled with the grout slurry. Take specific gravity of cement as 3.15.

(ii) Grouting is to be carried out in 12 m deep grout holes spaced at 3 m distance center to center for the problem discussed in (i) above. What will be the saving per group hole if 50% cement is replaced by Bentonite, given that the cost of cement is ₹ 250 per kN and that of Bentonite is ₹ 120 per kN? Assume that grout will permeate uniformly around each group hole, the volume soil grouted will be a cylinder of diameter 3 m around each grout hole.

[6 + 6 = 12 marks]

(e) The soil profile at a site for a proposed building is shown in figure.



The soil is a homogeneous, poorly graded sand. Determine, the increase in vertical effective stress at which a soil element at a depth of 3 m, under the center of the building will fail if the increase in lateral effective stress is 20% of the increase in vertical effective stress. The coefficient of lateral earth pressure at rest k_0 is 0.5. Assume all stresses are principal stresses.

[12 marks]

Q.2 (a) **(i)** Consider the following options:

(i) Constructing a cofferdam and casting the concrete in situ.

(ii) Floating a prefabricated box caisson and lowering it is to the bearing stratum.

(iii) Sinking a well foundation and plugging it.

Which of the above options would be most appropriate for constructing a 10 m wide foundation on a strong bearing stratum beneath a river bed for the following three cases?

Case A :

Depth of water above bed = 2 m, depth of strong bearing stratum below bed = 2 m.

Case B :

Depth of water above bed = 20 m, depth of strong bearing stratum below bed = 3 m.

Case C :

Depth of water above bed = 10 m, depth of strong bearing stratum below bed = 20 m.

(ii) A new canal is excavated to a depth of 5 m below ground level, through a soil having the following characteristics : $c = 14\ kN/m^2$, $\phi = 15°$, $e = 0.8$ and $G = 2.7$. The slope of banks is 1 in 1. Calculate the factor of safety with respect to cohesion when the canal runs full. If it is suddenly and completely emptied, what will be the factor of safety?

[Take, for $i = 45°$, $\phi = 15°$, $s_n = 0.083$ and for $i = 45°$, $\phi = 7.3°$, $s_n = 0.122$]

[10 + 10 marks]

(b) **(i)** What are the differences between reinforced soil walls and nailed soil walls?

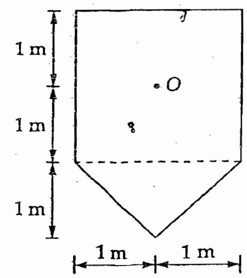
(ii) A foundation trench is to be excavated for a large project in a site. The soil investigation report shows the following details :

Depth from Ground Surface	Type of soil	Index Properties
0 - 8 m	Fine sand	Void ratio = 1.20, Sp.gr. = 2.62
8 - 10 m	Greyish clay	Void ratio = 0.76, Sp.gr. = 2.65
Below 10 m	Coarse sand	–

It is observed that an open excavation is stable up to 5.75 m depth with the existing water table. The excavation is to be made up to 8.5 m depth for which water table is to be lowered. What are the initial and final depths of water table?

[6 + 14 marks]

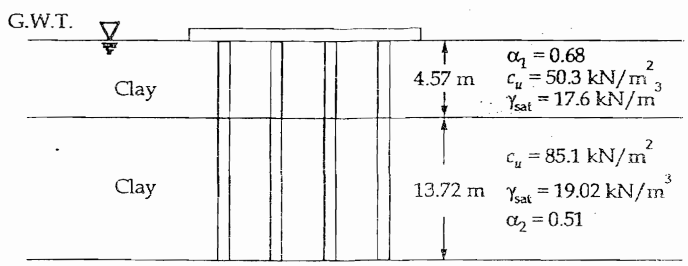
(c) (i) Compute the vertical stress on a horizontal plane situated at a depth of 2 m below point O in the figure shown below. The area is loaded uniformly to an intensity of 300 kN/m^2. [Use Boussinesq's theory]



(ii) In an unconfined compression test, a sample of clay 100 mm long and 50 mm in diameter fails under a load of 200 N at 10% strain. Calculate the shear resistance of the soil sample by taking into account the effect of change in cross-section of the sample.

[10 + 10 marks]

Q.3 (a) The section of a 3 × 4 group pile in a layered saturated clay is shown in figure.



The piles are square in cross-section (356 mm × 356 mm). The center-to-center spacing, d of the piles is 889 mm. Determine the allowable load carrying capacity of the pile group. Use FOS = 4.

[**Note :** Ground water table coincides with the ground surface. For group action of piles take $N_c = 8.57$]

[20 marks]

(b) An anchored sheet pile supports a sandy back fill of height 3 m having angle of shearing resistance of 30° and unit weight of 19 kN/m^3. The soil below dredge line is clay with a unit weight of 19 kN/m^3, cohesion 20 kN/m^2 and zero angle of internal resistance. The anchor rods are placed 1 m apart and 1 m below the level surface of the backfill. Assuming free earth support, calculate the force in anchor and the depth of sheet pile. Use Rankine's theory for earth pressure.

[20 marks]

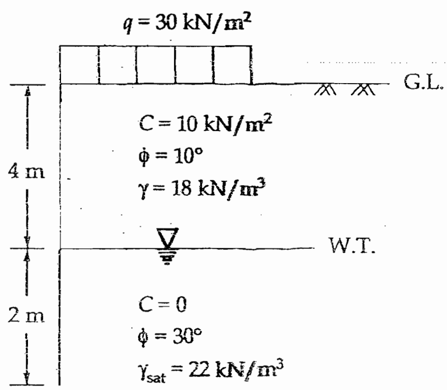
(c) A light weight building stands over a 10 m thick stratum of sand. Beneath the sand stratum a clay layer of 5 m thick exists. The clay layer is underlain by a rock stratum. The water table lies at a depth of 1.0 m below ground surface and the sand above the water table is saturated with capillary rise. The sand has a void ratio of 0.75 and specific gravity 2.65. During dry season, water is pumped out from the sand stratum till the water table is lowered by 4.0 m and sand above water table becomes dry.

Calculate the number of days when the building settles by 25 mm. Ignore settlement during pumping operation.

Take properties of clay : Void ratio = 0.60, Specific gravity = 2.70, Liquid limit = 40%, Coefficient of consolidation = 6×10^{-3} cm^2/s.

[20 marks]

Q.4 (a) Calculate the total active earth pressure on the retaining wall 6 m high as shown in the figure. Also calculate the line of action of the lateral force from the base of the wall.



[20 marks]

(b) A square mass concrete in footing usually implies raft concrete footing supporting a load of 3250 kN extends from ground level to 3.5 deep into a clay stratum. What will be the size of the footing allowing for a factor of safety of 4? Unit weight of concrete is 25 kN/m^3. Unit weight of soil 21 kN/m^3. Cohesion of soil 0.12 N/mm^2. Adhesion of clay with footing is 25 kN/m^2. The adhesion may be supposed to act over a depth of 2 m from the bottom of the foundation. For $\phi = 0°$, $N_C = 5.7$, $N_q = 1$, $N_\gamma = 0$

[20 marks]

(c) (i) Draw contact pressure distribution under the following cases:

(a) Rigid footing on cohesionless soil at shallow depth.

(b) Rigid footing on cohesive soil.

(c) Rigid footing on cohesionless soil at deeper depth.

(ii) Find an expression for the unconfined compressive strength q_u in terms of c', ϕ' and A_f (pore pressure parameter at failure). Take parameter $B = 1$ and initial capillary tension = U_c.

[5 + 15 marks]

Section B : Environmental Engineering

Q.5 (a) State the salient features of a water supply scheme and also draw a flow chart for the same.

[12 marks]

(b) Discuss the need of environmental impact assessment. Also discuss the environmental impact of thermal power plants.

[12 marks]

(c) Estimate the weight of net solids (sludge) produced per day in an activated sludge aeration system in which the influent BOD is reduced from 250 mg/l to 30 mg/l. The flow, Q = 4000 m^3/day; aeration tank volume = 700 m^3 and MLVSS = 3000 mg/l. Assume Y = 0.5, K_d = 0.09/day. Also compute θ_c and F/M.

[12 marks]

(d) What is shrouding of well? Explain with figure.

[12 marks]

(e) A rectangular sewer with width 1.5 times its depth is hydraulically equivalent to a circular one. Find the relation between the width of the rectangular sewer and the diameter of the circular sewer.

[12 marks]

Q.6 (a) (i) Demand of domestic water for a certain city is observed to follow the following pattern :

Time (hr)	0	2	4	6	8	10	12	14	16	18	20	22	24
Demand at the stated time (m^3/s)	0.00	0.10	0.15	0.20	0.50	0.60	0.40	0.30	0.15	0.20	0.25	0.10	0

Assuming uniform rise or fall in demand in the successive time interval, calculate the minimum required capacity of service reservoir, if treated water supply by pumping is constant throughout the day.

(ii) Explain self cleansing velocity and non-scouring velocity and their importance in the design of sewers.

[14 + 6 marks]

(b) (i) A sample of raw water contains, 200 mg/l alkalinity, 50 mg/l hardness as $CaCl_2$ and 75 mg/l hardness as $MgSO_4$. Compute the quantities of lime and soda required to treat 1 million litres of water. If slaked lime of 85% purity is available in place of pure lime, what will be the required quantity of slaked lime?

(ii) State various disadvantages of Zeolite process of water softening.

[12 + 8 marks]

(c) A rectangular sedimentation basin is required to handle 10 million litres/day of raw water. A detention basin of width to length ratio of $\frac{1}{3}$ is proposed to trap all particles larger than 0.04 mm in size. Assuming a relative density of 2.65 for the particles and 20°C as the average temperature, compute the basin dimensions. If the depth of tank is 3.5 m, calculate the detention time.

[20 marks]

Q.7 (a) The main sanitary sewer is to serve a population of 76000. Calculate the size and slope of the sewer for the following data:

Ratio of maximum flow in sewer to average flow is given by:

$$\frac{Q_{max}}{Q_{avg}} = \frac{18+\sqrt{P}}{4+\sqrt{P}}$$

where 'P' is the population in thousand

Average per capita water supply = 140 lpcd,

Average sewage flow = 80% of water supply.

Manning's roughness coefficient (for concrete sewer) = 0.013. Sewer should run half full while carrying the maximum flow. Velocity in sewer at maximum daily flow = 0.8 m/s.

[20 marks]

(b) (i) A river with saturation DO (at 25°C) 8.4 mg/l and self purification ratio, (f) 2.4 receives treated wastewater. Find the permissible BOD in the treated wastewater if rate constant k_1 (at 25°C) is 0.1/day (at base 10). The sewage flow is 80 cumecs and the river flow is 1200 cumecs.

(ii) Write a brief note on 'Tropospheric ozone' and 'Stratospheric ozone'?

[14 + 6 marks]

(c) What do you understand by development of well? Describe the various methods used for development of well.

[20 marks]

Q.8 (a) Pollutant concentration distribution for a continuous single emission source follows Gaussian distribution given as

$$C_{x,y} = \frac{Q}{\pi u \sigma_z \sigma_y} e^{-\frac{1}{2}\left[\frac{H^2}{\sigma_z^2} + \frac{y^2}{\sigma_y^2}\right]}$$

where C = Concentration of pollutant (in gm/m^3)

Q = Pollutant emission rate (in gm/sec)

u = Mean wind velocity (in m/sec)

x and y = downwind and crosswind horizontal distances (in m)

σ_y and σ_z = Plume's standard deviation

H = Effective height of stack

A coal fired thermal power plant burns 6.25 tonnes of coal per hour and discharges the combustion product through a stack having an effective height of 80 m. The coal has a sulphur content of 4.7% and the wind velocity is 8 m/sec. Determine the ground level concentration at a distance of 2 km downwind at

(i) the centre line of plume.

(ii) a crosswind distance of 0.5 km on either side of the centre line.

Given at x = 2 km, σ_z = 130, σ_y = 220

[20 marks]

(b) Design an oxidation pond for treating sewage from a hot climatic residential colony with 5000 persons, contributing sewage @ 120 litres per capita per day. The 5-day BOD of sewage is 300 mg/*l*.

[20 marks]

(c) (i) What is Vermi-composting? State various steps involved in Vermi-composting.

(ii) State the merits and demerits of incineration method of solid waste disposal.

[12 + 8 marks]

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Detailed Solutions

ESE-2019 Mains Test Series

Civil Engineering Test No : 1

Section A : Geo-technical & Foundation Engineering

Q.1 (a) Solution:

Given data : Diameter core cutter = 100 mm = 0.1 m, length = 130 mm = 0.13 m, mass of core cutter = 1.5 kg, mass of core cutter + soil = 3.865 kg, water content, w = 11%, specific gravity, G = 2.67

$$\text{Volume of core cutter} = \frac{\pi}{4} \times 0.1^2 \times 0.13 = 1.02 \times 10^{-3} \text{m}^3$$

$$\text{Mass of soil} = 3.865 - 1.5 = 2.365 \text{ kg}$$

$$\therefore \quad \text{Bulk unit weight of soil} = \frac{M.g}{V} = \frac{2.365 \times 9.81}{1.02 \times 10^{-3}} \times 10^{-3}$$

$$\gamma_b = 22.75 \text{ kN/m}^3$$

$$\text{Dry unit weight of soil, } \gamma_d = \frac{\gamma_b}{1+w} = \frac{22.75}{1+0.11} = 20.5 \text{ kN/m}^3$$

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

$$\Rightarrow \quad 20.5 = \frac{2.67 \times 9.81}{1+e}$$

$$\Rightarrow \quad e = 0.278$$

Q.1 (b) Solution:

Given : $C_u = 0$, $\phi_u = 15°$, $A = 0.92$

$\because$ The given soil is saturated normally consolidated clay so $c' = 0$

$$\because \quad A = \frac{U_f}{(\sigma_1 - \sigma_3)_f} = 0.92$$

$$\therefore \quad U_f = 0.92\,(\sigma_1 - \sigma_3)_f \qquad \text{...(i)}$$

$$\text{Also,} \quad \sigma_{1f} = \sigma_{3f}\tan^2\left(45 + \frac{15}{2}\right)$$

$$\sigma_{1f} = 1.698\,\sigma_{3f} \qquad \text{...(ii)}$$

$$\because \quad \sin\phi' = \frac{\bar{\sigma}_{1f} - \bar{\sigma}_{3f}}{\bar{\sigma}_{1f} + \bar{\sigma}_{3f}} = \frac{\sigma_{1f} - U_f - \sigma_{3f} + U_f}{\sigma_{1f} + \sigma_{3f} - 2U_f}$$

$$\therefore \quad \sin\phi' = \frac{(\sigma_1 - \sigma_3)_f}{(\sigma_1 + \sigma_3)_f - 2U_f}$$

From equation (i) and (ii), we get

$$\sin\phi' = \frac{(1.698 - 1)\sigma_{3f}}{(1.698 + 1)\sigma_{3f} - 2 \times 0.92(1.698 - 1)\sigma_{3f}}$$

$$\Rightarrow \quad \sin\phi' = \frac{0.698}{2.698 - 2 \times 0.92 \times 0.698} = 4937$$

$$\phi' = 29.6°$$

Second Approach,

Given : $C_u = 0$, $\phi = 15°$, A = 0.92

$\therefore$ The given soil is saturated normally consolidated clay so $c' = 0$

$$\because \quad A = \frac{U_f}{\sigma_{1f} - \sigma_{2f}} = 0.92$$

$$\therefore \quad U_f = 0.92(\sigma_{1f} - \sigma_{3f})$$

$$\text{Also,} \quad \sigma_{1f} = \sigma_{3f}\tan^2\left(45 + \frac{\phi}{2}\right)$$

$$\therefore \quad \sigma_{1f} = \sigma_{3f}\tan^2\left(45 + \frac{15}{2}\right)$$

$$\sigma_{1f} = 1.698\,\sigma_{3f}$$

$$U_f = 0.64216\,\sigma_{3f}$$

$$\bar{\sigma}_{1f} = \bar{\sigma}_{3f} \tan^2\left(45+\frac{\phi'}{2}\right)$$

$$\sigma_{1f} - U_f = \left(\sigma_{3f} - U_f\right)\tan^2\left(45+\frac{\phi'}{2}\right)$$

$$\left(1.698\sigma_{3f} - 0.92\times 0.698\sigma_{3f}\right) = \left(\sigma_{3f} - 0.92\times 0.698\sigma_{3f}\right)\tan^2\left(45+\frac{\phi'}{2}\right)$$

$$\Rightarrow \quad 1.05584 = \tan^2\left(45+\frac{\phi'}{2}\right)$$

$$\phi' = 29.58° \simeq 29.6°$$

Q.1 (c) Solution:

Standard Penetration test (SPT) : This is the most extensively used penetrometer test in India. The test employs a split-spoon sampler which consists of a driving shoe, a split-barrel of circular cross-section, which is longitudinally split into two parts and a coupling. IS:2131–1981 gives a standard procedure for carrying out the test.

(a) A borehole is excavated to the required depth and its bottom cleaned.

(b) The split-spoon sampler, attached to standard drill rods of required length is lowered into the borehole and rested at the bottom.

(c) The split-spoon sampler is driven into the soil for a distance of 450 mm by blows of a drop hammer of 65 kg falling vertically and freely from a height of 750 mm. The number of blows required to penetrate every 150 mm is recorded while driving the sampler. The number of blows required for the last 300 mm of penetration is added together and recorded as the N-value at that particular depth of the borehole. The number of blows required to effect the first 150 mm of penetration called seating drive is neglected.

(d) The SPT is carried out at every 0.75 m vertical intervals in a borehole. This can be increased to 1.50 m, if the depth of borehole is large. Due to the presence of boulders or rocks, it may not be possible to drive the sampler to a distance of 450 mm. In such a case, the N value can be recorded for the first 300 mm penetration.

Plate load test: In plate load test, test plate simulates a foundation. A test plate square or circular is used as a model for the prototype foundation. The plate is placed at the proposed level of the foundation and is subjected to incremental loading. Settlement at each increment of loading is measured and load-settlement curve is plotted. The bearing capacity and the settlement of the foundation can be determined with the help of the load-settlement curve for the test plate.

The test procedure is explained in IS:1888-1982. Terzaghi have recommended that the settlement of a footing on a cohesionless soil can be extrapolated from settlement experienced by a test plate at the same load intensity by the following equation;

$$\frac{S_f}{S_p} = \left[\frac{B_f(B_p+30)}{B_p(B_f+30)}\right]^2$$

where S_f = settlement of foundation of width B_f (cm)

S_p = Settlement of test plate of width B_p (cm) at the same load intensity as on the foundation.

Q.1 (d) Solution:

(i) Porosity, $n = \frac{e}{1+e} = \frac{0.6}{1+0.6} = \frac{0.6}{1.6} = 0.375$

$\therefore$ Void space in one m^3 of soil = 0.375 m^3

Volume of grout in one m^3 of soil = 0.5 × 0.375 = 0.19 m^3

Specific gravity of cement = 3.15

Specific gravity of grout having 6 parts by weight of water and 1 part by weight of cement = $\frac{6+1}{\frac{6}{1}+\frac{1}{3.15}} = \frac{7}{6.32} = 1.11$

$\therefore$ Unit weight of slurry = 1.11 × 10 = 11.1 kN/m^3

$\therefore$ Weight of grout in one m^3 of soil = $0.19 \times 11.1 = 2.1$ kN

Weight of cement in 1 m^3 of soil = $\frac{2.1}{7} = 0.3$ kN

Quantity of cement required for grouting = 0.3 kN per m^3 of soil

(ii) Volume of soil grouted around each grout hole

$$= \pi D^2 . \frac{L}{4} = \pi \times 3 \times 3 \times \frac{12}{4} = 84.8 \text{ m}^3$$

$\therefore$ Cement required per m^3 of soil = 0.3 kN

Cement required per grout hole = 0.3 × 84.8 = 25.4 kN

Cost of cement per grout hole = 25.4 × 250 = ₹6350/-

If 50% cement is replaced by Bentonite, then cost of cement + Bentonite per grout hole

$$= \frac{25.5}{2}(250) + \frac{25.5}{2} \times 120 = 3187.5 + 1530 = 4717.5 \simeq ₹4718/-$$

Saving per hole = 6350 – 4718 = ₹1632/-

Q.1 (e) Solution:

Initial effective stresses at a depth of 3 m,

$$(\bar{\sigma}_1)_0 = 18 \times 3 - 9.81 \times 2 = 34.38 \text{ kPa}$$

Lateral earth pressure, $(\bar{\sigma}_3)_0 = k_0(\bar{\sigma}_1)_0 = 0.5 \times 34.38 = 17.19 \text{ kPa} \simeq 17.2 \text{ kPa}$

At failure,
$$\frac{\bar{\sigma}_{1f}}{\bar{\sigma}_{3f}} = \frac{1+\sin\phi'}{1-\sin\phi'} = \frac{1+\sin 30°}{1-\sin 30°} = 3$$

Also, $\bar{\sigma}_{1f} = (\bar{\sigma}_1)_0 + \Delta\bar{\sigma}_1$ and $\bar{\sigma}_{3f} = (\bar{\sigma}_3)_0 + 0.2\Delta\bar{\sigma}_1$

where $\Delta\bar{\sigma}_1$ is the additional vertical effective stress to bring the soil to failure.

$$\therefore \quad \frac{(\bar{\sigma}_1)_0 + \Delta\bar{\sigma}_1}{(\bar{\sigma}_3)_0 + 0.2\Delta\bar{\sigma}_1} = \frac{34.38 + \Delta\bar{\sigma}_1}{17.2 + 0.2\Delta\bar{\sigma}_1} = 3$$

$$\Rightarrow \quad \Delta\bar{\sigma}_1 = 43 \text{ kPa}$$

Q.2 (a) Solution:

(i)

Case A : The depth of water is small as also the depth to the bearing stratum and thus constructing a cofferdam would enable the soil at the bed to be excavated and the foundation could be cast-in-situ.

Case B : The large water depth rules out the use of cofferdam. Since, the depth to bearing stratum is small, 3 m of soil can be removed by using a grab or a suction dredger. A prefabricated box caisson should work well.

Case C : The depth to bearing stratum is very large and the only feasible solution is sinking a well. A 15 m high section of the well can be cast on shore and floated out to the site. It can be lowered to the bed and sunk in increments by excavating soil from within the walls of the well. When the well reaches a depth of 20 m beneath the bed, the base of the well can be plugged by under water concreting.

(ii)

$$\gamma_{sat} = \frac{G+e}{1+e}\cdot\gamma_w = \frac{2.7+0.8}{1+0.8} \times 9.81 = 19.08 \text{ kN/m}^3$$

$$\gamma' = 19.08 - 9.81 = 9.27 \text{ kN/m}^3$$

(i) Submerged case

For $i = 45°, \phi = 15°, s_n = 0.083$

$$\therefore \quad F_c = \frac{c}{\gamma' H s_n} = \frac{14}{9.27 \times 5 \times 0.083} = 3.64$$

(ii) Drawdown case

$$\phi_w = \frac{\gamma'}{\gamma_{sat}} \cdot \phi = \frac{9.27}{19.08} \times 15 \simeq 7.3°$$

For $i = 45°$, $\phi = 7.3°$, $s_n = 0.122$

$$F_c = \frac{c}{\gamma_{sat} \cdot H \cdot s_n} = \frac{14}{19.08 \times 5 \times 0.122} = 1.2$$

Q.2 (b) Solution:

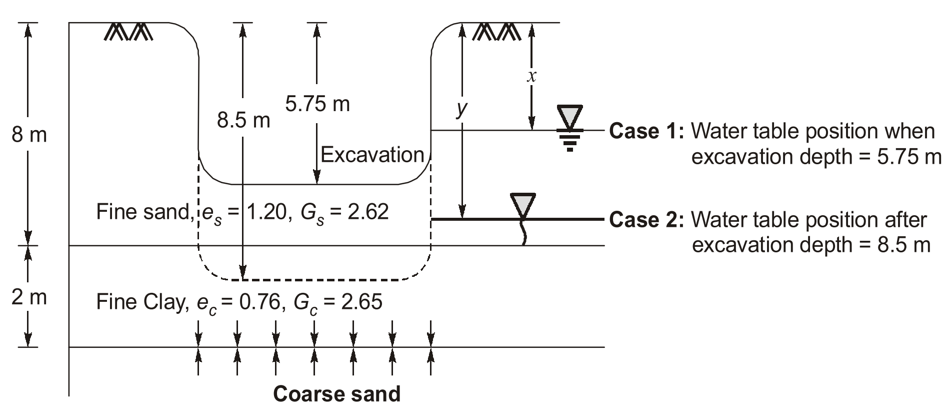
(i)

Both reinforced soil walls and nailed soil walls use the tensile force developed in the embedded reinforcement to oppose the movement of the soil mass. However, the following differences exist between the two :

- In reinforced walls, the reinforcement is placed in a soil that is not stressed to begin with. As the overburden builds up, the soil mass tends to move laterally and that is opposed by the reinforcement.

  In nailed soil walls, the reinforcement is placed in a soil that is under stress and that undergoes some stress relief and some movement during each stage of excavation prior to insertion of a nail at that stage. The nail opposes additional movement after its insertion.
- In reinforced soil walls, the reinforcement is usually flexible (strips, sheets, grids) whereas in nailed soil walls, the reinforcement is relatively rigid.
- The soil in a reinforced soil wall is selected granular fill and that in a nailed soil wall, it is the in situ soil as encountered.
- In reinforced soil walls, the reinforcement is laid horizontally, whereas in nailed soil walls the reinforcement is inclined downwards.

(ii)



Case 1: Excavation stable depth = 5.75 m

We know, $\gamma_{sat(clay)} = \left(\frac{G_c + e_c}{1 + e_c}\right)\gamma_w = \left(\frac{2.65 + 0.76}{1 + 0.76}\right) \times 9.81 = 19.00 \text{ kN/m}^3$

$\gamma_{sat(sand)} = \left(\frac{G_c + e_s}{1 + e_s}\right)\gamma_w = \left(\frac{2.62 + 1.20}{1 + 1.20}\right) \times 9.81 = 17.034 \text{ kN/m}^3$

Let x be initial depth of water table from ground surface.

We know, the bottom of excavation remains stable as long as the upward pressure due to artesian head does not become equal to the downward acting total stress at the bottom level of clay stratum.

Thus,

$\{(\gamma_{sat})_{sand} \times (8 - 5.75) + (\gamma_{sat})_{clay} \times 2\}\downarrow = (10 - x)\gamma_w\ (\uparrow)$

$\Rightarrow \quad 19 \times 2 + 17.034 \times 2.25 = (10 - x) \times 9.81$

$\Rightarrow \quad 10 - x = 7.7805$

or, $\quad x = 2.22$ m

Check for quick sand condition,

Pore water pressure in fine sand at depth of 8 m = 9.81 × (8 – 2.22) = 56.7 kN/m^2

Total stress below excavation in sand layer = (8 – 5.75) × 17.034 = 38.33 kN/m^2

Since total stress is less than pore water pressure (i.e. $\bar{\sigma} < 0$) in fine sand so there will be quick sand condition so we have to lower the water table for 5.75 m excavation.

Now, let 'x'' is new water table depth from top

$\Rightarrow \quad (8 - x') \times 9.81 \uparrow = (8 - 5.75) \times 17.034 \downarrow$

$x' = 4.09$ m

Case 2: Let the water after lowering by y m below ground surfaces for stable excavation made upto 8.5 m.

Total stress at bottom of clay layer (↓) = Total artesian head (↑)

$\Rightarrow \quad (2 - 0.5)(\gamma_{sat})_{clay}(\downarrow) = (10 - y)\gamma_w$

$\Rightarrow \quad 1.5 \times 19 = (10 - y) \times 9.81$

or, $\quad 10 - y = 2.905$

or, $\quad y = 7.095$ m (Final depth)

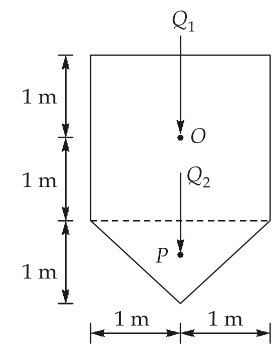
It means water table is lowered by, 7.095 – 4.09 = 3.005 m

Q.2 (c) Solution:

(i)

$$Q_1 = (2 \times 2) \times 300 = 1200 \text{ kN}$$

Acting at O, $\therefore$ $r_1 = 0$



$\Rightarrow$ $$Q_2 = \left(\frac{1}{2} \times 2 \times 1\right) \times 300 = 300 \text{ kN}$$

Acting at 'P'

Distance between P and O, $$r_2 = 1 + \frac{1}{3} = \frac{4}{3} \text{ m}$$

$$\sigma_z = k_{B_1}\frac{Q_1}{Z^2} + k_{B_2}\frac{Q_2}{Z^2}$$

$$= \frac{3}{2\pi}\left(\frac{1}{1+\frac{r_1^2}{Z^2}}\right)^{5/2}\frac{Q_1}{Z^2} + \frac{3}{2\pi}\left(\frac{1}{1+\frac{r_2^2}{Z^2}}\right)^{5/2}\frac{Q_2}{Z^2}$$

$$= \frac{3}{2\pi}\cdot\frac{1200}{(2)^2} + \frac{3}{2\pi}\left(\frac{1}{1+\left(\frac{1.33}{2}\right)^2}\right)^{5/2}\cdot\frac{300}{2^2}$$

$$= 143.239 + 14.28 = 157.519 \text{ kN/m}^2$$

(ii)

Given : $\in = \frac{\Delta L}{L} = 0.1$

$\because$ $$A_f = \frac{A}{1-\in} = \frac{A}{1-\frac{\Delta L}{L}} = \frac{\frac{\pi}{4}(50)^2}{1-0.1} = 2181.7 \text{ mm}^2$$

$$q_u = \frac{p_f}{A_f} = \frac{200}{2181.7} = 0.09167 \text{ N/mm}^2 = 91.67 \text{ kN/m}^2$$

$\therefore$ Shear resistance of soil sample $= \frac{q_u}{2} = \frac{91.67}{2} = 45.835 \text{ kN/m}^2 \simeq 45.84 \text{ kN/m}^2$

Q.3 (a) Solution:

For individual pile action

$$Q_u = n_1 n_2\left[9A_p C_{u_p} + \alpha_1 P \cdot C_{u_1}L_1 + \alpha_2 P \cdot C_{u_2}L_2\right]$$

$C_{u_1} = 50.3 \text{ kN/m}^2$, $C_{u_p} = C_{u_2} = 85.1 \text{ kN/m}^2$, $\alpha_1 = 0.68$, $\alpha_2 = 0.51$, $L_1 = 4.57$ m, $L_2 = 13.72$ m

A_p = 0.356 × 0.356 = 0.1267 m², P = 4 × 0.356 = 1.424 m, $n_1 n_2$ = 3 × 4 = 12

So, $Q_u = 12[9 \times 0.1267 \times 85.1 + 0.68 \times 1.424 \times 50.3 \times 4.57 + 0.51 \times 1.424 \times 85.1 \times 13.72]$

$\Rightarrow \qquad Q_u = 14010.79 \text{ kN} \qquad ...(i)$

For pile acting as a group,

$$L_g = 3 \times 0.889 + 0.356 = 3.023 \text{ m}$$
$$B_g = 2 \times 0.889 + 0.356 = 2.134 \text{ m}$$
$$Q_u = L_g B_g C_{u_p} N_c + \Sigma 2(L_g + B_g) C_u \Delta L$$

$\Rightarrow \qquad Q_u = 3.023 \times 2.134 \times 85.1 \times 8.57 + 2(3.023 + 2.134)\,[50.3 \times 4.57 + 85.1 \times 13.72]$

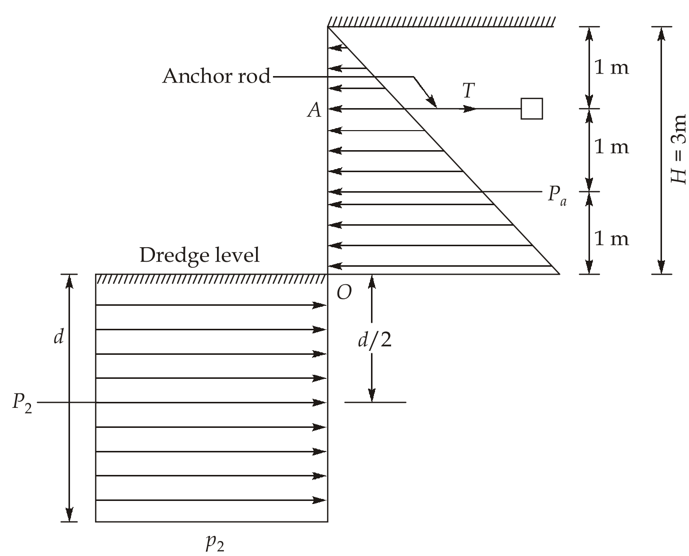
$$Q_u = 19118.05 \text{ kN} \qquad ...(ii)$$

Thus, from (i) and (ii),

$$Q_u = 14010.79 \text{ kN}$$
$$Q_a = \frac{14010.79}{4} = 3502.698 \text{ kN} \simeq 3502.7 \text{ kN}$$

Q.3 (b) Solution:

For given data



The above figure shows the pressure distribution in soil for cohesive soil below the dredge soil below the dredge level.

For soil above the dredge line i.e., sand

Unit weight, γ = 19 kN/m³

Frictional angle, ϕ = 30°

Coefficient of active earth pressure, k_a

$$\tan^2\left(45° - \frac{\phi}{2}\right) = \tan^2\left(45° - \frac{30}{2}\right) = \frac{1}{3}$$

Active earth pressure, $P_a = \frac{1}{2}\gamma k_a H^2 \times 1 = \frac{1}{2}\times 19 \times \frac{1}{3}\times 3^2 \times 1$

$= 28.5$ kN (for 1 m length)

Point of action of $P_a = \frac{2}{3}\times 3 = 2$ m (from top)

Below dredge line,

Passive earth pressure, $p_2 = 4C - \gamma H$

$= 4 \times 20 - 19 \times 3 = 23$ kN/m^2

Assuming depth below dredge line as 'd'

Taking moments about anchor rod,

$$M_A = 28.5 \times 1 - 23 \times d \times \left(2 + \frac{d}{2}\right) = 0$$

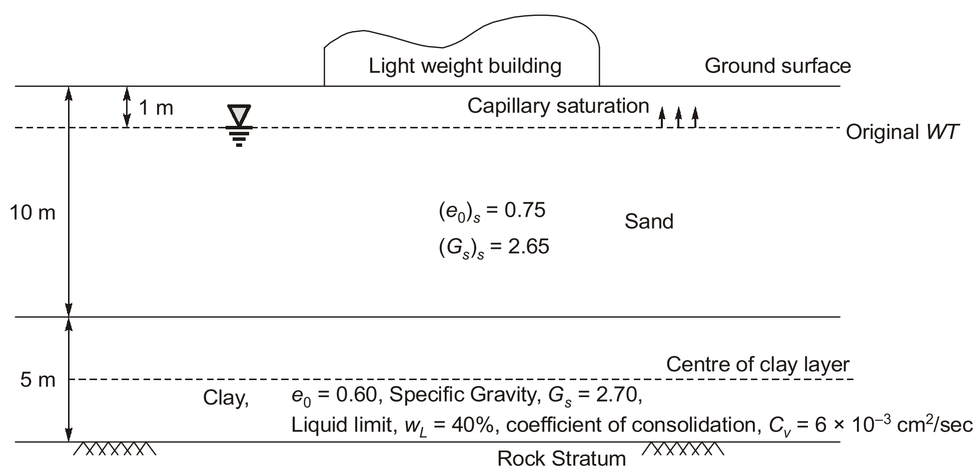
$\Rightarrow$ $28.5 - 11.5\, d\,(4 + d) = 0$

$\Rightarrow$ $d = 0.545$ m

$\therefore$ Depth of sheet pile wall = 3 + 0.545 = 3.545 m

Force in anchor, $T = 28.5 - 23 \times 0.545 = 15.965$ kN

Q.3 (c) Solution:



The above figure shows the subsoil profile below the light weight building

$$(\gamma_{sat})_{sand} = \left(\frac{G_s + e}{1 + e}\right)\gamma_w = \left(\frac{2.65 + 0.75}{1 + 0.75}\right)\times 9.81 = 19.06 \text{ kN/m}^3$$

$$(\gamma_{sat})_{clay} = \left(\frac{2.7 + 0.60}{1 + 0.60}\right)\times 9.81 = 20.233 \text{ kN/m}^3$$

$\because$ The total stress is the same whether the soil is saturated by gravity flow or capillary flow.

The sand is saturated by gravity flow below water table and by capillary flow upto 1 m height above water table.

Hence, initial effective stress at centre of clay layer, $\bar{\sigma}_0 = 19.06 \times (9.0 + 1.0) + 2.5 \times 20.233 - 9.81 \times 11.5$

$$\Rightarrow \quad \bar{\sigma}_0 = 128.37 \text{ kN/m}^2$$

Now, due to lowering of the water table by 4 m as a result of pumping of water from sand stratum, the effective stress will increase.

Final effective stress at centre of clay layer;

$$\bar{\sigma}_f = (\gamma_d)_{\text{sand}} \times 5 + (\gamma_{\text{sat}})_{\text{sand}} \times 5 + (\gamma_{\text{sat}})_{\text{clay}} \times 2.5 - \gamma_w \times 7.5$$

$$\because \quad (\gamma_d)_{\text{sand}} = \frac{G_s \gamma_w}{1+e} = \frac{2.65 \times 9.81}{1+0.75} = 14.855 \text{ kN/m}^3$$

$$\therefore \quad \bar{\sigma}_f = (14.855 \times 5 + 19.06 \times 5 + 20.233 \times 2.50 - 9.81 \times 7.50)$$

$$\Rightarrow \quad \bar{\sigma}_f = 146.583 \text{ kN/m}^2$$

We know, due to change in effective stress in clay,

Final consolidation settlement, $S_f = \frac{C_c H_0}{1+e} \log\left(\frac{\bar{\sigma}_f}{\bar{\sigma}_0}\right)$

where C_c = Coefficient of compression index = $0.009\,(W_L - 10)$

$= 0.009\,(40 - 10) = 0.270$

H = 5 m = 5000 mm = Thickness of clay layer

$$\therefore \quad S_f = \frac{0.27 \times 5000}{(1+0.60)} \times \log_{10}\left(\frac{146.583}{128.370}\right)$$

$$\Rightarrow \quad S_f = 48.62 \text{ mm}$$

For settlement, $S_t = 25$ mm after time t, we have

$$\text{Degree of consolidation, } U(\%) = \frac{S_i}{S_f} = \frac{25}{48.62} = 51.42\% < 60\%$$

Hence, Time factor, $T_v = \frac{\pi}{4} U^2 = \frac{\pi}{4}(0.5142)^2$

$$\Rightarrow \quad T_v = 0.20766$$

$$\because \quad T_v = \frac{C_v t}{H^2} = 0.20766 \text{ and } C_v = 6 \times 10^{-3} \text{ cm}^2/\text{sec}$$

$$\Rightarrow \quad \frac{6 \times 10^{-3} \times t}{(500)^2} = 0.20766$$

$$\Rightarrow \quad t = 8652500 \text{ sec} = 100.14 \simeq 100 \text{ days}$$

Hence, the building will settle in 100 days by 25 mm.

Q.4 (a) Solution:

For upper soil layer, $K_{a_1} = \dfrac{1-\sin\phi_1}{1+\sin\phi_1} = \dfrac{1-\sin 10°}{1+\sin 10°} = 0.70$

For bottom soil layer, $K_{a_2} = \dfrac{1-\sin\phi_2}{1+\sin\phi_2} = \dfrac{1-\sin 30°}{1+\sin 30°} = 0.33$

Active earth pressure at G.L., $p_{a_1} = K_{a_1}\cdot q + K_{a_1}\cdot\gamma\cdot Z - 2c\sqrt{K_{a_1}}$

$$= (0.70\times 30) + 0.70\times 18\times 0 - 2\times 10\times\sqrt{0.70}$$

$$= 4.27\ \text{kN/m}^2$$

Active earth pressure just **above W.T.,**

$$p_{a_2} = K_{a_1}\cdot q + K_{a_1}\cdot\gamma\cdot Z_1 - 2c\sqrt{K_{a_1}}$$

$$= (0.70\times 30) + 0.7\times 18\times 4 - 2\times 10\sqrt{0.70}$$

$$= 54.67\ \text{kN/m}^2$$

Active earth pressure just **below W.T.,**

$$p_{a_3} = K_{a_2}(q+\gamma\cdot Z_1) = 0.33\ (30 + 18\times 4)$$

$$= 33.66\ \text{kN/m}^2$$

Active earth pressure at **bottom**,

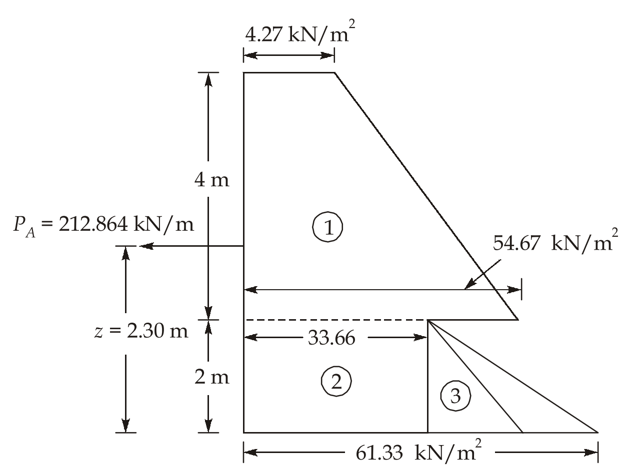
$$p_{a_4} = K_{a_2}(q+\gamma\cdot Z_1) + K_{a_2}\cdot(\gamma_{sat}-\gamma_w)\cdot Z_2 + \gamma_w\cdot Z_2$$

$$= 33.66 + 0.33\ (22 - 9.81)\times 2 + 9.81\times 2$$

$$= 33.66 + 27.665$$

$$= 61.3254\ \text{kN/m}^2 \simeq 61.33\ \text{kN/m}^2$$

Thrust Diagram:



Total active thrust, $P = A_1 + A_2 + A_3$

$$\Rightarrow \quad P_a = \left\{\frac{1}{2}(4.27+54.67)\times 4\right\} + (2\times 33.66) + \left\{\frac{1}{2}\times 27.665\times 2\right\}$$

$$\therefore \quad P_a = 212.865 \text{ kN/m}$$

Distance of line of action of force acting on area A2 from interface of two soil

$$= \frac{(4.27\times 4\times 2)+\left(\frac{1}{2}\times 4\times 50.4\times\frac{4}{3}\right)}{(4.27\times 4)+\left(\frac{1}{2}\times 4\times 50.4\right)} = \frac{168.56}{117.88} = 1.43 \text{ m}$$

Let distance of P_a be 'Z' m from bottom,

$$\therefore \quad Z = \frac{A_1Z_1 + A_2Z_2 + A_3z_3}{A_1 + A_2 + A_3}$$

$$\Rightarrow \quad Z = \frac{\left\{\frac{1}{2}(4.27+54.67)\times 4\times(1.43+2)\right\} + (2\times 33.6\times 1) + \left\{\frac{1}{2}\times 27.665\times 2\times\frac{1\times 2}{3}\right\}}{212.865}$$

$$\Rightarrow \quad Z = 2.30 \text{ m}$$

Q.4 (b) Solution:

For square footing, $q_u = 1.3\, CN_C + qN_q + 0.4\,\gamma BN_\gamma$

[Note: One can also use $q_u = 1.2\, CN_C + qN_q + 0.4\,\gamma BN_\gamma$, by using this formular B = 4.71m which is also correct]

$$= 1.3\times 5.7C + 35\times 21\times 1 \qquad \{\because N_\gamma = 0\}$$

$$q_{u_1} = 1.3 \times 5.7 \times 120 + 3.5 \times 21 \times 1$$
$$= 962.7 \text{ kN/m}^2$$

The base area of footing of size $B \times B$ will thus provide a bearing load,

$$Q_1 = 962.7B^2$$

Additional bearing capacity will be provided from the sides friction for 2 m depth.

$$Q_2 = 4B \times 2 \times 25 = 200B \text{ KN}$$

The total ultimate load carrying capacity,

$$Q_f = Q_1 + Q_2 = 962.7B^2 + 200B$$

$$\therefore \quad Q_a = \frac{Q_f}{F} = \frac{962.7B^2 + 200B}{4}$$

Total actual load = External load + Footing load

$$= 3250 + B^2 \times 3.5 \times 25$$
$$= 3250 + 87.5B^2$$

Thus, $$\frac{962.7B^2 + 200B}{4} = 3250 + 87.5B^2$$

$$612.7B^2 + 200B - 13000 = 0$$

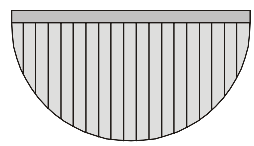
$\Rightarrow$ $$B = 4.4 \text{ m} \quad \text{say } 4.5 \text{ m}$$

Thus provide 4.5 m × 4.5 m wide square footing.

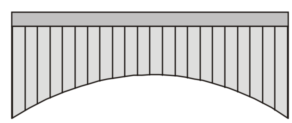
Q.4 (c) Solution:

(i)

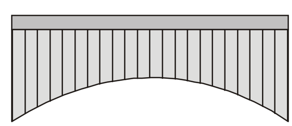
(a) Pressure distribution for rigid footing on cohesionless soil at shallow depth.



(b) Pressure distribution for rigid footing on cohesive soil.



(c) Pressure distribution for rigid footing on cohesionless soil at deeper depth.



(ii)

$\because$ $$\Delta U = B\left[\sigma_3 + A_f(\sigma_1 - \sigma_3)\right]$$

Now, by putting $B = 1$ and $\sigma_3 = 0$ (for unconfined test)

$$\Delta U = A_f \sigma_1 \quad \text{...(i)}$$

If U_f = Pore pressure at failure, we have

$$\Delta U = U_f - (-U_c) = U_f + U_c \quad \text{...(ii)}$$

From (i) and (ii)

$$\Delta U = U_f + U_c = A_f \sigma_1$$

$\Rightarrow$ $$U_f = A_f \sigma_1 - U_c$$

We have, $$\frac{\sigma_1' - \sigma_3'}{2} = c' \cos\phi' + \frac{\sigma_1' + \sigma_3'}{2} \sin\phi'$$

Putting $\sigma_3' = -U_f$ and $\sigma_1' = \sigma_1 - U_f$

$\Rightarrow$ $$\frac{\sigma_1}{2} = c' \cos\phi' + \left(\frac{\sigma_1}{2} - U_f\right) \sin\phi'$$

$$\frac{\sigma_1}{2}(1-\sin\phi') = c'\cos\phi' - u_f\sin\phi'$$

$$= c'\cos\phi' - (A_f\sigma_1 - U_c)\sin\phi'$$

$$\Rightarrow \quad \frac{\sigma_1}{2}\left[(1-\sin\phi') + 2A_f\sin\phi'\right] = c'\cos\phi' + U_c\sin\phi'$$

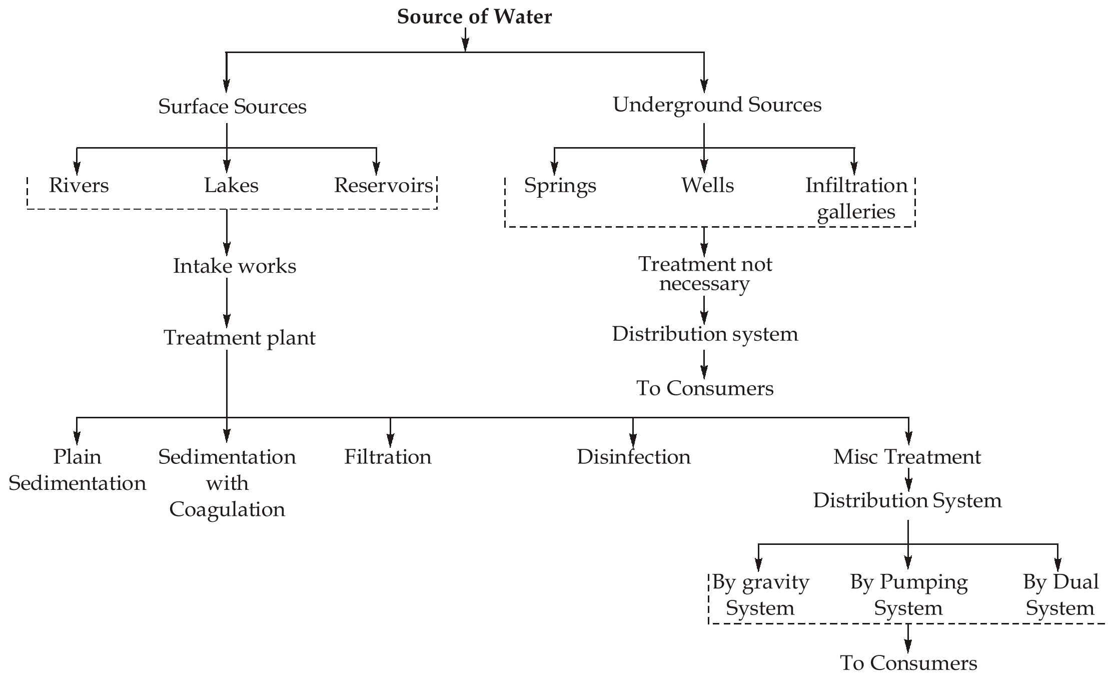
$$\sigma_1 = q_u = 2\cdot\frac{c'\cos\phi' + U_c\sin\phi'}{(1-\sin\phi') + 2A_f\sin\phi'}$$

Section B : Environmental Engineering

Q.5 (a) Solution:

Salient features of a water supply scheme :

1. **Population Forecast :** Every scheme should be such that it must run satisfactorily at least for the design period. So, the probable population of the town or city should be ascertained for the future decades.
2. **Assessment of Water Demand :** Depending upon the probable population, the total water requirement for the town or city should be estimated considering the domestic demand, public demand, industrial demand, fire demand etc.
3. **Record of Industry :** The nature and number of industries in a town or city should be recorded because, the industries require more water for operation and maintenance. This record also be updated from time to time.
4. **Record of Public Places :** The nature and number of public places like markets, cinema halls, auditoriums, parks, swimming pools, schools, colleges, etc. should be recorded for the provision of additional water requirement.
5. **Source of Water :** The cost of the water supply scheme depends on the selection of the site for the source of water. So, the source of water should be such that the cost of conveyance and water treatment may be reasonable.
6. **Quality of Water :** The water should not be too turbid and there should be no or minimum source of contamination to avoid any excessive treatment.
7. **Overhead Reservoir :** The water, after treatment, is generally stored an in overhead reservoir from where it is supplied to the consumers. The location of the reservoir should be such that the water can flow easily to the network of distribution system.



Flow chart of a typical water supply scheme

Q.5 (b) Solution:

Engineering projects involving development of thermal power, mining operations, and even river valley water resources developments, have been found to be causing certain adverse and negative impacts on our surrounding environment, which has forced us to make it compulsory to evaluate these adverse impacts in details, well before the project is cleared for execution. With this end in view, all project clearance cells do evaluate and examine the detailed environmental assessment report, which is prepared and submitted along with the DPR (Detailed Project Report) of every such project. Submission of such Environmental Impact Assessments or Environmental Impact Statements (EIS) have been made compulsory by the Indian Government for all projects, which are likely to cause harm to our surrounding environment. These statements are thoroughly examined by the concerned Ministries before giving environmental clearance to the project, without which, administrative and financial sanction to the project, will not be given. All such impact assessments should thoroughly examine and discuss the various possible environmental damages, whether pertaining to water pollution, air pollution, ground (land) pollution, noise pollution, or any other kind of environmental pollution; and their suggested remedial measures to prevent or to mitigate such hazardous environmental effects.

Environmental Impacts of Thermal Power Plants: Thermal power plants, generally use coal as the fuel for producing steam to run their turbines for production of electricity. Fuel oil is also sometimes used as fuel. Use of fuel gas is the most modern advancement in this field.

Fossil fuels, including coal as well as fuel oil, when used in the power plants, prove very harmful to the air environment, as they release very heavy amounts of pollutants into the atmosphere.

If coal is used, pollutants like fly ash, sulphur dioxide, and nitrogen oxides, are produced on a large scale. In case of oil, however, only sulphur dioxide and nitrogen oxides are produced, as the major pollutants. Coal, thus, proves to be a worse fuel, and is an important source responsible for particulate air pollution. The amount of fly ash and sulphur dioxide produced by the coal depends upon its quality, and sulphur and ash content in it.

It has also been observed that the fly ash from a thermal power plant falls out, upto large distances from the plant. Heavy amount of fly ash has been observed to be falling even upto distances as large as 3 to 6 km. The fallout rates are found to increase in dry windy seasons.

The fallout rates of fly ash at the thermal power plant at Korba in Madhya Pradesh State has been found to be as high as 300-550 t/km^2/month in the vicinity of the plant, about 130-550 t/km^2/month at distances of about 2.5 km, and about 60-450 t/km^2/month at distances of about 4 km.

Q.5 (c) Solution:

$$\text{BOD removed} = (250 - 30)4000 \times 10^3/10^6 = 880 \text{ kg/day}$$

$$\text{Total MLVSS} = (3000)(700) \times 10^3/10^6 = 2100 \text{ kg}$$

$$\text{Net solids produced/day} = [Y\,(\text{BOD removed}) - K_d\,(\text{Solids})]$$

$$= (0.5)\,(880) - (0.09)\,(2100)$$

$$= 251 \text{ kg/day}$$

$$\therefore \quad \theta_c = \frac{2100}{251} = 8.37 \text{ days}$$

$$\text{Detention time, } t = \frac{V}{Q} = \frac{700 \times 24}{4000} = 4.2 \text{ hours}$$

$$\frac{F}{M} = \frac{880}{2100} = 0.42 \text{ kg BOD}_5, \text{ per day per kg MLVSS}$$

Q.5 (d) Solution:

The method of filling the annular space between the casing pipe or aquifer soil and the tube well pipe by an aggregate of gravel and coarse sand is termed as shrouding. It is required for slotted type well in sandy and unconsolidated soil. The shrouding is done for the following reasons:

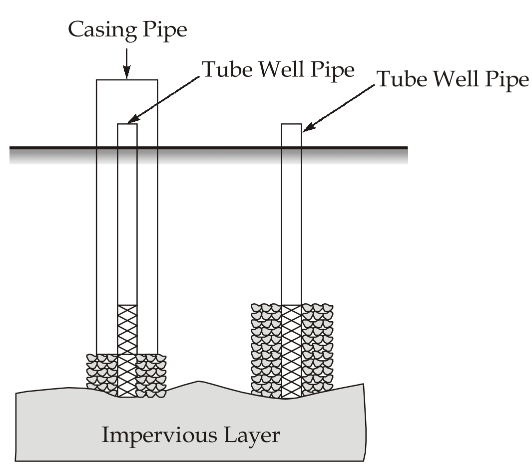
(a) It prevents the finer particles of the soil coming in contact with the strainer.

(b) It prevents chocking of the strainer.

(c) It protects the well pipe from the corrosive effect of surrounding soil.

(d) It increases the effective diameter of well.

Procedure : The shrouding materials should be well graded. Shrouding is essential when actual tube well pipe is to be sunk with help of casing pipe, where an annular space will appear when the casing pipe is withdrawn. Here, the casing pipe is sunk upto the required depth, then the tube well pipe fitted with strainer (slotted pipe) is inserted fully. The casing pipe is then withdrawn to a height of about 60 cm and the hollow space is immediately filled with shrouding materials (mixture of gravel and coarse sand). The casing pipe is again lifted to a height of 30 cm and the space is filled up by the same materials. In this way, the casing pipe is withdrawn stage by stage and the spaces are filled up with the shrouding materials until the slotted strainer is covered completely.



(a) Casing Pipe Partially Withdrawn **(b)** Casing Pipe Fully Withdrawn

Q.5 (e) Solution:

Let B and D_1 represents the width and depth of the rectangular sewer, respectively.

$\therefore$ $$B = 1.5\, D_1$$

Now, when this rectangular sewer is running completely full, the area of cross-section (For hydraulically equivalent section, both the sewer must run full)

$$A = BD_1 = 1.5\, D_1^{\,2}$$

The wetted perimeter, $P = 2\,(B + D_1) = 5D_1$

$\therefore$ Hydraulic radius, $$R = \frac{A}{P} = \frac{1.5D_1^2}{5D_1} = 0.3D_1$$

$\therefore$ Discharging capacity of rectangular sewer $= \dfrac{A}{N} R^{2/3}\sqrt{S}$

$$= \frac{1}{N}\left(1.5D_1^2\right)\left(0.3D_1\right)^{2/3}\sqrt{S} \quad \text{...(i)}$$

If D is the diameter of the circular sewer, then its capacity at full depth of flow

$$= \frac{1}{N}\left(\frac{\pi D^2}{4}\right)\left(\frac{D}{4}\right)^{2/3}\sqrt{S} \quad \text{...(ii)}$$

For hydraulically equivalent sections, equating (i) and (ii), we get

$$\frac{1}{N}\left(1.5D_1^2\right)\left(0.3D_1\right)^{2/3}\sqrt{S} = \frac{1}{N}\left(\frac{\pi D^2}{4}\right)\left(\frac{D}{4}\right)^{2/3}\sqrt{S}$$

$$\Rightarrow \quad 1.5D_1^{8/3}(0.448) = \frac{\pi}{4}\,\frac{1}{2.52}\,D^{8/3}$$

$$\Rightarrow \quad D_1^{\,8/3} = \frac{\pi}{4 \times 2.52 \times 1.5 \times 0.448} D^{8/3}$$

$$\Rightarrow \quad D^{8/3} = 2.156 D_1^{8/3}$$

$$\Rightarrow \quad D = (2.156)^{0.375} D_1$$

$$\Rightarrow \quad D = 1.334\, D_1$$

But $$B = 1.5\, D_1$$

$$\Rightarrow \quad D_1 = \frac{B}{1.5}$$

$$\therefore \quad D = 1.334\frac{B}{1.5} = 0.889B$$

This is the required relation, where D is the diameter of circular sewer and B is the width of the rectangular sewer.

Q.6 (a) Solution:

(i)

Demand of a particular time interval = $\left(\frac{Q_1 + Q_2}{2}\right) \times \text{time} = \left(\frac{Q_1 + Q_2}{2}\right) \times 3600 \times 2 \times 10^3$

$= 3.6(Q_1 + Q_2)$ million litres

Rate of pumping $= \frac{21.24}{24} \times 2 = 1.77$ million litres per two hours

Time (hrs)	Demands (× 10^6 litres)	Accumulated demand (× 10^6 litres)	Accumulated supply (× 10^6 litres)	(Accumulated Demand – Accumulated supply) × 10^6 litres)
0 - 2	0.36	0.36	1.77	–1.41
2 - 4	0.9	1.26	3.54	–2.28
4 - 6	1.26	2.52	5.31	–2.79 (A)
6 - 8	2.52	5.04	7.08	–2.04
8 - 10	3.96	9	8.85	0.15
10 - 12	3.6	12.6	10.62	1.98
12 - 14	2.52	15.12	12.39	2.73 (B)
14 - 16	1.62	16.74	14.16	2.58
16 - 18	1.26	18	15.93	2.07
18 - 20	1.62	19.62	17.7	1.92
20 - 22	1.26	20.88	19.47	1.41
22 - 24	0.36	21.24	21.24	0

Balancing capacity of reservoir $= A + B = 2.79 + 2.73 = 5.52$ million litres

(ii)

Self cleansing velocity and its importance: The self cleansing velocity may be defined as the velocity at which the solid particles will remain in suspension, without settling at the bottom of sewer. Also it is that velocity at which even the scouring of the deposited particles of a given size will take place. It is not possible to maintain this self cleansing velocity throughout the day because of large fluctuations in sewage flow. During minimum flow of sewage, the velocity of flow is less than self cleansing velocity. It should be maintained atleast a day. The self cleansing velocity is given by,

$$V_s = \sqrt{\frac{8\beta}{f}(G_s - 1) g d_s}$$

where, β = Characteristics of solids flowing in sewage in suspension

f = Darcy Weisbach friction factor

G_s = Specific gravity

d_s = Diameter of solid particles

Non-scouring velocity and its importance: Though the minimum velocity in sewage flow should be equal to the self cleansing velocity so that particles do not settle and stick to the sewer invert, there is also some upper limit of velocity of flow so that interior surface of the sewer is not damaged due to wear. At higher velocity, the flow becomes turbulent, resulting in continuous abrasion of the interior surface of the sewer, by the suspended particles. Hence, maximum velocity of flow is also limited. The maximum velocity at which no such scouring action or abrasion takes place is non-scouring velocity.

Evidently such a velocity depends upon the material used for the construction of sewers.

Of the ceramic materials used in sewers, vitrified tiles and glazed bricks are more resistant to wear while burnt clay bricks and concrete are less resistant to wear.

For sewers is flat country, the design of sewers should be done in such a way that self cleansing velocity is obtained at maximum discharge.

Q.6 (b) Solution:

(i)

Lime is required to react with alkalinity as well as $MgSO_4$ while soda ash is required for both $CaCl_2$ as well as $MgSO_4$.

(i) Lime required for alkalinity ($CaCO_3$)

Molecular weight of CaO = 40 + 16 = 56

Molecular weight of $CaCO_3$ = 40 + 12 + 3 × 16 = 100

∴ CaO required for 200 mg/l alkalinity

$$= 200 \times \frac{56}{100} = 112 \text{ mg}/l = 112 \text{ kg/M}l$$

(ii) Lime required for $MgSO_4$

Molecular weight of $MgSO_4$ = 24 + 32 + 4 × 16 = 120

∴ CaO required for 75 mg/l of $MgSO_4$

$$= 75 \times \frac{56}{120} = 35 \text{ mg}/l = 35 \text{ kg/M}l$$

∴ Total lime required = 112 + 35 = 147 kg/Ml

(iii) Soda required for $CaCl_2$

Molecular weight of soda (Na_2CO_3) = 2 × 23 + 12 + 3 × 16 = 106

Molecular weight of $CaCl_2$ = 40 + 2 × 35.5 = 111

∴ Soda required for 50 mg/l of $CaCl_2$

$$= \frac{106}{111} \times 50 = 47.75 \text{ mg}/l = 47.75 \text{ kg/M}l$$

(iv) Soda required for $MgSO_4$

Molecular weight of soda (Na_2CO_3) = 2 × 23 + 12 + 3 × 16 = 106

Molecular weight of $MgSO_4$ = 24 + 32 + 4 × 16 = 120

∴ Soda required for 75 mg/*l* of $MgSO_4$

$$= \frac{106}{111} \times 75 = 71.62 \text{ mg}/l = 71.62 \text{ kg/M}l$$

∴ Total soda required = 47.75 + 71.62 = 119.37 kg/M*l*

Amount of slaked lime required

Molecular weight slaked (or hydrated) lime $Ca(OH)_2$

= 40 + 2 × 16 + 2 × 1 = 74

Molecular weight of pure lime (CaO) = 40 + 16 = 56

∴ Quantity of slaked lime required $= \frac{74}{56} \times 147 = 194.25$ kg/M*l*

But the available slaked lime has purity of 85% only.

∴ Actual quantity of market available slaked lime required

$$= \frac{194.25}{0.85} = 228.5 \text{ kg/M}l$$

(ii)

Disadvantages of Zeolite Process

1. This method is unsuitable for highly turbid water, since suspended particles get deposited around the zeolite particles.
2. The process is unsuitable for water containing iron and manganese. Iron-bearing or manganese-bearing waters either deposit hydroxides on the surface of the zeolite or react with the zeolite to substitute iron or manganese for sodium in the zeolite, which is an irreversible reaction.
3. The process is unsuitable for acidic waters which irreversibly substitute hydrogen for sodium in the zeolite. The acidic water may aggressively attack the zeolite by the dissolving alumina or silica from it.
4. Zeolite softeners should be operated carefully to avoid injury to the zeolite, to the equipment, or to the quality of the water.
5. There is likelihood of growth of bacteria on the bed of zeolite. It should therefore be flushed regularly with chlorinated water.

Q.6 (c) Solution:

$$\text{Settling velocity, } v_s = 418(G-1)d^2\left(\frac{3T+70}{100}\right) \text{ for } d < 0.1 \text{ mm}$$

$$= 418(2.65-1)\times(0.04)^2\left(\frac{130}{100}\right) \text{ mm/sec}$$

$$= 1.435 \text{ mm/sec} = 0.1435 \text{ cm/sec}$$

Also, $$\frac{v}{v_s} = \frac{L}{H}$$

$$\Rightarrow \quad v = 0.1435\frac{L}{H}\text{cm/sec}$$

where v is the max. flow velocity in the tank

Also, L = Flow velocity × Detention time (t)

$$\Rightarrow \quad L = \left[0.1435\frac{L}{H}(t\times60\times60)\right] \text{cm} \qquad \text{where } t \text{ is in hr}$$

$$\Rightarrow \quad L = \left[0.1435\frac{L}{H}\times\frac{3600t}{100}\right] \text{m}$$

$$\Rightarrow \quad L = 5.166\frac{Lt}{H}$$

$$\Rightarrow \quad t = \frac{H}{5.166} \qquad \text{...(i)}$$

Also, the capacity of the tank of t hr detention period = Q_t

$$= \frac{10\times10^6}{10^3}\times\frac{t}{24} \text{ m}^3 = 416.67t$$

$$\Rightarrow \quad \text{B.L.H} = 416\ t \qquad \text{where } L = 3B \text{ (given)}$$

$$\therefore \quad 3\cdot B^2\cdot H = 416.67t$$

Putting value of t from (i) into (ii), we get

$$3\cdot B^2\cdot H = 416.67\times\frac{H}{5.166}$$

$$\therefore \quad B = 5.19 \text{ m ; say } 5.25 \text{ m}$$

and $L = 3B = 3 \times 5.19 = 15.6$ m **Ans.**

Now, when H = Depth i.e. Height of the tank = 3.5 m (given),

$$t = \frac{H}{5.166} = \frac{3.5}{5.166} = 0.68 \text{ hr} \simeq 41 \text{ minutes}$$ **Ans.**

Q.7 (a) Solution:

Given:

Per capita water supply = 140 lpcd

Total water supply per day = 76000 × 140 = 10640 × 10^3 litres = 10640 m^3

As 80% of water supply goes to sewage flow

Average sewage flow = 0.8 × 10640 = 8512 m^3/day

Q_{avg} = **0.0985 m^3/s**

As $\frac{Q_{max}}{Q_{avg}} = \frac{18+\sqrt{P}}{4+\sqrt{P}} = \frac{18+\sqrt{76}}{4+\sqrt{76}}$

⇒ $Q_{max} = 2.10\, Q_{avg}$

⇒ Maximum sewage flow = 2.10 × 0.0985 = 0.207 m^3/s

For half full sewer of diameter 'D'

Area, $A = \frac{\pi D^2}{8}$

Perimeter, $P = \frac{\pi D}{2}$

Hydraulic radius, $R = \frac{A}{2} = \frac{\pi D^2/8}{\pi D/2} = \frac{D}{4}$

Using, $Q = AV$

$$0.207 = \left(\frac{\pi}{8}D^2\right) \times 0.80$$

⇒ Diameter, $D = 0.81$ m

Also, Velocity, $V = \frac{1}{N}R^{2/3}S^{1/2}$

$$\Rightarrow \quad 0.80 = \frac{1}{0.013} \times \left(\frac{0.81}{4}\right)^{2/3} \times S^{1/2}$$

⇒ Bed slope, $S = \frac{1}{1099.43} \simeq \frac{1}{1100}$

Q.7 (b) Solution:

(i)

Given, $(DO)_{saturation}$ at 25°C = 8.4 mg/l

Self purification ratio, $f = \frac{k_R}{k_D} = 2.4$

k_D = 0.1 day^{-1} at 25°C

Given $Q_{sewage(effluent)} = Q_e$ = 80 cumecs and $Q_{stream} = 1200 \text{ m}^3/\text{sec}$

$(DO)_{effluent} = 0$

$(DO)_{stream} = 8.4 \text{ mg}/l$

$$\therefore \quad (DO)_{mix} = \frac{(8.4 \times 1200) + (0 \times 80)}{(1200 + 80)} = 7.875 \text{ mg}/l$$

$\therefore$ Initial DO deficit $= D_0 = 8.4 \text{ mg}/l - 7.875 \text{ mg}/l = 0.525 \text{ mg}/l$

Assume for survival of fishes, minimum DO to be maintained in stream = 4 mg/l

$\therefore$ Max permissible DO deficit $= D_C = (8.4 - 4) = 4.4 \text{ mg}/l$

Using Streeter Phelp's equation, the first stage BOD of mixture of sewage and stream is

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

$$\left[\frac{L_0}{2.4 \times 4.4}\right]^{(2.4-1)} = 2.4\left[1 - 1.4 \times \frac{0.525}{L_0}\right]$$

$$\Rightarrow \quad \frac{L_0^{1.4}}{27.11} = \left\{2.4 - \frac{1.764}{L_0}\right\}$$

or, $L_0^{2.4} = 65.064L_0 - 47.822$

or, $L_0^{2.4} - 65.064L_0 + 47.822 = 0$

By trial and error,

$\therefore \quad L_0 = 19.1925 \text{ mg}/l$

Now,
$$(L_0)_{mix} = 19.1925 = \frac{(L_0)_{waste} \times Q_W + (L_0)_{stream} \times Q_S}{(Q_W + Q_S)}$$

$$\Rightarrow \quad 19.1925 = \frac{(L_0)_{waste} \times 80 + 0}{(80 + 1200)}$$

$(L_0)_{waste} = 307.08 \text{ mg}/l$

$(BOD_5)_{waste} = (L_0)_{waste}(1 - 10^{-0.1 \times 5})$

$\Rightarrow \quad (BOD_5)_{waste} = 307.08(1 - 10^{-0.1 \times 5}) = 209.97 \text{ mg}/l$

(ii)

Tropospheric Ozone: The 10% of the ozone in the earth's atmosphere is found in the troposphere, which is the portion of the atmosphere from the earth's surface to about 12 km or 7 miles up. In the troposphere, ozone is not wanted. Ozone is even more scarce in the troposphere than the stratosphere with concentrations of about 0.02 to 0.3 parts per million. But even in such small doses, this molecule can do a lot of damage since ozone in the troposphere is one of the greenhouse gases.

Stratospheric Ozone: Ozone and oxygen molecules in the stratosphere absorb ultraviolet light from the sun, providing a shield that prevents this radiation from passing to the earth's surface. While both oxygen and ozone together absorb 95 to 99.9% of the sun's ultraviolet radiation, only ozone effectively absorbs the most energetic ultraviolet light, known as UV-C and UV-B, which causes biological damage. The protective role of the ozone layer in the upper atmosphere is so vital that scientists believe life on land probably would not have evolved and could not exist today without it. About 90% of the ozone in the earth's atmosphere lies in the region called the stratosphere between 16 and 48 kilometers (10 and 30 miles) above the earth's surface.

Q.7 (c) Solution:

The method of extracting and removing the fine sand particles from the soil around the strainer is termed as well development. The well development is done for the following reasons:

(a) To prevent sand particles from entering the well.

(b) To increase the specific capacity of the well;

(c) To increase the life of well.

The well development is generally done by the following methods:

1. **By Pumping :** In this method, the pumping of the well is done repeatedly. At the beginning, the pumping operation is started and is continued till clear water comes out. Then the pumping is stopped. After a specific interval of time, the pumping is again started and continued until clear water comes out. In this way by successive operation, it is found that the sand particles are completely removed and the maximum discharge capacity has been attained, then the well is said to be completely developed.
2. **By Compressed Air :** An air pipe is introduced into the well pipe and extended upto the zone of strainer. Then the compressed air having pressure 7 kg/cm^2 is sent through the air pipe by opening the air valve. The pressure of the air in the well develops a powerful agitation and the water flows outwards through the strainer and loosens the fine materials. The air valve is then closed. The inside pressure is decreased and consequently the water from outside enters the well with tremendous force bringing the loosened materials with it. The water of the well is then pumped out. Again, the air valve is opened and the same process is followed. This process is repeated several times till clear water comes out.
3. **By Back Washing :** This method employs of an air compressor, a discharge pipe and an air pipe. The discharge pipe and air pipe assembly is introduced into well pipe.

The compressed air is then sent through the air pipe which forces the water in the well carrying the fine sand particles to come out through the discharge pipe. When clear water comes out of the well the air compressor is shut off. The water in the well is allowed to return to the static level. The process is repeated for several times until clear water is discharged.

4. **By Chemicals :** This method involves the use of some chemical compounds like hydrochloric acid and solid carbon dioxide (dry ice). At first hydrochloric acid is poured into the well and the well top is capped. The compressed air is sent into the well through the air pipe which forces the hydrochloric acid to enter the surrounding soil formation. The well cap is removed; dry ice is introduced into it and the well top is capped again. The gaseous carbon dioxide is released suddenly and a high pressure is created in the well. This high pressure forces the muddy water to come out of the well in the form of jet through the spout. The process is repeated for several times. Thus the well is developed to give clear water.

5. **By Surging :** In this method, the sand particles are removed from filter with the help of a plunger. The plunger is inserted in the well and strokes are given up and down vigorously to loosen the sand particles sticking to strainer. Then the water is pumped out. This process is repeated for several times untill clear water comes out.

Q.8 (a) Solution:

Emission rate of SO_2

$$\text{Coal burnt per hour} = 6.25t = 6250 \text{ kg}$$

$$\text{Sulphur content} = 4.7\%$$

$$\therefore \quad \text{Sulphur produced per hour} = \frac{6250 \times 4.7}{100} = 293.75 \text{ kg}$$

Now, $S + O_2 \rightarrow SO_2$

Since, atomic mass of S and molecular mass of O_2 both are 32 and so they combine on a one to one basis.

$$\therefore \quad 32 \text{ kg of S} \equiv 64\text{g of } SO_2$$

$$\Rightarrow \quad 293.75 \text{ kg of S} = \frac{64}{32} \times 293.75 = 587.5 \text{ kg of } SO_2$$

$$\text{Emission rate of } SO_2 \text{ in gm/sec} = \frac{587.5 \times 1000}{60 \times 60} = 163.19 \text{ gm/sec}$$

(i)

Concentration at x = 2 km along centre line of plume, means y = 0 and x = 2 km. This concentration is given by equation as

$$C_{(x,\,0)} = \frac{Q}{\pi u \sigma_z \sigma_y} e^{-\frac{1H^2}{2\sigma_z^2}}$$

where given σ_z = 130 and σ_y = 220

$$\therefore \quad C_{(2,\,0)} = \frac{163.19}{3.14 \times 8 \times 130 \times 220} (e)^{-\frac{80^2}{2 \times (130)^2}} \text{ gm/m}^3$$

$$= 2.27 \times 10^{-4} \times (e)^{-0.189} \text{ gm/m}^3$$

$$= 2.27 \times 10^{-4} \times \frac{1}{(e)^{0.189}} \text{ gm/m}^3$$

$$= 2.27 \times 10^{-4} \times \frac{1}{1.208} \text{ gm/m}^3$$

$$= 1.879 \times 10^{-4} \text{ gm/m}^3 = 187.8 \ \mu\text{g/m}^3$$ **Ans.**

(ii)

Concentration at x = 2 km and y = 0.5 km (i.e., 500 m) is given by equation as

$$C_{(x,\,y)} = \frac{Q}{\pi u \cdot \sigma_z \cdot \sigma_y} e^{\left(-\frac{H^2}{2\sigma_z^2}\right)} \cdot e^{\left(-\frac{y^2}{2\sigma_y^2}\right)}$$

$$= \frac{163.19}{3.14 \times 8 \times 130 \times 220} (e)^{-\frac{80^2}{2 \times (130)^2}} \times (e)^{-\frac{500^2}{2(220)^2}} \text{ gm/m}^3$$

$$= (1.879 \times 10^{-4}) \cdot (e)^{-2.583} \text{ gm/m}^3$$

$$= 1.879 \times 10^{-4} \times 0.0756 \text{ gm/m}^3$$

$$= 0.142 \times 10^{-4} \text{ gm/m}^3 = 14.2 \ \mu.\text{ gm/m}^3$$ **Ans.**

Q.8 (b) Solution:

The quantity of sewage to be treated per day

= 5000 × 120 = 600000 litres

= 0.6 M.litres = 600 cu.m

The BOD content per day = 0.6 Ml × 300 mg/l = 180 kg

Now, assuming the organic loading in the pond (in hot climates) as say 300 kg/hectare/day, we have

The surface area required = $\frac{180\,\text{kg/d}}{300\,\text{kg/ha.d}} = \frac{180}{300}\text{ha} = \frac{180}{300} \times 10^4\,\text{m}^2 = 6000\,\text{m}^2$

Assuming the length of tank (L), as twice of its width (B), we have

$$A = LB = 2B^2 = 6000$$

$$\Rightarrow \quad B = \sqrt{3000} = 54.8\text{ m} \simeq 55\text{ m}$$

$$\therefore \quad L = \frac{6000}{55} \approx 110\text{ m}$$

Using a tank with effective depth as 1.2 m, we have

$$\text{Capacity} = 110 \times 55 \times 1.2 = 7260\text{ m}^3$$

Now, Capacity = Sewage flow per day × Detention time in days

$$\therefore \quad \text{Detention time in days} = \frac{\text{Capacity in cu.m}}{\text{Sewage flow per day in cu.m/day}}$$

$$= \frac{7260}{600} = 12.1\text{ days} \simeq 12\text{ days}$$

Hence, use an oxidation pond with length = 110 m; width = 55 m and overall depth = (1.2 + 1 free board) = 2.2 m with a detention period of 12 days.

Design of inlet pipe: Assuming an average velocity of sewage as 0.9 m/sec and daily flow for 8 hours only.

$$\text{Discharge} = \frac{600}{8 \times 60 \times 60}\text{cumecs}$$

$$\therefore \quad \text{Area of inlet pipe required} = \frac{\text{Discharge}}{\text{Velocity}} = \left(\frac{600}{8 \times 60 \times 60}\right)\frac{1}{0.9}\text{m}^2$$

$$= \frac{1}{7.2 \times 6}\text{m}^2 = \frac{1}{43.2}\text{m}^2 \simeq 232\text{ cm}^2$$

$$\therefore \quad \text{Diameter of inlet pipe} = \sqrt{\frac{4 \times 232}{\pi}} = 17.2\text{ cm} \simeq 18\text{ cm}$$ **Ans.**

Diameter of outlet pipe may be taken as 1.5 times that of the inlet pipe = 1.5 × 18 = 27 cm **Ans.**

Q.8 (c) Solution:

(i) Vermi-composting uses the natural composting process of decomposition of biodegradable organic matter by the soil bacteria as in ordinary composting technique, but takes the assistance of cultured earth worms, that are now produced commercially. These earth worms do help in quicker decomposition of the organic matter. The method helps in adopting the composting technique in individual bungalows and institutions, to dispose of the domestic waste, and more particularly for disposing of the yard and garden wastes, particularly the leaves and grass clippings, which cannot be thrown away with MSW. The various steps involved in applying the Vermi-composting technique at individual domestic level are summarised below :

(i) Dig a small pit-about 0.5 m square and 1 m deep.
(ii) Line the pit with straw or dried leaves and grass.
(iii) Organize the disposal of organic domestic waste (such as vegetable wastes) into the pit as and when generated.
(iv) Introduce a culture of worms that is now produced commercially.
(v) Cover the pit contents daily, by sprikling of dried leaves and soil every day.
(vi) Water the pit once or twice a week to keep it moist.
(vii) Turn over the contents of the pit every 15 days.
(viii) In about 45 days, the waste will be decomposed by the action of the microorganisms.
(ix) The produced humus (soil) in the pit is fertile and rich in soil nutrients. It can, hence, be used in the garden.

(ii)

The various merits and demerits of incineration method are given below:

Merits:

(i) This is the most sanitary method of refuse disposal, and ensures complete destruction of pathogenic bacteria and insects.
(ii) There is no odour trouble or dust nuisance.
(iii) Some cost can be recovered by selling the steam power and clinkers.
(iv) The disposal site can be conveniently located within the city near the outskirts, and transportation problems sorted out easily.
(v) It requires very less space for refuse disposal.

Demerits

(i) It is very costly method, and requires a lot of technical know-how.
(ii) Solid wastes to be burnt should have a high calorific value.
(iii) Smoke, odour and ash nuisance may result due to the improper and incompetent operation of the plant, particularly if substances like plastics, giving high calorific value to the wastes, are present in the wastes.
(iv) Transport vehicles are required in slightly large numbers, as there may occur delays in the their emptying near the incinerators.

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