



MADE EASY
India's Best Institute for IES, GATE & PSUs

Detailed Solutions

ESE-2022
Mains Test Series

Civil Engineering
Test No : 1

Q.1 (a) Solution:

- (i) Given: Diameter of soil sample = 4 cm
Length of soil sample = 8 cm
Mass of soil = 185 gm
 $G = 2.70$

$$\therefore \text{Volume of soil sample, } V_{\text{soil}} = \frac{\pi}{4}(4)^2(8) = 100.53 \text{ cc}$$

$$\text{Water content, } w = \frac{W_w}{W_{\text{solid}}} = 0.15$$

$$\Rightarrow 0.15 = \frac{W_{\text{soil}} - W_{\text{solid}}}{W_{\text{solid}}}$$

$$\Rightarrow 0.15 = \frac{185 - W_{\text{solid}}}{W_{\text{solid}}}$$

$$\Rightarrow 0.15(W_{\text{solid}}) = 185 - W_{\text{solid}}$$

$$\Rightarrow W_{\text{solid}} = 160.87 \text{ gm}$$

$$\therefore W_w = 0.15 \times 160.87 = 24.13 \text{ gm}$$

$$\therefore V_w = \frac{W_w}{\gamma_w} = 24.13 \text{ cc}$$

$$\text{Now, } G = \frac{\gamma_{\text{solid}}}{\gamma_w} = \frac{W_{\text{solid}}}{V_{\text{solid}}\gamma_w}$$

$$\Rightarrow 2.7 = \frac{160.87}{V_{\text{solid}} \times 1}$$

$$\Rightarrow V_{\text{solid}} = 59.58 \text{ cc}$$

$$\begin{aligned} \therefore V_v &= V_{\text{soil}} - V_{\text{solid}} \\ &= 100.53 - 59.58 \\ &= 40.95 \text{ cc} \end{aligned}$$

$$\therefore \text{Volume of air, } V_a = V_v - V_w = 40.95 - 24.13 = 16.82 \text{ cc}$$

$$\therefore \text{Percentage air voids, } n_a = \frac{V_a}{V_{\text{soil}}} = \frac{16.82}{100.53} = 0.1673 = 16.73\%$$

(ii) We know that

$$\text{Water content, } w = \frac{W_w}{W_{\text{solid}}} \quad \dots(\text{i})$$

$$\text{Specific gravity, } G = \frac{\gamma_{\text{solid}}}{\gamma_w} = \frac{W_{\text{solid}}}{V_{\text{solid}} \gamma_w} \quad \dots(\text{ii})$$

$$\text{Also, } \gamma_w = \frac{W_w}{V_w}$$

$$\Rightarrow W_w = \gamma_w V_w \quad \dots(\text{iii})$$

Put eq. (ii) and eq. (iii) in eq. (i)

$$w = \frac{\gamma_w V_w}{G V_{\text{solid}} \gamma_w}$$

$$\Rightarrow w = \frac{V_w}{G V_{\text{solid}}}$$

Multiply by V_v (Volume of voids) in numerator and denominator, we have

$$Gw = \frac{V_w}{V_{\text{solid}}} \times \frac{V_v}{V_v}$$

$$\text{We know that, } \frac{V_w}{V_v} = S \quad \text{and} \quad \frac{V_v}{V_{\text{solid}}} = e$$

$$\therefore Gw = \left(\frac{V_w}{V_v} \right) \left(\frac{V_v}{V_{\text{solid}}} \right) = Se$$

Q.1 (b) Solution:

- (i) (a) **Chloride content:** The presence of high amount of chloride in a river or stream water may indicate pollution of water due to sewage and other human or industrial waste. Presence of chlorides above certain amount produce a noticeable salty taste in drinking water and are, thus, objectionable. Permissible limit for chloride content for potable water is 250 ppm.
- (b) **Total hardness:** Hardness in water is that characteristic which prevents the formation of sufficient lather or foam when hard water is mixed with soap. It is usually caused by the presence of multivalent cations like Ca^{+2} , Mg^{+2} , Al^{+3} etc. For drinking purpose, hardness should be in the range of 75 to 115 ppm.
- (c) **Total coliform:** Testing and counting of pathogenic bacteria can be done but only with great difficulty. Hence, these tests are not performed, generally, in routine. The usual routine tests are generally conducted to detect and count the presence of coliforms, which themselves are harmless aerobic lacteal fermentary organisms but their presence or absence indicates the presence and absence of pathogenic bacteria. Coliforms also known as bacteria coli (B-coli) or Escherichia coli (E-coli) are important harmless aerobic microorganisms, which are found residing in the intestine of all warm blooded animals including human beings, therefore, are excreted with their faeces. Since, they are harmless organisms of coliform group, live longer in water than the pathogenic bacteria. It is generally presumed that the water will be safe and free from pathogenic bacteria, if no coliform bacteria are present in it.
- (d) **Turbidity:** Presence of large amount of suspended matter such as clay, silt or some other finely divided organic materials make water to appear muddy and cloudy in appearance. Although suspended particle may not be harmful to health, yet they are removed for aesthetic and psychological reasons. Permissible limit of turbidity for drinking water is 1 NTU.

(ii)

S.No.	Item	Slow sand filters	Rapid gravity filters
1.	Filtration mechanisms	Certain micro-organisms and bacteria are generally present in the voids of filter. These micro-organisms require organic impurities as their food for their survival. Hence micro-organisms utilise such organic impurities and convert them into harmless compounds.	As the size of suspended particles present in water is larger than the voids in sand, hence these impurities cannot pass through these voids and get arrested in them. Even small size of suspended particles are also arrested in these voids because void spaces act like tiny coagulation-sedimentation tanks.
2.	Effluent quality	Very efficient in removing bacteria (98 to 99%) but less efficient in removing colour.	Less efficient in removing bacteria (80 to 90%) but very efficient in removing colour.
3.	Cleaning process	Scrapping and removing 1.5 to 3 cm thick layer and wasting down by hoses.	Agitating the sand grains and back washing with or without compressed air.

Q.1 (c) Solution:

Given: Normal stress, $\sigma_n = \frac{\text{Normal load}}{\text{Area of specimen}} = \frac{371}{5 \times 5} = 14.84 \text{ N/cm}^2$

Shear stress, $\tau = \frac{\text{Shear load}}{\text{Area of specimen}} = \frac{149.9}{5 \times 5} = 5.996 \text{ N/cm}^2$

\therefore For failure conditions, $\tau = c + \sigma_n \tan \phi$

We know, for dry sand, $c = 0$

\therefore $5.996 = 0 + 14.84 \tan \phi$

$\Rightarrow \phi = \tan^{-1} \left(\frac{5.996}{14.84} \right)$

$\Rightarrow \phi = 22^\circ$

\therefore Critical angle, $\theta_c = 45^\circ + \frac{\phi}{2} = 45^\circ + \frac{22^\circ}{2} = 56^\circ$

Now, $\sigma_n = \sigma_1 \cos^2 \theta + \sigma_3 \sin^2 \theta$

$\Rightarrow 14.84 = \sigma_1 \cos^2 (56^\circ) + \sigma_3 \sin^2 (56^\circ)$

$\Rightarrow 14.84 = 0.3127 \sigma_1 + 0.6873 \sigma_3 \quad \dots(1)$

Now, $\tau = (\sigma_1 - \sigma_3) \sin \theta \cos \theta$

$\Rightarrow 5.996 = (\sigma_1 - \sigma_3)(0.4636)$

$5.996 = 0.4636 \sigma_1 - 0.4636 \sigma_3 \quad \dots(2)$

Solving eq. (1) and eq. (2)

$\therefore \sigma_1 = 23.729 \text{ N/cm}^2 = 237.29 \text{ kN/m}^2$

$\sigma_3 = 10.796 \text{ N/cm}^2 = 107.96 \text{ kN/m}^2$

Q.1 (d) Solution:

Given: $d_w = 20 \text{ cm}$

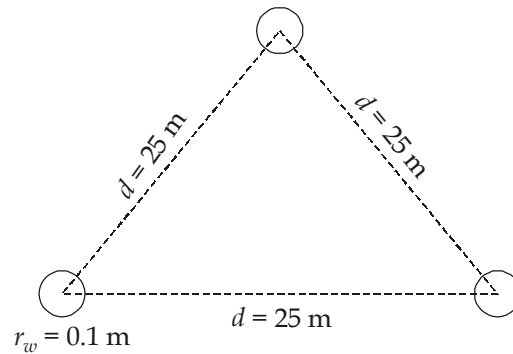
$\Rightarrow r_w = 0.1 \text{ m}$

$k = 25 \text{ m/day}$

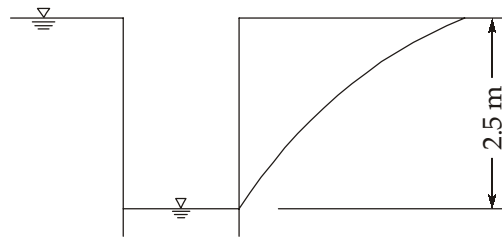
$S = 2.5 \text{ m}$

$D = 15 \text{ m}$

$R = 400 \text{ m}$



(a) **When cones of depression do not intersect.**



Discharge through each well,

$$Q = \frac{2\pi kDS}{2.303 \log\left(\frac{R}{r_w}\right)} = \frac{2\pi \times 25 \times 15 \times 2.5}{2.303 \log\left(\frac{400}{0.1}\right)} = 710.206 \text{ m}^3/\text{d}$$

Total discharge from three wells

$$= 3 \times Q = 3 \times 710.206 = 2130.62 \text{ m}^3/\text{d}$$

(b) **When cones of depression of wells intersect**

Discharge through each well,

$$Q' = \frac{2\pi kDS}{2.303 \log\left(\frac{R^3}{r_w d^2}\right)}$$

$$\Rightarrow Q' = \frac{2\pi \times 25 \times 15 \times 2.5}{2.303 \log\left(\frac{400^3}{0.1 \times 25^2}\right)} = 425.637 \text{ m}^3/\text{d}$$

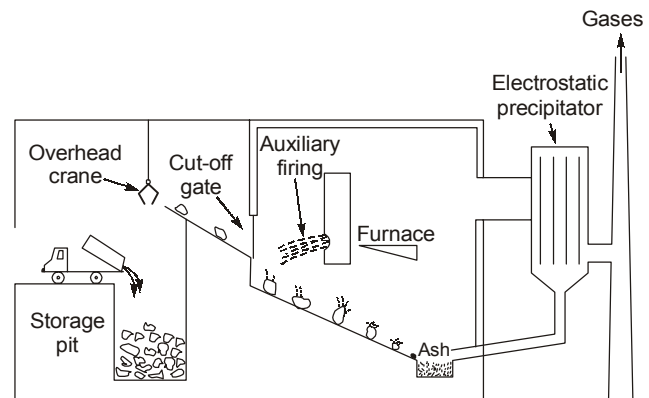
\therefore Total discharge from three wells = $3 \times Q' = 1276.911 \text{ m}^3/\text{d}$

(c) **Change in discharge under interference through each well,**

$$\Delta Q = \frac{(Q - Q') \times 100}{Q} = \frac{(710.206 - 425.637) \times 100}{710.206} = 40.07\%$$

Q.1 (e) Solution:

- Burning of refuse at high temperatures in furnace, called incinerators, is quite a sanitary method of refuse disposal, and is widely adopted in developed countries like USA, where the collected refuse is of high calorific value, and is, hence, quite suitable to burning.
- Only the combustible matter, such as garbage, rubbish and dead animals are burnt, and the incombustible matter like broken glass, chinaware, metal etc. are either left unburnt or are separated out for recycling and refuse, before burning the solid wastes. Prior separation of such materials will reduce the load on the furnace and shall more than compensate the cost of this separation.
- One of the most effective methods of reducing the volume and weight of solid waste is by burning it in a well designed furnace.
- When the available land is scarce, disposal requirements are string out and destruction of toxic water is necessary, incineration is the best method for treatment of solid wastes.
- There are mainly two stages involved in the process of incineration first drying and then combustion. Drying and combustion may be accomplished either in separate units or successively in the same unit depending on temperature constraints and control parameters.



- Estimation of oxygen requirement and heat balance are very vital for efficient functioning of the incineration process.
- Large scale air pollution particularly due to the emissions of dioxins remains a serious problem with the incinerators.
- While operating the incinerators, the following points should be carefully observed:
 - (a) The charging should be thorough and rapid.
 - (b) Each batch of refuse entering the furnace should be well mixed, and the proportion of the fuel in the charge be adjusted to provide complete combustion, and proper temperature.

- (c) The minimum temperature in the combustion chamber should be sufficient (normally larger than 670°C), so as to incinerate all organic matter and oxidise foul smelling gases.

Advantages:

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

Disadvantages:

- It is a very costly method and requires a lot of technical knowledge.
- Solid waste to be burnt should have a high calorific value.
- Smoke odour and ash nuisance may result due to the improper and incompetent operation of the plant, particularly if substances like plastic, giving high calorific value of the wastes, are present in the wastes.

Q.2 (a) Solution:

- (i) (a) **Specific capacity:** Specific capacity of a well is the rate of flow from a well per unit of drawdown. It should be determined for the fall of the first meter, as it is not the same for all the drawdowns.
- (b) **Storage coefficient:** In general, storage coefficient (S) is defined as the volume of water that an aquifer releases or stores per unit surface area per unit decline or rise of water table.
- (c) **Zone of saturation:** In the zone of saturation, water exists within the interstices and is known as groundwater. This is the most important zone for a ground water hydraulic engineer, because he has to tap out this water. Water in this zone is under hydrostatic pressure.
- (ii) (a) Sludge age, $\theta_c = 10$ days
 Discharge, $Q = 10,000 \text{ m}^3/\text{day}$
 Inflow BOD, $S_0 = 180 \text{ mg/l}$
 Outflow BOD, $S = 10 \text{ mg/l}$
 MLSS concentration, $X = 300 \text{ mg/l}$

Underflow biomass concentration,

$$X_u = 10,000 \text{ mg/l}$$

Now, we know that,
$$\frac{1}{\theta_c} = \frac{Q_0(S_0 - S)y}{VX} - k_d$$

$$\Rightarrow \frac{1}{10} = \frac{10000(180 - 10) \times 0.5}{V \times 300} - 0.05$$

$$\Rightarrow V = 18888.89 \simeq 18889 \text{ m}^3$$

(b) Sludge age,
$$\theta_c = \frac{\text{Mass of solids in reactor}}{\text{Mass of solids wasted}} = \frac{VX}{Q_w X_u}$$

Mass of solid wasted,

$$Q_w X_u = \frac{VX}{\theta_c} = \frac{18889 \times 300 \times 10^{-3}}{10} \text{ kg/d} = 566.7 \text{ kg/d}$$

\therefore Mass of solids wasted per day is 566.7 kg

Concentration of solids in the underflow is 10,000 mg/l

i.e.,
$$X_u = 10,000 \text{ mg/l}$$

$$\therefore Q_w \times 10,000 = \frac{18889 \times 300}{10}$$

$$\Rightarrow Q_w = 56.67 \text{ m}^3/\text{day}$$

(c) **Recirculation ratio:**

Using mass balance equation,

$$(Q + Q_r)X = (Q - Q_w) X_e + (Q_r + Q_w) X_u$$

Assume
$$X_e = 0$$

$$\therefore (Q + Q_r)X = (Q_r + Q_w) X_u$$

$$\Rightarrow Q_r (X_u - X) = QX - Q_w \times X_u$$

$$\Rightarrow Q_r = \frac{QX - Q_w X_u}{X_u - X}$$

$$\Rightarrow Q_r = \frac{(10,000)(300) - 56.67 \times 10,000}{10,000 - 300}$$

$$\Rightarrow Q_r = 250.85 \text{ m}^3/\text{d}$$

$$\therefore \text{Recirculation ratio} = \frac{Q_r}{Q} = \frac{250.85}{10,000} = 0.025 \simeq 0.03$$

Q.2 (b) Solution:

(i) We know,
$$B = \frac{\Delta u_3}{\Delta \sigma_3} = \frac{[20 - (-40)]}{(80 - 0)} = \frac{60}{80} = 0.75$$

Now,
$$\bar{A} = \frac{\Delta u_d}{\Delta \sigma_d}$$

$$\Rightarrow AB = \frac{\Delta u_d}{\Delta \sigma_d} \quad (\because \bar{A} = AB)$$

$$\Rightarrow A(0.75) = \frac{-50 - 20}{400}$$

$$\Rightarrow A = -0.233$$

Total change in pore water pressure,

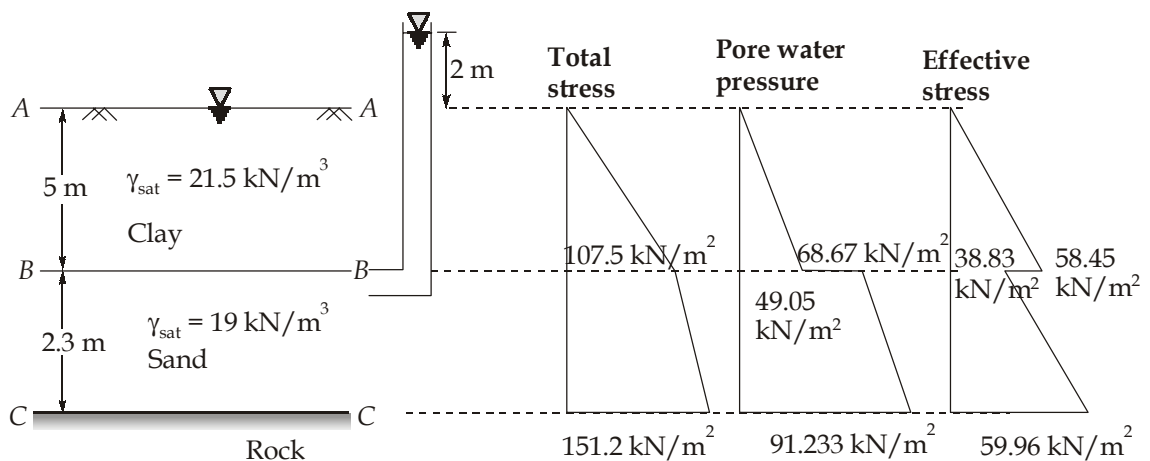
$$\Delta u = B\Delta\sigma_3 + \bar{A}(\Delta\sigma_1 - \Delta\sigma_3)$$

$$\Rightarrow \Delta u = B(\Delta\sigma_3) + AB(\Delta\sigma_d)$$

$$\Rightarrow \Delta u = 0.75(80) + (-0.233 \times 0.75)(400)$$

$$\Rightarrow \Delta u = -9.9 \text{ kN/m}^2$$

(ii)



Section A-A

$$\sigma = 0, u = 0, \sigma' = \sigma - u = 0$$

Section B-B (Clay)

$$\sigma = 21.5 (5) = 107.5 \text{ kN/m}^2$$

$$u = 9.81 (5) = 49.05 \text{ kN/m}^2$$

$$\sigma' = \sigma - u = 58.45 \text{ kN/m}^2$$

Section B-B (Sand)

$$\sigma = 21.5 \times 5 = 107.5 \text{ kN/m}^2$$

$$u = 9.81 (5 + 2) = 68.67 \text{ kN/m}^2$$

$$\sigma' = \sigma - u = 38.83 \text{ kN/m}^2$$

Section C-C (Sand)

$$\sigma = 21.5 (5) + 19 (2.3) = 151.2 \text{ kN/m}^2$$

$$u = 9.81 (5 + 2.3 + 2) = 91.233 \text{ kN/m}^2$$

$$\sigma' = \sigma - u = 59.967 \text{ kN/m}^2$$

When artesian pressure is reduced by 0.5 m, then at section C-C

$$\sigma = 21.5 (5) + 19 (2.3) = 151.2 \text{ kN/m}^2$$

$$u = 9.81 (5 + 2.3 + 2 - 0.5) = 86.328 \text{ kN/m}^2$$

$$\sigma' = 151.2 - 86.328 = 64.872 \text{ kN/m}^2$$

Increase in effective stress at the top of rock,

$$\Delta\sigma' = 64.872 - 59.967 = 4.905 \text{ kN/m}^2$$

(iii) Given,

$$Q = 15000 \text{ kN}$$

$$D = 8 \text{ m}$$

$$\therefore R = \frac{8}{2} = 4 \text{ m}$$

$$Z = 2.5 \text{ m}$$

$$\therefore q = \frac{Q}{\frac{\pi}{4}D^2} = \frac{15000}{\frac{\pi}{4} \times 8^2} = 298.416 \text{ kN/m}^2$$

Using Boussinesq's formula, for circular foundation,

$$\sigma_z = q \left[1 - \left\{ \frac{1}{1 + \left(\frac{R}{Z}\right)^2} \right\}^{3/2} \right]$$

$$\Rightarrow \sigma_z = 298.416 \left[1 - \left\{ \frac{1}{1 + \left(\frac{4}{2.5}\right)^2} \right\}^{3/2} \right]$$

$$\Rightarrow \sigma_z = 253.988 \text{ kN/m}^2 \simeq 254 \text{ kN/m}^2$$

Q.2 (c) Solution:

(i) Waste water characteristics,

$$Q_w = 0.2 \text{ m}^3/\text{s}$$

$$y_w = (\text{BOD})_5 = 50 \text{ mg/l}$$

$$(\text{DO})_w = 2 \text{ mg/l}$$

$$\text{Temperature} = 27^\circ\text{C}$$

Surface stream characteristics

$$Q_s = 0.6 \text{ m}^3/\text{s}$$

$$(\text{BOD})_5 = y_s = 2.5 \text{ mg/l}$$

$$(\text{DO})_s = 8.2 \text{ mg/l}$$

$$\text{Temperature} = 21^\circ\text{C}$$

$$\text{Now, } \text{DO}_{\text{mix}} = \frac{(0.6 \times 8.2) + (0.2 \times 2)}{0.6 + 0.2} = 6.65 \text{ mg/l}$$

$$y_{\text{mix}} = (\text{BOD})_{5\text{mix}} = \frac{(2.5 \times 0.6) + (50 \times 0.2)}{(0.6 + 0.2)} = 14.375 \text{ mg/l}$$

$$(\text{Temperature})_{\text{mix}} = \frac{(21 \times 0.6) + (27 \times 0.2)}{0.8} = 22.5^\circ\text{C}$$

$$\begin{aligned} (k_D)_{22.5} &= (k_D)_{20} (1.047)^{22.5 - 20} \\ &= 0.23 (1.047)^{2.5} = 0.26 \text{ day}^{-1} \end{aligned}$$

$$\begin{aligned} (k_R)_{22.5} &= (k_R)_{20} (1.016)^{22.5 - 20} \\ &= 0.4 (1.016)^{2.5} \\ &= 0.42 \text{ day}^{-1} \end{aligned}$$

$$\begin{aligned} \text{Initial oxygen deficit, } D_0 &= (\text{DO})_{\text{equilibrium}} - (\text{DO})_{\text{mix}} \\ &= 9 - 6.65 = 2.35 \text{ mg/l} \end{aligned}$$

$$\text{Critical time, } t_c = \frac{1}{k_R - k_D} \ln \left[\frac{k_R}{k_D} \left(1 - \frac{D_0}{L_0} \frac{(k_R - k_D)}{k_D} \right) \right]$$

$$y_{\text{mix}} = L_0 (1 - e^{-k_D \times 5})$$

$$\Rightarrow 14.375 = L_0 (1 - e^{-0.26 \times 5})$$

$$\Rightarrow L_0 = \frac{14.375}{(1 - e^{-0.26 \times 5})} = 19.76 \text{ mg/l}$$

$$\begin{aligned} \text{Now, } t_c &= \frac{1}{0.42 - 0.26} \ln \left[\frac{0.42}{0.26} \left\{ 1 - \frac{2.35}{19.76} \frac{(0.42 - 0.26)}{0.26} \right\} \right] \\ &= 2.52 \text{ days} \end{aligned}$$

$$\text{Critical oxygen deficit, } D_c = \frac{k_D}{k_R} L_0 e^{-k_D \times t_c}$$

$$\Rightarrow D_c = \frac{0.26}{0.42} \times 19.76 \times e^{-0.26 \times 2.52}$$

$$\Rightarrow D_c = 6.35 \text{ mg/l}$$

Given, velocity of mix is 0.2 m/s.

∴ Distance of point of critical DO deficit from point of discharge is given by

$$x = \frac{0.2 \times 2.52 \times 86400}{1000} = 43.55 \text{ km}$$

(ii) DO stands for dissolved oxygen. It is the amount of oxygen present in water at any temperature. DO is one of the most important constituent of natural water system. At atmospheric pressure, maximum DO content which may be present in water at any temperature and pressure is called as saturation DO at that temperature and pressure conditions.

DO is a direct indicator of pollution. Any deficiency of oxygen in water with respect to its saturated values indicate biological activity. It is necessary to ensure at least 4 mg/l of DO in streams otherwise fishes are likely to be killed.

DO test is done to find out the pollution level of any water source. Lesser DO indicates that oxygen is consumed by microorganisms to decompose the organic matter.

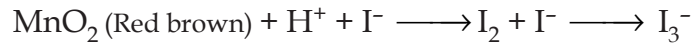
Determine of DO using modified Winkler's test:

Water is first mixed with MnSO_4 and alkali-iodide reagent is added.

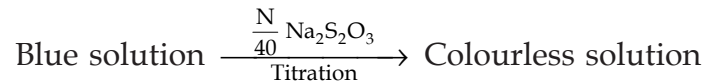
If white precipitate of Mn(OH)_2 is formed, then it indicates that DO is absent.

If red brown precipitate of MnO_2 is formed, then it indicates that DO is present.

To calculate the amount of DO, H_2SO_4 is added to the solution and DO is then measured by titrating the sample with N/40 $\text{Na}_2\text{S}_2\text{O}_3$ (sodium thiosulphate) using starch as indicator. End point of titration is when solution turns colourless from blue.

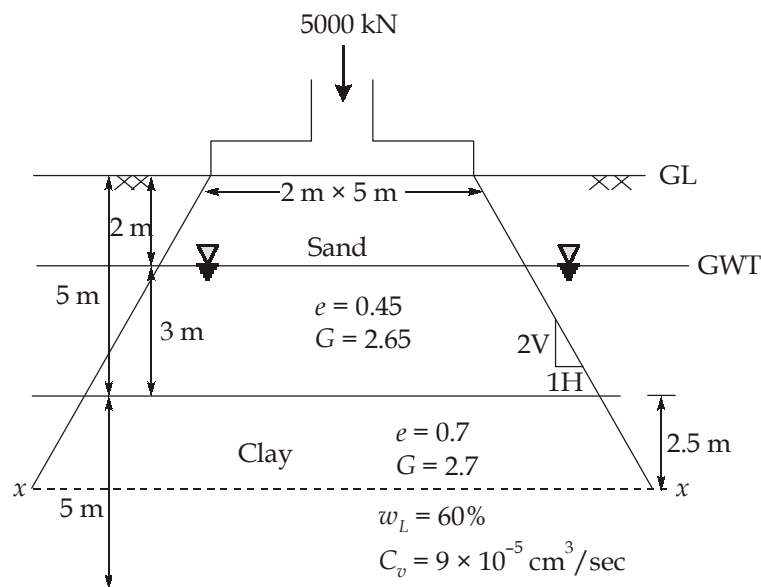


End point:



$$\begin{aligned} \text{Volume of } \frac{N}{40} \text{Na}_2\text{S}_2\text{O}_3 \text{ used} &= \text{No. of gm. equivalents of Na}_2\text{S}_2\text{O}_3 \\ &= \text{No. of gm equivalents of O}_2 \end{aligned}$$

Q.3 (a) Solution:



Pervious layer

$$(\gamma_d)_{\text{sand}} = \frac{G\gamma_w}{1+e} = \frac{2.65 \times 9.81}{1+0.45} = 17.93 \text{ kN/m}^3$$

$$(\gamma_{\text{sat}})_{\text{sand}} = \frac{G+e}{1+e} \gamma_w = \frac{2.65+0.45}{1+0.45} \times 9.81 = 20.97 \text{ kN/m}^3$$

$$(\gamma_{\text{sat}})_{\text{clay}} = \frac{G+e}{1+e} \times \gamma_w = \frac{2.7+0.7}{1+0.7} \times 9.81 = 19.62 \text{ kN/m}^3$$

$$\begin{aligned} \sigma'_{xx} &= \sigma_{xx} - u_{xx} \\ &= [17.93 (2) + 20.97 (3) + 19.62 (2.5)] - [9.81 (2.5+ 3)] \\ &= 93.865 \text{ kN/m}^2 \end{aligned}$$

Now,

$$\Delta\sigma' = \frac{\text{Load}}{\text{Area at section } x-x}$$

$$\text{Width of footing at } x-x = 2 + \frac{1}{2}(2 + 3 + 2.5) + \frac{1}{2}(2 + 3 + 2.5) = 9.5 \text{ m}$$

$$\text{Length of footing at } x-x = 5 + \frac{1}{2}(2 + 3 + 2.5) + \frac{1}{2}(2 + 3 + 2.5) = 12.5 \text{ m}$$

$$\therefore \Delta\sigma' = \frac{5000}{9.5 \times 12.5} = 42.105 \text{ kN/m}^2$$

$$\text{Now, } C_c = 0.009(w_L - 10) = 0.009(60 - 10) = 0.45$$

$$\begin{aligned} \Delta H &= \frac{C_c H_0}{1 + e_0} \log\left(\frac{\sigma'_0 + \Delta\sigma'}{\sigma'_0}\right) \\ &= \frac{0.45 \times 5}{1 + 0.7} \log\left(\frac{93.865 + 42.105}{93.865}\right) \\ &= 0.213 \text{ m} \simeq 21.3 \text{ cm} \end{aligned}$$

$$\text{For 15 cm settlement, } U = \frac{\Delta h}{\Delta H} = \frac{15}{21.30} = 0.7042 > 0.6$$

$$\begin{aligned} \therefore T_v &= -0.9332 \log(1 - U) - 0.0851 \\ &= -0.9332 \log(1 - 0.7042) - 0.0851 \\ &= 0.4086 \end{aligned}$$

$$\therefore T_v = \frac{C_v t}{d^2} \quad \left(d = \frac{H_0}{2} = 2.5 \text{ m}\right)$$

$$\Rightarrow 0.4086 = \frac{9 \times 10^{-5} \times 10^{-4} \times t}{2.5^2}$$

$$\Rightarrow t = 283750000 \text{ sec}$$

$$\Rightarrow t = 3284.14 \text{ days} \simeq 9 \text{ years}$$

For settlement of 15 cm,

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

$$\Rightarrow \Delta e = \frac{0.2130 \times (1 + 0.7)}{5} = 0.07242$$

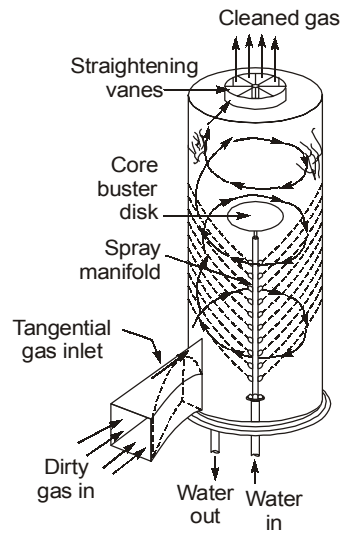
$$\text{Now, } U = \frac{\Delta h}{\Delta H} = \frac{e_0 - e_t}{e_0 - e_{100}}$$

$$\Rightarrow \frac{15}{21.30} = \frac{0.7 - e_t}{0.07242}$$

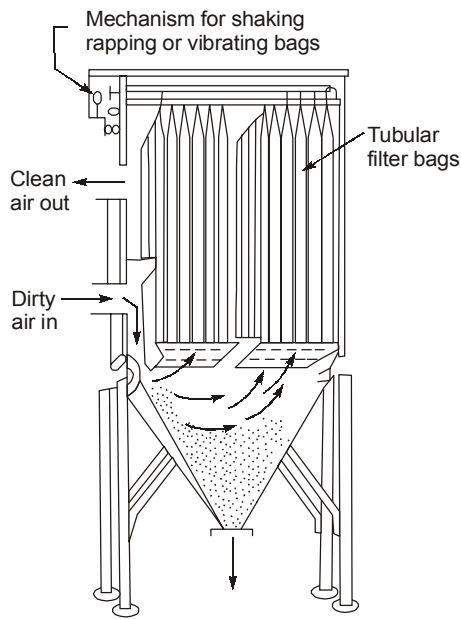
$$\Rightarrow e_t = 0.649$$

Q.3 (b) Solution:

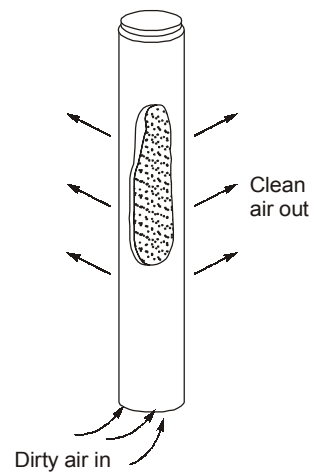
(i) Wet Cyclone Scrubbers



Fabric Filters:



(i)



(ii)

S. No.	Name of Mechanical Device	Minimum Particle size that can be removed in μm	Efficiency %	Merits	Demerits	Principle of Working and Uses
1.	Wet Scrubbers or Collectors Spray tower Wet Cyclonic scrubber Venturi Scrubber	 > 10 μm > 2.5 μm > 0.5 μm	 < 80% < 80% < 99%	(i) The spray tower and venturi scrubber can be made to remove gaseous pollutants also, along with removing particulate matter. (ii) Hot gases can be cooled down. (iii) Corrosive gases can be recovered and neutralized. (iv) The separated gases through contact with aqueous chemicals may produce useful byproducts such as chemicals and fertilisers.	(i) A lot of waste water, needing disposal, may be produced. (ii) Maintenance cost is high, when corrosive materials are collected. (iii) Wet outlet gases cannot rise high from the stack (iv) Poses freezing problems in cold countries. (v) Plume may sometimes be visible in the sky due to the pressure of water vapour.	In these devices, the flue gas is made to push up against a down falling water (liquid) current. The particulate matter mixes up with water droplets and, thus, falls down and gets removed. Water solutions, when replaced with other aqueous chemical solutions, like lime, potassium carbonate, slurry of MnO and MgO, etc. do help in removing gaseous pollutants also from the flue gases.
2.	Fabric Filters	> 1 μm	99%	(i) Fabric filters can give high efficiency, and can even remove very small particles in dry state. (ii) Performance decrease becomes visible, giving prewarning.	(i) High temp gases need to be cooled to the range 100-450°C, within which, the filters are stable. (ii) The flue gases must be dry, as otherwise, there is a risk of condensation inside the filter, which can cause clogging.	In such a system, the flue gas is allowed to pass through a woven or felted fabric, which filters out the particulate matter and allows the gas to pass. Small particles are retained on the fabric, initially through interception and later on, when a dust mat is formed, the fabric starts collecting particles more efficiently. A bag house filter unit, provided in an ordinary room of the factory, contains several vertically hanging fabric cylindrical bags (1.8 to 9 m long), the upper ends of the bags are closed and lower ends are attached to a hopper, where also, the inlet of the flue gas is located. The upward moving gas drops out particulate matter in these bags, which settles down into the hopper, and cleaner gas goes out through the fabric filters. The framework, housing the hanging bags, is provided with an automatic shaking device for cleaning the bags of the collected dust.

(ii) Given: $L_{P_1} = 92 \text{ dB}, L_{P_2} = 94 \text{ dB}, L_{P_3} = 93 \text{ dB}$

Sound pressure level, $L_P = 20 \log_{10} \left(\frac{P_{rms}}{20 \mu\text{Pa}} \right)$

$\Rightarrow P_{rms} = \left(10^{\left(\frac{L_P}{20} \right)} \right) \times 20 \mu\text{Pa}$

$$\therefore P_{rms_1} = \left(10^{\left(\frac{92}{20}\right)}\right) \times 20 = 796214.34 \mu\text{Pa}$$

$$P_{rms_2} = \left(10^{\left(\frac{94}{20}\right)}\right) \times 20 = 1002374.47 \mu\text{Pa}$$

$$P_{rms_3} = \left(10^{\left(\frac{93}{20}\right)}\right) \times 20 = 893367.18 \mu\text{Pa}$$

$$P_{rms} = \sqrt{P_{rms_1}^2 + P_{rms_2}^2 + P_{rms_3}^2}$$

$$\Rightarrow P_{rms} = 1561030.68 \mu\text{Pa}$$

Cumulative sound pressure level,

$$L_{p_t} = 20 \log_{10} \left(\frac{P_{rms}}{20} \right) = 20 \log_{10} \left(\frac{1561030.68}{20} \right) = 97.85 \text{ dB}$$

(iii) Noise pollution's causes, effects and remedies:

Causes:

- (i) Traffic including air traffic, road traffic and sea shore and inland water traffic.
- (ii) Industrialization
- (iii) Human activities such as blaring of loud speaker and sirens, shouting of hawkers and playing of children, etc.

Effects: Noise of sufficient intensity and duration can induce health problems like temporary and sometimes permanent hearing loss, besides causing several other diseases like general annoyance, irritation, disturbance, headaches, insomnia, fatigue, mental torture, nausea, high blood pressure, high pulse rate, greater perspiration, etc.

Remedies:

- (i) By enforcing laws and ordinances, the sounds from loudspeakers, sirens, etc., can be controlled.
- (ii) By use of good technology in vehicles and others machines which produces noise.
- (iii) By proper town planning techniques e.g. the residential complexes should be separated from commercial and industrial complexes. Parks, playgrounds should be provided for children separately.
- (iv) Noise produced by trains and automobiles can be abated by construction of walls or green belt on both sides of roads and railway lines.

Q.3 (c) Solution:

Water content, w	0.075	0.112	0.143	0.178	0.195	0.21
Mass of wet soil, m (g)	1700	1850	2000	1950	1920	1900
Bulk density, ρ (g/cc) $\rho = \frac{m}{V} = \frac{m}{950}$	1.789	1.947	2.105	2.053	2.021	2.000
Dry density, ρ_d (g/cc) $\rho_d = \frac{\rho}{1+w}$	1.664	1.750	1.842	1.743	1.691	1.653
Void ratio, $e = \frac{G\rho_w}{\rho_d} - 1$	0.5925	0.5143	0.4387	0.5204	0.5671	0.6031
Degree of saturation (S)(%) $S = \frac{wG}{\left(\frac{G\rho_w}{\rho_d} - 1\right)}$	33.54	57.73	86.39	90.65	91.12	92.27
Percentage air voids (η_a)(%) $\rho_d = \frac{G\rho_w}{1+wG}(1-\eta_a)$	24.73	14.36	4.15	3.20	3.21	2.91
Theoretical max. dry density (g/cc) $(\gamma_d)_{\max} = \frac{G\rho_w}{1+wG}$	2.2106	2.0435	1.9218	1.8006	1.7472	1.7025

Q.4 (a) Solution:

- (i) In a fixed film attached growth aerobic process like a trickling filter, aerobic conditions are maintained for the decomposition of organic matter. The surface of the medium is covered with biofilm or the biological layer and as the waste water trickles through the medium, organic matter in the waste water comes in contact with the microbes and get decomposed. As more and more organic matter is applied the thickness of this biological layer increases. Due to which, the conditions at the biofilm medium interface start becoming anaerobic because of unavailability of O_2 . Due to anaerobic conditions so developed, foul smelling gases are produced and due to unavailability of food, endogeneous respiration predominates at the biofilm-medium interface.

As the thickness of this bio-film increases and becomes excessive, it gets sheared off and this process of shearing of bio-film is called as 'sloughing'.

Due to sloughing action, bio-film gets detached from the surface. Thus aerobic conditions again become dominant in the filter.

The major operational troubles of a standard rate trickling filter are :

(a) Fly Nuisance:

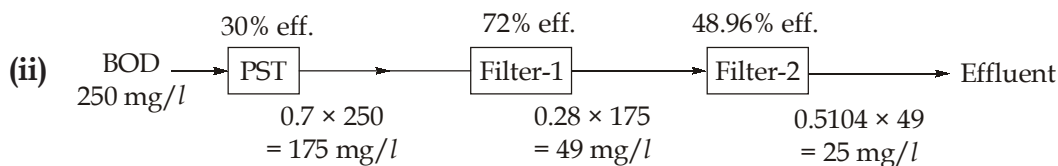
- The filter fly psychoda which develops in the filter particles, may prove to be nuisance, as the same may be carried away into the habitation.
- This problem may be controlled by flooding the filter with sewage for 24 hours or more. The flooding will destroy the larvae, and usually interferes slightly with the results of operation.
- Another method of controlling fly nuisance is by using insecticides such as DDT, chlordane and BHC in the filter plant.

(b) Odour Nuisance:

- Odours generally do not prevail in trickling filters using rotary distributors; but however when fixed nozzles are used, H_2S and other odorous gases are frequently released from the sprays into the atmosphere.
- The usual remedy is to chlorinate the sewage to prevent formation of H_2S or to neutralize the H_2S that has already formed.

(c) Ponding trouble:

- Sometimes, the voids in the filter media gets clogged due to heavy growth of fungi and algae. This may result in ponding of the sewage over the filter bed.
- This trouble can be controlled by chlorinating the sewage which kills the algae, thus causing unloading of the accumulated material.
- Another method of controlling algae is to add $CuSO_4$ to the sewage and leaving the filter bed for sometime.



Given: $BOD_i = 250 \text{ mg/l}$

$BOD_e = 25 \text{ mg/l}$

Depth of filter, $d = 1.8 \text{ m}$

Recirculation ratio, $R = 1.5$

$Q = 8000 \text{ m}^3/\text{d}$

BOD removal in PST = 30%

Efficiency of first filter, $E_1 = 72\%$

BOD left after PST = $250 \times (1 - 0.3) = 175 \text{ mg/l}$

Overall efficiency of two stage trickling filter,

$$E = \frac{(175-25)}{175} \times 100 = 85.71\%$$

$$\Rightarrow E_1 + E_2(1 - E_1) = 0.8571$$

$$\Rightarrow 0.72 + E_2(1 - 0.72) = 0.8571$$

$$\Rightarrow E_2 = 0.4896 = 48.96\%$$

Recirculation factor, $F = \frac{1+R}{(1+0.1R)^2} = \frac{1+1.5}{(1+0.1 \times 1.5)^2} = 1.89$

Let $w_1 =$ BOD or organic loading for first filter

$$\Rightarrow w_1 = (175 \times 10^{-6} \times 10^3)(8000) = 1400 \text{ kg/d}$$

Now, $E_1 = \frac{100}{1 + 0.44 \sqrt{\frac{w_1}{V_1 F}}}$

$$\Rightarrow 72 = \frac{100}{1 + 0.44 \sqrt{\frac{1400}{V_1 \times 1.89}}}$$

$$\Rightarrow V_1 = 948.24 \text{ m}^3$$

Now, $w_2 =$ BOD or organic loading for second filter

$$\Rightarrow w_2 = (1 - 0.72)(175 \times 10^{-6} \times 10^3)(8000)$$

$$\Rightarrow w_2 = 392 \text{ kg/d}$$

Now, $E_2 = \frac{100}{1 + \frac{0.44}{1 - E_1} \sqrt{\frac{w_2}{V_2 F}}}$

$$\Rightarrow 48.96 = \frac{100}{1 + \frac{0.44}{(1 - 0.72)} \sqrt{\frac{392}{V_2 \times 1.89}}}$$

$$\Rightarrow V_2 = 471.28 \text{ m}^3$$

$$\text{BOD loading rate for first filter} = \frac{w_1}{V_1} = \frac{1400}{948.24} = 1.476 \text{ kg/m}^3/\text{d}$$

$$\text{BOD loading rate for second filter} = \frac{w_2}{V_2} = \frac{392}{471.28} = 0.832 \text{ kg/m}^3/\text{d}$$

Q.4 (b) Solution:

(i) For sudden drawdown condition

$$\tan \phi_w = \frac{\gamma'}{\gamma_{sat}} (\tan \phi')$$

$$\phi_w = \tan^{-1} \left[\frac{20-10}{20} \times \tan 10^\circ \right]$$

$$\phi_w = 5.03^\circ \simeq 5^\circ$$

For

$$\phi_w = 5^\circ \text{ and } i = 25^\circ$$

$$S_n = 0.110 - \left[\frac{0.110 - 0.068}{30 - 15} \times (30 - 25) \right] = 0.096$$

Now,

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

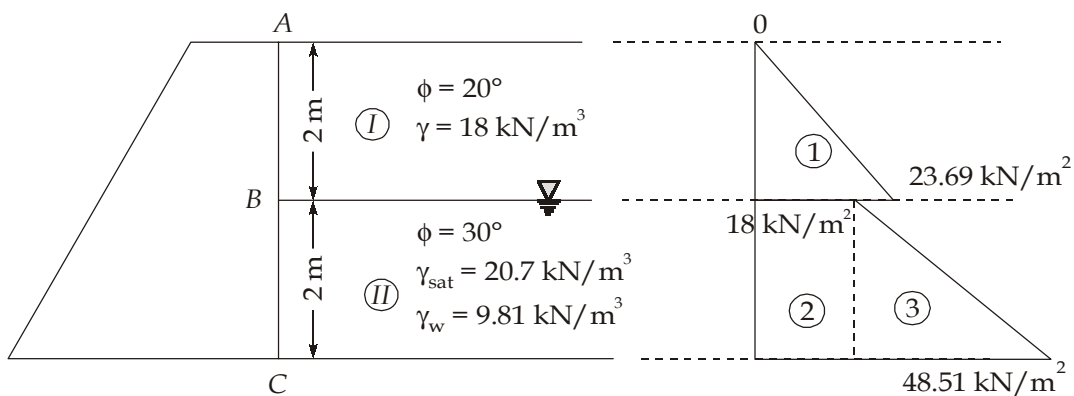
$$S_n = \frac{c_m}{\gamma H}$$

$$0.096 = \frac{c_m}{20 \times 25}$$

$$c_m = 48 \text{ kN/m}^2$$

$$\text{FOS} = \frac{c}{c_m} = \frac{40}{48} = 0.833$$

(ii)



$$\text{For at rest condition, } K_{0_1} = 1 - \sin \phi_1 = 1 - \sin 20^\circ = 0.658$$

$$K_{0_2} = 1 - \sin \phi_2 = 1 - \sin 30^\circ = 0.5$$

$$p_A = 0$$

Now,

$$p_{B_1} = K_{0_1} \gamma_1 H_1 = 0.658(18)(2) = 23.69 \text{ kN/m}^2$$

$$p_{B_2} = K_{0_2} \gamma_1 H_1 = 0.5(18)(2) = 18 \text{ kN/m}^2$$

$$\begin{aligned} p_C &= K_{0_2} \gamma_1 H_1 + K_{0_2} \gamma_2' H_2 + \gamma_w H_2 \\ &= 0.5(18)(2) + 0.5(20.7 - 9.81)(2) + 9.81(2) \\ &= 48.51 \text{ kN/m}^2 \end{aligned}$$

- Total active thrust = Area of pressure diagram

$$A_1 = \frac{1}{2}(23.69)(2) = 23.69 \text{ kN/m}$$

$$A_2 = (18)(2) = 36 \text{ kN/m}$$

$$A_3 = \frac{1}{2}(48.51 - 18)(2) = 30.51 \text{ kN/m}$$

∴ Total active thrust on wall,

$$\begin{aligned} A &= A_1 + A_2 + A_3 \\ &= (23.69 + 36 + 30.51) \text{ kN/m} \\ &= 90.2 \text{ kN/m} \end{aligned}$$

- For location of lateral earth pressure (from the base of wall)

$$y_1 = 2 + \frac{1}{3} \times 2 = \frac{8}{3} \text{ m} \quad A_1 = 23.69 \text{ kN/m}$$

$$y_2 = \frac{2}{2} = 1 \text{ m} \quad A_2 = 36 \text{ kN/m}$$

$$y_3 = \frac{1}{3} \times 2 = \frac{2}{3} \text{ m} \quad A_3 = 30.51 \text{ kN/m}$$

∴ Location of resultant earth pressure,

$$\begin{aligned} \bar{y} &= \frac{A_1 y_1 + A_2 y_2 + A_3 y_3}{A_1 + A_2 + A_3} \\ &= \frac{23.69 \left(\frac{8}{3} \right) + 36(1) + 30.51 \left(\frac{2}{3} \right)}{23.69 + 36 + 30.51} \\ &= 1.325 \text{ m from bottom} \end{aligned}$$

Q4 (c) Solution:

(i) Given,

$$\begin{aligned} D_f &= 1.5 \text{ m}, \gamma_{\text{sat}} = 19 \text{ kN/m}^3, N_c = 25.1 \\ Q_{\text{safe}} &= 500 \text{ kN}, \gamma = 16 \text{ kN/m}^3, N_q = 12.7 \end{aligned}$$

$$\text{FOS} = 2.5, C = 20 \text{ kN/m}^2, B = ?$$

$$Q_{\text{safe}} = \left(\frac{q_{\text{ult}} - \gamma D_f}{\text{FOS}} + \gamma D_f \right) \times A_f$$

\therefore Footing is square and water table is at foundation level

$$\therefore Q_{\text{safe}} = \left(\frac{q_{\text{ult}} - \gamma D_f}{\text{FOS}} + \gamma D_f \right) \times B^2 \quad \dots(i)$$

$$q_{\text{ult}} = 1.3cN_c + \gamma D_f N_q + 0.4\gamma' B N_\gamma$$

$$\begin{aligned} q_{\text{ult}} &= 1.3(20)(25.1) + 16 \times 1.5 \times 12.7 + 0.4(19 - 9.81)(B) \times 9.7 \\ &= 957.4 + 35.66 B \end{aligned}$$

$$Q_{\text{safe}} = \left[\left(\frac{957.4 + 35.66B - 16 \times 1.5}{2.5} \right) + 16 \times 1.5 \right] \times B^2$$

$$1000 = \left[\frac{933.4 + 35.66B}{2.5} + 24 \right] \times B^2$$

$$1000 = [373.36 + 14.264B + 24] B^2$$

$$1000 = [397.36 + 14.264B] B^2$$

$$\Rightarrow 14.264B^3 + 397.36B^2 - 1000 = 0$$

(ii) Given: $Q_{\text{safe}} = 7500 \text{ kN}$

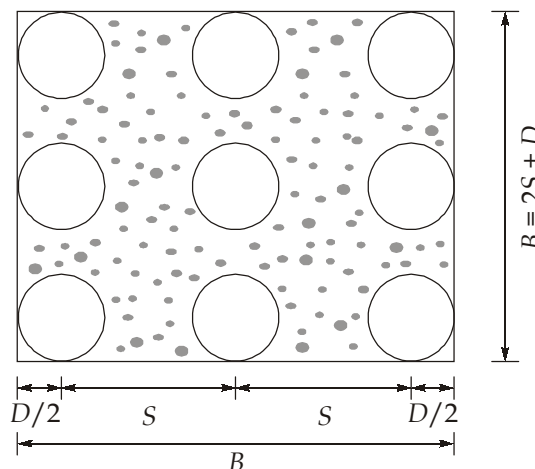
$$D = 1 \text{ m}$$

$$L = 7.5 \text{ m}$$

Cohesion, $C = \frac{100}{2} = 50 \text{ kN/m}^2$

Let spacing between the piles = S

Given, $\text{FOS} = 3$



$$Q_{ug} = 9CB^2 + \alpha\bar{C}(4BL)$$

$$\Rightarrow 7500 \times 3 = 9(50)B^2 + (1)(50)(4 \times B \times 7.5)$$

$$\Rightarrow 22500 = 450B^2 + 1500B$$

$$\Rightarrow B = 5.598 \simeq 6 \text{ m}$$

But,

$$B = 2S + D$$

$$\Rightarrow 6 = 2S + 1$$

$$\Rightarrow S = 2.5 \text{ m centre-to-centre}$$

Q.5 (a) Solution:**(i) Given:**

$$D = 0.3 \text{ m}, \quad L = 5.5 \text{ m}$$

Air flow rate, $Q = 12 \text{ m}^3/\text{s}$

Approach filter velocity, $V = 2.0 \text{ m/min} = \frac{2}{60} \text{ m/s}$

$$\text{Cloth area required} = \frac{12 \times 60}{2} = 360 \text{ m}^2$$

$$\begin{aligned} \text{Area of one filter bag} &= \pi DL \\ &= \pi \times 0.3 \times 5.5 \\ &= 5.18 \text{ m}^2 \end{aligned}$$

$$\text{Total number of bags required} = \frac{360}{5.18} = 69.5 \simeq 70 \text{ bags}$$

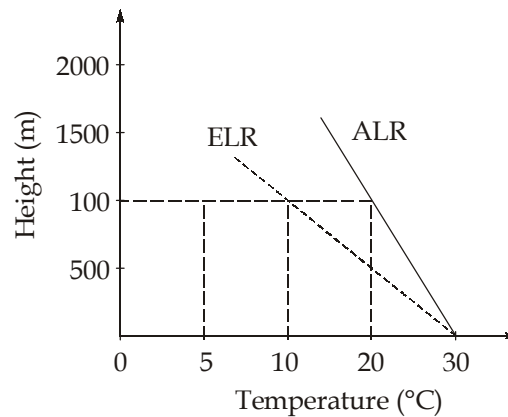
Thus, no. of bags required is 70.

- (ii) Lapse Rate:** In the troposphere, the temperature of the ambient air usually decreases with an increase in altitude. This rate of change in temperature with altitude is called lapse rate.

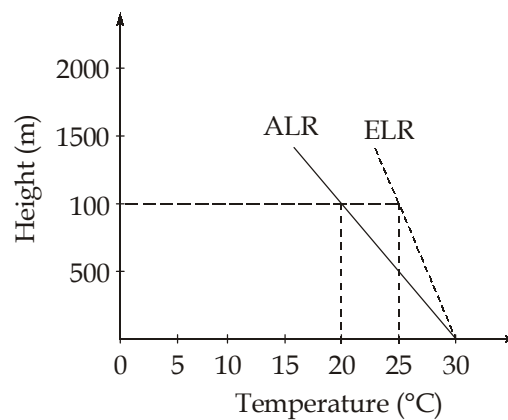
Environmental Lapse Rate (ELR): The temperature gradient of ambient air is called as ELR.

Adiabatic Lapse Rate (ALR): The rate at which temperature of an air parcel changes in response to compression or expulsion associated with elevation change is called as ALR.

Super Adiabatic Environmental Condition: When ELR is more than ALR then ambient lapse rate is super adiabatic and environment is said to be unstable. Dispersion of pollutants will be rapid due to rapid vertical mixing of air thereby making the environment unstable.



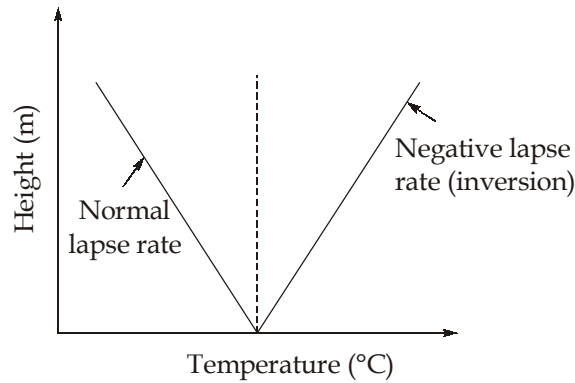
Sub-Adiabatic Environmental Condition: When ELR is less than ALR the environmental conditions are said to be sub-adiabatic. Under such conditions, atmosphere is said to be stable.



Inversion: When the temperature of environment increases with altitude then the lapse rate becomes inverted or negative. Negative lapse rate occurs under condition usually referred to as inversion.

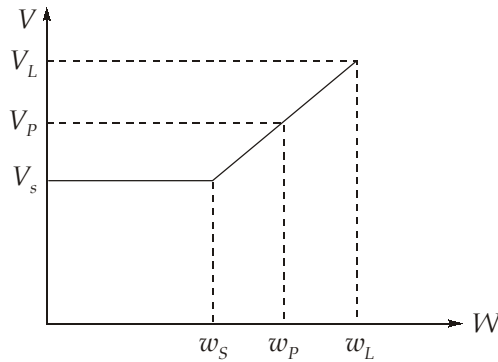
There are two types of inversion:

1. **Radiation inversion:** Radiation inversion is a phenomena occurring from unequal cooling rates for the earth and air above the earth i.e., when the earth cools rapidly and more quickly than air above it, then naturally temperature in the environment will be less at the earth and will increase above it causing negative lapse rate.
2. **Subsidence inversion:** This type of inversion is associated with a high pressure system and is caused by the characteristic sinking of air in a high pressure area i.e., anticyclones. It is also called as mechanical inversion.



Q.5 (b) Solution:

(i)



As per given information,

$$\frac{V_L - V_S}{V_S} \times 100 = 40$$

$$\Rightarrow V_L - V_S = 0.4 V_S$$

$$\Rightarrow V_L = 1.40 V_S \quad \dots(i)$$

Also,
$$\frac{V_P - V_S}{V_S} \times 100 = 25$$

$$\Rightarrow V_P - V_S = 0.25 V_S$$

$$\Rightarrow V_P = 1.25 V_S \quad \dots(ii)$$

From the graph,
$$\frac{V_L - V_S}{w_L - w_S} = \frac{V_P - V_S}{w_P - w_S}$$

$$\Rightarrow \frac{1.40V_S - V_S}{45 - w_S} = \frac{1.25V_S - V_S}{30 - w_S}$$

$$\begin{aligned} \Rightarrow \quad & \frac{0.4V_s}{45 - w_s} = \frac{0.25V_s}{30 - w_s} \\ \Rightarrow \quad & 0.40(30 - w_s) = 0.25(45 - w_s) \\ \Rightarrow \quad & 12 - 0.40w_s = 11.25 - 0.25w_s \\ \Rightarrow \quad & 12 - 11.25 = -0.25 w_s + 0.40 w_s \\ \Rightarrow \quad & w_s = 5\% \\ \therefore \quad & \text{Shrinkage limit} = 5\% \end{aligned}$$

(ii) Base exchange capacity:

The cations attracted to the negatively charged surface of the soil particles are not strongly attached. These cations can be replaced by other ions and are, therefore, known as exchangeable ions.

The phenomenon of replacement of cations is called cation exchange or base exchange. The net negative charge on the mineral which can be satisfied by exchangeable cations is termed cation-exchange capacity or base-exchange capacity. In other words, base-exchange capacity is the capacity of the clay particles to change the cation adsorbed on the surface.

Base-exchange capacity is expressed in terms of the total number of positive charges adsorbed per 100 gm of soil. It is measured in milliequivalent (meq), which is equal to 6×10^{20} electronic charges. Thus, one meq per 100 gm means that 100 gm of material can exchange 6×10^{20} electronic charges if the exchangeable ions are univalent, such as Na^+ , K^+ etc.

According to another definition, one milliequivalent (meq) is also equal to one milligram of hydrogen or its equivalent other material which will replace one milligram of hydrogen. For example, calcium is divalent in contrast to hydrogen which is univalent. Therefore, one mg of hydrogen is equivalent to 20 mg of calcium in base material which is $60/20$ i.e., 3 meq/100 gm.

The base-exchange capacity of clay depends upon the pH value of the water in the environment. If the water is acidic ($\text{pH} < 7$), then the base-exchange capacity is reduced.

Some cations are more strongly adsorbed than others. The adsorbed cations commonly found in soils, arranged in a series in terms of their affinity for attraction are as follows:



Q.5 (c) Solution:

(i) Functional elements of solid waste management.

Component	Description
Waste generation	Those activities in which materials are identified as no longer being of value and are either thrown away or gathered together for disposal
On site handing, storage, and processing	Those activities associated with the handling, storage and processing of solid wastes at or near the point of generation.
Collection	Those activities associated with the gathering of solid wastes and the hauling of wastes after collection to the location where the collection vehicle is emptied
Transfer and transport	Those activities associated with (1) the transfer of wastes from the smaller collection vehicle to the larger transport equipment and (2) the subsequent transport of the wastes, usually over long distance, to the disposal site.
Processing and recovery	Those techniques equipment and facilities used to improve the efficiency of the other functional elements and to recover usable materials, conversion products or energy from solid wastes
Disposal	Those activities associated with ultimate disposal of solid wastes, including those wastes collected and transported directly to a landfill site, semisolid wastes (sludge) from wastewater treatment plants, incinerator residue, compost or other substances from the various solid-waste processing plants that are of no further use.

(ii)

Component	% by mass	% Moisture	Density (kg/m ³)	Energy (kJ/kg)	Dry mass (kg)	Volume (m ³)	Total Energy (kJ)
Food waste	20	70	290	4650	6	0.07	9300
Paper	40	6	85	16750	37.6	0.47	670000
Card board	15	5	50	16300	14.25	0.3	244500
Plastics	7.5	2	65	32600	7.35	0.11	244500
Garden trimming	7.5	60	105	6500	3	0.07	48750
Wood	5	20	240	18600	4	0.02	9300
Tin cans	5	3	90	700	4.85	0.05	3500
					77.05	1.09	1397250

(a) Moisture content = $\left(\frac{100 - 77.05}{100}\right) \times 100 = 22.95\%$

(b) Density = $\left(\frac{100}{1.09}\right) = 91.74 \text{ kg/m}^3$

(c) Energy on dry basis = $\frac{100}{100 - \% \text{moisture}} \times (\text{kJ/kg as discarded})$

$$\text{Unit energy content} = \frac{\text{Total energy}}{\text{Total weight}} = \frac{1397250}{100} = 13972.50 \text{ kJ/kg}$$

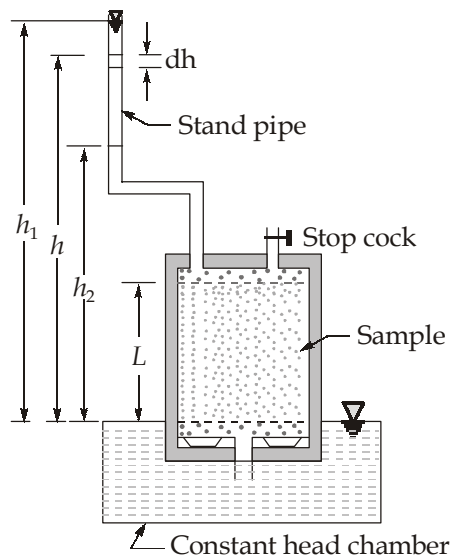
$$\text{Energy on dry basis} = \left(\frac{100}{100 - 22.95} \right) \times 13972.50 = 18134.33 \text{ kJ/kg}$$

(d) Energy content on ash-free dry basis

$$= 13972.50 \left(\frac{100}{100 - 22.95 - 5} \right) = 19392.78 \text{ kJ/kg}$$

Q.5 (d) Solution:

(i)



The test is started by allowing the water in the stand pipe to flow through the soil sample to the constant head chamber from which it overflow and spills out. As the water flows through the soil, the water level in standpipe drops. The time required for the water level to fall from a known initial head (h_1) to a known final head (h_2) is determined. The head is measured with reference to the level of water in the constant-head chamber.

Let us consider the instant when the head is h . For the infinitesimal small time dt , the head falls by dh . Let the discharge through the soil sample be q . From continuity of flow,

$$adh = -qdt$$

where a is cross-sectional area of the standpipe.

$$\therefore a \, dh = -(A \times k \times i) \times dt$$

$$\Rightarrow a \, dh = -Ak \times \frac{h}{L} \times dt$$

$$\Rightarrow \frac{Akdt}{aL} = -\frac{dh}{h}$$

$$\text{Integrating, } \frac{Ak}{aL} \int_{t_1}^{t_2} dt = -\int_{h_1}^{h_2} \frac{dh}{h}$$

$$\Rightarrow \frac{Ak}{aL}(t_2 - t_1) = \log_e \left(\frac{h_1}{h_2} \right)$$

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

where, $t = (t_2 - t_1)$, the time interval during which the head reduces from h_1 to h_2 .

Expression for 'k' can also be written as:

$$k = \frac{2.30aL}{At} \log_{10} \left(\frac{h_1}{h_2} \right)$$

(ii) Given:

$$x_1 = 2 \text{ cm}, x_2 = 6.5 \text{ cm}, x_3 = 18 \text{ cm}$$

$$S = 85 \%, h = 25\%$$

$$h_1 = 60 \text{ cm}, h_2 = 190 \text{ cm}$$

$$t_2 - t_1 = 6 \text{ minutes}$$

$$t_3 - t_2 = 20 \text{ minutes}$$

We know that the result of capillary permeability test is

$$\frac{x_2^2 - x_1^2}{t_2 - t_1} = \frac{2k}{Sn} (h_1 + h_c)$$

$$\text{For stage (1), } \frac{6.5^2 - 2^2}{6 \times 60} = \frac{2k}{0.85 \times 0.25} (60 + h_c)$$

$$\Rightarrow 60k + kh_c = 0.01129 \quad \dots(i)$$

$$\text{For stage (2), } \frac{18^2 - 6.5^2}{20 \times 60} = \frac{2k}{0.85 \times 0.25} \times (180 + h_c)$$

$$\Rightarrow 180k + kh_c = 0.02494 \quad \dots(ii)$$

Solving eq. (i) and eq. (ii)

$$60k + kh_c = 0.01129$$

$$180k + kh_c = 0.02494$$

$$\hline -120k = -0.01365$$

$$\Rightarrow k = 1.1375 \times 10^{-4} \text{ cm/sec}$$

Q.5 (e) Solution:

(i) Given: $i = 10^\circ$, $\delta = 25^\circ$, $\phi = 30^\circ$, $\beta = 70^\circ$, $\gamma = 17.5 \text{ kN/m}^3$, $H = 5 \text{ m}$

Active earth pressure on wall is given by,

$$P_a = \frac{1}{2} k_a \gamma H^2 \quad \dots(i)$$

where,

$$k_a = \frac{\sin^2(\beta + \phi)}{\sin^2 \beta \times \sin(\beta - \delta) \left[1 + \sqrt{\frac{\sin(\phi + \delta) \sin(\phi - i)}{\sin(\beta - \delta) \sin(\beta + i)}} \right]^2}$$

$$\Rightarrow k_a = \frac{\sin^2(70^\circ + 30^\circ)}{\sin^2 70^\circ \sin(70^\circ - 25^\circ) \left[1 + \sqrt{\frac{\sin(30^\circ + 25^\circ) \sin(30^\circ - 10^\circ)}{\sin(70^\circ - 25^\circ) \sin(70^\circ + 10^\circ)}} \right]^2}$$

$$\Rightarrow k_a = \frac{0.9698}{0.8830 \times 0.7071 \times \left[1 + \sqrt{\frac{0.8192 \times 0.3420}{0.7071 \times 0.9848}} \right]^2}$$

$$\Rightarrow k_a = 0.5816$$

Now put value of k_a in eq. (i),

$$\therefore P_a = \frac{1}{2} \times 0.5816 \times 17.5 \times 5^2 = 127.225 \text{ kN/m}$$

(ii) Given: $\sigma_3 = 70 \text{ kN/m}^2$, $\sigma_d = 230 \text{ kN/m}^2$

$$\therefore \sigma_1 = \sigma_3 + \sigma_d = 300 \text{ kN/m}^2$$

For sand,

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

$$\Rightarrow 300 = 70 \tan^2 \left(45 + \frac{\phi}{2} \right)$$

$$\Rightarrow \phi = 38.435^\circ$$

$$\therefore \theta_c = 45^\circ + \frac{\phi}{2} = 64.2175^\circ$$

Now,

$$\sigma_n = \frac{\sigma_1 + \sigma_3}{2} + \left(\frac{\sigma_1 - \sigma_3}{2} \right) \cos 2\theta_c$$

$$\Rightarrow \sigma_n = \frac{70 + 300}{2} + \left(\frac{300 - 70}{2} \right) \cos 2(64.2175^\circ)$$

$$\Rightarrow \sigma_n = 113.513 \text{ kN/m}^2$$

Now,

$$\tau = c + \sigma_n \tan \phi$$

$$\Rightarrow \tau = 0 + 113.513 \tan (38.435^\circ)$$

$$\Rightarrow \tau = 90.082 \text{ kN/m}^2$$

Now,

$$\sigma_R = \sqrt{\sigma_n^2 + \tau^2}$$

$$\Rightarrow \sigma_R = \sqrt{113.513^2 + 90.082^2}$$

$$\Rightarrow \sigma_R = 144.914 \text{ kN/m}^2$$

Q.6 (a) Solution:

(i)

$$P_{2000} = 13850507$$

$$\bar{x} = 2574747$$

$$P_{2030} = P_{2000} + 3(\bar{x})$$

$$\Rightarrow P_{2030} = 21574748$$

$$\text{Initial design capacity} = P_{2030} \times 245 \times 1.8 \times 10^{-3}$$

$$= 9514463.868 \text{ m}^3/\text{day}$$

But plant will reach its capacity in 2020, by which population of Delhi in 2020 is 21574748.

Geometric growth rate, $r = \left[\left(\frac{P_{2020}}{P_{2000}} \right)^{1/2} - 1 \right] \times 100$

$$\Rightarrow r = \left[\left(\frac{21574748}{13850507} \right)^{1/2} - 1 \right] \times 100$$

$$\Rightarrow r = (0.2481) \times 100$$

$$\Rightarrow r = 24.81\% \text{ per decade}$$

$$\begin{aligned}
 \text{Actual population in 2030} &= (P_{2020})_{act} \left(1 + \frac{r}{100} \right) \\
 &= 21574748 \left(1 + \frac{24.81}{100} \right) \\
 &= 26927442.98 \\
 &\simeq 26927443
 \end{aligned}$$

$$\begin{aligned}
 \text{Actual demand in year 2030} &= 1.8 \times 245 \times 26927443 \times 10^{-3} \text{ m}^3/\text{day} \\
 &= 11875002.36 \text{ m}^3/\text{day}
 \end{aligned}$$

$$\begin{aligned}
 \therefore \text{Capacity of new unit} &= (\text{Actual demand in 2030}) - 0.8 (\text{Capacity of old unit}) \\
 &= 11875002.36 - (0.8 \times 9514463.868) \\
 &= 4263431.268 \text{ m}^3/\text{day}
 \end{aligned}$$

(ii) Population of Delhi in 2030 = 26927443

(a) Kuichling's formula

$$Q = 3182\sqrt{P} \quad \text{where } P \text{ is in thousand}$$

$$\Rightarrow Q = 3182\sqrt{26927.443}$$

$$\Rightarrow Q = 522152.95 \text{ l/min}$$

(b) Freeman formula

$$Q = 1136 \left[\frac{P}{10} + 10 \right] \quad \text{where } P \text{ is in thousand}$$

$$\Rightarrow Q = 1136 \left[\frac{26927.443}{10} + 10 \right]$$

$$\Rightarrow Q = 3070317.5 \text{ l/min}$$

(c) Buston's formula

$$Q = 5663\sqrt{P} \quad \text{where } P \text{ is in thousand}$$

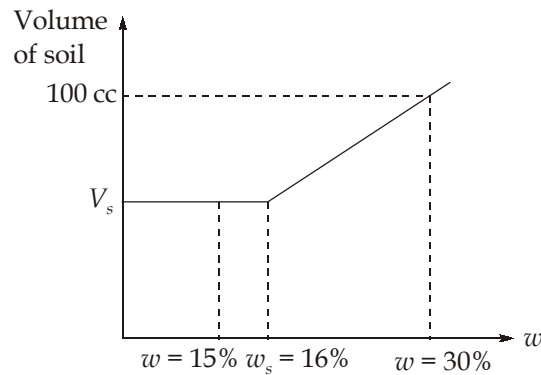
$$\Rightarrow Q = 5663\sqrt{26927.443}$$

$$\Rightarrow Q = 929274.7 \text{ l/min}$$

Q.6 (b) Solution:

(i) Given: $V_{\text{soil}} = 100 \text{ cc}$, $G = 2.7$, $w = 30\%$, $w_s = 16\%$

V_{soil} at 15% water content = ?



$$\therefore w_s = \frac{1}{G_D} - \frac{1}{G}$$

$$\Rightarrow 0.16 = \frac{1}{G_D} - \frac{1}{2.7}$$

$$\Rightarrow \frac{1}{G_D} = 0.16 + \frac{1}{2.7}$$

$$\Rightarrow G_D = 1.8855$$

We know, shrinkage ratio,

$$R = G_D = \frac{\frac{V_1 - V_s}{V_s} \times 100}{(w_1 - w_s)}$$

$$\Rightarrow 1.8855 = \frac{\frac{100 - V_s}{V_s} \times 100}{(30 - 16)}$$

$$\Rightarrow 0.2640 = \frac{100 - V_s}{V_s}$$

$$\Rightarrow 0.2640 V_s + V_s = 100$$

$$\Rightarrow V_s = 79.114 \text{ cc}$$

\therefore Below shrinkage limit volume of soil remains same

$\therefore V_{\text{soil}}$ at 15% water content is also 79.114 cc.

(ii) Volume of water collected in 13 minutes = 500 ml

$$\therefore Q = \frac{500}{13 \times 60} = 0.641 \text{ cm}^3/\text{sec}$$

$$\text{Area of soil sample} = \frac{\pi}{4}(5)^2 = 19.635 \text{ cm}^2$$

$$\Delta h = 15 \text{ cm, } L = 40 \text{ cm (given)}$$

$$\therefore i = \frac{\Delta h}{L} = \frac{15}{40} = 0.375$$

$$Q = Aki$$

$$\Rightarrow 0.641 = 19.635 \times k \times 0.375$$

$$\Rightarrow k = 0.087 \text{ cm/sec}$$

$$\text{Now, } \gamma_d = \frac{W_{\text{solid}}}{V_{\text{soil}}} = \frac{1320}{\frac{\pi}{4}(5)^2 \times 40} = 1.68 \text{ g/cc}$$

$$\text{We know that, } \gamma_d = \frac{G\gamma_w}{1+e}$$

$$\Rightarrow e = \frac{G\gamma_w}{\gamma_d} - 1 = \frac{2.6 \times 1}{1.68} - 1 = 0.5469$$

$$\therefore n = \frac{e}{1+e} = 0.3536$$

$$\therefore V = ki = 0.087 \times 0.3536 = 0.0308 \text{ cm/sec}$$

$$\begin{aligned} \therefore V_s &= \frac{V}{n} = \frac{0.0308}{0.3536} \\ &= 0.0871 \text{ cm/sec} = 8.71 \times 10^{-4} \text{ m/s} \end{aligned}$$

- (iii) (a) **Flow Index:** Flow Index (I_F) is slope of flow curve obtained between the number of blows and the water content in Casagande's method of determination of liquid limit.

$$I_F = \frac{w_1 - w_2}{\log_{10} \left(\frac{N_2}{N_1} \right)}$$

where N_2 and N_1 are number of blows required at water content of w_2 and w_1 respectively.

- The flow index is the rate at which a soil mass losses its shear strength with an increase in water content.

- (b) **Toughness Index:** It is defined as ratio of plasticity index (I_p) to flow index (I_F)

$$I_t = \frac{I_p}{I_F}$$

- It measures shearing strength of soil at plastic limit.
- It's value lies between 0 to 3.0. A value of toughness index less than unity indicates that the soil is friable at plastic limit.

(c) **Liquidity Index:** Liquidity index (I_L or LI) is defined as

$$I_L = \frac{w - w_p}{I_p} \times 100$$

where, w = Natural water content

- The liquidity index of soil indicates the measure of it's water content to its liquid limit.

If $w > w_L \rightarrow I_L = +ve \rightarrow$ Liquid state

If $w < w_p \rightarrow I_L = -ve \rightarrow$ Semisolid state

If $w_p < w < w_L \rightarrow 0 < I_L < 1 \rightarrow$ Plastic state

(d) **Activity of soil:** It is the ratio of plasticity index and the percentage of clay fraction less than 2μ .

$$A = \frac{I_p}{F}$$

- Activity is a measure of water holding capacity of clayey soil. The change in volume of clayey soil during swelling or shrinkage depends upon the activity.

Activity	Type of soil
< 0.75	Inactive soil
> 1.25	Active soil
0.75 to 1.25	Normal soil

- The soil containing clay mineral montmorillonite has very high activity (>4), and the soil containing kaolinite is least active (<1) and soil containing illite is moderately active (1 to 2).

Q.6 (c) Solution:

(i) (a) **Building sewer:** Building sewer, sometimes called building connections, connect to the building plumbing and is used to convey wastewater from the buildings to lateral or branch sewer, or any other sewer except another building sewer. Building sewers are normally laid outside the building foundation. The distance from the foundation wall to where the sewer begins depends on the local building regulations.

(b) **Lateral sewer:** Lateral sewers form the first element of a wastewater collection system and are usually laid in streets or special easements. They are used to

collect wastewater from one or more building sewers and convey it to a main sewer.

(c) **Main sewer:** Main sewers are used to convey wastewater from one or more lateral sewers to trunk sewers or to intercepting sewers.

(d) **Intercepting sewer:** Intercepting sewers are larger sewers that are used to intercept a number of main or trunk sewer and convey the wastewater to wastewater treatment or other disposal facilities.

(ii) Given: $D = 950$ mm, $S = 0.0001$, $d = 700$ mm, $n = 0.015$

$$\frac{d}{D} = \frac{1 - \cos \frac{\alpha}{2}}{2}$$

$$\Rightarrow \frac{700}{950} = \frac{1 - \cos \frac{\alpha}{2}}{2}$$

$$\Rightarrow \alpha = 236.55^\circ$$

$$\therefore \frac{a}{A} = \frac{\alpha}{360} - \frac{\sin \alpha}{2\pi}$$

$$\Rightarrow a = \frac{\pi}{4}(0.950)^2 \left[\frac{236.55^\circ}{360^\circ} - \frac{\sin(236.55^\circ)}{2\pi} \right]$$

$$= 0.5599 \text{ m}^2 \simeq 0.56 \text{ m}^2$$

$$\frac{p}{P} = \frac{\alpha}{360^\circ}$$

$$\Rightarrow p = \pi \times 0.950 \times \frac{236.55^\circ}{360^\circ} = 1.96 \text{ m}$$

Using Manning's formula,

$$\text{Discharge, } q = a \left(\frac{1}{n} r^{2/3} S^{1/2} \right)$$

$$\Rightarrow q = \frac{a}{n} \left(\frac{a}{p} \right)^{2/3} (S)^{1/2}$$

$$\Rightarrow q = \frac{0.56}{0.015} \left(\frac{0.56}{1.96} \right)^{2/3} (0.0001)^{1/2}$$

$$\Rightarrow q = 0.162 \text{ m}^3/\text{s}$$

(iii) Given: $d = 0.2$ mm, $G = 2.6$, $Q = 12000 \text{ m}^3/\text{day}$, $v_h = 0.25 \text{ m/s}$

Assume rectangular cross-section with depth = 1.5 times width

$$\text{i.e., } D = 1.5 B$$

$$\text{Area of cross-section, } A = B \times D$$

$$\Rightarrow A = 1.5 B^2$$

$$\text{Flow through velocity, } v_h = \frac{Q}{A} = \frac{12000}{1.5B^2}$$

$$\Rightarrow 0.252 \text{ m/s} = \frac{12000}{86400 \times (1.5B^2)}$$

$$\Rightarrow B = 0.61 \text{ m}$$

$$\therefore D = 1.5 \times 0.61 \text{ m}$$

$$\Rightarrow D = 0.915 \text{ m}$$

$$\text{Settling velocity, } v_s = \frac{(G-1)\gamma_w d^2}{18\mu}$$

$$\Rightarrow v_s = \frac{(G-1)gd^2}{18\nu}$$

$$\Rightarrow v_s = \frac{(2.6-1) \times 9.81 \times (0.2 \times 10^{-3})^2}{18 \times 1.3 \times 10^{-6}}$$

$$\Rightarrow v_s = 0.0268 \text{ m/s} \simeq 0.027 \text{ m/s}$$

$$\text{Detention time, } t_D = \frac{D}{v_s} = \frac{0.915}{0.027}$$

$$\Rightarrow t_D = 33.89 \text{ s}$$

$$\text{Length of tank, } L = t_d \times v_h$$

$$\Rightarrow L = 33.89 \times 0.252$$

$$\Rightarrow L = 8.54 \text{ m}$$

Therefore, dimensions of detention tank are,

$$L = 8.54 \text{ m}$$

$$B = 0.61 \text{ m}$$

$$D = 0.915 \text{ m}$$

Q.7 (a) Solution:

- (i) The natural hazardous events like dust storms, volcanoes etc. or from human activities like burning of wood, coal, oil in homes or industries or automobiles etc., are called the primary pollutants. The important primary air pollutants are:

- (i) Oxides of sulphur, particularly the sulphur dioxide (SO₂)

- (ii) Oxides of carbon like carbon monoxide (CO) and carbon dioxide (CO₂), particularly the carbon monoxide (CO)
- (iii) Oxide of nitrogen, like NO, NO₂ (expressed as NO_x)
- (iv) Volatile organic compounds, mostly hydrocarbons

Certain less important primary pollutants are hydrogen sulphide, hydrogen fluoride and other fluorides.

These primary pollutants react with one another or with water vapour, aided and abetted by the sunlight to form entirely a new set of pollutant called the secondary pollutants. The important secondary air pollutants are:

- (i) Sulphuric acid (H₂SO₄)
 - (ii) Ozone (O₃)
 - (iii) Formaldehydes
 - (iv) Peroxy acetyl-nitrate (PAN)
 - (v) Photochemical Smog
- (ii) **Smog:** Smog is combination of two words smoke and fog. It can be of two types viz. photochemical or coal induced. The photochemical smog is caused by the interaction of some hydrocarbons and oxidants (mainly nitrogen oxides) under the influence of sunlight giving rise to dangerous peroxy acetyl nitrate (PAN).



Its main constituents are nitrogen oxides, PAN, hydrocarbons, carbon monoxide and ozone. It reduces visibility, causes eye irritation, damage to vegetable and cracking of rubber. Air pollution caused from vehicular emission from internal combustion engines and also industrial fumes react in the atmosphere with sunlight to form secondary pollutants and also combine with the primary emission to form photochemical smog. Coal induced smog consists of smoke, sulphur compound and fly ash.

- (iii) (a) **Sulphur dioxide:** SO₂ is an irritant gas which effects mucous membrane when inhaled. It leads to bronchial spasms. Asthma patients are badly affected.
- (b) **Carbon monoxide:** Carbon monoxide has a strong affinity for combining with the haemoglobin of the blood to form carboxyhaemoglobin, COHb. This reduces the ability of the haemoglobin to carry oxygen to the body tissues. CO has about two hundred times the affinity of oxygen for attaching itself to the haemoglobin so that low levels of CO can still result in high levels of COHb. Carbon monoxide also affects the central nervous system.

- (c) **Hydrocarbon vapours:** The effect of it is primarily irritating. It is a major contributor to eye and respiratory irritation caused by photochemical smog.
- (d) **Oxides of nitrogen:** Among several oxides of nitrogen that are known to exist in the ambient air, only two are thought to affect human health. These are nitric oxide (NO) and nitrogen dioxide (NO₂). It causes eye and nasal irritation and pulmonary discomfort.
- (e) **Ozone:** O₃ is a gas that has an irritant action in the respiratory tract, reaching much deeper into lungs than the oxides of sulphur.
- (iv) **The concept of L_{eq} :** L_{eq} is that statistical value of sound pressure level that can be equated to any fluctuating noise level. Let us take an example where a sound of 90 dB exists for 5 minutes and is followed by a sound of 60 dB lasting for next 50 minutes. It will compose a fluctuating noise level which can be represented by a certain dB value which is indicative of producing the same effect over the entire time period of 5 + 50 = 55 minutes as the original fluctuating noise. This value is called equivalent continuous equal energy level or equivalent noise level.

Thus, it may be defined as the constant noise level, which over a given time, expends the same amount of energy, as is expended by the fluctuating levels over the same time.

The above fluctuating sound with its equivalent energy level (L_{eq}) is represented graphically which reflects that high occasional sounds do influence the resultant equivalent value by a large extent.

The equivalent noise level (L_{eq}) constitutes an important parameter for evaluating the impact of fluctuating noises of all kinds, such as from aircraft, street and road traffic, rail traffic, industrial machines, sports stadiums, playgrounds etc. Also, the term $L_{eq}(8)$ denotes L_{eq} is based on 8 hour measurement when however no such time is mentioned, then L_{eq} always corresponds to one hour measurement.

Q.7 (b) Solution:

(i) Given: $e_0 = 0.75$, $C_c = 0.1$, $C_v = 2 \times 10^{-7} \text{ m}^2/\text{s}$
 $G = 2.65$, $C_R = 0.02$, $U = 90\%$

$$\therefore \gamma_{\text{sat}} = \frac{G + e}{1 + e} \gamma_w = \frac{2.65 + 0.75}{1 + 0.75} \times 9.81 = 19.06 \text{ kN/m}^3$$

$$\therefore \gamma' = \gamma_{\text{sat}} - \gamma_w = 19.06 - 9.81 = 9.25 \text{ kN/m}^3$$

Initial effective stress at centre of clay layer,

$$\sigma_0' = \gamma' (1.5) = 9.25 \times 1.5 = 13.875 \text{ kN/m}^2$$

Preconsolidation pressure,

$$\sigma_1' = 50 \text{ kN/m}^2$$

Addition surcharge, $\Delta\sigma' = 60 \text{ kN/m}^2$

$$\Delta H = \frac{C_R H_0}{1 + e_0} \log\left(\frac{\sigma_1'}{\sigma_0'}\right) + \frac{C_C H_0}{1 + e_0} \log\left(\frac{\sigma_0' + \Delta\sigma'}{\sigma_1'}\right)$$

$$\Rightarrow \Delta H = \frac{0.02 \times 3}{1 + 0.75} \log\left(\frac{50}{13.875}\right) + \frac{0.1 \times 3}{1 + 0.75} \log\left(\frac{13.875 + 60}{50}\right)$$

$$\Rightarrow \Delta H = 0.048 \text{ m} = 4.81 \text{ cm}$$

Now, for 90% settlement,

$$T_v = -0.9332 \log(1 - U) - 0.0851$$

$$\Rightarrow T_v = -0.9332 \log(1 - 0.9) - 0.0851$$

$$\Rightarrow T_v = 0.8481$$

$$\therefore T_v = \frac{C_v t}{d^2} \quad (d = H_0 \text{ for one-way drainage})$$

$$\Rightarrow 0.8481 = \frac{2 \times 10^{-7} \times t}{3^2}$$

$$\Rightarrow t = 38164500 \text{ seconds} = 441.72 \text{ days} \simeq 442 \text{ days}$$

(ii) **Assumption of Terzaghi's theory:** Terzaghi's theory of one-dimensional consolidation is based upon the following assumptions:

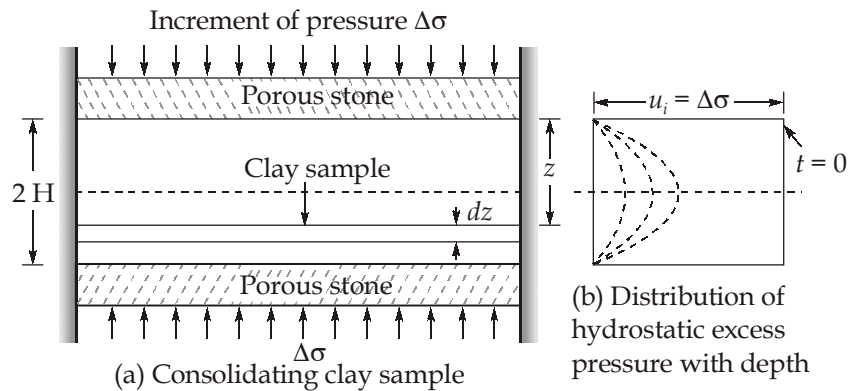
1. The soil is homogeneous and isotropic.
2. The soil is completely saturated (i.e., $S = 100\%$)
3. The soil grains and water are virtually incompressible (i.e., γ_w is constant and volume change of soil is only due to change in void ratio).
4. The behaviour of infinitesimal masses in regard to expulsion of pore water and consequent consolidation is no different from that of larger representative soil mass.
5. The compression is one-dimensional (i.e., u varies with z only)
6. The flow of water in the soil voids is one-dimensional and Darcy's law is valid.

$$\left(\frac{\partial v_x}{\partial x} = \frac{\partial v_y}{\partial y} = 0 \text{ and } v_z = k_z \frac{\partial h}{\partial z} \right)$$

Also, flow occurs on account of hydrostatic excess pressure ($h = u/\gamma_w$)

7. Certain soil properties such as permeability and modulus of volume change are constant; these actually vary somewhat with pressure. (k and m_v are independent of pressure).
8. The pressure versus void ratio relationship is taken to be the idealised one, (i.e., a_v is constant).
9. Hydrosynamic lag alone is considered and plastic lag is ignored, although it is known to exist. (i.e., the effect of k alone is considered on the rate of expulsion of pore water).

Now, derivation of Terzaghi’s equation of 1-D consolidation w.r.t lab oedometer sample with double drainage as shown in figure.



Let us consider a layer of unit area of cross-section and of elementary thickness dz at depth z from the pervious boundary. Let the increment of pressure applied be $\Delta\sigma$. Immediately on application of the pressure increment, pore water starts to flow towards the drainage face. Let ∂h be the head lost between the two faces of this elementary layer, corresponding to a decrease of hydrostatic excess pressure ∂u ,

$$\therefore k_x \frac{\partial^2 h}{\partial x^2} + k_z \frac{\partial^2 h}{\partial z^2} = \frac{1}{(1+e)} \left[e \frac{\partial s}{\partial t} + S \frac{\partial e}{\partial t} \right] \quad \dots(i)$$

For non-dimensional flow situation, this reduces to:

$$k_z \frac{\partial^2 h}{\partial z^2} = \frac{1}{(1+e)} \left[e \frac{\partial s}{\partial t} + S \frac{\partial e}{\partial t} \right]$$

During the process of consolidation, the degree of saturation is taken to remain constant at 100%, while void ratio changes causing reduction in volume and dissipation of excess hydrostatic pressure through expulsion of pore water, that is

$$S = 100\% \text{ or } 1, \text{ and } \frac{\partial S}{\partial t} = 0$$

$$\therefore k_z = \frac{\partial^2 h}{\partial z^2} = \frac{1}{(1+e)} \frac{\partial e}{\partial t} = -\frac{\partial}{\partial t} \left[\frac{e}{1+e} \right]$$

Negative sign infers decrease in the value of e with increase in the value of h . Since volume decrease can be due to a decrease in the void ratio only as the pore water and soil grains are virtually incompressible, $\frac{\partial}{\partial t} \left[\frac{e}{1+e} \right]$ represents time-rate of volume change per unit volume.

The flow is only due to the hydrostatic excess pressure,

$$h = \frac{u}{\gamma_w}, \text{ where } \gamma_w = \text{unit weight of water}$$

$$\therefore \frac{k}{\gamma_w} \frac{\partial^2 u}{\partial z^2} = -\frac{\partial V}{\partial t} \quad \dots(\text{ii})$$

Here k is the permeability of soil in the direction of flow, and ∂V represents the change in volume per unit volume of soil. The change in hydrostatic excess pressure, ∂u , changes the intergranular or effective stress by the same magnitude and the total stress remains constant.

The change in volume per unit volume, ∂V , may be written, as per the definition of the modulus of volume change, m_v as:

$$\partial V = m_v \partial \bar{\sigma} = -m_v \partial u,$$

Since an increase in the value of $\partial \bar{\sigma}$ represents a decrease in ∂u .

Differentiating both sides with respect to time,

$$\frac{\partial V}{\partial t} = -m_v \frac{\partial u}{\partial t} \quad \dots(\text{iii})$$

From eq. (ii) and eq. (iii) we have

$$\frac{\partial u}{\partial t} = \frac{k}{\gamma_w m_v} \frac{\partial^2 u}{\partial z^2}$$

This is written as:

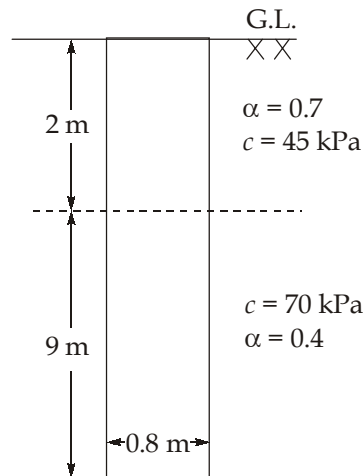
$$\frac{\partial u}{\partial t} = C_v \frac{\partial^2 u}{\partial z^2} \quad \dots(\text{iv})$$

where, $C_v = \frac{k}{\gamma_w m_v}$

where, C_v is known as the "Coefficient of consolidation". u represents the hydrostatic excess pressure at a depth z from the drainage face at time t from the start of the process of consolidation.

Q.7 (c) Solution:

Load carrying capacity of single pile



$$Q_{up} = 9cA_b + \alpha \bar{c}A_s$$

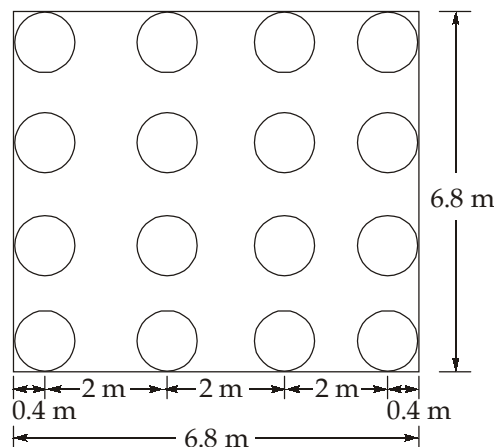
$$\Rightarrow Q_{up} = 9(70)\left(\frac{\pi}{4} \times 0.8^2\right) + 0.7(45)(\pi \times 0.8 \times 2) + (0.4 \times 70 \times \pi \times 0.8 \times 9)$$

$$\Rightarrow Q_{up} = 1108.35 \text{ kN}$$

Load carrying capacity of 16 piles,

$$= 16 \times 1108.35 = 17733.66 \text{ kN}$$

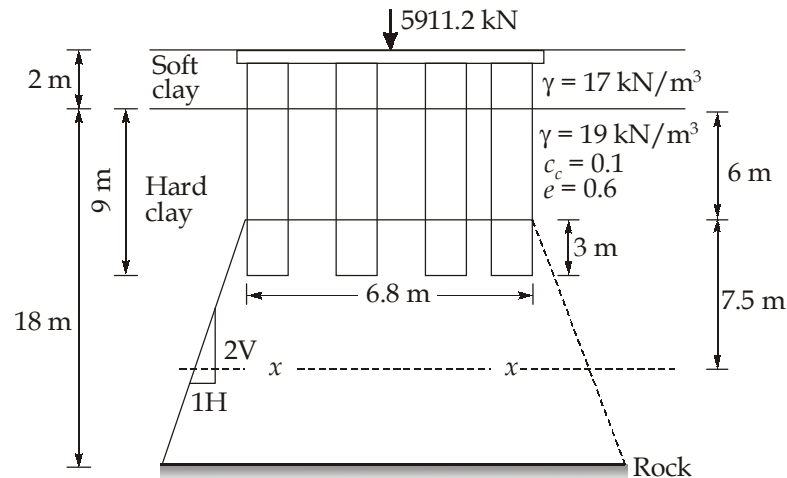
Load carrying capacity of pile group



$$\begin{aligned}
 Q_{ug} &= 9cA_b + \alpha \bar{c}A_s \quad \{\alpha = 1\} \\
 &= 9cB^2 + \alpha \bar{c}(4BL) \\
 &= 9(70)(6.8)^2 + 1(45)(4 \times 6.8) \times (2) + 1(70)(4 \times 6.8 \times 9) \\
 &= 48715.2 \text{ kN}
 \end{aligned}$$

$$\begin{aligned}
 Q_{\text{safe}} &= \min. \left\{ \begin{array}{l} \frac{n \times Q_{up}}{FOS} \\ \frac{Q_{ug}}{FOS} \end{array} \right. \\
 &= \min. \left\{ \begin{array}{l} \frac{16 \times 1108.35}{3} = 5911.2 \text{ kN} \\ \frac{48715.2}{3} = 16238.4 \text{ kN} \end{array} \right.
 \end{aligned}$$

∴ Allowable load on group of pile is 5911.2 kN



Equivalent raft will exist at $\frac{L_2}{3}$ i.e., 3 m from base of pile group.

Initial effective stress at $x-x = 17(2) + 19(6 + 7.5) = 290.5 \text{ kN/m}^2$

Width of pile group at $x-x = 6.8 + \frac{7.5}{2} + \frac{7.5}{2} = 14.3 \text{ m}$

∴ Increment in pressure = $\frac{\text{Load}}{\text{Area}} = \frac{5911.2}{14.3 \times 14.3} = 28.907 \text{ kN/m}^2$

∴
$$\Delta h = \frac{C_c H_0}{1 + e_0} \log \left(\frac{\sigma_0' + \Delta \sigma'}{\sigma_0'} \right)$$

$$\begin{aligned}
 &= \frac{0.1 \times (9+3)}{1+0.6} \log \left(\frac{290.5 + 28.907}{290.5} \right) \\
 &= 0.03089 \text{ m} = 3.089 \text{ cm}
 \end{aligned}$$

Q.8 (a) Solution:**(i) Size and number of filter beds:**

$$\begin{aligned}
 \text{Maximum water demand} &= 1.8 \times \text{Average daily water demand} \\
 &= 1.8 \times 175 \times 100,000 \\
 &= 31.5 \times 10^6 \text{ l/day} \\
 &= 31.5 \text{ MLD}
 \end{aligned}$$

Assume 4% of filtered water is required for backwashing every day.

$$\therefore \text{Total filtered water required} = \frac{31.5}{0.96} = 32.8125 \text{ MLD}$$

Assume it takes 30 minutes for backwash of filter.

$$\therefore \text{Filtered water required per day} = \frac{32.8125}{23.5} \times 24 = 33.51 \text{ MLD}$$

Given rate of filtration = 100 l/min/m²

$$\text{Area of filter required} = \frac{33.51 \times 10^6}{100 \times 60 \times 24} \text{ m}^2 = 232.71 \text{ m}^2$$

Number of filter beds as per Morell and Wallace,

$$N = 1.22\sqrt{Q}$$

$$\Rightarrow N = 1.22\sqrt{33.51}$$

$$\Rightarrow N = 7.06 \simeq 8 \text{ filters}$$

Thus provide 9 filters with 8 operational unit and 1 standby unit.

$$\text{Taking } \frac{L}{B} = 1.5$$

$$\text{Area of each unit, } L \times B = \frac{232.71}{8}$$

$$\Rightarrow 1.5 \times B \times B = \frac{232.71}{8}$$

$$\Rightarrow B = 4.4 \text{ m}$$

$$\therefore L = 1.58B = 6.6 \text{ m}$$

Hence, adopt 9 filter units each of plan dimension 4.4 × 6.6 m.

(ii) Design of manifold lateral drainage system:

Manifold lateral system is provided beneath the filter bed for receiving the filtered water and to allow backwashing for cleaning the filter. Let us assume area of perforations to be 0.2% of filter area

$$\therefore \text{Total area of perforations} = (4.4 \times 6.6) \times \frac{0.2}{100} = 0.05808 \text{ m}^2$$

Now assuming the area of each lateral = 4 × Area of perforations in it.

$$\therefore \text{Total area of laterals} = 4 \times 0.05808 = 0.2323 \text{ m}^2$$

Now assuming the area of manifold to be twice the area of laterals.

$$\text{Area of manifold} = 2 \times 0.2323 = 0.4646 \text{ m}^2$$

\therefore Diameter of manifold (d) is given by

$$\frac{\pi}{4} d^2 = 0.4646$$

$$\Rightarrow d = 0.7691 \text{ m} \simeq 77 \text{ cm}$$

Hence, use a 77 cm diameter manifold pipe laid lengthwise along the centre of the filter bottom.

Lateral running perpendicular to manifold (i.e., width wise) may be laid at a spacing of say 15 cm (max. 30 cm).

The number of laterals is then given as,

$$\text{No. of laterals on each side} = \frac{\text{Length of filter bed}}{\text{Spacing between laterals}}$$

$$\therefore \text{No. of laterals on each side} = \frac{6.6 \times 100}{15} = 44$$

Hence, use 88 laterals in all, in each filter unit.

The diameter of the laterals is adopted as 6 mm.

$$\begin{aligned} \text{Now, length of each lateral} &= \frac{\text{Width of filter}}{2} - \frac{\text{Diameter of manifold}}{2} \\ &= \frac{4.4}{2} - \frac{0.77}{2} = 1.815 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{Now, total area of perforations} &= \text{Area of each lateral} \\ &\quad \times \text{Total no. of perforations in 88 laterals (N)} \\ \Rightarrow 0.05808 &= \frac{\pi}{4} \times \left(\frac{6}{1000}\right)^2 \times \text{Total no. of perforation in 88 laterals (N)} \\ \Rightarrow N &= 2054.16 \simeq 2055 \text{ (say)} \\ \text{No. of perforations in each lateral} &= \frac{2055}{88} = 23.35 \simeq 24 \end{aligned}$$

$$\therefore \text{Area of perforation per lateral} = 24 \times \frac{\pi}{4} \times (0.6)^2 = 6.79 \text{ cm}^2$$

$$\begin{aligned} \text{Now, area of each lateral} &= 4 \times \text{Area of perforation in it} \\ &= 4 \times 6.73 = 27.16 \text{ cm}^2 \end{aligned}$$

$$\text{Dia. of each lateral} = \sqrt{\frac{27.16 \times 4}{\pi}} = 5.88 \text{ cm}$$

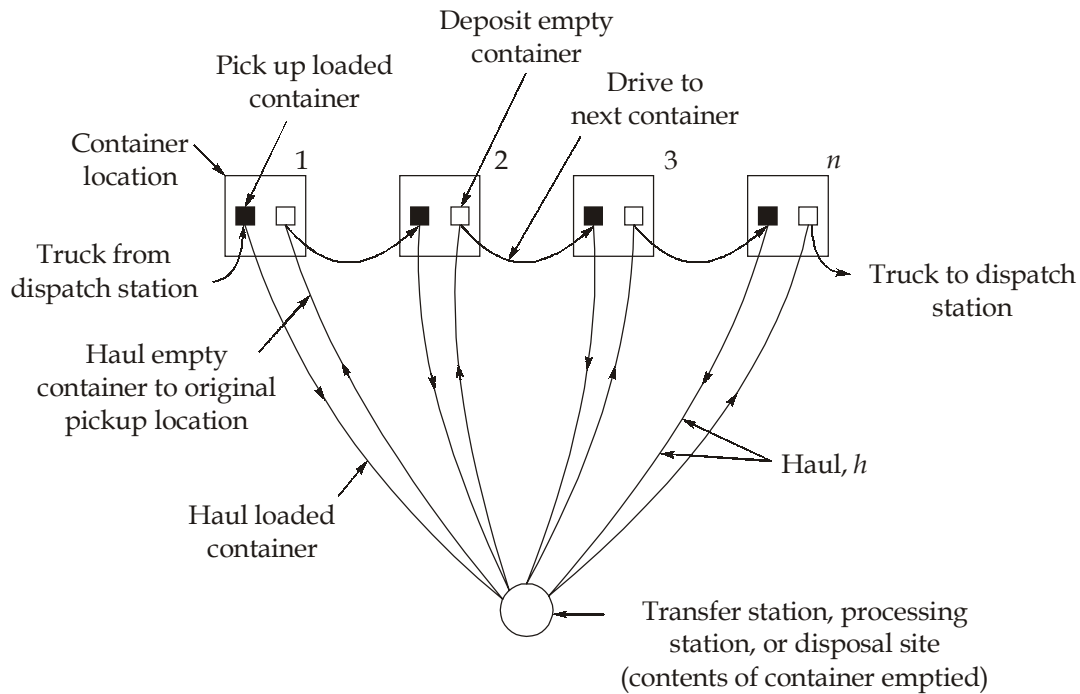
Hence, use 88 laterals each of 5.88 cm dia. @ 15 cm c/c spacing, each having 24 perforations of 6 mm size with 77 cm diameter manifold.

Check:

$$\frac{\text{Length of each lateral}}{\text{Dia. of each lateral}} = \frac{1.815 \times 100}{5.88} = 30.87 < 60 \quad \text{(Hence OK)}$$

Q.8 (b) Solution:

- (i) **Hauled Container System:** The truck (collection vehicle) spends a time t_1 in driving from the dispatch station to the first collection point, designated as a "container location." In the hauled-container system, the container is so large that it is not emptied at the collection point but is mounted into a collection vehicle and hauled to a transfer station, processing station, or disposal site, called collectively as destination point. Let the time taken to mount the container into the collection vehicle be ' m ', and let ' s ' be the time spent to unload the cargo of solid waste at the destination point. From the destination point, the vehicle then goes back to the container location and since the container is very large, it will also take time to unload this container. Let the time for this unloading be u . Also, let h be the haul time, which is the time it takes to drive from the collection point to the destination point and back. If more than one collection point or container location is serviced, then time will also be spent in driving from one collection point to another.



Let d_1 be the average between-collection-point driving time per collection point. The activities involved are mounting the container, driving to the destination point, unloading the cargo, driving back to the collection point, unloading the container and driving between collection points and all these constitute a trip. If t_{net} is the job time used per trip, then

$$t_{\text{net}} = m + u + d_1 + s + h$$

(ii) **Processing techniques are used in solid waste managements system to serve the following purposes:**

- (a) To improve the efficiency of solid-waste disposal systems
- (b) To recover resources (usable materials)
- (c) To prepare materials for the recovery of conversion product and energy.

Important processing techniques used routinely in municipal solid-waste system include compaction, thermal volume reduction (incineration) and manual separation of waste components.

1. Mechanical Volume Reduction: It is the most important factor in the development and operation of solid-waste management systems. Vehicles equipped with compaction mechanisms are used for the collection of most municipal solid wastes. Wastes are compacted to increase the useful life of landfills.

2. **Thermal Volume Reduction:** The volume of municipal wastes can be reduced by more than 90 percent by incineration. Incineration was quite common in the past, however, with more restrictive air pollution control requirements only a limited number of municipal incinerators are currently in operations.
 3. **Manual Component Separation:** The manual separation of solid waste components can be accomplished at the source where solid wastes are generated, at a transfer station, at a centralized processing station, or at the disposal site. Manual sorting at the source of generation is the most positive way to achieve the recovery and reuse of materials. The number and types of components salvaged or sorted (e.g., cardboard and high quality paper, metals and wood) depend on the location, the opportunities for recycling and the resale market.
- (iii) **Indore Method:** It uses manual turning of piled up mass (refuse + night soil) for its decomposition under aerobic conditions. In this method, layers of vegetable wastes and night soil are alternatively piled in depths of about 7.5 to 10 cm each, to a total depth of about 1.5 m in a trench or above the ground to form a mound called a windrow. The mixture is kept aerobic by turning regularly for 2 to 3 months. This compost mass is then left for another about 1 to $1\frac{1}{2}$ months without any turning after which, the compost becomes ready for use. The entire process thus takes about 4 months. This method is primarily aerobic in nature.

Bangalore Method: The Bangalore method of composting, involves anaerobic decomposition of wastes, and does not involve any turning or handling of the mass, and is, hence, cleaner than the Indore method. This method is, therefore, widely adopted by municipal authorities throughout India. The refuse and night soil, in this method, are therefore piled up in layers in an underground earthen trench of about (10 m x 1.5 m x 1.5 m).

This mass is covered at its top by layer of earth of about 15 cm depth, and is finally left over for decomposition. Within 2 to 3 days of burial, intensive biological action starts taking place and organic matter begins to disintegrate. Considerable heat gets evolved in this process which raises the temperature of the decomposing mass to about 75°C. This heat prevents the breeding of flies by destroying the larvae. After about 4 to 5 months (depending upon the season), the refuse gets fully stabilised and changes into a brown coloured odourless innocuous powdery mass, called as humus. This humus is removed from the trenches, sieved on 12.5 mm

sieves to remove stones, broken glass, brickbats, etc. and then sold out in the market as manure. The empty trenches can again be used for receiving further batches of refuse.

Q.8 (c) Solution:

(i) Given:

$$G = 2.6$$

$$n = 0.30$$

$$\therefore \text{Void ratio, } e = \frac{n}{1-n} = \frac{0.3}{1-0.3} = \frac{0.3}{0.7} = 0.429$$

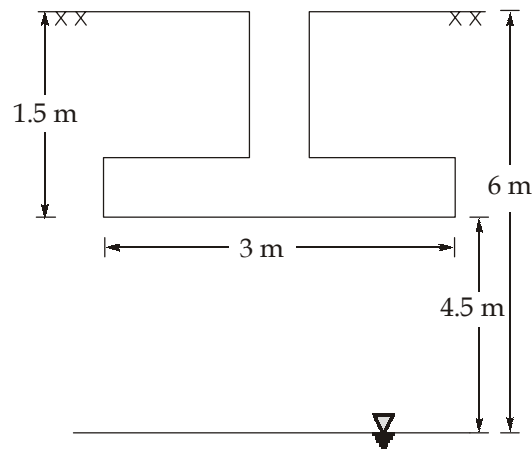
Since given soil is sand

$$\therefore \text{Cohesion, } c = 0$$

$$\therefore \gamma_d = \frac{G\gamma_w}{1+e} = \frac{2.6 \times 9.81}{1+0.429} = 17.85 \text{ kN/m}^3$$

$$\text{and } \gamma_{\text{sat}} = \frac{G+e}{1+e} \gamma_w = \frac{2.6+0.429}{1+0.429} \times 9.81 = 20.79 \simeq 20.80 \text{ kN/m}^3$$

1. When GWL is 6 m below ground level



In this situation, there is no effect of water.

$$q_u = cN_c S_c d_c i_c + \gamma D_f S_q i_q d_q N_q + \frac{1}{2} \gamma B N_\gamma i_\gamma d_\gamma S_\gamma \quad \dots(i)$$

$$\Rightarrow q_u = 17.85(1.5)(1.33)(1)(1.263)(18.4) + \frac{1}{2} (17.85)(3)(18.08)(1)(1)(0.733)$$

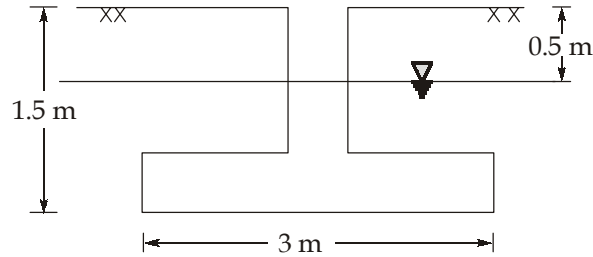
$$\Rightarrow q_u = 1182.4 \text{ kN/m}^2$$

$$\text{Now, } Q_{\text{safe}} = \left[\frac{q_u - \gamma D_f}{\text{FOS}} + \gamma D_f \right] (B \times L)$$

$$\Rightarrow Q_{\text{safe}} = \left[\frac{1182.4 - 17.85(1.5)}{3} + 17.85(1.5) \right] \times 3 \times 5$$

$$\Rightarrow Q_{\text{safe}} = 6179.75 \text{ kN}$$

2. When GWT is 0.5 m below ground level,



Water table correction will be applied in the second and the third terms in eq. (i)

$$q_u = \gamma_{\text{avg}} D_f N_q S_q i_q d_q R_q^* + \frac{1}{2} \gamma' B N_\gamma S_\gamma i_\gamma d_\gamma$$

$$\gamma_{\text{avg}} = \frac{17.85(0.5) + 20.80(1)}{0.5 + 1} = 19.82 \text{ kN/m}^3$$

$$\gamma' = \gamma_{\text{sat}} - \gamma_w = 20.80 - 9.81 = 10.99 \text{ kN/m}^3$$

$$R_q^* = \frac{1}{2} \left(1 + \frac{D_f}{B} \right) = \frac{1}{2} \left(1 + \frac{0.5}{3} \right) = 0.5833$$

$$\therefore q_u = 19.82(1.5)(18.4)(1.33)(1.263)(1)(0.5833) + \frac{1}{2} (10.99)(3)(18.08)(0.733)(1)(1)$$

$$\Rightarrow q_u = 754.463 \text{ kN/m}^2$$

Now,

$$Q_{\text{safe}} = \left[\frac{q_u - \gamma_{\text{avg}} D_f R_q^*}{\text{FOS}} + \gamma_{\text{avg}} D_f R_q^* \right] (B \times L)$$

$$\Rightarrow Q_{\text{safe}} = \left[\frac{754.463 - 19.82(1.5)(0.5833)}{3} + 19.82(1.5 \times 0.5833) \right] \times 3 \times 5$$

$$\Rightarrow Q_{\text{safe}} = 3945.73 \text{ kN}$$

(ii) Details of pit:

$$w = 0.20$$

$$e = 0.60, G = 2.7$$

$$\therefore \gamma = \frac{G\gamma_w}{1+e}(1+w)$$

$$\Rightarrow \gamma = \frac{2.79.81}{1+0.6}(1+0.2) = 19.87 \text{ kN/m}^3$$

$$\therefore \gamma_d = \frac{\gamma}{1+w} = \frac{19.87}{1+0.2} = 16.56 \text{ kN/m}^3$$

Details of fill in place:

$$V_{\text{soil}} = 20000 \text{ m}^3$$

$$\gamma_d = 19 \text{ kN/m}^3$$

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

$$\Rightarrow e = \frac{G\gamma_w}{\gamma_d} - 1$$

$$\Rightarrow e = \frac{2.7 \times 9.81}{19} - 1$$

$$\Rightarrow e = 0.394$$

$$\therefore (V_{\text{solid}})_{\text{pit}} = (V_{\text{solid}})_{\text{fill}}$$

$$\Rightarrow \left(\frac{V_{\text{soil}}}{1+e} \right)_{\text{pit}} = \left(\frac{V_{\text{soil}}}{1+e} \right)_{\text{fill}}$$

$$\Rightarrow \frac{(V_{\text{soil}})_{\text{pit}}}{1+0.6} = \frac{20000}{1+0.394}$$

$$\Rightarrow (V_{\text{soil}})_{\text{pit}} = 22955.52 \text{ m}^3 \text{ of soil has to be excavated.}$$

$$\therefore \text{Cost of excavation} = 10 \times 22955.52 = \text{Rs. } 2,29,555.2$$

Now,

$$\therefore \gamma_{\text{soil of pit}} = 19.87 \text{ kN/m}^3$$

Weight of soil to transported,

$$19.87 \times 22955.53 = 456126.38 \text{ kN}$$

No. of trucks required,

$$\frac{456126.38}{150} = 3040.84 \approx 3041$$

Now, transportation cost = Rs. 8/m³/km/Truck

$$= \frac{2 \times 22955.52 \times 80 \times 3041}{7.55}$$

$$= \text{Rs. } 1479369247$$

$$\therefore \text{Total cost} = 299555.2 + 1479369247$$

$$= \text{Rs. } 147,96,68,802$$

(iii) Given:

$$P = \text{Percentage finer than } 75 \mu = 60\%$$

$$w_L = 55\%$$

$$w_p = 40\%$$

$$\therefore I_p = w_L - w_p = 55 - 40 = 15\%$$

$$\therefore GI = 0.2a + 0.005ac + 0.01bd$$

$$a = P - 35 = 60 - 35 = 25 \not\geq 40$$

$$b = P - 15 = 60 - 15 = 45 \not\geq 40 \quad (\therefore b = 40)$$

$$c = 55 - 40 = 15 \not\geq 20$$

$$d = 15 - 10 = 5 \not\geq 20$$

$$\therefore GI = 0.2(25) + 0.005(25 \times 15) + 0.01(40 \times 5)$$

$$= 8.875$$

