Detailed Solutions

ESE-2021 Mains Test Series

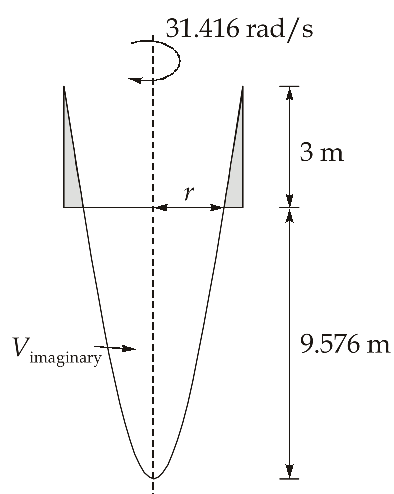
Civil Engineering Test No : 11

Q.1 (a) Solution:

(i) Angular rotation, $\omega = \dfrac{2\pi N}{60} = \dfrac{2\pi \times 300}{60} = 31.416 \text{ rad/s}$

Depth of cavity formed when cylinder is rotated about its axis

$$Z = \frac{R^2\omega^2}{2g} = \frac{(0.5)^2 \times (31.416)^2}{2 \times 9.81} = 12.576 \text{ m}$$



Let r be the radius upto which bottom will be exposed

$$Z = \frac{\omega^2 r^2}{2g}$$

$$\Rightarrow \quad 9.576 = \frac{(31.416)^2 \times r^2}{2g}$$

$$\Rightarrow \quad r = 0.436 \text{ m}$$

Initial volume, $V_i = \pi \times 0.5^2 \times 3 = 2.356 \text{ m}^3$

Final volume, $V_f = V_i - \left[V_{\text{cavity}} - V_{\text{imaginary}}\right]$

$$V_{\text{cavity}} = \frac{1}{2} \times \pi \times 0.5^2 \times 12.576 = 4.939 \text{ m}^3$$

$$V_{\text{imaginary}} = \frac{1}{2} \times \pi \times 0.436^2 \times 9.576 = 2.86 \text{ m}^3$$

$$\therefore \quad V_f = 2.356 - [4.939 - 2.86] = 0.277 \text{ m}^3$$

Spilled volume, $V_{\text{spilled}} = V_i - V_f = 2.356 - 0.277 = 2.079 \text{ m}^3$

(ii) For pure water and clean glass, angle of contact:

$$\theta = 0°$$

$\therefore$ Capillary rise, $h = \dfrac{4\sigma \cos\theta}{\gamma d}$

$$\Rightarrow \quad h = \frac{4\sigma}{\gamma d} = \frac{4 \times 0.075}{9810 \times 2.5 \times 10^{-3}}$$

$$= 0.01223 \text{ m} = 12.23 \text{ mm}$$

So, the correction of 12.23 mm should be applied to the manometric reading of tube.

Q.1 (b) Solution:

(i) Nitrogen can be present in water in the following four different forms:

(a) Ammonia nitrogen (free and saline ammonia)

(b) Albuminoid nitrogen

(c) Nitrite

(d) Nitrate

(a) Ammonia nitrogen: The occurrence of free ammonia indicates the direct inclusion of organic matter, particularly those arising from the excrement (urine) of animal and human species. Surface water may also get polluted from ammonia. Underground waters drawn from strata overlaid with clay may sometimes suffer deoxygenation and comparatively large quantities of free ammonia can arise from reduction of nitrate. Free ammonia is estimated in the laboratory by distillation of mildly alkalized water, the ammonia in the distillate being measured from the colour produced with Nessler's reagent.

(b) Albuminoid nitrogen: The albuminoid nitrogen is normally derived from the animal and plant life normal to the aquatic environment. Its determination gives an approximate indication of the quantity of proteinaceous nitrogen present in water. Its presence also infers the presence of organic pollution in a water supply. The quantities of albuminoid nitrogen is determined by adding alkaline solution of potassium permanganate or sulphuric acid to the water sample and then boiling the same when it liberates ammonia gas.

(c) Nitrite: Nitrite, a stage in the nitrogen cycle, occurs in water as an intermediate stage in oxidation or reduction process. Nitrate can arise either directly from biological disruption of organic matter via ammonium compounds or by the reduction of nitrate effected by biological environs favouring anaerobics . In raw surface supplies, the trace amounts of nitrite indicates presence of pollution. In order to determine it, the nitrite in the sample is mixed with sulphanilic acid, the diazo salt so formed couples with an amine to give a red colour which is matched against that produced with a series of standard nitrite solutions.

(d) Nitrate: Nitrate constitutes the final stage in the oxidation of nitrogen compounds, and normally reaches important concentrations in the final stages of biologic oxidation. The nitrate contained in pure well waters derived from an extensive catchment is largely the result of biological activity in the surface layers of the soil, enhanced by cultivation and the application of manures. When the nitrate is in excessive amounts, it contributes to the illness known as infant methemoglobinemia. Nitrate is measured either by reduction to ammonia or by matching the colours produced with phenoldislphonic acid.

(ii) Given: Surface overflow rate,

$$V_o = 4000 \text{ lit/hr/m}^2$$

$$= 4 \text{ m}^3\text{/hr/m}^2 = 4 \text{ m/hr}$$

$$= \frac{4}{3600} = 1.11 \times 10^{-3} \text{ m/s}$$

$$G_s = 2.65, \nu = 1.10 \times 10^{-6} \text{ m}^2\text{/s}$$

As per Stoke's law,

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

$\Rightarrow$ $$V_s = \frac{9.81}{18}(2.65 - 1) \times \frac{d^2}{1.10 \times 10^{-6}} = 817500 d^2 \text{ m/s}$$

Percentage of particles removed i.e., efficiency of sedimentation tank is given by,

$$\eta = \frac{V_s}{V_o} \times 100$$

(a) For d = 0.05 mm

$$V_s = 817500 \times (0.05 \times 10^{-3})^2 = 2.04375 \times 10^{-3} \text{ m/s}$$

$$\therefore \quad \eta = \frac{2.04375 \times 10^{-3}}{1.11 \times 10^{-3}} \times 100 = 184.12\% > 100\%$$

Hence, all the particles of diameter 0.05 mm will settle.

(b) For d = 0.02 mm

$$V_s = 817500 \times (0.02 \times 10^{-3})^2 = 3.27 \times 10^{-4} \text{ m/s}$$

$$\therefore \quad \eta = \frac{3.27 \times 10^{-4}}{1.11 \times 10^{-3}} \times 100 = 29.5\%$$

Q.1 (c) Solution:

$$L = 10 \text{ km} = 10{,}000 \text{ m}$$

$$h_1 = 104.771 \text{ m}; \quad h_2 = 104.5 \text{ m}$$

$$A_1 = 73.293 \text{ m}^2; \quad A_2 = 93.375 \text{ m}^2$$

$$R_1 = 2.733 \text{ m}; \quad R_2 = 3.089 \text{ m}$$

$$n = 0.02$$

$$K_e = 0.3 \text{ (expansion)}$$

$$= 0.1 \text{ (contraction)}$$

$$K_1 = \frac{1}{n} A_1 R_1^{2/3} \text{ and } K_2 = \frac{1}{n} A_2 R_2^{2/3}$$

$$\therefore \quad K_1 = \frac{1}{0.02} \times 73.293 \times (2.733)^{2/3} = 7163.505 \simeq 7164 \text{ m}^3/\text{s}$$

$$K_2 = \frac{1}{0.02} \times 93.375 \times (3.089)^{2/3} = 9902.52 \simeq 9903 \text{ m}^3/\text{s}$$

Average K for the reach, $K_{av} = \sqrt{K_1 K_2} = \sqrt{7164 \times 9903} = 8422.89 \text{ m}^3/\text{s}$

1st iteration: Assume $v_2 = v_1$ and neglect h_e; then

$$h_f = h_1 - h_2 = 104.771 - 104.5 = 0.271 \text{ m}$$

$$\bar{S}_f = \frac{h_f}{L} = \frac{0.271}{10{,}000}$$

$$Q = K_{av}\sqrt{\bar{S}_f} = 8422.89\sqrt{\frac{0.271}{10,000}} = 43.85 \text{ m}^3/\text{s}$$

Now,

$$v_1 = \frac{Q}{A_1} = \frac{43.85}{73.293} = 0.598 \text{ m/s}$$

$$\therefore \quad \frac{v_1^2}{2g} = \frac{(0.598)^2}{2g} = 0.018 \text{ m}$$

$$v_2 = \frac{Q}{A_2} = \frac{43.85}{93.375} = 0.47 \text{ m/s}$$

$$\therefore \quad \frac{v_2^2}{2g} = \frac{0.47^2}{2g} = \frac{(0.47)^2}{2\times 9.81} = 0.011 \text{ m}$$

$$h_e = K_e\left(\frac{v_1^2}{2g} - \frac{v_2^2}{2g}\right)$$

$(K_e = 0.3;$ stream is expanding from A to $B)$

$$= 0.3\,(0.018 - 0.011) = 0.0021$$

$$h_f = (h_1 - h_2) + \left(\frac{v_1^2}{2g} - \frac{v_2^2}{2g}\right) - h_e$$

$$= 0.271 + 0.007 - 0.0021 = 0.2759 \simeq 0.276$$

2nd iteration:

$$\bar{S}_f = \frac{h_f}{L} = \frac{0.276}{10,000}$$

$$\therefore \quad Q = 8422.89\sqrt{\frac{0.276}{10,000}} = 44.25 \text{ m}^3/\text{s}$$

So,

$$v_1 = \frac{Q}{A_1} = \frac{44.25}{73.293} = 0.6 \text{ m/s}$$

$$\therefore \quad \frac{v_1^2}{2g} = \frac{0.6^2}{2g} = 0.0183 \simeq 0.018\text{m}$$

$$v_2 = \frac{Q}{A_2} = \frac{44.25}{93.375} = 0.474 \simeq 0.47 \text{ m/s}$$

$$\therefore \quad \frac{v_2^2}{2g} = \frac{0.474^2}{2g} = 0.01145 \simeq 0.011 \text{ m}$$

Since there is no change in the newly computed values of $\frac{v_1^2}{2g}$ and $\frac{v_2^2}{2g}$, no further iterations are required and hence the computed discharge of **44.25 m³/s** can be considered as the final result.

Q.1 (d) Solution:

(i) **Duty:** It is the area which can be irrigated in hectares when one cumec of discharge is available throughout the base period of a crop.

For example if 2 cumecs of discharge is available throughout the base period of a crop and 2000 hectares can be irrigated by this discharge, then duty of water for the given crop is

$$D = \frac{2000}{2} = 1000 \text{ ha/cumecs}$$

Delta: It is the total depth of water required by a crop during its entire base period. For example if fodder requires 10 waterings in its base period and in every watering 10 cm depth of water is supplied, then total depth of water supplied is given by

Delta, $\Delta = 10 \times 10 = 100$ cm

Base Period: The time between the first watering of a crop at the time of its sowing to its last watering before harvesting is called the base period or the base of the crop.

Relation between duty, delta and base period of a crop:

Let 1 cumec of discharge is supplied for entire base period of B days, then total volume of water applied to this crop

$$= B \times 24 \times 60 \times 60 \times 1 = 86400\, B \text{ m}^3$$

If this volume is used to irrigate D hectares of land and Δ is the total depth due to 1 cumec supply, then

$$86400\, B = D \times 10^4 \times \Delta$$

$$\Rightarrow \quad D = \frac{8.64\, B}{\Delta}$$

where B is base period of crop in days, D is duty of crop in ha/cumec and Δ is delta of crop in m.

(ii) The monthly consumptive use or evapotranspiration (in cm) is calculated by Blaney-Criddle formule i.e.,

$$C_u = \frac{kp}{40} \times (1.8t + 32)$$

where k is consumptive use coefficient, p is monthly percent of sunshine hours and t is mean monthly temperature in °C.

If $\frac{p}{40}(1.8t+32) = f$

then $C_u = kf$

Seasonal consumptive use,

$$C_u = k\Sigma f$$

The calculations are tabulate below:

Month	***t***	***p***	***Re***	$f = \frac{p}{40}(1.8t+32)$
October	**25**	**7.4**	**4**	14.245
November	**18**	**7.1**	**4.5**	11.431
December	**14**	**7.9**	**3.5**	11.297
January	**12**	**7.3**	**3**	9.782
				$\Sigma f = 46.755$ cm

∴ Seasonal consumptive use or evapotranspiration,

$$C_u = k\,\Sigma f = 0.73 \times 46.755 = 34.131 \text{ cm}$$

Q.1 (e) Solution:

Given: Head, $H = 35$ m

Inlet diameter, $D_1 = 1$ m

Outlet diameter, $D_2 = 0.5$ m

Vane angle at entrance, $\theta = 90°$

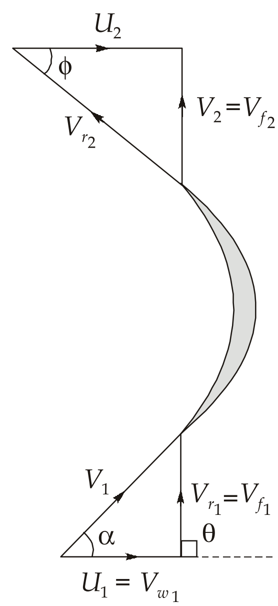
Guide blade angle, $\alpha = 20°$

Velocity of flow is constant, i.e., $V_{f_1} = V_{f_2}$

When, $\theta = 90°$, the peripheral velocity at inlet U_1 is equal to velocity of whirl at inlet V_{w_1}

No shock condition, i.e, velocity of whirl at outlet V_{w_2} is zero.

From inlet velocity triangle, we have



$$\tan\alpha = \frac{V_{f_1}}{V_{w_1}}$$

$$\Rightarrow \quad \tan 20° = \frac{V_{f_1}}{U_1}$$

$$\Rightarrow \quad V_{f_1} = U_1 \tan 20° \quad \text{...(i)}$$

We know that, head utilized by the turbine is given by

$$H_e = \frac{U_1 V_{w_1} - U_2 V_{w_2}}{g}$$

$$\Rightarrow \quad H_e = \frac{U_1 V_{w_1}}{g} \quad [\because V_{w_2} = 0] \text{ ...(ii)}$$

But,
$$H_e = H - \frac{(V_2)^2}{2g}$$

$\therefore$ From eq. (ii)

$$\frac{U_1 V_{w_1}}{g} = H - \frac{(V_2)^2}{2g}$$

$$\Rightarrow \quad \frac{(U_1)^2}{g} + \frac{(V_{f_1})^2}{2g} = H \quad \left[\because V_{w_1} = U_1 \text{ and } V_2 = V_{f_2} = V_{f_1}\right]$$

$$\Rightarrow \quad 2 \times (U_1)^2 + (U_1 \tan 20°)^2 = 2gH$$

$$\Rightarrow \quad (U_1)^2\left[2+(\tan 20°)^2\right] = 2gH$$

$$\Rightarrow \quad U_1^2 = \frac{2\times 9.81\times 35}{2+(\tan 20°)^2}$$

$$\Rightarrow \quad U_1 = 17.94 \text{ m/s}$$

But, $$U_1 = \frac{\pi D_1 N}{60}$$

$$\Rightarrow \quad 17.94 = \frac{\pi\times 1\times N}{60}$$

$$\Rightarrow \quad N = 342.63 \text{ rpm}$$

$$\Rightarrow \quad N = 5.711 \text{ rps}$$

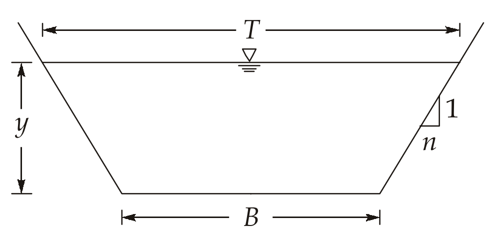
Q.2 (a) Solution:

(i) For most efficient trapezoidal channel:

(a) Hydraulic radius, $R = \dfrac{y}{2}$

(b) Area of channel section, $A = \dfrac{y^2}{n}$

(iii) Side slope of the channel section, $n = \dfrac{1}{\sqrt{3}}$



We know that, $$A = (B+ny)y$$

$$\Rightarrow \quad \frac{y^2}{n} = (B+ny)y$$

$$\Rightarrow \quad \sqrt{3}y = B+\frac{y}{\sqrt{3}}$$

$$\Rightarrow \quad B = \frac{2y}{\sqrt{3}}$$

$$\therefore \quad A = \left(\frac{2y}{\sqrt{3}}+\frac{y}{\sqrt{3}}\right)y = y^2\sqrt{3}$$

Now, by Manning's equation, we have

$$Q = \frac{1}{N} \times A \times (R)^{2/3} \times (S)^{1/2}$$

$$\Rightarrow \quad 80 = \frac{1}{0.012} \times y^2\sqrt{3} \times \left(\frac{y}{2}\right)^{2/3} \left(\frac{1}{4500}\right)^{1/2}$$

$$\Rightarrow \quad y = 4.615 \text{ m}$$

Hydraulic depth,

$$D = \frac{A}{T} = \frac{(B+ny)y}{B+2ny} = \frac{\sqrt{3} \times y^2}{4y/\sqrt{3}} = \frac{3y}{4}$$

$$\Rightarrow \quad D = \frac{3}{4} \times 4.615 = 3.46 \text{ m}$$

Velocity of flow,

$$V = \frac{Q}{A} = \frac{80}{(4.615)^2 \times \sqrt{3}} = 2.169 \text{ m/s}$$

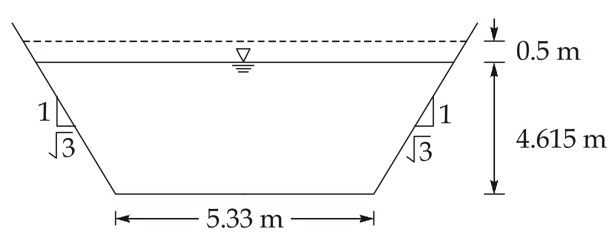
Froude number,

$$F_r = \frac{V}{\sqrt{gD}} = \frac{2.169}{\sqrt{9.81 \times 3.46}} = 0.372$$

$$\text{Free board} = \frac{10}{100} \times y = \frac{10}{100} \times 4.615 = 0.4615 \text{ m} \simeq 0.5 \text{ m}$$

$$B = \frac{2}{\sqrt{3}} y = \frac{2}{\sqrt{3}} \times 4.615 = 5.33\text{m}$$

Channel cross-section:



(ii) The discharge per meter width of the spillway is

$$q = \frac{2}{3} C_d \sqrt{2g} \times H_d^{3/2}$$

Now, $H_d = 3.5$ m, $C_d = 0.85$

$$q = \frac{2}{3} \times 0.85 \times \sqrt{2g} \times (3.5)^{3/2}$$

$$\therefore \quad q = 16.435 \text{ m}^3/\text{s/m}$$

Velocity at toe free before the jump,

$$V_1 = \sqrt{2g(H_{total})}$$

$$\text{Total head} = 60 + 3.5 = 63.5 \text{ m}$$

$$\therefore \quad \text{Velocity,} \quad V_1 = \sqrt{2 \times 9.81 \times 63.5} = 35.3 \text{ m/s}$$

$$q = 16.435 \text{ m}^3/\text{s/m}$$

$$\therefore \quad y_1 = \frac{q}{V_1} = \frac{16.435}{35.3} = 0.466 \text{ m}$$

$$\therefore \quad F_1 = \frac{V_1}{\sqrt{gy_1}} = \frac{35.3}{\sqrt{9.81 \times 0.466}} = 16.51$$

Now, as we know,

$$y_2 = \frac{y_1}{2}\left(\sqrt{1+8F_1^2} - 1\right)$$

$$\Rightarrow \quad y_2 = \frac{0.466}{2}\left[\sqrt{1+8 \times 16.51^2} - 1\right]$$

$$\Rightarrow \quad y_2 = 10.65 \text{ m}$$

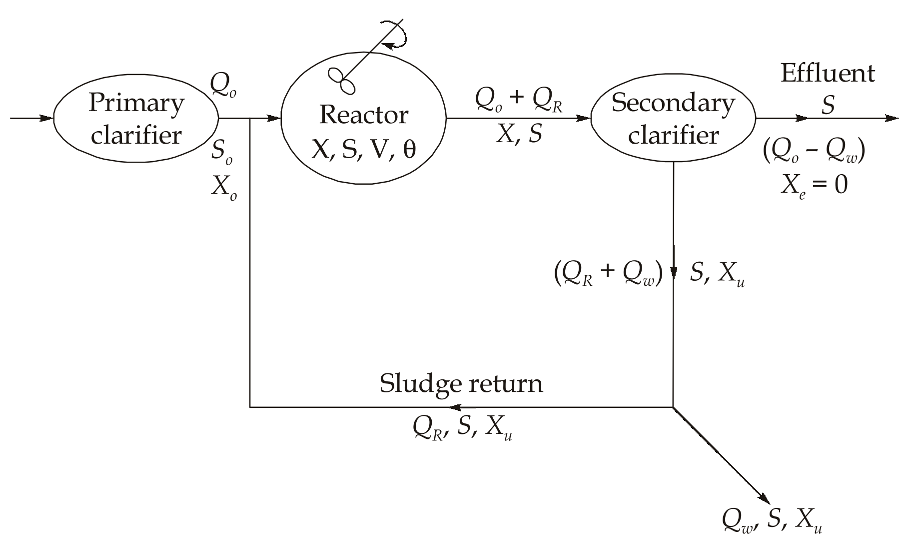
Energy loss,

$$E_L = \frac{(y_2 - y_1)^3}{4y_1y_2} = \frac{(10.65 - 0.466)^3}{4 \times 0.466 \times 10.65}$$

$$\Rightarrow \quad E_L = 53.21 \text{ m}$$

Q.2 (b) Solution:

A schematic flow diagram of a completely mixed biological reactor with provision of recycling of solids is shown in the figure.



$$Q_0 = 18300\text{ m}^3/d = 18.3\text{ MLD}$$
$$X_u = 12000\text{ mg}/l; \qquad S_0 = 160\text{ mg}/l$$
$$X = 3000\text{ mg}/l; \qquad S = 5\text{ mg}/l$$
$$k_d = 0.04\ d^{-1}$$
$$y = 0.5\text{ kg/kg}$$
$$\theta_c = \text{Sludge age/mean cell residence time} = 9\text{ days.}$$

(a) Since, $X_e \simeq 0$

$$\therefore \quad \frac{Q_o y(S_0 - S)}{VX} = \frac{1}{\theta_c} + k_d$$

$$\Rightarrow \quad \frac{18.3 \times 0.5 \times (160 - 5)}{V(\text{in m}^3) \times \dfrac{3000 \times 10^{-6}}{10^{-3}}} = \frac{1}{9} + 0.04 \qquad \because \text{MLD} \times \text{mg}/l = \text{kg/day}]$$

$$\Rightarrow \quad V = 3128.5\text{ m}^3$$

(b) Sludge age,
$$\theta_c = \frac{\text{Total biomass present}}{\text{Rate of wastage of biomass}}$$

$$\Rightarrow \quad \theta_c = \frac{VX}{(Q_o - Q_w)X_e + Q_w \times X_u}$$

$$\Rightarrow \quad \theta_c = \frac{VX}{Q_w \times X_u} \qquad (\because X_e = 0)$$

$$\Rightarrow \quad Q_w X_u = \frac{VX}{\theta_c} = \frac{3128.5 \times 3000 \times 10^{-6}}{10^{-3} \times 9}$$

$$= 1042.83\text{ kg/day}$$

$\therefore$ Mass of solids that must be wasted per day = 1042.83 kg

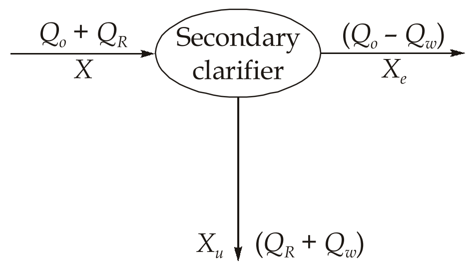
Also, underflow concentration,

$$X_u = 12000\text{ mg}/l$$

$$\therefore \quad Q_w = \frac{1042.83}{\left(\dfrac{12000 \times 10^{-6}}{10^{-3}}\right)} = 86.9\text{m}^3/\text{day}$$

$\therefore$ Volume of solids that must be wasted per day = 86.9 m^3.

(c) Consider secondary clarifier,



Apply mass balance around the secondary clarifier.

$$(Q_O + Q_R) \times X = (Q_O - Q_w)X_e + (Q_R + Q_w)X_u$$

$$\Rightarrow \quad (Q_R + Q_O) \times X = (Q_R + Q_w)X_u \qquad (X_e = 0)$$

$$\Rightarrow \quad Q_R(X_u - X) = Q_O X - Q_w X_u$$

$$\Rightarrow \quad Q_R = \frac{Q_O X - Q_w X_u}{X_u - X} = \frac{18300 \times 3000 - 86.9 \times 12000}{12000 - 3000}$$

$$= 5984.13 \text{ m}^3/\text{day}$$

∴ Recirculation ratio,

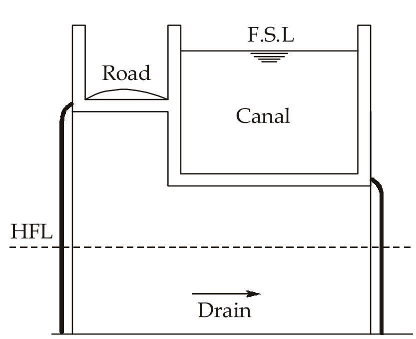
$$\frac{Q_R}{Q_O} = \frac{5984.13}{18300} = 0.33$$

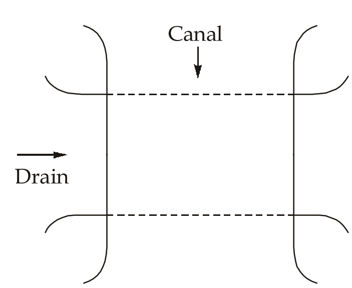
Q.2 (c) Solution:

(i) Different types of cross drainage works when a canal crosses a natural drain:

(a) Aqueduct and Syphon Aqueduct:

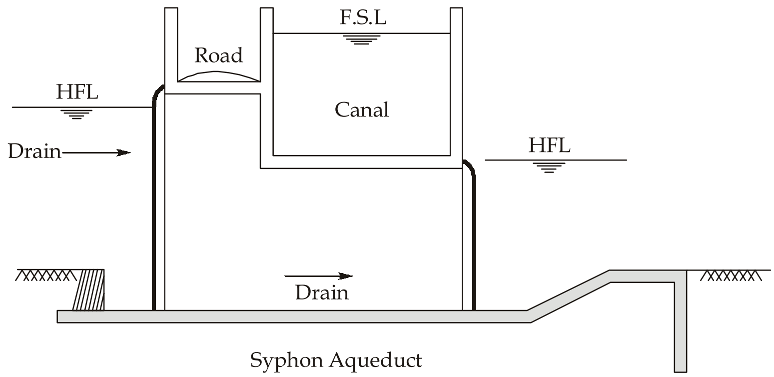
- In these works, the canal is taken over the natural drain, such that the drainage water runs below the canal either freely or under syphoning pressure.
- When the HFL of the drain is sufficiently below the bottom of the canal, so that the drainage water flows freely under gravity, the structure is known as an aqueduct.





Plan of crossing

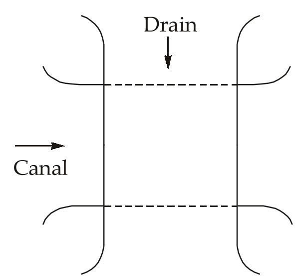
- If the HFL of the drain is higher than the canal bed level and the water passes through the aqueduct barrels under syphonic action, then the structure is known as syphon aqueduct.



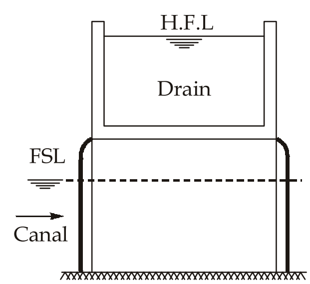
Syphon Aqueduct

(b) Super Passage and Syphon:

- In these works, the drain is taken over the canal such that the canal water runs below the drain either freely or under syphoning pressure.
- When FSL of the canal is sufficiently below the bottom of the drain trough, so that the canal water flows freely under gravity, the structure is known as super passage.

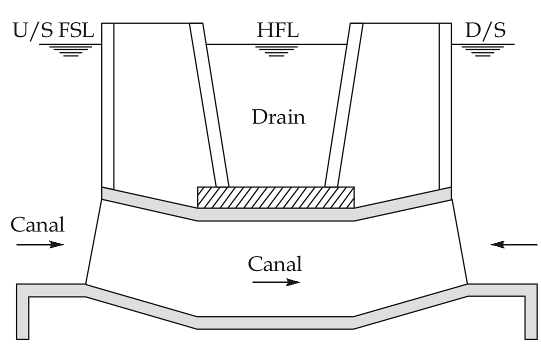


Crossing (Plan)



Super Passage

- If the FSL of the canal is sufficiently above the bed level of the drainage trough, so that the canal flows under syphonic action under the trough, the structure is known as a canal syphon or a syphon.



Syphon

(c) Level Crossing:

- In this type of cross-drainage work, the canal water and drain water are allowed to intermingle with each other.
- A level crossing is provided generally when a large canal and a high drainage approach each other practically at the same level.

(d) Inlets and Outlets:

- An inlet is a structure constructed in order to allow the drainage water to enter the canal and get mixed with the canal water and thus to help in augmenting the canal supplies.
- Such a structure is generally adopted when the drainage discharge is small and the drain crosses the canal with its bed level equal to or at slightly higher level than the canal FSL.
- When the drainage discharge is high or if the canal is small, so that the canal cannot take the entire drainage water, an outlet may sometimes be constructed to escape out the additional discharge at a suitable site, a little downstream along the canal.

(ii) Design procedure for Lacey's theory is as follows:

(a) Velocity, $$V = \left(\frac{Qf^2}{140}\right)^{1/6}$$

where Q = Discharge in cumecs

$$f = \text{Silt factor} = 1.76\sqrt{d\,(\text{mm})}$$

$$\Rightarrow \quad f = 1.76\sqrt{0.7} = 1.473$$

$$\therefore \quad V = \left[\frac{15 \times (1.473)^2}{140}\right]^{1/6} = 0.784 \text{ m/s}$$

(b) Hydraulic mean depth, $$R = \frac{5}{2}\frac{V^2}{f} = \frac{5}{2} \times \frac{(0.784)^2}{1.473} = 1.043 \text{ m}$$

(c) Area of channel section,

$$A = \frac{Q}{V} = \frac{15}{0.784} = 19.133 \text{ m}^2$$

(d) Wetted perimeter,

$$P = 4.75\sqrt{Q} = 4.75\sqrt{15} = 18.4 \text{ m}$$

Assume a trapezoidal channel with side slope $\frac{1}{2}H:1V$

Now, for a trapezoidal channel with side slope of $\frac{1}{2}H:1V$

$$P = B+2y\sqrt{N^2+1}$$

and $$A = (B+Ny)y$$

$\therefore$ $$A = (B+0.5y)y = 19.133 \quad ...(i)$$

and $$P = B+2y\sqrt{(0.5)^2+1} = 18.4 \quad ...(ii)$$

Eq. (i) can be written as,

$$By+0.5y^2 = 19.133 \quad ...(iii)$$

Eq. (ii) can be written as,

$$B = 18.4 - 2.236y \quad ...(iv)$$

Substituting the value of B in eq. (iii), we get

$$\Rightarrow \quad (18.4-2.236y)y+0.5y^2 = 19.133$$

$$\Rightarrow \quad -1.736y^2+18.4y-19.133 = 0$$

$$\Rightarrow \quad 1.736y^2 - 18.4y + 19.133 = 0$$

Solving above quadratic eq., we get two values of y i.e.,

$y_1 = 9.43$ m; corresponding width, $B_1 = -2.68$ m [using eq. (iv)]

$y_2 = 1.17$ m; corresponding width, $B_2 = 15.8$ m [using eq. (iv)]

So take, depth $y = 1.17$ m and width $B = 15.8$ m

(e) Bed slope, $$S = \frac{f^{5/3}}{3340Q^{1/6}} = \frac{(1.473)^{5/3}}{3340\times(15)^{1/6}}$$

$$\Rightarrow \quad S = \frac{1}{2750.576} \simeq \frac{1}{2751}$$

Q.3 (a) Solution:

(i) In case of hydraulic jump over a spillway, gravity forces are predominant, hence Froude model law is applied.

(a) For geometric similarity, $L_r = d_r$

$$\Rightarrow \qquad \frac{L_m}{L_p} = \frac{d_m}{d_p}$$

$$\Rightarrow \qquad \frac{1}{25} = \frac{115}{d_P}$$

$$\Rightarrow \qquad d_P = 2875 \text{ mm} = 2.875 \text{ m}$$

Thus a hydraulic jump of 2.875 m will be formed in the prototype.

(b) For kinematic similarity velocity scale ratio is given by

$$V_r = \frac{L_r}{T_r}$$

But according to Froude model law

$$V_r = \sqrt{L_r}$$

$$\therefore \qquad \sqrt{L_r} = \frac{L_r}{T_r}$$

$$\Rightarrow \qquad T_r = \sqrt{L_r}$$

$$\Rightarrow \qquad \frac{T_m}{T_P} = \sqrt{\frac{L_m}{L_P}}$$

$$\Rightarrow \qquad \frac{90}{T_P} = \sqrt{\frac{1}{25}}$$

$$\Rightarrow \qquad T_P = 450 \text{ seconds}$$

$\therefore$ Time in the prototype to produce the same surge is 450 seconds.

(c) We know that, $Q = AV$

$$Q_r = A_r \times V_r$$

$$\therefore \qquad Q_r = (L_r)^2 \times V_r$$

But according to Froude model law

$$V_r = \sqrt{gL_r}$$

$$\therefore \qquad V_r = \sqrt{L_r}$$

($\because$ g is constant in model and prototype)

$$\therefore \qquad Q_r = (L_r)^{5/2}$$

$$\Rightarrow \quad \frac{Q_m}{Q_P} = \left(\frac{L_m}{L_P}\right)^{5/2}$$

$$\Rightarrow \quad \frac{Q_m}{1200} = \left(\frac{1}{25}\right)^{5/2}$$

$$\Rightarrow \quad Q_m = 0.384 \text{ m}^3/\text{s}$$

(ii) Length of plate, $L = 0.9$

Width of plate, $B = 0.3$ m

Free stream velocity, $U_\infty = 9$ m/s

Kinematic viscosity of oil, $\nu = 1.2 \times 10^{-4}$ m²/s

We know that, Reynold's number at the trailing edge is given by

$$\text{Re}_L = \frac{U_\infty L}{\nu} = \frac{9 \times 0.9}{1.2 \times 10^{-4}} = 67500 < 5 \times 10^5$$

Hence the boundary layer is laminar over the entire length of plate.

Average drag coefficient,

$$C_D = \frac{1.328}{\sqrt{\text{Re}_L}} = \frac{1.328}{\sqrt{67500}} = 5.11 \times 10^{-3}$$

Friction drag on both sides of the plate,

$$F_D = 2 \times \left[\frac{1}{2} \times C_D \times \rho \times A \times U_\infty^2\right]$$

$$\Rightarrow \quad F_D = 5.11 \times 10^{-3} \times 910 \times 0.3 \times 0.9 \times 9^2 = 101.7 \text{ N}$$

Thickness of boundary layer at the trailing edge is given by,

$$\delta_L = \frac{5 \times L}{\sqrt{\text{Re}_L}} = \frac{5 \times 0.9}{\sqrt{67500}} = 0.01732 \text{ m} = 17.32 \text{ mm}$$

Shear stress at the trailing edge is given by,

$$\frac{2 \times \tau_0}{\rho U_\infty^2} = \frac{0.664}{\sqrt{\text{Re}_L}}$$

$$\Rightarrow \quad \frac{2 \times \tau_0}{910 \times 9^2} = \frac{0.664}{\sqrt{67500}}$$

$$\Rightarrow \quad \tau_0 = 94.19 \text{ N/m}^2 \simeq 94.2 \text{ N/m}^2$$

Q.3 (b) Solution:

Given: Population to be served = 8000; Sewage flow = 160 lpcd, Influent BOD = 300 mg/l; Effluent BOD = 30 mg/l, Location = 24° latitude; Elevation: 900 m above MSL

Total BOD load,

$$\text{Total sewage produced} = 8000 \times 160 = 1280000\ l/\text{day} = 1.28\ \text{MLD}$$

$$\text{BOD applied} = 1.28 \times 300 = 384\ \text{kg/day}$$

$$\text{Organic loading rate} = 225\ \text{kg/ha/day}$$

$$\text{Correction factor for elevation} = 1 + 0.003 \times \frac{900}{100} = 1.027$$

Corrected factor for sky clearance = 0.95

$$\therefore \quad \text{Corrected organic loading rate} = \frac{225 \times 0.95}{1.027} = 208.13$$

$$\simeq 210\ \text{kg/ha/day} \qquad \text{(Say)}$$

$$\therefore \quad \text{Pond area required,} \quad A = \frac{\text{Total BOD applied}}{\text{Organic loading rate}} = \frac{384}{210} = 1.83\ \text{ha}$$

$$\text{Detention period:} \quad D_t = \frac{1}{k_D} \times \log_{10}\left(\frac{l_o}{l_o - y}\right)$$

$$l_o = \text{Influent BOD} = 300\ \text{mg}/l$$

$$(l_o - y) = \text{Effluent BOD} = 30\ \text{mg}/l$$

$$\text{Also, at } 10°\text{C} \quad k_D = (k_D)_{20°C} \times (1.047)^{T-20}$$

$$= 0.1(1.047)^{10-20} = 0.0632 d^{-1}$$

$$\therefore \quad D_t = \frac{1}{0.0632} \times \log_{10}\left(\frac{300}{30}\right) = 15.82 \simeq 16\ \text{days}$$

$$\therefore \quad \text{Total inflow volume} = 1.28 \times 10^3 \times 16 = 20480\ \text{m}^3$$

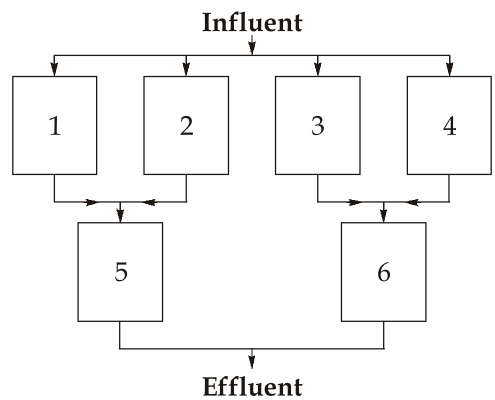
$$\text{Depth of pond} = \frac{20480}{1.83 \times 10^4} \simeq 1.12\ \text{m}$$

Provide a depth of 1.2 m, with a free board of 0.6 m.

$$\text{Total depth of pond} = 1.2 + 0.6 = 1.8\ \text{m}$$

Let us adopt a parallel series system of 6 ponds with 4 primary ponds and 2 secondary ponds of equal area; with 2 primary bonds feeding a secondary pond in each set as shown in figure.

$$\text{Area of each pond} = \frac{1.83}{6} = 0.305\ \text{ha} = 3050\ \text{m}^2$$



Assume, $\frac{L}{B} = 2.5$

$\therefore$ $A = 2.5B^2 = 3050$

$\Rightarrow$ $B = \sqrt{\frac{3050}{2.5}} = 34.93 \text{ m} \simeq 35 \text{ m}$

$\therefore$ $L = 35 \times 2.5 = 87.5 \text{ m}$

$\therefore$ Dimensions of pond = 87.5 m × 35 m × 1.8 m

Q.3 (c) Solution:

We will first of all calculate the frequencies of the various storms by using the equation $N = T \times m$ as shown in table below, using total number of years $N = 11$ and $T = \frac{11}{m}$.

S. No. (1)	5 minutes ppt (2)	10 minutes ppt (3)	15 minutes ppt (4)	30 minutes ppt (5)	60 minutes ppt (6)	90 minutes ppt (7)	120 minutes ppt (8)	m = ranking of storm (9)	T = frequency $= \frac{N}{m} = \frac{11}{\text{Col.(9)}}$ (10)
1.	0.85	1.20	1.40	1.74	2.15	2.46	2.97	1	11
2.	0.76	1.04	1.18	1.55	1.92	2.38	2.63	2	5.5
3.	0.73	0.93	1.11	1.36	1.70	2.14	2.34	3	3.7
4.	0.72	0.88	1.03	1.22	1.45	1.81	2.12	4	2.8
5.	0.66	0.84	0.97	1.18	1.40	1.65	1.83	5	2.2
6.	0.62	0.80	0.92	1.10	1.33	1.50	1.64	6	1.8
7.	0.51	0.78	0.90	1.05	1.25	1.40	1.55	7	1.6
8.	0.45	0.68	0.82	1.01	1.20	1.36	1.51	8	1.4
9.	0.36	0.52	0.67	0.95	1.14	1.34	1.46	9	1.2
10.	0.28	0.51	0.62	0.83	1.11	1.27	1.41	10	1.1
11.	0.21	0.39	0.50	0.79	1.09	1.23	1.34	11	1.0

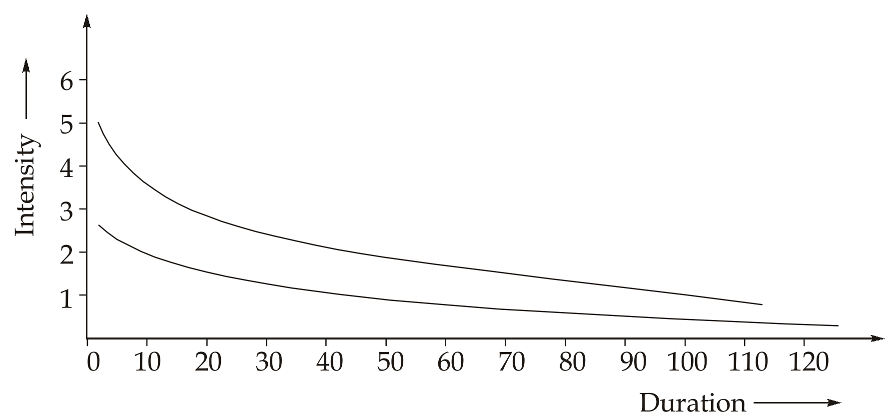
Average intensities for different durations such as 5, 10, 15, 30, 60, 90 and 120 minutes are then worked out for two frequencies of 1.4 years and 1 year, as desired in the question and shown below:

(a) Frequency = 1.4 years

Duration (min.)	5	10	15	30	60	90	120
Ppt. from table	0.45	0.68	0.82	1.01	1.2	1.36	1.51
Avg. intensity (cm/hr)	$0.45 \times \frac{60}{5} = 5.40$	4.08	3.28	2.02	1.2	0.9	0.76

(b) Frequency = 1 year

Duration (min.)	5	10	15	30	60	90	120
Ppt. from table	0.21	0.39	0.5	0.79	1.09	1.23	1.34
Avg. intensity (cm/hr)	2.52	2.34	2	1.58	1.09	0.82	0.67



Q.4 (a) Solution:

By geometry, the length of gate is $\left(\sqrt{1.8^2 + 2.4^2}\right)$m = 3 m from A to B, and its centroid is halfway between i.e., or at an elevation of 0.9 m above point B. The depth h_{CG} is thus,

$$h_{CG} = 4.5 - 0.9 = 3.6 \text{ m}$$

Gate area = 1.5 × 3 = 4.5 m^2

Hydrostatic force on the gate is

$$F = \rho g h_{CG} A = \gamma \times h_{CG} \times A$$

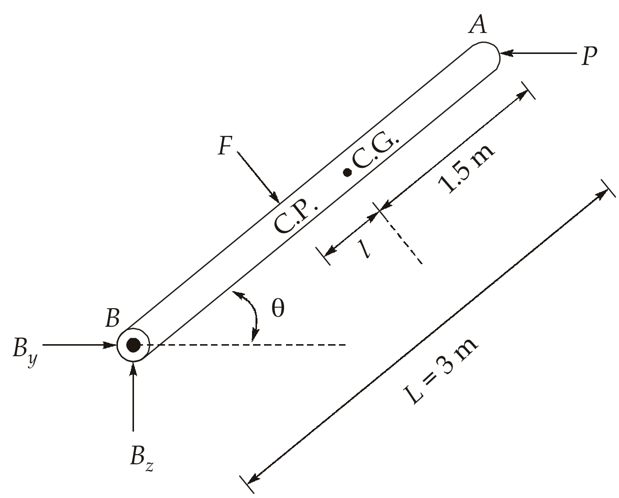
$$= \frac{10^4 \times 3.6 \times 4.5}{10^3} = 162 \text{ kN}$$

For rectangular gate, the centre of pressure, $\bar{h}_{CP}$ is

$$\bar{h}_{CP} = h_{CG} + \frac{I_{xx}\sin^2\theta}{Ah_{CG}} \qquad \left[\tan\theta = \frac{1.8}{2.4}, \sin\theta = \frac{1.8}{3}\right]$$

$$\Rightarrow \quad \bar{h}_{CP} = 3.6 + \frac{1.5\times 3^3 \times \left(\frac{1.8}{3}\right)^2}{12\times 1.5\times 3\times 3.6} = 3.675 \text{ m}$$

Distance l from CG to the CP is given by



$$l = \frac{\bar{h}_{CP} - h_{CG}}{\sin\theta} = \frac{3.675 - 3.6}{\left(\frac{1.8}{3}\right)} = 0.125 \text{ m}$$

Distance of point B free line of action of force F is thus,

$$= 3 - (1.5 + l)$$

$$= 3 - (1.5 + 0.125) = 1.375 \text{ m}$$

$$\Sigma M_B = 0$$

$$\Rightarrow \quad PL\sin\theta - F \times 1.375 = 0$$

$$\Rightarrow \quad P = \frac{162\times 1.375}{3\times \frac{1.8}{3}} = 123.75 \text{ kN}$$

Now, with F and P known, the reactions B_y and B_z are determined as

$$\Sigma F_y = 0$$

$$\Rightarrow \quad B_y + F\sin\theta - P = 0$$

$$\Rightarrow \quad B_y = 123.75 - 162\times\frac{1.8}{3} = 26.55 \text{ kN}$$

Also, $\Sigma F_z = 0$

$$\Rightarrow \quad B_z - F\cos\theta = 0 \qquad \left\{\cos\theta = \frac{2.4}{3}\right\}$$

$$\Rightarrow \quad B_z = 162\times\frac{2.4}{3} = 129.6 \text{ kN}$$

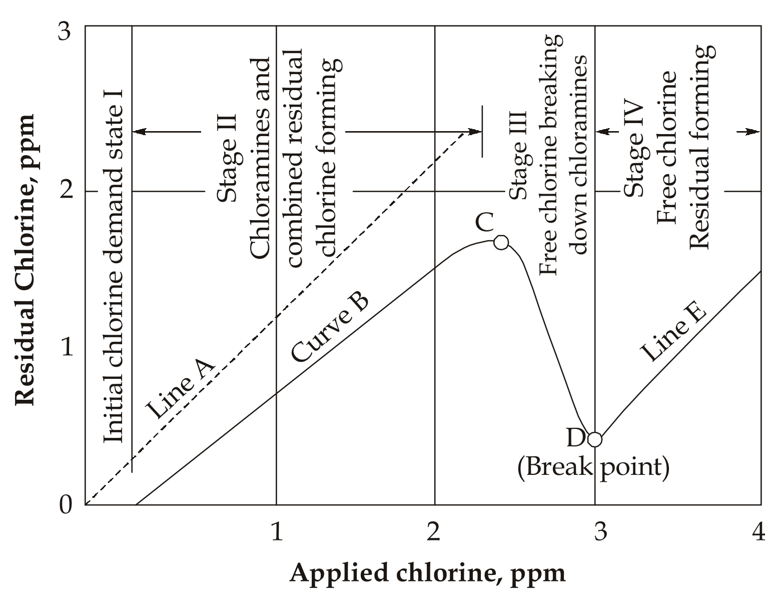
Q.4 (b) Solution:

(i) **Break point chlorination:** When chlorine is applied to water, two actions take place one after the other:

(i) It kills bacteria and disinfection is effected, and

(ii) It oxidizes the organic matter

When chlorine is added to pure water which has no chlorine demand, a curve, such as line *A* shown in figure is obtained between the applied chlorine and residual chlorine relationship. Generally, however, water has a chlorine demand, with the result that curve *B* as shown in figure is obtained between residual chlorine and applied chlorine. The chlorine first performs the function of removing bacteria. During the disinfection process, the amount of residual chlorine will be less in the beginning (marked by stage I in figure), during which various chemicals such as ions of ferrous iron, sulphides or nitrites present in water, will be oxidized, while during stage II, the combined residual chlorine will gradually increase as the demand for disinfection is satisfied, till a point C is reached where the amount of combined residual chlorine will be maximum.



This stage of point *C* is sometimes accompanied by bad taste and odour. Stage II reflects the forming of combined residuals as the ammonia or amines react with HOCl that has formed. Further increase in the applied chlorine will result in decrease in the residual chlorine, indicating the beginning of the second action, i.e., oxidation of organic matter present in water. During this action, the relation between applied-residual chlorine is represented by curve *CD*, wherein free chlorine breaks down, chloramines changing them to nitrogen compounds while the chlorine residual actually drops. At point *D*, the bad smell and taste suddenly disappear and the oxidation of organic matter is also complete.

The residual chlorine has its minimum value. Further addition of applied chlorine results in increase in the residual chlorine as represented by line *E* the slope of which will be 45°. Point *D* on the curve represents break point since further addition of chlorine in water appears as residual chlorine. Actually, upto point *C* on curve *B*, chloramines have been recorded as residual chlorine while at point *D* (break point), true residual free chlorine is revealed.

The break point in the chlorination of water may be defined as the point on applied-residual curve at which all, or nearly all, the residual chlorine is free chlorine. Free chlorine residual is that part of the total residual remaining in water (after a specified contact period) that will react chemically or biologically as hypochlorous acid or hypochlorite ion.

Break point chlorination (or free residual chlorination) has practical significance since application of chlorine at or slightly higher than the break point concentration will have the following advantages:

- It will remove taste and odour.
- It will have adequate chlorine residual.
- It will leave a desired chlorine residual.
- It will complete the oxidation of ammonia and other compounds.
- It will remove colour due to organic matter.

The break-point stage should be determined by laboratory tests; it is represented by instantaneous yellow colour if the orthotolidine test is applied. In some cases, a distinguishable break point is not obtained, while in other cases, changes in the quality of raw water may effect rapid changes in break point. A recognizable break point may be induced by addition of ammonia to water. Generally, the break point lies between 3 to 7 ppm of chlorine dose, though this is greatly influenced by the quantity of free ammonia present in water.

(ii) (a) Given: Particle size, d = 0.45 mm, Specific gravity (G_s) = 2.65

Before backwashing:

Porosity, (n) = 0.42, Depth of bed (D) = 0.67 m

After backwashing:

Depth of expanded bed (D') = 1.5 × 0.67 m

$$\rho_w = 998.2 \text{ kg/m}^3$$

$$\mu = 1.002 \times 10^{-3} \text{ kg/m-s}$$

$\therefore$ Kinematic viscosity, $\nu = \frac{\mu}{\rho} = \frac{1.002 \times 10^{-3}}{998.2} = 1.004 \times 10^{-6} \text{ m}^2/s$

Also, loss of head through the bed before and after backwashing is same,

$$\Rightarrow \quad D'(G_s - 1)(1 - n') = D(G_s - 1)(1 - n)$$

$$\Rightarrow \quad 1.5 \times 0.67(1 - n') = 0.67 \times (1 - 0.42)$$

$$\Rightarrow \quad 1.5(1 - n') = 0.58$$

$$\Rightarrow \quad n' = 1 - \frac{0.58}{1.5} = 0.613$$

Now, $n' = \left(\frac{V_b}{V_s}\right)^{0.22}$

where V_s = Settling velocity

$$= \sqrt{\frac{4}{3} \times \frac{g(G_s - 1)d}{C_D}} = \sqrt{\frac{4}{3} \times \frac{9.81(2.65 - 1) \times 0.45 \times 10^{-3}}{\frac{18.5}{\left(\frac{V_s(0.45 \times 10^{-3})}{1.004 \times 10^{-6}}\right)^{0.6}}}}$$

After solving, V_s = 0.0622 m/s = 6.22 cm/s

$$\therefore \quad n' = 0.613 = \left(\frac{V_b}{6.22}\right)^{0.22}$$

$$\Rightarrow \quad V_b = (0.613)^{1/0.22} \times 6.22$$

$$= 0.673 \text{ cm/s}$$

(b) Head loss, $h_L = D(G_s - 1) \times (1 - n)$

$$= 0.67(2.65 - 1)(1 - 0.42)$$

$$= 0.64 \text{ m} = 64 \text{ cm}$$

Q.4 (c) Solution:

(i)

Component (1)	% by mass (2)	Moisture content(%) (3)	Dry content (%) (4)	Energy as discarded content (kJ/kg) (5)	Total dry mass (kg) (6) = $\frac{\text{Col. (2)} \times \text{Col. (4)}}{100}$	Total energy as discarded (kJ) (7) = Col. (2) × Col. (5)
Food waste	15	70	30	4650	4.5	69750
Paper	45	6	94	16750	42.3	753750
Cardboard	10	5	95	16300	9.5	163000
Plastics	10	2	98	32600	9.8	326000
Garden trimmings	10	60	40	6500	4	65000
Wood	5	20	80	18600	4	93000
Tin cans	5	3	97	700	4.85	3500
					Σ = 78.95	Σ = 1474000

∴ From table above,

Total dry mass (based on 100 kg of MSW sample) = 78.95 kg

$$\therefore \quad \text{Moisture content} = \left(\frac{100 - 78.95}{100}\right) \times 100 = 21.05\% \simeq 21\%$$

$$\text{Energy content} = \frac{1474000}{100} = 14740 \text{ kJ/kg}$$

Energy content (on a dry basis)

$$= (\text{Energy content as discarded}) \times \frac{100}{100 - \%m.c.}$$

$$= 1474000 \times \frac{100}{100 - 21} = 1865822.785 \text{ kJ/kg}$$

Energy content on ash-free dry basis:

$$= (\text{Energy content as discarded}) \times \frac{100}{100 - \%m.c. - \%\text{Ash}}$$

$$= 1474000 \times \frac{100}{100 - 21 - 5} = 1991891.892 \text{ kJ/kg}$$

(ii) **(a)** **Effect of air pollution on plants:** Air pollution has long been known to have adverse effect on plants. Air pollutants affecting plants are (i) sulphur dioxide (ii) hydrogen fluroride (iii) hydrogen chloride (iv) chlorine (v) ozone (vi) oxides of nitrogen (vii) ammonia (viii) mercury (ix) ethylene (x) hydrogen sulphide (xi) hydrogen cyanide (xii) PAN (xii) herbicides and (xiv) smog. The most obvious damage caused by air pollutants to plants and vegetation occurs in the leaf structure. The stomata of leaf gets clogged thereby reducing intake of CO_2 and thus affecting photosynthesis. The adverse effects range from reduction in growth rate to death of the plant.

(b) Effect of air pollution on animals: The effect of pollutants on farm animals takes place in two steps: (i) accumulation of air pollutants in the vegetation, plants and foliage, and (ii) subsequent poisoning of the animals when they eat the contaminated vegetation. Important contaminants that affect the livestock are (a) fluorine, (b) arsenic and (c) lead. These pollutants originate either from the industries situated nearby, or form dusting and spraying. Out of the these contaminants, fluorine contamination is the most prominent since cattle and sheep are found to be more susceptible to it. Symptoms of advanced fluorosis include lack of appetite, general ill health due to malnutrition, lowered fertility, reduced milk production and growth retardation. Arsenic in dusts or sprays on plants can causes poisoning of cattles leading to salivation, thirst, vomiting, uneasiness, feeble and irregular pulse and respiration. Lead contamination takes place on account of various industries such as smelters, coke ovens, and other coal based industries. Prostration, staggering and inability to rise are the prominent symptoms of lead poisoning. There is complete loss of appetite, paralysis of digestive tract and diarrhoea.

(c) Effect of air pollution on human health: The inhalation of undesirable gases from the atmosphere has marked adverse effects of human health. These adverse effects can be divided into two classes: acute effects and chronic effects. Acute effects manifest themselves immediately upon short term exposure to air pollutants of high concentrations while chronic effects become evident only after continuous exposure to low levels of air pollution. Following is a list of health effects of air pollutants: (i) Ear, nose and throat irritation (ii) Irrigation of respiratory tract (iii) Odour nuisance due to hydrogen sulphide, ammonia merceptans, even at low concentrations (iv) Chronic pulmonary diseases (such as bronchitis, asthma) etc. are aggravated by high concentrations of SO_2, NO_2, particulate matter and photochemical smog (v) Pollutants initiate asthamatic attacks (vi) Carcinogenic agents cause cancer (vii) Respiratory disease is caused by dust particles. Silicosis is caused by silica dust of cement factories and asbestosis is caused by asbestos plants (viii) Lead poisoning is caused due to entry of lead through the lungs (ix) Bone fluorosis and mottling of teeth is caused by hydrogen fluoride (x) Carbon monoxide may cause death by asphyxiation. It also increases stress on person suffering from cardiovascular and pulmonary diseases (x) Air pollution in general cause increase in mortality rate and morbidity rate (xii) Radio-active fallout may cause (a) cancer (b) shortening of life span and (c) genetic disorders.

(d) Effect of air pollution on physical features of the atmosphere: The physical effects of pollutants on the atmosphere can be classified under three heads: (i) Effect on visibility: (ii) Effects on urban atmosphere and weather conditions and (iii) Effect on atmospheric constituents.

1. ***Effects on visibility:*** The visibility is reduced due to the concentration and physical properties of particulate pollutants present in the atmosphere. The immurement of prevailing visibility is a standard meteorological effect. The stormy wind raises dust particles resulting in decrease in the visibility. In unsaturated humidity conditions, the hygroscopic particles pick up moisture and as they increase in size, the visibility is affected. Due to the angle of the sun, visibility observation in polluted areas show strong directional variations. Other meteorological factors such as inversion, height and wind sped, presence of hygroscopic particles and relative humidity also affect the visibility. Fog and photochemical smog reduce the visibility considerably.
2. ***Effects of urban atmosphere and weather condition:*** Urban air pollution is mainly caused due to smoke, dust, fog and other aerosols, and all of these affect the weather conditions. Polluted area becomes more cloudy, more foggy, resulting in reduction of solar radiation up to an extent of about 30%. The area may have 5 to 10% more precipitation, since air pollutants can add to the condensation of nuclei of the cloud system.
3. ***Effects on atmospheric constituents:*** Due to air pollution, the balance between various constituents of air is disturbed. Atmospheric carbon dioxide is the main source of organic carbon in the biosphere. It has been noted that there is steady increase in the percentage of CO_2 in the atmosphere due to combustion and other factors causing air pollution. CO_2 is interpreted as a factor responsible for rise in ambient temperature. Due to continued air pollution, the lead aerosol concentration is now 30 times more than that in pre-industrial days. Freezing nuclei are formed in large numbers when automobile exhaust gases are exposed to minute quantities of iodine vapours. These nuclei are the main base of weather modification cloud seeding operations.

Q.5 (a) Solution:

Given: Length of sample, $L = 25$ cm

Cross-section area of sample $= 30\ \text{cm}^2$

Discharge collected, $q = 100\ \text{cm}^3/\text{min}$

Head, $h = 39 \text{ cm}; G_s = 2.67$

(i) $$k = \frac{qL}{hA} = \frac{\left(\frac{100}{60}\right)\times 25}{39\times 30} = 0.0356 \text{ cm/s}$$

(ii) Mass of dry sand, $M_d = 1350 \text{ gm}$

∴ Dry density, $$\rho_d = \frac{1350}{30\times 25} = 1.8 \text{ gm/cc}$$

$$e = \frac{G_s\rho_w}{\rho_d} - 1 = \frac{2.67\times 1}{1.8} - 1 = 0.483$$

Porosity, $$n = \frac{e}{1+e} = \frac{0.483}{1+0.483} = 0.326$$

Superficial velocity, $$V = \frac{q}{A} = \frac{100}{60\times 30} = 0.056 \text{ cm/s}$$

(iii) Seepage velocity, $$V_s = \frac{V}{n} = \frac{0.056}{0.326} = 0.172 \text{ cm/s}$$

Q.5 (b) Solution:

Length of summit curve (L) for stopping sight distance (SSD)

(a) For $L >$ SSD

The equation for length L of the parabolic curve is given by

$$L = \frac{NS^2}{\left(\sqrt{2H}+\sqrt{2h}\right)^2}$$

and for $L <$ SSD

$$L = 2S - \frac{\left(\sqrt{2H}+\sqrt{2h}\right)^2}{N}$$

Calculation of SSD:

∴ $$\text{SSD} = 0.278Vt + \frac{V^2}{254f} \quad (V \text{ in km/h})$$

Given:

$V = 80$ kmph

$t = 2.5$ secs

$f = 0.35$

$$\text{SSD} = 0.278\times 80\times 2.5 + \frac{(80)^2}{254\times 0.35}$$

$$= 127.6 \text{ m} \simeq 128 \text{ m}$$

Given: $N = 0.025, H = 1.4\text{ m}, h = 0.2\text{ m}$

Assuming, $L > \text{SSD}$

$$\therefore \quad L = \frac{NS^2}{\left(\sqrt{2H}+\sqrt{2h}\right)^2} = \frac{0.025\times128^2}{\left(\sqrt{2\times1.4}+\sqrt{2\times0.2}\right)^2}$$

$$= 77.04\text{ m} < \text{SSD } (= 128\text{ m})$$

Here we find that L < SSD which shows that the assumption made earlier is incorrect. Therefore now assuming L < SSD for the calculation of length of curve.

$$\therefore \quad L = 2S - \frac{\left(\sqrt{2H}+\sqrt{2h}\right)^2}{N}$$

$$\Rightarrow \quad L = 2\times128 - \frac{\left(\sqrt{2\times1.4}+\sqrt{2\times0.2}\right)^2}{0.025}$$

$$\Rightarrow \quad L = 43.336\text{ m} < \text{SSD } (= 128\text{ m})$$

∴ Assumption is correct.

Therefore length of summit curve = 43.336 m ≃ 44 m

Q.5 (c) Solution:

(i) Main Track

Given, $D = 3°, V_{max} = 60$ kmph

$$\therefore \quad R = \frac{1720}{3}\text{ m}, G = 1.676\text{ m}$$

V_{max} at per Martin's Formula

$$V_{max} = 4.35\sqrt{R-67}$$

$$= 4.35\sqrt{\frac{1720}{3}-67} = 97.88\text{ kmph} > 60\text{ kmph}$$

$$\therefore \quad V_{max} = 60\text{ kmph}$$

We know,

$$(e_{th})_{MT} = (e_{act})_{MT} + D \qquad \{\text{Take cant deficiency} = 7.6\text{ cm}\}$$

$$\frac{G\,V_{max}^2}{127\,R} = (e_{act})_{MT} + D$$

$$\Rightarrow \quad \frac{1.676\times60^2}{127\times\frac{1720}{3}} = (e_{act})_{MT} + \frac{7.6}{100}$$

$$\Rightarrow \quad (e_{act})_{MT} = 6.864\times10^{-3}\text{ m}$$

Branch Track

$$D = 6°, \quad R = \frac{1720}{6}\text{ m}$$

$$G = 1.676 \text{ m}$$

We know,

$$-(e_{act})_{MT} = (e_{act})_{BT}$$

$$\therefore \quad (e_m)_{BT} = (e_{act})_{MT} + D$$

$$\Rightarrow \quad \frac{G(V_{max})_{BT}^2}{127\,R} = -(e_{act})_{MT} + D$$

$$\Rightarrow \quad \frac{1.676 \times (V_{max})_{BT}^2}{127 \times \frac{1720}{6}} = -6.864 \times 10^{-3} + \frac{7.6}{100}$$

$$\Rightarrow \quad (V_{max})_{BT} = 38.75 \text{ kmph}$$

Check with Martin's Formula,

$$(V_{max})_{BT} = 4.35\sqrt{R - 67}$$

$$= 4.35\sqrt{\frac{1720}{6} - 67} = 64.47 \text{ kmph} > 38.75 \text{ kmph}$$

$$\therefore \quad (V_{max})_{BT} = 38.75 \text{ kmph}$$

(ii) The internal force developed due to rise in temperature = $E\alpha T A_s$.

$$\Rightarrow \quad F_s = (1.25 \times 10^{-5}) \times (21 \times 10^5)(25)(7686 \times 10^{-2})$$

$$\Rightarrow \quad F_s = 50439.375 \text{ kg}$$

$$\text{No. of sleepers required} = \frac{F_s}{R} = \frac{50439.375}{380} = 132.735 \simeq 133$$

$\therefore$ Length of welded rail required

$$= (n-1)S$$

$$= (133 - 1) \times 72 = 9504 \text{ cm} = 95.04 \text{ m}$$

$$\therefore \quad \text{Breathing length} = 2(n-1)S = 2 \times 95.04 = 190.08 \text{ m}$$

$\therefore$ Length required to overcome temperature stress

$$= \frac{50439.375}{630} = 80.06 \text{ km}$$

$\therefore$ To prevent creep for equilibrium the length of welded rail

$$= 2 \times 80.06 = 160.12 \text{ km}$$

Q.5 (d) Solution:

Value (i)	Mean (ii)	Deviation (d) (iii) = (i) – (ii)	d^2 (iii)^2
162° 20′ 00″	162° 20′ 46.67″	–46.67″	36′ 18.09″
162° 21′ 20″		+33.33″	18′ 31.56″
162° 21′ 40″		+53.33″	47′ 24.09″
162° 20′ 40″		–6.67″	44.49″
162° 19′ 40″		–1′ 6.67″	74′ 4.89″
162° 21′ 20″		+33.33″	18′ 30.9″
		$\Sigma d = 0$	$\Sigma d^2 = 30°15' 34.02''$

$$\text{Mean} = \frac{162°20'00'' + 162°21'20'' + 162°21'40'' + 162°20'40'' + 162°19'40'' + 162°21'20''}{6}$$

$$= 162°\ 20'\ 46.67''$$

(a) Probable error of a single observation,

$$E_s = \pm 0.6745\sqrt{\frac{\Sigma d^2}{n-1}} = \pm 0.6745\sqrt{\frac{3°15'34.02''}{(6-1)}}$$

$$E_s = 32.675''$$

(b) Probable error of the mean,

$$E_m = \frac{E_s}{\sqrt{n}} = \frac{32.675''}{\sqrt{6}} = 13.34''$$

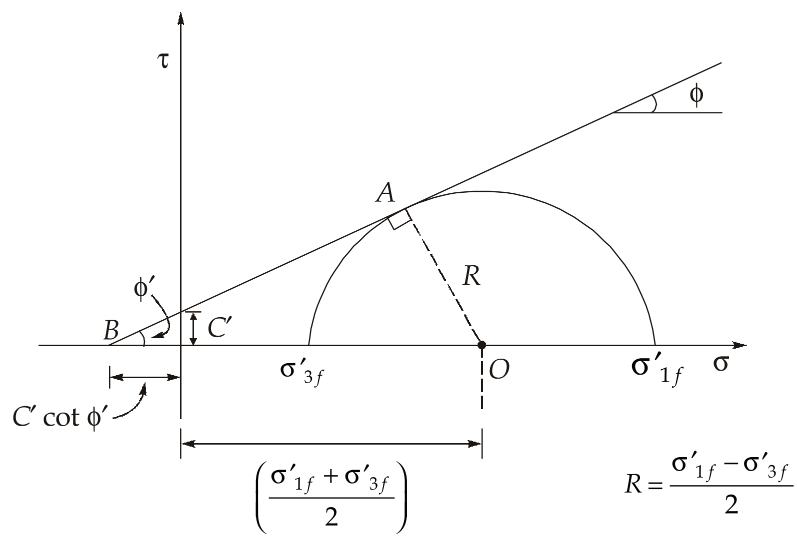
(c) Most probable value of the angle

$$= 162°20'\ 46.67'' \pm 13.34''$$

$$= 162°21'\ 0.01''$$

Q.5 (e) Solution:

For a C-ϕ soil:



From figure, $$\sin\phi' = \frac{R}{OB} = \frac{\left(\frac{\sigma'_{1f} - \sigma'_{3f}}{2}\right)}{C'\cot\phi' + \left(\frac{\sigma'_{1f} + \sigma'_{3f}}{2}\right)}$$

$$\Rightarrow \left(\frac{\sigma'_{1f} + \sigma'_{3f}}{2}\right)\sin\phi' + C\cos\phi' = \left(\frac{\sigma'_{1f} - \sigma'_{3f}}{2}\right)$$

$$\therefore \left(\frac{\sigma'_{1f} - \sigma'_{3f}}{2}\right) = \left(\frac{\sigma'_{1f} + \sigma'_{3f}}{2}\right)\sin\phi' + C'\cos\phi'$$

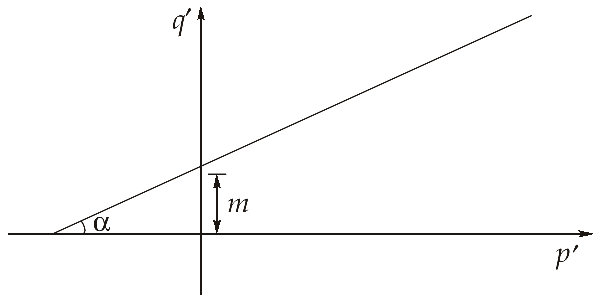
On $q' - p'$ plot

Now, $$q' = \left(\frac{\sigma'_{1f} - \sigma'_{3f}}{2}\right)$$

$$p' = \left(\frac{\sigma'_{1f} + \sigma'_{3f}}{2}\right)$$

$$\therefore \quad q' = p'\sin\phi' + C'\cos\phi' \quad \text{... (i)}$$

Given: $$q' = m + p'\tan\alpha = p'\tan\alpha + \text{m} \quad \text{... (ii)}$$



Comparing equation (i) and (ii)

$$\tan \alpha = \sin\phi'$$

∴ $$\alpha = \tan^{-1}(\sin\phi')$$

Also, $$m = C'\cos\phi'$$

Q.6 (a) Solution:

(i) Given:

Soil P:

Initial pressure, $\bar{\sigma}_i = 150 \text{ kN/m}^2$

$e_o = 0.56$

Final pressure, $\bar{\sigma}_f = 200 \text{ kN/m}^2$

$e_f = 0.51$

Thickness, $H = 35$ mm

Degree of consolidation, $U = 50\%$

Time, $t_p = 0.3t_Q$

Soil Q:

Initial pressure, $\bar{\sigma}_i = 150 \text{ kN/m}^2$

$e_o = 0.65$

Final pressure, $\bar{\sigma}_f = 200 \text{ kN/m}^2$

$e_f = 0.63$

Thickness, $H = 25$ mm

Degree of consolidation, $U = 50\%$

Time: t_Q

∵ $$T_V = \frac{C_v t}{d^2}$$

Assume single drainage in both the soils i.e., $d = H$

$$\therefore \quad t = \frac{T_V d^2}{C_V}$$

Also, $$C_V = \frac{k}{m_v \times \gamma_w}$$

$$\therefore \quad t = \frac{T_V \times d^2}{k} m_v \times \gamma_w$$

$$\Rightarrow \quad t \propto \frac{d^2 m_v}{k}$$

$$\Rightarrow \quad k \propto \frac{d^2 m_v}{t}$$

$$\therefore \quad \frac{k_P}{k_Q} = \frac{(d_p)^2 \times (m_V)_P}{(d_Q)^2 \times (m_V)_Q} \times \frac{t_Q}{t_P}$$

$$\because \quad m_V = \frac{a_V}{1+e_0} = \frac{\Delta e}{(\Delta\bar{\sigma}) \times (1+e_0)}$$

$$\therefore \quad \frac{k_P}{k_Q} = \frac{35^2 \times \dfrac{0.56-0.51}{(200-150)\times(1+0.56)}}{25^2 \times \dfrac{0.65-0.63}{(200-150)\times(1+0.65)}} \times \frac{1}{0.3} = 17.3$$

Hence, the ratio of coefficient of permeability of soil P and Q is 17.3.

(ii) Differences between compaction and consolidation:

Compaction	Consolidation
1. It is an instantaneous process.	It is a gradual process.
2. Reduction in volume of soil is due to expulsion of pore air.	Reduction in volume of soil is due to expulsion of pore water.
3. Soil will always remain unsaturated.	Soil will always remain saturated.
4. Compaction is done before construction of structure.	Consolidation start as soon as construction begins.
5. It is a dynamic process.	It is a static process.

Compaction is done to change the engineering properties of soil such as:

(i) To reduce the void ratio of soil.

(ii) To reduce the permeability and compressibility of soil.

(iii) To increase the degree of denseness of soil

(iv) To increase the stability, shear strength, bearing capacity of the soil.

Q.6 (b) Solution:

(i) Correction for elevation $= \dfrac{7}{100} \times 1620 \times \dfrac{270}{300} = 102.06 \text{ m} \simeq 102 \text{ m}$

$\therefore$ Corrected runway length $= 1620 + 102 = 1722$ m

Standard atmospheric temperature at a given elevation

$= 15°C - 0.0065 \times 270 \simeq 13.25°C$

Rise of temperature $= 32.90°C - 13.25°C$

$= 19.65°C$

Correction for temperature $= \dfrac{1722}{100} \times 19.65 = 338.37 \text{ m}$

Corrected length $= 1722 + 338.37 = 2060.37$ m

Total correction in percentage $= \dfrac{2060.37 - 1620}{1620} \times 100 = 27.18\% < 35\%$ (OK)

According to ICAO, this should not exceed 35%.

Correction for gradient $= \dfrac{20}{100} \times 2060.37 \times 0.2 = 82.41 \text{ m}$

$\therefore$ Corrected runway length $= 2060.37 + 82.41 = 2142.78$ m

(ii) **Airport Capacity:** The number of aircraft movements which an airport can process within a specified period of time, with an average delay to the departing aircraft within the acceptable time limit is defined as airport capacity. Each aircraft makes two movement, viz., landing and takeoffs.

The following factors affect the airport operating capacity:

- Runway configurations and the connected taxiway
- Aircraft characteristics and their arrival to departure ratio
- Weather conditions
- Terrain and man-made obstructions
- Loading apron space
- Navigational aids
- Aircraft processing technique
- **Runway configurations and the connected taxiway:** The runway configuration affects the capacity. The appurtenant taxiways are important to clear the landing aircraft from the runways as soon as possible.

- **Aircraft characteristics and their arrival to departure ratio:** Smaller and slower aircrafts occupy the runway for less time and can be spaced closer than bigger and faster aircrafts. Therefore, the capacity of airport serving smaller aircrafts is generally higher than the one serving bigger and faster aircrafts.
- **Weather conditions:** Airport capacity during IFR conditions is usually less than during VFR conditions.
- **Terrain and man-made obstructions:** Terrain or man-made obstructions in the vicinity of the airport restrict the number of inbound and outbound air routes from the airport.
- **Loading apron space:** If sufficient space is not available for loading, unloading and parking aircraft, then it may result in delay in the terminal area or even the reduction in the number of aircraft operations. Thus the airport capacity may be reduced.
- **Navigational aids:** This is particularly important in poor visibility conditions.
- **Aircraft processing technique:** If the controller is provided with the computer facility, he may be able to process the aircrafts rapidly, thereby reducing the delays.

Q.6 (c) Solution:

Effective size of photograph $= [23(1 - 0.65)] \times [23(1 - 0.28)]$

$= 8.05 \text{ cm} \times 16.56 \text{ cm}$

Flying height,
$$S = \frac{f}{H - h_{avg}}$$

$$\Rightarrow \quad \frac{1}{25000} = \frac{200 \times 10^{-3}}{H - 335}$$

$$\Rightarrow \quad H = 5335 \text{ m}$$

Theoretical ground spacing of flight lines $= \dfrac{16.56}{100} \times 25000 = 4140 \text{ m}$

Number of photographs required along width,

$$N_1 = \frac{105 \times 10^3}{4140} + 1 = 26.36 \approx 27$$

Actual spacing of flight lines $= \dfrac{105 \times 10^3}{27} = 3888.89 \text{ m}$

Theoretical ground distance between exposure = $\frac{8.05 \times 25000}{100} = 2012.5$ m

$$\text{Exposure internal} = \frac{2012.5 \times 3600}{270 \times 10^3} = 26.83 \text{ sec} \simeq 26.5 \text{ sec}$$

($\because$ LC of intervalometer is 0.5 sec)

Actual ground distance between exposures

$$= 75 \times 26.5 = 1987.5 \text{ m}$$

Number of photographs along the length,

$$N_2 = \frac{150 \times 10^3}{1987.5} + 1 = 76.47 \simeq 77$$

Total number of photographs required = $N_1 \times N_2 = 77 \times 27 = 2079$

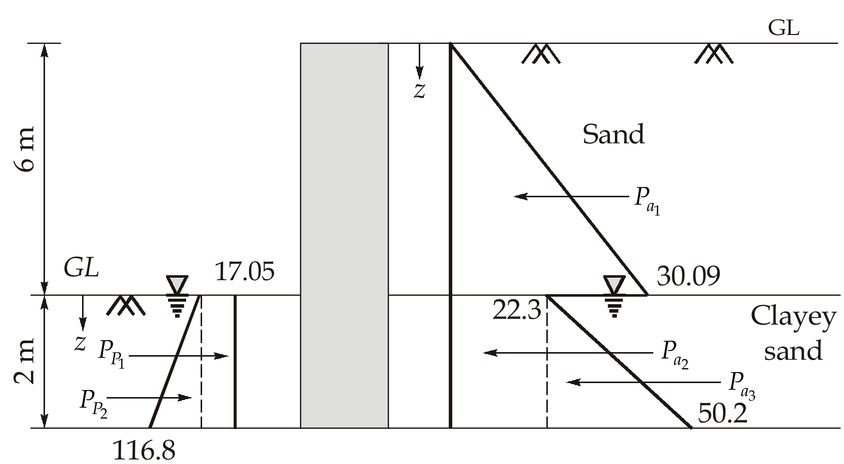
Q.7 (a) Solution:

Earth pressure coefficient,

For sand, $k_a = \frac{1-\sin\phi'}{1+\sin\phi'} = \frac{1-\sin 33°}{1+\sin 33°} = 0.295$

For clayey sand, $k_a = \frac{1-\sin\phi'}{1+\sin\phi'} = \frac{1-\sin 25°}{1+\sin 25°} = 0.406$

$$k_p = \frac{1+\sin\phi'}{1-\sin\phi'} = \frac{1+\sin 25°}{1-\sin 25°} = 2.46$$



Passive Earth pressure diagram (in kN/m^2)

Active Earth pressure diagram (in kN/m^2)

Calculation of active earth pressure: (Right side):

For $0 \leq z \leq 6$ m

At $z = 0$ m; $\bar{\sigma} = 0$

At $z = 6$ m; $\bar{\sigma}_Z = \gamma \times 6 = 17 \times 6 = 102$ kN/m^2

∴ Active earth pressure just above clayey sand

$$p_a = k_a\bar{\sigma}_z - 2c'\sqrt{k_a} = 0.295 \times 102 - 0 = 30.09 \text{ kN/m}^2$$

For $6 \text{ m} \le z \le 8 \text{ m}$

$$p_a \text{ (just below)} = 0.406 \times 102 - 2 \times 15 \times \sqrt{0.406} = 22.3 \text{ kN/m}^2$$

At $z = 8 \text{ m}$

$$\bar{\sigma}_z = \gamma \times 6 + \gamma_{sub} \times 2$$

$$= 17 \times 6 + (20 - 9.81) \times 2 = 122.38 \text{ kN/m}^2$$

$$\therefore \quad p_a = \left(k_a \times \bar{\sigma}_z - 2c\sqrt{k_a}\right) + \gamma_w H$$

$$= \left(0.406 \times 122.38 - 2 \times 15\sqrt{0.406}\right) + 9.81 \times 2$$

$$= 50.2 \text{ kN/m}^2$$

Now, active earth pressure thrusts and their location:

$$P_{a_1} = \frac{1}{2} \times (30.09) \times 6 = 90.27 \text{ kN/m} \ @ \ \bar{x}_1 = 2 + \frac{6}{3} = 4\text{m}$$

(from bottom)

$$P_{a_2} = (22.3 \times 2) = 44.6 \text{ kN/m} \ @ \ \bar{x}_2 = 1 \text{ m} \text{ (from bottom)}$$

$$P_{a_3} = \frac{1}{2} \times (50.2 - 22.3) \times 2 = 27.9 \text{ kN/m} \ @ \ \bar{x}_3 = \frac{2}{3} \text{ m}$$

(from bottom)

∴ Total active earth pressure thrust

$$P_a = P_{a_1} + P_{a_2} + P_{a_3}$$

$$= 90.27 + 44.6 + 27.9$$

$$= 162.77 \text{ kN/m}$$

Location of active earth pressure thrust

$$\bar{x} = \frac{P_{a_1} \times \bar{x}_1 + P_{a_2} \times \bar{x}_2 + P_{a_3} \times \bar{x}_3}{P_{a_1} + P_{a_2} + P_{a_3}}$$

$$= \frac{90.27 \times 4 + 44.6 \times 1 + 27.9 \times \frac{2}{3}}{162.77}$$

$$= 2.6 \text{ m from bottom}$$

Calculation of passive earth pressure (Left side):

For $0 \le z \le 2\text{ m}$

At $z = 0; \quad \bar{\sigma} = 0$

$$\therefore \quad p_p = k_p \times \bar{\sigma}_z + 2c\sqrt{k_p}$$

$$= 0 + 2 \times 15 \times \sqrt{2.46} = 47.05\text{ kN/m}^2$$

At $z = 2\text{ m}$

$$\bar{\sigma}_z = (20 - 9.81) \times 2 = 20.38\text{ kN/m}^2$$

$$p_p = k_p \times \bar{\sigma}_z + 2c\sqrt{k_p} + \gamma_w \times z$$

$$= 2.46 \times 20.38 + 2 \times 15 \times \sqrt{2.46} + 9.81 \times 2$$

$$= 116.8\text{ kN/m}^2$$

Passive earth pressure thrusts and their location:

$$P_{p_1} = 47.05 \times 2 = 94.10\text{ kN/m @ } \bar{x}_1 = 1\text{ m from bottom}$$

$$P_{p_2} = \frac{1}{2} \times (116.8 - 47.05) \times 2 = 69.75\text{ kN/m @ } \bar{x}_2 = \frac{2}{3}\text{ m}$$

from bottom

$\therefore$ Total passive earth pressure thrust,

$$P_p = 94.10 + 69.75 = 163.85\text{ kN/m}$$

Location of passive earth pressure thrust:

$$\bar{x} = \frac{P_{p_1} \times \bar{x}_1 + P_{p_2} \times \bar{x}_2}{P_{p_1} + P_{p_2}} = \frac{94.10 \times 1 + 69.75 \times \frac{2}{3}}{163.85}$$

$$= 0.86\text{ m from bottom of the retaining wall.}$$

Q.7 (b) Solution:

(i) Standard load value obtained from the average of large number of tests conducted on crushed stones are 1370 kg and 2055 kg respectively at 2.5 mm and 5 mm penetration.

Consider specimen-I:

The load penetration curve for specimen no. 1 is consistent i.e., convex throughout and needs no correction.

Load dial reading at 2.5 mm penetration = 36 divisions

$\because$ 50 divisions represent 80 kg then 1 division will represent

$$\frac{80}{50} = 1.6\text{ kg}$$

Therefore 36 divisions will represent

$$1.6 \times 36 = 57.6 \text{ kg}$$

CBR value at 2.5 mm penetration $= \dfrac{57.6 \times 100}{1370} = 4.2\%$

CBR value at 5 mm penetration $= \dfrac{1.6 \times 52 \times 100}{2055} = 4.049\% \simeq 4.05\%$

$\therefore$ CBR value of specimen 1 $= \max(CBR_{2.5}, CBR_5)$

$= \max(4.2\%, 4.05\%)$

$= 4.2\%$

Consider specimen-2:

CBR value at 2.5 mm penetration $= \dfrac{1.6 \times 33 \times 100}{1370} = 3.854\%$

CBR value at 5 mm penetration $= \dfrac{1.6 \times 48 \times 100}{2055} = 3.737\%$

CBR value of specimen-2 $= \max(CBR_{2.5}, CBR_5)$

$= \max(3.854, 3.77)$

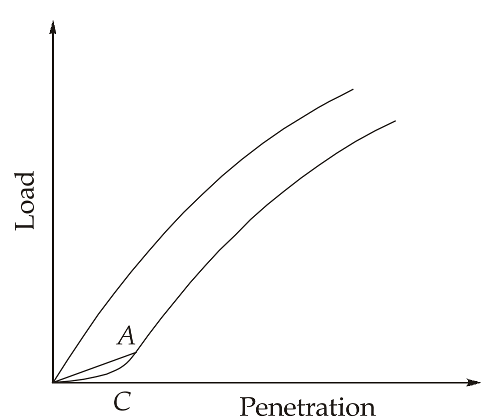
$= 3.854\%$

Therefore mean CBR value of the soil sample

$$= \frac{4.2 + 3.854}{2} = 4.027\%$$

Two typical types of curves may be obtained.

The normal curve is with convexity upwards. Sometimes a curve with initial upward concavity is obtained, indicating the necessity of correction. In this case, the corrected origin is established by drawing a tangent AC from the steepest point A on the curve. The load values corresponding to 2.5 and 5 mm penetration values from the corrected origin.



The causes for the initial concavity of the load penetration curve calling for the correction in origin are due to

(i) the bottom surface of the plunger not being truly horizontal.

(ii) the top surface of the soil specimen not being truly horizontal.

(iii) the top layer of the specimen being too soft or irregular.

(ii) Theoretical specific gravity of the mixture

$$G_t = \frac{W_1 + W_2 + W_3 + W_4 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_4}{G_4} + \frac{W_b}{G_b}}$$

$$\Rightarrow \quad G_t = \frac{825 + 1000 + 320 + 180 + 100}{\frac{825}{2.63} + \frac{1000}{2.51} + \frac{320}{2.46} + \frac{180}{2.43} + \frac{100}{1.04}}$$

$$= \frac{2425}{313.688 + 398.406 + 130.081 + 74.074 + 96.154}$$

$$= 2.395$$

Mass specific gravity of mixture,

$$G_m = \frac{\text{Weight of Marshall specimen}}{\text{Volume of Marshall specimen}}$$

$$= \frac{1200}{520} = 2.308$$

(a) Percentage air voids,

$$V_a = \frac{G_t - G_m}{G_t} = \frac{2.395 - 2.308}{2.395} \times 100 = 3.633\%$$

(b) Percentage bitumen by volume

$$V_b = \frac{G_m}{G_b} \times \frac{W_b}{W_{mould}} \times 100$$

$$\Rightarrow \quad V_b = \frac{2.308}{1.04} \times \frac{100}{1200} \times 100 = 18.494\%$$

(c) Percentage voids in mineral aggregate

$$\text{VMA} = \%V_a + \%V_b$$

$$= 3.633 + 18.494$$

$$= 22.127\%$$

Q.7 (c) Solution:

(i) **Line ranger:** It is a small instrument used to establish intermediate points between two distant points on a chain line without the necessity of sighting from one of them. It consists of two right angled isosceles triangular prisms or two plane mirrors placed one above the other, with their reflecting surfaces normal to each other.

Optical square: This is a compact hand instrument to set out right angles and is superior to the cross-staff. It is a cylindrical metal box about 50 mm in diameter and 12.5 mm in depth.

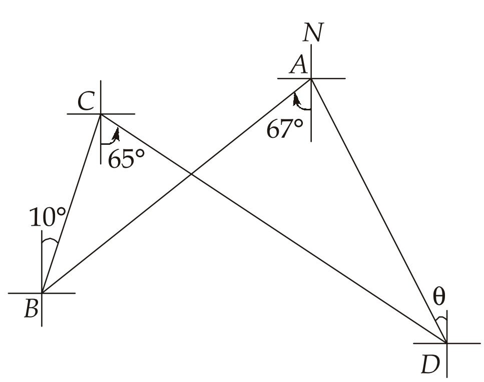
Prism square: It is based on the same principle as the optical square and is used in the same manner. It has an advantage over the optical square in that no adjustment is required, since the angles between the reflecting surfaces of prisms is kept fixed at 45°.

Clinometer: It is an instrument used for measuring the angle of a slope. There is a variety of forms of which the simplest one consists of a graduated semicircle resembling a protector. A plumb bob is suspended from its center. Two sight pins A and B are attached along the side of the upper straight diametrical portion.

Distomat: A distomat is the most precise and modern E.D.M. instrument. Two distomats are used, one at each station. One is called 'master distomat' which sets the signal and the other is called 'remote distomat' which receives, monitors, and reflects back the signal. The distomat has an advantage over the other E.D.M. instruments in that it searches the remote station within 2 to 3 seconds and because of the tilting axis, it can be pointed like a theodolite telescope.

Tellurometer: The instrument was developed under the auspices of the South African Council for Scientific and Industrial Research by T.L. Wadley. There are two types of tellurometers of which one gives the delay line output reading in terms of transit time and the other gives a direct reading in meters. It uses high-frequency radio waves. Two identical instruments are set up at the two stations between which the distance is required. The master instrument sets the signal and the remote instrument receives, monitors, and returns it to the master. The distance so obtained is checked by reversing the roles of the master and remote tellurometes. It can be used both during day as well as night.

(ii)



Line	Length	Bearing (WCB)
AB	1000 steps	180° + 67° = 247°
BC	512 steps	10°
CD	1504 steps	180° – 65° = 115°
DA	L	θ

For a closed traverse,

$$\Sigma L = 0$$

$$\Rightarrow 1000 \times \cos247° + 512 \times \cos10° + 1504 \times \cos115° + L\cos\theta = 0$$

$$\Rightarrow (-390.73) + (504.222) + (-635.618) + L\cos\theta = 0$$

$$\Rightarrow \quad L\cos\theta = 522.128 \quad \text{... (i)}$$

$$\Sigma D = 0$$

$$\Rightarrow 1000 \times \sin247° + 512 \times \sin10° + 1504 \times \sin115° + L\sin\theta = 0$$

$$\Rightarrow (-920.505) + (88.908) + (1363.087) + L\sin\theta = 0$$

$$\Rightarrow \quad L\sin\theta = -531.49 \quad \text{... (ii)}$$

Performing $(i)^2 + (ii)^2$

$$L^2 = (522.126)^2 + (-531.49)^2$$

$$\Rightarrow \quad L = 745.048 \approx 745 \text{ steps}$$

Dividing (ii) ÷ (i)

$$\frac{\sin\theta}{\cos\theta} = -\frac{531.49}{522.126}$$

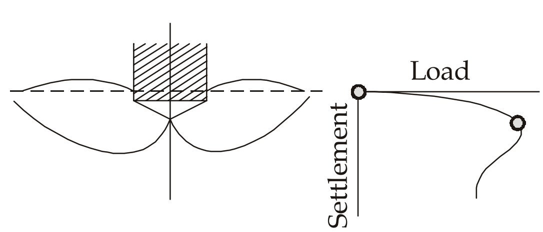
$$\Rightarrow \quad \theta = -45.509°$$

$$\therefore \quad \theta = 45.509° \text{ or N } 45.509° \text{ W}$$

Q.8 (a) Solution:

(i) General shear failure

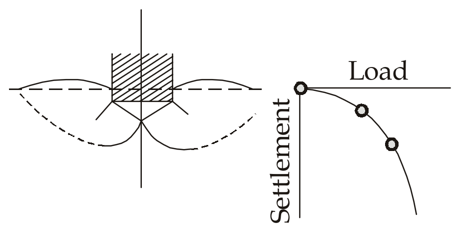
- General shear failure is usually associated with medium to dense or stiff soils of relatively low compressibility.
- At the time of failure, most of the soil within stress zone reaches plastic state except the central portion.



- Main characteristics of general shear failure are :
  (a) A well defined slip surface developed on both or one side of the footing.
  (b) A sudden, catastrophic failure accompanied by tilting of foundation.
  (c) Bulging of ground surface adjacent to the foundation before failure.

2. Local shear failure

- Local shear failure is an intermediate failure mode characterized by well defined slip surface immediately below the footing but extending only a short distance into the soil mass, as shown in figure.



- Since, the stress zone does not extend upto ground level. Therefore, there is only little bulging of soil around the footing.
- Main characteristics of local shear failure are :
  (a) Occurs in loose sands and soft clays in shallow foundations.
  (b) Well defined wedge and slip surface only below the footing.
  (c) Slip surface not visible beyond the edges of the foundation.
  (d) Soil below the footing is more stressed as compared to adjacent soil.

(ii) (a) Shallow foundation: It is founded at a depth equal to or less than the width of footing.

Deep foundation: It is founded at a depth more than width of the footing.

(b) Gross bearing capacity: The bearing capacity inclusive of the pressure exerted by the weight of the soil standing on the foundation.

Net bearing capacity: Gross bearing capacity minus the original overburden pressure or surcharge pressure at the foundation level.

(c) Safe bearing capacity: Maximum intensity of loading which can be transmitted to the soil without the risk of shear failure, irrespective of the settlement that may occur.

Allowable bearing pressure: The maximum allowable net loading intensity on the soil at which the soil neither fails in shear nor undergoes excessive or intolerable settlement, detrimental to the structure.

(iii) Here, $B' = B - 2e = 1.5 - 2 \times 0.15 = 1.2$ m

For cohesionless soil:

$$q'_u = qN_q F_{qd} \cdot F_{qi} + \frac{1}{2}\gamma \cdot B' N_\gamma \cdot F_{\gamma d} \cdot F_{\gamma i}$$

$$= (16 \times 1) \times 33.3 \times 1.17 \times 0.605$$

$$+ \frac{1}{2} \times 16 \times 1.2 \times 48.03 \times 1 \times 0.184$$

$$= 461.98 \text{ kN/m}^2$$

∴ Inclined ultimate load,

$$Q_u = \frac{Q'_u}{\cos\beta} \times B' = \frac{461.98}{\cos 20^\circ} \times 1.2$$

$$= 589.95 \text{ kN/m} \simeq 590 \text{ kN/m}$$

Q.8 (b) Solution:

(i) Let, V_i = Mid speed of vehicle or range given

q_i = No. of vehicle/hr for particular V_i

Then, time mean speed, $V_t = \dfrac{\Sigma q_i V_i}{\Sigma q_i}$

Space mean speed, $V_s = \dfrac{\Sigma q_i}{\Sigma \dfrac{q_i}{V_i}}$

$$V_t = \frac{8294}{168} = 49.37 \text{ kmph}$$

$$V_s = \frac{168}{3.7372} = 44.95 \text{ kmph}$$

Speed range (kmph)	Mid speed (kmph), V_i	Traffic volume (Veh/hr)		
		q_i	q_iV_i	q_i/V_i
11-15	13	2	26	2/13 = 0.1538
16-20	18	2	36	1/9 = 0.1111
21-25	23	3	69	3/23= 0.1304
26-30	28	4	112	4/28 = 0.1428
31-35	33	10	330	10/33 = 0.303
36-40	38	13	494	13/38 = 0.3421
41-45	43	24	1032	24/43 = 0.5581
46-50	48	35	1680	35/98 = 0.7291
51-55	53	32	1996	32/53 = 0.6037
56-60	58	15	870	15/58 = 0.2586
61-65	63	8	504	8/63 = 0.1269
66-70	68	9	612	9/68 = 0.1323
71-75	73	5	365	5/73 = 0.0684
76-80	78	6	468	6/78 = 0.0769
		$\Sigma q_i = 168$	$\Sigma q_i V_i = 8294$	$\Sigma q_i / V_i = 3.7372$

(ii) The individual thickness of each layer is converted to their respective gravel equivalent using the following relationship

$$\frac{t_g}{t} = \left(\frac{C}{C_g}\right)^{1/5}$$

where

t_g = Gravel thickness

t = Individual thickness

C_g = Cohesionmeter value of gravel = 15

C = Respective C-value

For bituminous concrete,

$$t_g = \left(\frac{60}{15}\right)^{1/5} \times 15 = 19.793 \text{ cm}$$

For base course, $$t_g = \left(\frac{225}{15}\right)^{1/5} \times 20 = 34.375 \text{ cm}$$

For sub-base course, $t_g = \left(\frac{15}{15}\right)^{1/5} \times 10 = 10$ cm

Therefore actual pavement thickness

$= 15 + 20 + 10 = 45$ cm

This is equivalent to gravel thickness

$= 19.793 + 34.375 + 10 = 64.168$ cm

Now, $\frac{t_g}{T} = \left(\frac{C}{C_g}\right)^{1/5}$

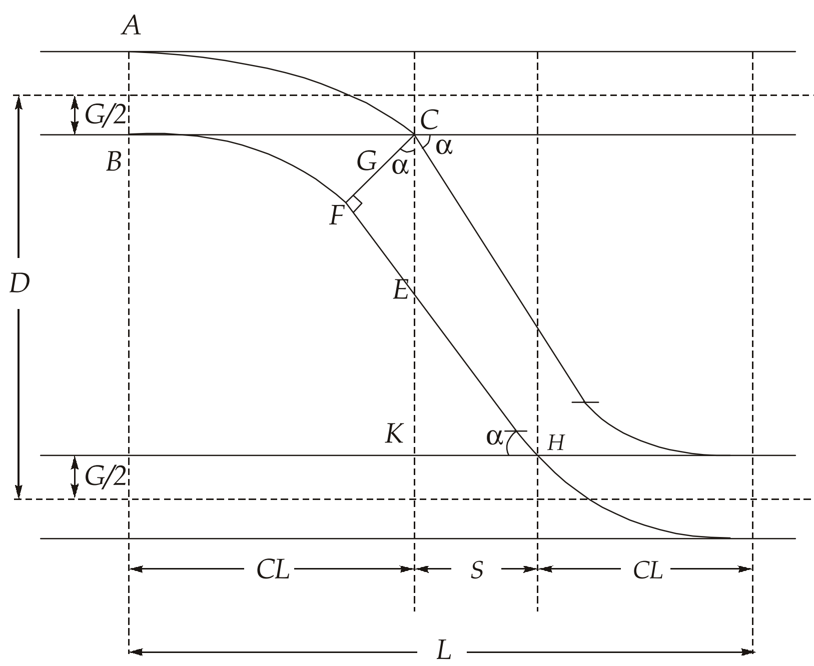
$\Rightarrow \left(\frac{64.168}{45}\right) = \left(\frac{C}{15}\right)^{1/5}$

$\Rightarrow C = 88.434$

The equivalent C-value of the pavement section is 88.434.

Q.8 (c) Solution:

(i)



D = distance between centers of parallel tracks

α = Angle of crossing

S = Horizontal projection of intermediate portion of main track

CL = Curve lead G

Gauge length

N = No. of crossing

We know, $\cot\alpha = N$

$$\therefore \quad \sec\alpha = \sqrt{1+\tan^2\alpha} = \sqrt{1+\frac{1}{N^2}} = \sqrt{\frac{N^2+1}{N^2}}$$

$$CK = D - \frac{G}{2} - \frac{G}{2} = D - G$$

From ΔCEF, $\cos\alpha = \frac{G}{CE}$

$$\Rightarrow \quad CE = G\sec\alpha$$

$$\therefore \quad EK = D - G - CE$$

$$\Rightarrow \quad EK = (D-G) - G\sec\alpha$$

From ΔEHK, $\tan\alpha = \frac{EK}{KH} = \frac{EK}{S}$

$$\Rightarrow \quad S = EK\cot\alpha$$

$$\Rightarrow \quad S = [D - G - G\sec\alpha]\, N$$

$$\Rightarrow \quad S = (D-G)\, N - GN\sec\alpha$$

$$\Rightarrow \quad S = (D-G)\, N - GN\sqrt{\frac{1+N^2}{N^2}}$$

$$l = CL + S + CL$$

$$\Rightarrow \quad l = 2\, CL + S$$

$$\Rightarrow \quad l = 2\,[2\, GN] + [(D-G)\, N - G\sqrt{1+N^2}\,]$$

$$\Rightarrow \quad l = 4\, GN + DN - GN - G\sqrt{1+N^2}$$

$$\Rightarrow \quad l = 3\, GN + DN - G\sqrt{1+N^2}$$

Now given, $N = 10$

$$G = 1.676 \text{ m}$$

$$\therefore \quad D = 8.5 - \frac{1.676}{2} - \frac{1.676}{2}$$

$$\Rightarrow \quad D = 6.824 \text{ m}$$

$$\therefore \quad l = 3\,(1.676)\,(10) + 6.824\,(10) - 1.676\sqrt{1+10^2}$$

$$\Rightarrow \quad l = 101.676 \text{ m}$$

(ii) Rise between points 1 and 2 = 1.325 m

Hence, F.S. on point 2 = 3.125 – 1.325 = 1.8 m

R.L. of point 2 = 125.505 m

Rise from point 1 to 2 = 1.325

Hence, R.L. of point 1 = 125.505 – 1.325 = 124.180 m

Fall from point 2 to 3 = 0.055 m

I.S. on point 3 = 2.320 m

Hence, B.S. of point 2 = 2.320 – 0.055 = 2.265 m

R.L. of point 3 = 125.505 – 0.055 = 125.450 m

R.L. of point 4 = 125.850 m

Hence, rise from point 3 to 4=125.850 – 125.450 = 0.40 m

Now, I.S. on point 3 = 2.320 m

Rise from point 3 to 4 = 0.40 m

I.S. on point 4 = 2.320 – 0.40 = 1.920 m

Fall from point 4 to 5 = 2.655 – 1.920 = 0.735 m

Hence, R.L. of point 5 = 125.85 – 0.735 = 125.115 m

F.S. on point 6 = 3.205 m

Fall from point 5 to 6 = 2.165 m

Hence, B.S. on point 5 = 3.205 – 2.165 = 1.040 m

R.L. of point 6 = 1.620 m

I.S. on point 7 = 3.625 m

Fall from point 6 to 7 = 3.625 – 1.620 = 2.005 m

R.L. of point 7 = 122.950 – 2.005 = 120.945 m

R.L. of point 8 = 123.090 m

Hence, rise from point 7 to 8=123.090 – 120.945 = 2.145 m

I.S. on point 7 = 3.625 m

Rise from point 7 to 8 = 2.145 m

Hence, F.S. on point 8 = 3.625 – 2.145 = 1.480 m

Point	B.S.	I.S.	F.S.	Rise	Fall	R.L.	Remarks
1	3.125					124.18	B.M.
2	2.265		1.800	1.325		125.505	C.P.
3		2.320			0.055	125.450	
4		1.920		0.400		125.850	
5	1.040		2.655		0.735	125.115	C.P.
6	1.620		3.205		2.165	125.950	C.P.
7		3.625			2.005	120.945	
8			1.480	2.145		123.090	T.B.M.

Check:

$$\Sigma B.S. - \Sigma F.S. = 8.05 - 9.14 = -1.09 \text{ m}$$

$$\Sigma Rise - \Sigma Fall = 3.87 - 4.96 = -1.09 \text{ m}$$

$$\text{Last R.L.} - \text{First R.L.} = 123.090 - 124.18 = -1.09 \text{ m}$$

■■■■