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Detailed Solutions

ESE-2025 Mains Test Series

Civil Engineering Test No : 4

Section A : Transportation Engineering

Q.1 (a) Solution:

Given: Length of skid mark before collision, $L_1 = 50$ m

Length of skid mark after collision, $L_2 = 15$ m

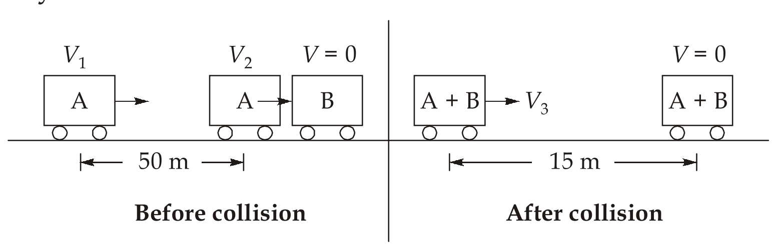
$$W_B = 60\%\ W_A = 0.60\ W_A$$

$$\Rightarrow \quad m_B = 0.60\ m_A$$

Coefficient of friction, $f = 0.60$

Assume:

- Collision is perfectly plastic.
- Brake efficiency = 100%



After collision for vehicle (A) + (B)

$$V_3^2 = 2gf\,L_2$$

$$\Rightarrow \quad V_3 = \sqrt{2\times9.81\times0.6\times15} = 13.288 \text{ m/s}$$

Applying momentum conservation equation,

$$m_A V_2 + m_B \times 0 = (m_A + m_B)V_3$$

$$\Rightarrow \quad V_2 = \frac{(m_A + 0.6m_A)}{m_A} \times 13.288$$

$$\Rightarrow \quad V_2 = 21.26 \text{ m/s}$$

Before collision of vehicle (A)

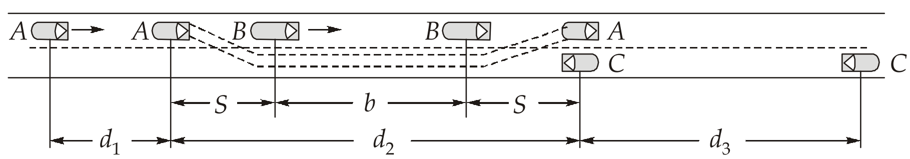
$$V_1^2 - V_2^2 = 2gfL_1$$

$$\Rightarrow \quad V_1 = \sqrt{(21.26)^2 + (2 \times 9.81 \times 0.6 \times 50)}$$

$$\Rightarrow \quad V_1 = 32.26 \text{ m/s}$$

Q.1 (b) Solution:

(i)



Overtaking manoeuvre

Overtaking sight distance is given by

$$\text{OSD} = d_1 + d_2 + d_3$$

$$V_A = 80 \text{ kmph}$$

$$\Rightarrow \quad V_A = 80 \times \frac{5}{18} \text{ m/s} = 22.22 \text{ m/s}$$

$$V_B = 50 \text{ kmph} = 50 \times \frac{5}{18} \text{ m/s} = 13.89 \text{ m/s}$$

$$\text{Acceleration, } a = 2.5 \text{ kmph per second}$$

$$\Rightarrow \quad a = 2.5 \times \frac{5}{18} = 0.694 \text{ m/s per sec.}$$

$$\text{Reaction time, } t = 2 \text{ sec}$$

$$\text{Spacing between vehicles, } S = 16 \text{ m}$$

$$d_1 = V_B t = 13.89 \times 2 = 27.78 \text{ m}$$

$$T = \sqrt{\frac{4S}{a}} = \sqrt{\frac{4 \times 16}{0.694}} = 9.60 \text{ sec}$$

Now,

$$d_2 = V_B \times T + 2S = 13.89 \times 9.6 + 2 \times 16 = 165.34 \text{ m}$$

$$d_3 = V_C T = 22.22 \times 9.6 = 213.31 \text{ m} \quad (\because V_C = V_A)$$

$$\text{Overtaking sight distance} = \text{OSD} = d_1 + d_2 + d_3$$

$$= 27.78 + 165.34 + 213.31 = 406.43 \text{ m}$$

(ii)

In the construction of WBM roads, following steps are followed:

(i) Preparation of foundation for receiving the WBM course. The foundation layer, i.e., subgrade, sub-base or base course is prepared at required grade and the surface is moistened.

(ii) Provision for lateral confinement may be done by constructing shoulders of thickness equal to that of compacted WBM layer.

(iii) Spreading of coarse aggregates uniformly on the prepared foundation.

(iv) Rolling is started from the edges and then gradually shifted towards the centre line.

(v) Screenings are applied gradually over the surface to fill the intersections.

(vi) Sprinkling and grouting with water, to swept the screenings into the voids.

(vii) After the application of binding material in successive layers, WBM is allowed to set over-night. Next day 'hungry' spots are filled with screenings and rolled.

Advantages of WBM:

(i) Design is simple.

(ii) No need of skilled workers.

(iii) Can be constructed using locally available materials.

(iv) Most economical and hence suitable in rural areas.

Disadvantages of WBM:

(i) WBM roads get damaged more frequently due to heavy and mixed traffic.

(ii) In dry weather dust is formed which creates nuisance.

(iv) WBM roads are pervious in nature, so these cannot be used in heavy rainfall areas.

Q.1 (c) Solution:

Basic runway length, L = 1900 m

Elevation of airport site = 600 m

Monthly mean of average daily temperature for the hottest month of the year,

$$T_a = 16°\text{C}$$

Monthly mean of maximum dairy temperature for the same month,

$$T_m = 21°\text{C}$$

Effective gradient, g = 0.6%

Correction for elevation:

Correction for elevation as recommended by ICAO. is 7% per 300 m elevation

Therefore, Correction $= \frac{7}{100} \times \frac{\text{Elevation}}{300} \times L$

$\Rightarrow$ Correction $= \frac{7}{100} \times \frac{600}{300} \times 1900 = 266\,\text{m}$

$\therefore$ Corrected length, $L' = L + 266$

$\Rightarrow$ $L' = 1900 + 266$

$\Rightarrow$ $L' = 2166$ m

Correction for temperature:

Standard atmospheric temperature at given elevation,

$$T_s = 15 - 0.0065 \times 600$$
$$= 11.1°\text{C}$$

[Temperature gradient of standard temperature is – 0.0065°C/m and standard temperature at mean sea level is 15°C]

Airport reference temperature, $T_R = T_a + \frac{T_m - T_a}{3}$

$\Rightarrow$ $T_R = 16 + \frac{21 - 16}{3}$

$T_R = 17.67°\text{C}$

Rise in temperature $= T_R - T_S$
$= 17.67 - 11.1$
$= 6.57°\text{C}$

As per ICAO, correction for temperature is 1% for every 1°C rise in temperature.

$\therefore$ Correction $= \left(\frac{1}{100}\right) \times \left(\frac{\text{Rise in temperature}}{1}\right) \times L'$

where, L' = Runway length after correction for elevation is applied

$\therefore$ Correction $= \frac{1}{100} \times 6.57 \times 2166 = 142.3062$ m

$\therefore$ Corrected length, $L = 2166 + 142.3062 = 2308.306$ m

Check:

As per ICAO, total correction for elevation plus temperature should not exceed 35% of basic runway length. Total correction for elevation and temperature

$= 266 + 142.3062 = 408.3062$ m

Total correction in percentage $= \frac{408.3062}{1900} \times 100 = 21.49\% < 35\%$ (OK)

Correction for gradient:

FAA recommends that runway length after having been corrected for elevation and temperature should be further be increased at the rate of 20% for every 1% of effective gradient.

$\therefore$ Correction for gradient $= \frac{20}{100} \times g \times L$

$\therefore$ Correction $= \frac{20}{100} \times 0.6 \times 2308.306 = 276.997 \text{ m} \simeq 277 \text{ m}$

$\therefore$ Final runway length = L + 277 = 2585.3 m

Q.1 (d) Solution:

Given: Number of wagons = 20

Total weight of wagons = 20 × 18 = 360 tonnes

Weight of locomotive = 120 tonnes

Tractive effort = 15 tonnes

Rolling resistance of wagon = 2.5 kg/tonne

Rolling resistance of locomotive = 3.5 kg/tonne

Let, steepest gradient is 1 in 'G'.

Resistance dependent on speed = 2.65 tonnes

Now,

Total train resistance = Rolling resistance (R_1) + Resistance dependent on speed (R_2) + Resistance due to gradient (R_3) + Atmospheric resistance (R_4) ...(i)

Rolling resistance, R_1 = 2.5 × 360 + 3.5 × 120 = 1320 kg = 1.32 tonne

Resistance dependent on speed, R_2 = 2.65 tonne (given)

Atmospheric resistance, R_4 = 0.0000006 WV^2

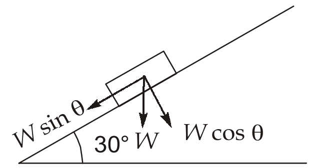
where W = weight of whole train (in tonnes) i.e. wagon + locomotive

$\Rightarrow$ W = 360 + 120 = 480 tonnes

V = Velocity in kmph = 50 kmph (given)

$\therefore$ R_4 = 0.0000006 × 480 × 50^2 = 0.72 tonne

Resistance due to gradient, R_3



$$\Rightarrow \quad R_3 = W\sin\theta$$

$$\sin\theta = \tan\theta = \frac{1}{G} \quad (\because \theta \text{ is very small})$$

$$\therefore \quad R_3 = \frac{W}{G} = \frac{480}{G}$$

Putting values of R_1, R_2, R_3 and R_4 in equation (i), we get

$$\text{Total train resistance} = 1.32 + 2.65 + \frac{480}{G} + 0.72$$

$$= \left(4.69 + \frac{480}{G}\right) \text{tonnes}$$

In order to move the train, tractive effort must be equal to or greater than total train resistance

i.e.,
$$\text{Tractive effort} \geq \left(4.69 + \frac{480}{G}\right)$$

To find maximum value of gradient we must consider limiting case, i.e.,

$$\text{Tractive effort} \geq 4.69 + \frac{480}{G}$$

$$\Rightarrow \quad 15 \geq 4.69 + \frac{480}{G}$$

$$\Rightarrow \quad G \geq 46.56$$

Steepest gradient for given conditions will be 1 in 46.56.

Q.1 (e) Solution:

(i)

Theoretical specific gravity of the mixture,

$$G_t = \frac{W_1 + W_2 + W_3 + W_4 + W_5}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_4}{G_4} + \frac{W_5}{G_5}}$$

$$\Rightarrow \quad G_t = \frac{800 + 1200 + 350 + 150 + 100}{\frac{800}{2.62} + \frac{1200}{2.52} + \frac{350}{2.40} + \frac{150}{2.42} + \frac{100}{1.042}} = 2.3956$$

Mass specific gravity of mixture,

$$G_m = \frac{\text{Weight of Marshall specimen}}{\text{Volume of Marshall specimen}} = \frac{1100}{475} = 2.316$$

1. Percentage air voids $= \dfrac{G_t - G_m}{G_t} \times 100$

$$\Rightarrow \quad V_v = \frac{2.3956 - 2.316}{2.3956} \times 100 = 3.323\%$$

2. Percentage bitumen by volume $= \dfrac{G_m}{G_b} \times \dfrac{W_b}{W_{\text{total}}} \times 100$

$$\Rightarrow \quad V_b = \frac{2.316}{1.042} \times \frac{100}{(800+1200+350+150+100)} \times 100 = 8.548\%$$

3. Percentage voids in mineral aggregate.

$$\text{VMA} = V_v + V_b = 3.323 + 8.548 = 11.871\%$$

(ii)

Diamond crossing:

- It consists of two acute angle crossings, two obtuse angle crossings and four check rails.
- Indian Standard specifies the flattest diamond as 1 in 10 for broad gauge and 1 in $8\frac{1}{2}$ for other gauges.
- We have four crossings, so we have wing rails provided at this location.
- At diamond crossing, the train cannot change its direction.
- The biggest disadvantage with diamond crossing is that only straight directional movement is allowed.

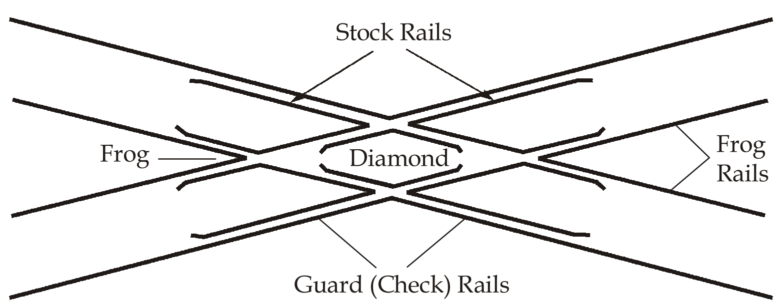


Fig. Diamond Crossing

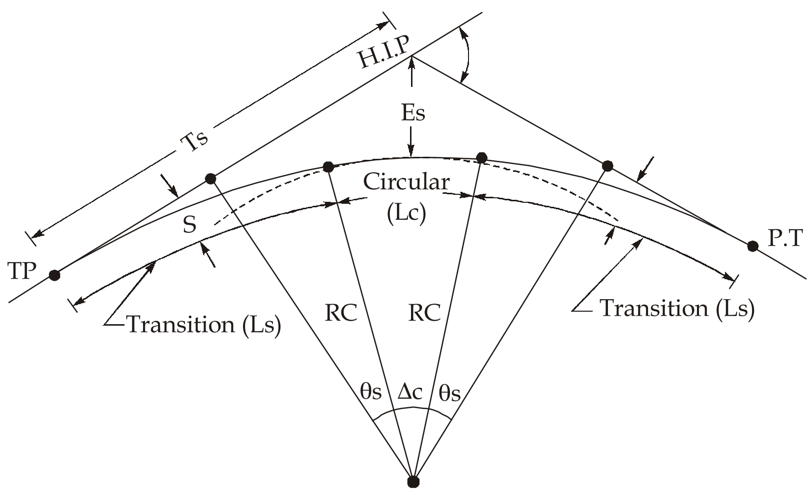
Salient features of different parts of the crossing are :

- It consist of two acute angle crossings (α), two obtuse angle crossings (β) and four check rails.

- The length of the gap betwen two noses of an obtuse crossing increases as the acute angle of crossing decreases.
- As per Indian Standards, the limit of flattest diamond is 1 in 10 for broad-gauge and 1 in $8\frac{1}{2}$ for other gauges. Crossing of tracks at sharper angles to this limit is undesirable.

Q.2 (a) Solution:

(i)



Tangent point	T.P.P.T.
Horizontal intersection point	H.I.P.
Total deviation angle	Δ
Deviation and central angle of circular arc	Δc
Deviation angle of transition curve	Δs
Radius of circular curve	Rc
Shift	s
Tangent distance	Ts
Length of transition	Ls
Length of circular curve	Lc

Given: Radius of curve, R = 60 m

- $e = 0.07$
- Rate of attainment of super-elevation = 1 in 60. $\Rightarrow$ $N = 60$
- $C = \frac{80}{75+V}$, subject to a maximum of 0.8 and a minimum of 0.5.

  where: V = speed of vehicle in km/hr
- Rotation of super-elevation about pavement centre line.

1. Length of transition curve for satisfactory rate of change of centrifugal acceleration

$$L_S = \frac{v^3}{CR} = \frac{0.0215V^3}{CR}$$

where;
$$C = \frac{80}{75+V} = \frac{80}{75+40} = 0.70$$

$\therefore$
$$L_S = \frac{0.0215\times 40\times 40\times 40}{0.70\times 60} = 32.8\,\text{m} \quad \text{...(i)}$$

Now, $e = \frac{(0.75 \times V)^2}{127R} = \frac{(0.75 \times 40)^2}{127 \times 60} = 0.12 > 0.07$

This is high and should be restricted to 0.07 i.e. $e = 0.07$

Extra widening on curve $= \frac{nl^2}{2R} + \frac{V}{9.5 \times \sqrt{R}}$ Assume $l = 6$ m

$= 2 \times \frac{6^2}{2 \times 60} + \frac{40}{9.5 \times \sqrt{60}} = 1.1435\text{m} \simeq 1.144\text{m}$

Total pavement width = 7.0 + 1.144 = 8.144 m

Total raising of pavement = 0.07 × 8.144 = 0.57 m

2. Assuming that raising of super-elevation is done by rotation about centre-line,

Length of transition curve $= \frac{0.57}{2} \times 60 = 17.1\,\text{m}$ ...(ii)

3. As per IRC for snow bound region, $L_s = \left(\frac{V^2}{R}\right) = \frac{40^2}{60} = 26.67\,\text{m}$ ...(iii)

$$L_{TC} = \text{Max.}\begin{cases} 32.8\text{ m} \\ 17.1\text{ m} \\ 26.67\text{ m} \end{cases}$$

$\Rightarrow$ $L_{TC} = 32.8$ m

Deflection angle, $\Delta = 60°$

Shift, $s = \frac{L_{TC}^2}{24R} = \frac{32.8^2}{24 \times 60} = 0.75\,\text{m}$

Tangent length, $T_s = \frac{L_{TC}}{2} + (R+s)\tan\frac{\Delta}{2} = \frac{32.8}{2} + (60+0.75)\tan\frac{60}{2}$

$\Rightarrow$ $T_s = 51.47$ m

Now, $\theta = \frac{L_{TC}}{2R} = \frac{32.8}{2 \times 60} \times \frac{180}{\pi} = 15.66°$

$\therefore$ $\theta_s = 60° - 2 \times 15.66° = 60 - 31.32 = 28.68°$

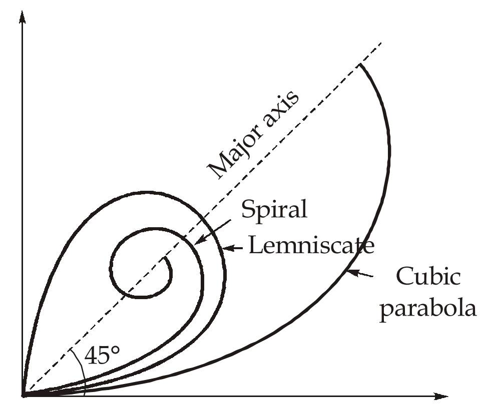
Length of circular curve $= \frac{2\pi R}{360} \times 28.68 = \frac{2\pi \times 60 \times 28.68}{360} = 30.04\,\text{m}$

$\therefore$ Total length of curve = 30.04 + 2 × 32.8 = 95.64 m

(ii)

The different types of curve that can be adopted as shape of transition curves are :

1. Spiral
2. Lemniscate
3. Cubic parabola



Types of transition curves

General shapes of these three curves are shown in figure. All the three curves follow almost the same path upto deflection angle of 4° and practically there is no significance even upto 9°. The characteristics of these curves is that their radii decrease as length increase. But rate of change of radius and consequently rate of change of centrifugal acceleration is not constant in case of lemniscate and cubic parabola, especially at higher deflection angles. In spiral curve, radius decreases constantly as length increases. Hence, it is the recommended shape for transition curve by IRC. Another reason for spiral shape being adopted as transition curve is geometric property of spiral which makes calculation and setting of transition curve very easy.

Q.2 (b) Solution:

(i)

Given: $q_A = 400$ PCU/hr, $q_B = 250$ PCU/hr

$S_A = 1250$ PCU/hr, $S_B = 1000$ PCU/hr

Loss time, $L = 2n + R$

$\Rightarrow$ $L = 2 \times 2 + 12 = 16$ sec

$$Y = y_A + y_B = \frac{q_A}{s_A} + \frac{q_B}{s_B}$$

$$Y = \frac{400}{1250} + \frac{250}{1000} = 0.57$$

$$\text{Cycle length, } C_0 = \frac{1.5L + 5}{1 - Y} = \frac{1.5 \times 16 + 5}{1 - 0.57}$$

$\Rightarrow \quad C_0 = 67.44$ sec

Effective green time for road A

$$G_A = \frac{y_B}{Y}(C_0 - L) = \frac{0.32}{0.57}(67.44 - 16)$$

$\Rightarrow \quad G_A = 28.88 \simeq 29$ sec

Effective green time for road B

$$G_B = \frac{y_B}{Y}(C_0 - L) = \frac{0.25}{0.57}(67.44 - 16)$$

$\Rightarrow \quad G_B = 22.56 \simeq 23$ sec

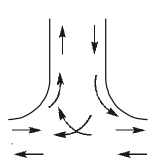
$\therefore \quad$ Total cycle length = (29 + 2) + (23 + 2) + 12 = 68 sec

G_1	t_{SL}	All red	R_1		
29 sec	2 sec	12 sec	25 sec		= 68 sec
31 sec		12 sec	23 sec	2 sec	= 68 sec
R_2			G_2	t_{sL}	

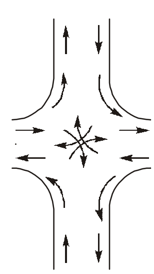
(ii)

Unchannelized intersections : The intersection area is paved and these is absolutely no restriction to vehicles to use part of intersection area.

Hence, the unchannelized intersections are the lowest class of intersection, easiest in design, but most complex in traffic operations resulting in maximum conflict area and more number of accidents unless controlled by traffic signals or traffic police.

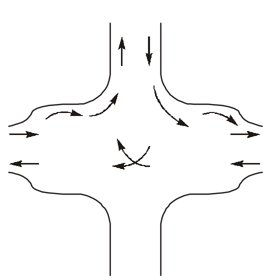


Tee (Plain)

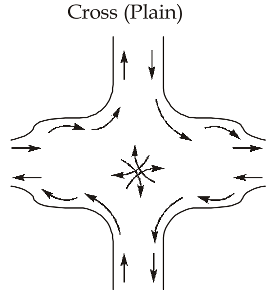


Cross (Plain)

Skew (Plain)

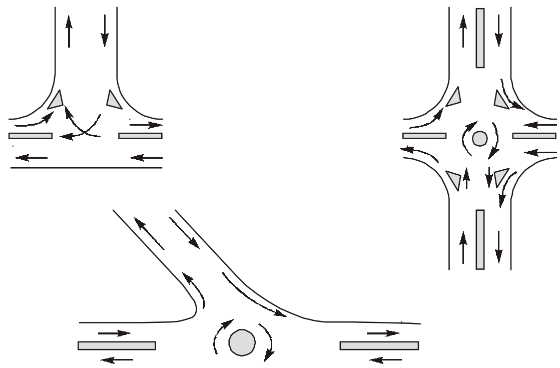


Tee (Flared)



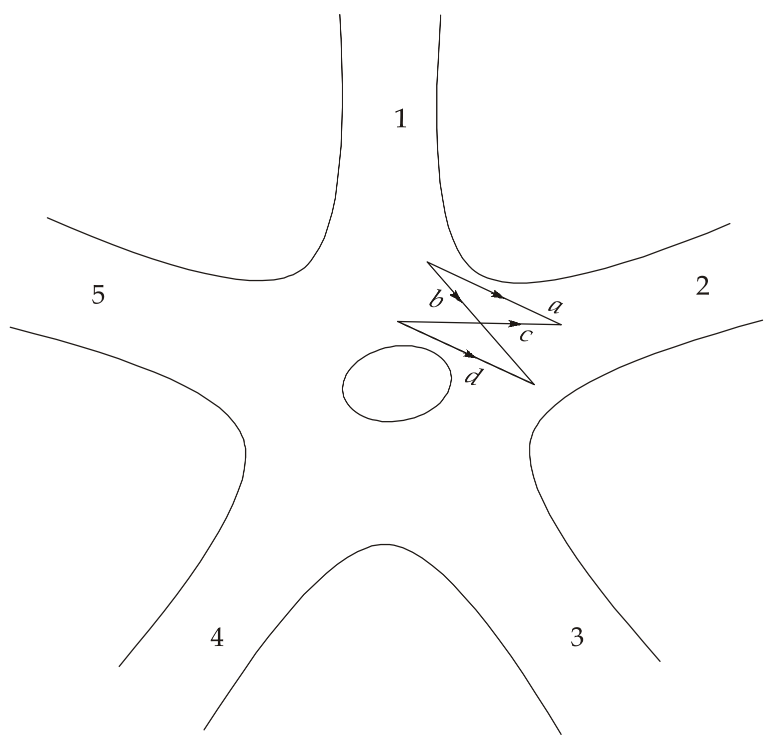
Cross (Flared)

Channelized intersections : Channelized intersection is achieved by introducing islands into the intersectional area, thus reducing the total conflicting area available in the unchannelized intersections. The radius of the entrance and exit curves and the area are suitably designed to accommodate the channelizing islands of proper shape and size.



Channelized intersections

Q.2 (c) Solution:



Calculation for proportioning ratio (p),

$$p = \frac{\text{Crossing/Weaving Traffic}}{\text{Total Traffic}}$$

$\Rightarrow \quad p = \dfrac{b+c}{a+b+c+d}$ (proportioning ratio always lies between 0.4 and 1)

Where, a = Left turning traffic moving along left extreme lane

b = Crossing/Weaving traffic turning towards right while entering to the rotary

c = Crossing/Weaving traffic turning towards left while leaving rotary

d = Right turning traffic moving along right extreme lane

$a = V_{12} = 37$

$b = V_{13} + V_{14} + V_{15} = 303 + 64 + 52 = 419$

$c = V_{52} + V_{42} + V_{32} = 132 + 54 + 122 = 308$

$d = V_{53} + V_{54} + V_{43} = 62 + 15 + 18 = 95$

$$\therefore \quad p = \frac{b+c}{a+b+c+d} = \frac{419+308}{37+419+308+95} = 0.8463$$

As per IRC,

Weaving length, L = 50 m

Width of carriageway at entry and exit is 10 m.

$$\text{Width of weaving section, } W = \frac{e_1+e_2}{2} + 3.5 = \frac{10+10}{2} + 3.5 = 13.5 \text{ m}$$

$$e = \frac{e_1+e_2}{2} = 10 \text{ m}$$

$$\text{Capacity of rotary, } Q_p = \frac{280W\left(1+\frac{e}{W}\right)\left(1-\frac{P}{3}\right)}{\left(1+\frac{W}{L}\right)}$$

$$= \frac{280\times 13.5\left(1+\frac{10}{13.5}\right)\left(1-\frac{0.8463}{3}\right)}{\left(1+\frac{13.5}{50}\right)}$$

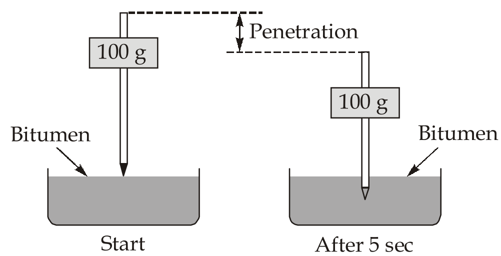
$$\Rightarrow \quad Q_p = 3719.5 \simeq 3720 \text{ PCU per hour}$$

Q.3 (a) Solution:

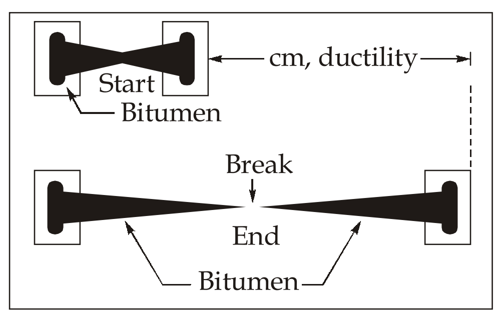
(i)

Tests on bitumen

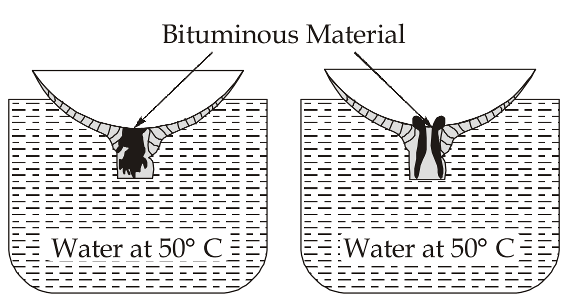
1. **Penetration Test:** Hardness of bitumen is obtained by the penetration test. It measures the distance upto which a standard blunt pointed needle will vertically penetrate a sample of bitumen material at 27°C, the load being 100g and time of application of load being 5 seconds.



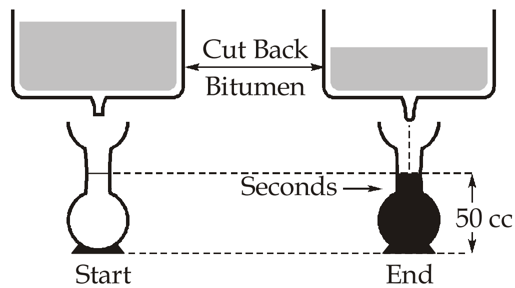
2. **Ductility Test:** Bitumen should be sufficiently ductile and capable of being stretched without breaking. Ductility is measured as the distance in cm to which a standard briquette of size 10 × 10 mm can be stretched before the thread breaks at a standard temperature of 27°C and the rate of elongation is 50 mm per minute.



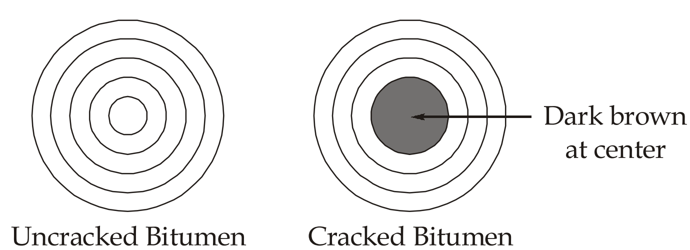
3. **Float Test:** This test is used to measure the consistency of bitumen for which penetration and viscosity test cannot be used. Higher the float value, the stiffer is the bitumen.



4. **Viscosity Test:** Viscosity is the inverse of fluidity and it is a measure of resistance to flow. The viscosity of liquid bitumen is measured by efflux viscometer. In this test, viscosity is measured by time taken in seconds by 50 m*l* of bitumen to flow from a container through a specified orifice of size 10 mm under standard test conditions and temperature of 25°C.



5. **Solubility Test:** This test is used to measure the quantity of impurity present in the bitumen. Pure bitumen is soluble in carbon disulphide (CS_2) and carbon tetrachloride (CCl_4) while the impurities are insoluble.
6. **Softening Point Test:** The softening point is the temperature at which the substance attains a particular degree of softening under specified condition of test. Apparatus used to determine softening point of bitumen is RING AND BALL assembly. A steel ball is placed over the bitumen sample and then liquid is heated at the rate of 5°C per minute. The temperature at which the softened bitumen touches the metal placed at a particular specified distance below the ring is taken as softening point of bitumen.
7. **Spot Test:** It is used to detect whether the bitumen is cracked or not. In this test 2g of bitumen is dissolved in 10 m*l* of naptha. A drop of this solution is taken on a filter paper. If the stain of the spot on the paper is uniform in colour, the bitumen is accepted as uncracked but if the spots form dark brown or black circle in the centre, the bitumen is considered to be over heated or cracked.



8. **Loss on Heating Test:** When bitumen is heated, it loses the volatiles and gets hardened. This test is conducted by an accelerated heat test. 50 g of sample is heated at a temperature of 163°C for 5 hours in a special oven designed for this test. Not more than 1% loss in weight is desirable. Lesser the loss on heating, the better is the bitumen.

9. **Water Content Test:** It is desirable that the bitumen contains minimum water content to prevent foaming of the bitumen when it is heated above the boiling point of water. The water content in bitumen is determined by mixing a known weight of bitumen sample in pure petroleum distillate which is free from water, heating and distilling off the water. The weight of water condensed and collected is expressed as percentage by weight of original sample. The maximum water content in bitumen should not exceed 0.2 percent by weight.

(ii)

Joints form the break in the cement concrete pavement and these allow the infiltration of water and ingress of stone grits. The infiltration of water damages the soil subgrade and gives rise to the phenomenon known as mud pumping especially if the subgrade is of clayey soil. If stone grit enters into the joint space, the effective joint width gets reduced and faults like spalling of joint edges take place. In extreme cases the blowups take place. Thus the joint spaces are filled with compressible filler materials and the top of the joints are sealed using a sealer.

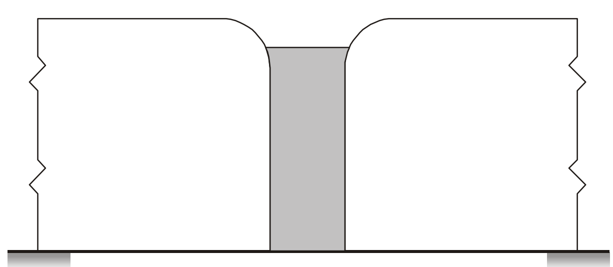
Joint Filler : Joint filler should possess the following properties:

(a) Compressibility

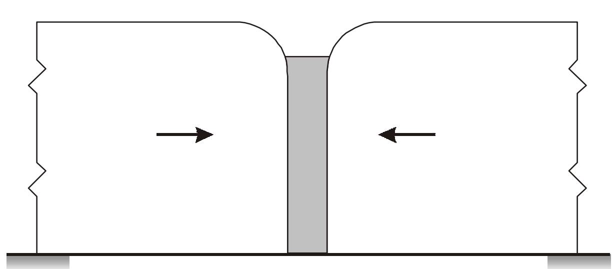
(b) Elasticity

(c) Durability

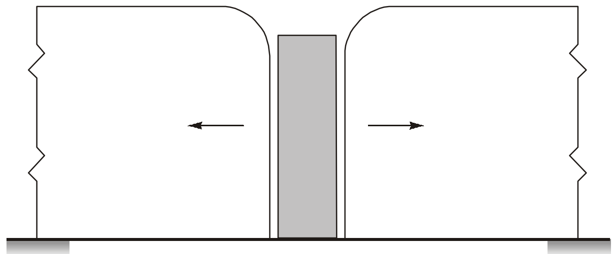
Thus the filler material should be compressible and elastic i.e., it should be able to get compressed and on release of the compression, should be able to regain its shape and be elastic.



(a) At the time of construction



(b) During summer



(c) During winter

Above figures explain the functioning of the filler during changes in seasons. The filler is placed during construction as in figure (a) and when the summer approaches, the pavement expands and the joint gap thereby reduces as shown in figure (b); at this time, the filler is compressed. During winters that follows in a cycle, the slab edges move back and if the filler is inelastic, there will be formation of gaps which are detrimental and in fact render the joint with a gap.

Types of joint filler: Following are the few types of joints filler materials:

(a) Soft wood

(b) Impregnated fibre board

(c) Cork or cork bound with bitumen

Thus pre-formed fillers are made from fibres of soft board, or fibre or cook. It is required that the performed strips of these materials are properly bonded together with bitumen. Various properties required for the satisfactory filler materials are as given below. These are based on IRC recommendations.

(i) Compression : The pressure required to compress the specimen to 50 percent of its original thickness should be between 7 to 53 kg/cm^2. Materials should not show loss of its original weight by more than 3 percent.

(ii) Recovery : Specimen should recover at least 70 percent of original thickness after the load is applied and released after one hour at the end of third application of load.

(iii) Extrusion : The extrusion of one edge should not be more than 6.5 mm when the specimen is compressed to 50 percent of its thickness with these edges restrained.

The specimen should not show disintegration of fibres when tested. Non-extruding and resilient type bitumen-impregnated fibre may be preferred as joint filler material.

Joint Sealer : For effective sealing of joint for a long period, it is essential that the sealing compounds possess the following properties:

(a) Adhesion to cement concrete edges.

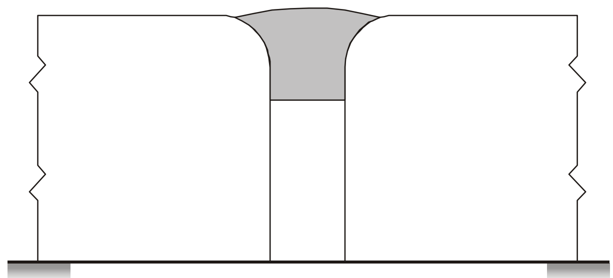
(b) Extensibility without fracture.

(c) Resistance to ingress of grit.

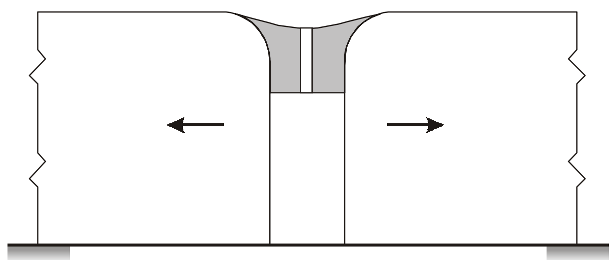
(d) Durability

Different types of sealing compounds are in use. Bitumen is used either alone or with mineral filler as a sealing compound. Rubber-bitumen compounds are also used for the purpose. Air-blown bitumen may be used with advantages, as they are less susceptible to the temperature changes.

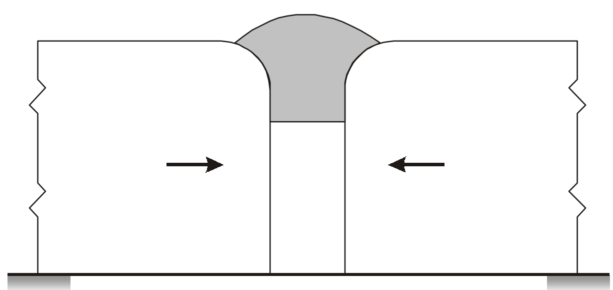
The functioning of sealer is explained through below figure.



(d) At the time of construction



(e) During winter



(f) During summer

The proper positioning of sealer is shown in figure (d). As the winter approaches, the slab edge move apart causing an extension in the sealer material.

At this instance, the sealer forms a thin film and depending on its extensibility, either it maintains its continuity or it breaks. Once the sealer breaks the chains of maintenance, problems show up at the joints or slab edges as shown in figure (e).

Contrary to this, in summer depending upon the flow characteristics of the sealer material, the bitumen would flow and spread around the joint to spoil the appearance of the cement concrete pavement and also decreases the smooth riding quality of surface. This will render the film thickness unsuitable for the subsequent cyclic variation during winter.

The sealing compound should be

(i) Impermeable

(ii) Flexible to accommodate the slab movements

(iii) Not flow in hot season or become brittle in cold season

Q.3 (b) Solution:

(i)

We know that $v^2 = u^2 - 2aS$

where v is the final speed of the vehicle in m/s

u is the initial speed of the vehicle in m/s

a is the deceleration of the vehicle in m/s^2

S is the braking distance in m

Here $v = 0$, $u = 0.278 \times 50 = 13.9$ m/s, $a = 3$ m/s^2

$$\therefore \quad v^2 = u^2 - 2aS$$

$$\Rightarrow \quad 0 = (13.9)^2 - 2 \times 3 \times S$$

$$\Rightarrow \quad S = \frac{(13.9)^2}{6}$$

$$\Rightarrow \quad S = 32.20 \text{ m}$$

Distance travelled during the reaction time of driver is given by

$$S' = ut$$

where 't' is the perception reaction time in seconds and 'u' is the speed of vehicle in m/s

Here $u = 0.278 \times 50$ m/s and $t = 1.5$ sec

$$\therefore \quad S' = 0.278 \times 50 \times 1.5 = 20.85 \text{ m}$$

$$\therefore \quad \text{Total distance} = S + S' = 32.20 + 20.85 = 53.05 \text{ m}$$

Now time required to stop the vehicle

$$= \frac{v-u}{a} = \frac{0-(0.278 \times 50)}{-3} = 4.63 \text{ sec}$$

$\therefore$ Total time required to stop the vehicle

$$= 1.5 + 4.63 = 6.13 \text{ sec}$$

The vehicle which has travelled a distance of 53.05 m to stop, if decides to cross the intersection, then total distance to be travelled will be

$$= 53.05 + \text{Intersection width} + \text{Car length}$$

$$= 53.05 + 15 + 4.6 = 72.65 \text{ m}$$

Thus time required to cross the intersection with a speed to 50 kmph will be

$$= \frac{72.65}{0.278 \times 50} = 5.23 \text{ sec}$$

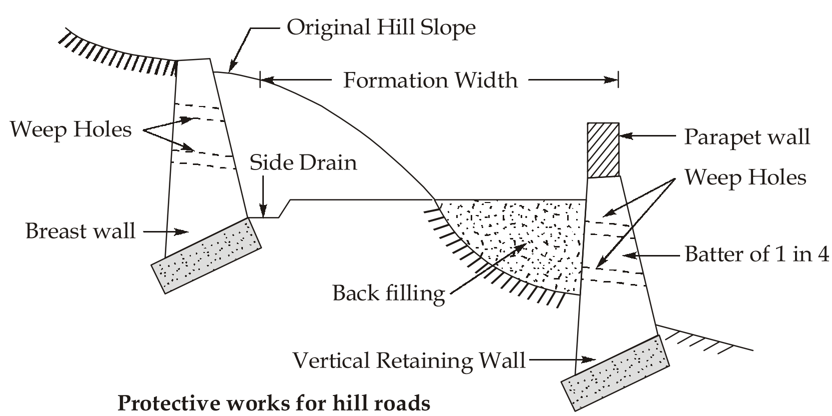
Now we have the time to stop the vehicle = 6.13 sec and time required to cross the intersection = 5.23 sec

Both these times are more than the amber duration i.e. 4.5 sec, hence the driver's claim is correct.

(ii)

Protective works for hill roads : In order to give stability and a sense of safety to the hill roads, the following three types of protective works are provided:

1. **Retaining walls :** The formation of a hill road is generally prepared by the excavation of the hill and the material which is excavated is dumped or stacked along the cut portion. The retaining wall is constructed on the valley side of the roadway to prevent the sliding of back filling as shown in figure below. Thus, the main function of a retaining wall for hill roads is to retain the back filling and it is provided at the following places:
   - At all re-entrant curves;
   - At places where the hill section is partly in cutting and partly in embankment.
   - At places where the road crosses a drainage.



Protective works for hill roads

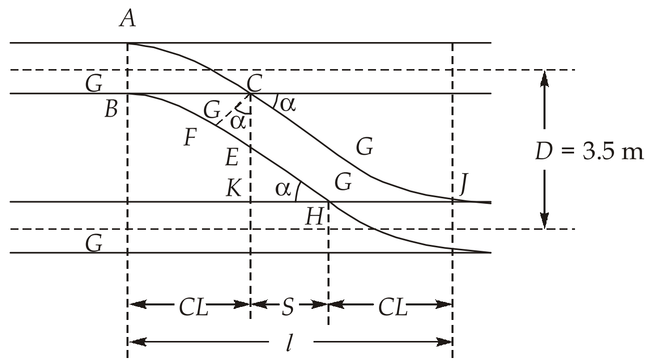
2. **Breast walls :** The cut portion of hill is to be prevented from sliding and the wall which is constructed for this purpose is known as breast wall. The weep holes, as in case of retaining walls, are provided with slope outwards and sometimes, the vertical gutters connecting the weep holes to the side drain are provided.
3. **Parapet walls :** The parapet walls are usually provided all along the valley side of the road except where the hill slope is very gentle. They are constructed immediately above the retaining wall and they prevent the wheels of the vehicles from coming on the retaining wall. It is to be noted that the construction of a parapet wall merely gives a sense of security to the driver and the passengers and it is very rare unless constructed in stone masonry with cement mortar that they act as protecting structures in the event of an accident.

Q.3 (c) Solution:

(i)

Given, $n = 12, G = 1.0$ m

and $D = 3.5$ m



1. Intermediate straight distance, i.e.

$$S = (D-G)N - G\sqrt{1+N^2}$$

$$\Rightarrow \quad S = (3.5-1)12 - 1\sqrt{1+12^2}$$

$$\Rightarrow \quad S = 30 - 12.04 = 17.96 \text{ m}$$

2. Over-all length of the cross-over, i.e.,

$$l = 2CL + S = 4GN + S$$

$$\Rightarrow \quad l = (4 \times 1 \times 12 + 17.96) \text{ m}$$

$$= 48 + 17.96 = 65.96 \text{ m}$$

(ii)

Given: Turn off speed, $V = 65$ kmph

Coefficient of lateral friction, $f = 0.13$

(i) Turning radius based on lateral friction;

$$R = \frac{V^2}{125f} = \frac{65^2}{125 \times 0.13} = 260 \text{ m}$$

(ii) Turning radius based on Horonjeff's equation:

$$R = \frac{0.388\,W^2}{\frac{T}{2} - S}$$

$$S = 6 + \frac{7.0}{2} = 9.5 \text{ m}$$

$$\therefore \qquad R = \frac{0.388 \times 18^2}{\left(\frac{22.5}{2}\right) - 9.5} \simeq 72 \text{ m}$$

(iii) For super sonic aircrafts, minimum radius is taken as 180 m.

$\therefore$ Taxiway turning radius = Maximum of (i), (ii) and (iii) = 260 m

Q.4 (a) Solution:

(i)

Given: Wheel load, P = 4100 kg

Modulus of elasticity of cement concrete,

E = 3.3×10^5 kg/cm^2

Pavement thickness, h = 18 cm

Poisson's ratio of concrete, μ = 0.15

Modulus of subgrade reaction, K = 25 kg/cm^3

Radius of contact area, a = 12 cm

$$\text{Radius of relative stiffness, } l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{1/4}$$

$$= \left[\frac{3.3 \times 10^5 \times 18^3}{12 \times 25(1-0.15^2)}\right]^{1/4} = 50.61 \text{ cm}$$

Radius of equivalent distribution of pressure is given by

$$b = \sqrt{1.6a^2 + h^2} - 0.675h$$

Since, $$\frac{a}{h} = \frac{12}{18} = 0.67 < 1.724$$

$$b = \sqrt{1.6 \times 12^2 + 18^2} - 0.675 \times 18 = 11.40 \text{ cm}$$

Stress at interior region,

$$S_i = \frac{0.316P}{h^2}\left[4\log_{10}\left(\frac{l}{b}\right) + 1.069\right]$$

$$\Rightarrow \qquad S_i = \frac{0.316 \times 4100}{18^2}\left[4\log_{10}\left(\frac{50.61}{11.40}\right) + 1.069\right]$$

$$= 14.63 \text{ kg/cm}^2$$

$$\text{Stress at edge region, } S_e = \frac{0.572P}{h^2}\left[4\log_{10}\left(\frac{l}{b}\right) + 0.359\right]$$

$$\Rightarrow \qquad S_e = \frac{0.572 \times 4100}{18^2}\left[4\log_{10}\left(\frac{50.61}{11.40}\right) + 0.359\right]$$

$$= 21.34 \text{ kg/cm}^2$$

Stress at corner region, $S_c = \dfrac{3P}{h^2}\left[1 - \left(\dfrac{a\sqrt{2}}{l}\right)^{0.6}\right]$

$$\Rightarrow \qquad S_c = \frac{3 \times 4100}{18^2}\left[1 - \left[\frac{12\sqrt{2}}{50.61}\right]^{0.6}\right] = 18.26 \text{ kg/cm}^2$$

(ii)

1. Some of the failures in flexible pavements are as follows:

(a) Alligator (Map) cracking:

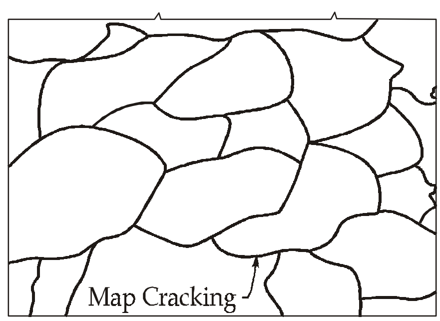
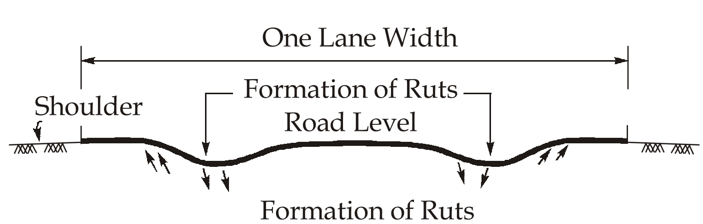


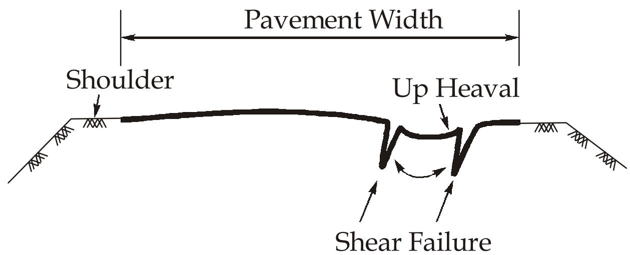
Figure shows the general pattern of alligator cracking of the bituminous surfacing. This is the most common type of failure and occurs due to relative movement of pavement layer materials. This may be caused by the repeated application of heavy wheel loads resulting in fatigue failure or due to moisture variations resulting in swelling and shrinkage of subgrade and other materials.

(b) Consolidation of pavement layers:



Formation of ruts are mainly attributed to the consolidation of one or more layers of pavement. The repeated application of loads along the same wheel path cause cumulative deformation resulting in consolidation deformation.

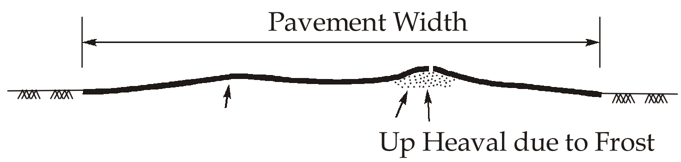
(c) Shear failure and cracking:



Shear Failure Cracking

Shear failures are associated with the inherent weakness of the pavement mixtures, the shearing resistance being low due to inadequate stability or excessively heavy loading. The shear failure causes upheaval of pavement materials by forming a fracture or cracking.

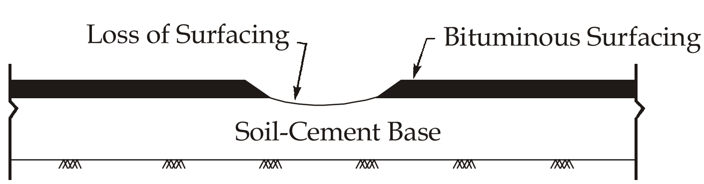
(d) Frost heaving:



Failure due to Frost Heave

Frost heaving are often misunderstood for shear or other types of failures. In case of frost heaving, there is mostly a localized heaving-up of pavement portion depending upon the ground water and climatic conditions. Due to frost action and differential volume changes in subgrade, longitudinal cracking is caused in pavement.

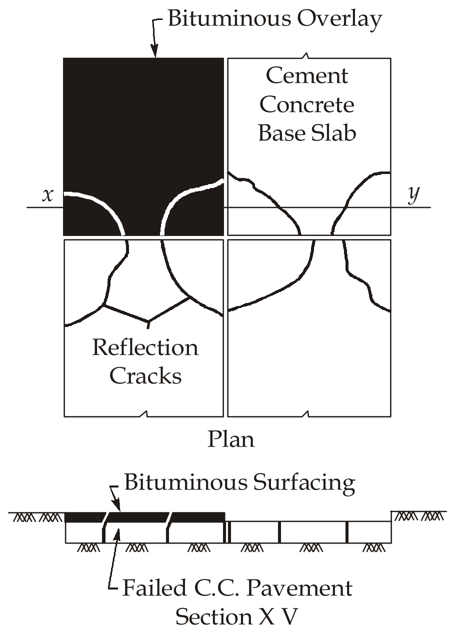
(e) Lack of binding with lower layer:



Failure due to Lack of Binding

Slipping occurs when the surface course is not bound with underlying base. This results in opening up and loss of pavement materials forming patches or pot holes. Such conditions are more frequent in case when the bituminous surfacing is provided over the existing cement concrete base course or soil-cement base course.

(f) Reflection cracking:



Formation of Reflection Cracks

This type of cracking is observed in bituminous overlays provided over existing cement concrete pavements. The crack pattern as existing in cement concrete pavements are mostly reflected on bituminous surfacing in the same pattern.

Q.4 (b) Solution:

(i)

Maximum permissible speed on main line,

$$V_{max} = 70 \text{ kmph}$$

By Martin's formula, allowable speed for main curve of 3°,

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

$$= 4.35\sqrt{\frac{1720}{D^\circ}-67} = 4.35\sqrt{\frac{1720}{3}-67}$$

$$= 97.88 \text{ kmph} > 70 \text{ kmph}$$

Hence, safe.

Theoretical cant required for main line,

$$e_{th} = \frac{GV^2}{127R_{main}} = \frac{1.676\times(70)^2}{127\times\frac{1720}{3}} = 0.1129 \text{ m}$$

$$e_{th} = 11.28 \text{ cm} < 16.5 \text{ cm} \quad \text{(OK)}$$

Maximum cant deficiency for BG track = 7.6 cm

$\therefore$ Actual cant for main track = 11.28 – 7.6

$$e_{Act} = 3.68 \text{ cm}$$

Now for branch track

$$e_{Act} \text{ of branch track} = -e_{Act} \text{ of main track}$$

$$\therefore \quad e_{Act} \text{ of branch track} = -3.68 \text{ cm}$$

Theoretical super elevation for branch track

$$e_{th} = e_{Act} + \text{Cant deficiency}$$
$$= -3.68 + 7.6$$
$$= 3.92 \text{ cm}$$

Maximum permissible speed on branch line

$$e_{th} = \frac{GV_{max}^2}{127R}$$

$$\Rightarrow \quad \frac{3.92}{100} = \frac{1.676 \times (V_{max})^2}{127 \times \frac{1720}{7}}$$

$$\Rightarrow \quad V_{max} = 27.02 \text{ kmph}$$

According to Martin's formula, allowable speed on branch track,

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

$$= 4.35\sqrt{\frac{1720}{7} - 67} = 58.15 \text{ kmph} \qquad \text{OK}$$

So, the restricted maximum speed on branch track = 27.02 kmph, say 25 kmph.

(ii)

Given:

Free mean stream, V_f = 80 km/h

Jam density = 70 veh/km

When, flow velocity, V = 0,

Traffic density = Jam density

Also, when flow velocity = Free mean velocity

Traffic density = 0

Given linear relationship between flow velocity and density

$$V = V_f - \frac{k}{k_j} \times V_f = 80 - \frac{80}{70}k$$

Traffic volume, $q = \text{Velocity } (V) \times \text{Density } (k)$

$$= \left(80 - \frac{80}{70}k\right)k = 80k - \frac{80}{70}k^2$$

For maximum flow, $\frac{\partial q}{\partial k} = 0$

i.e., $80 - 2 \times \frac{80}{70}k = 0$

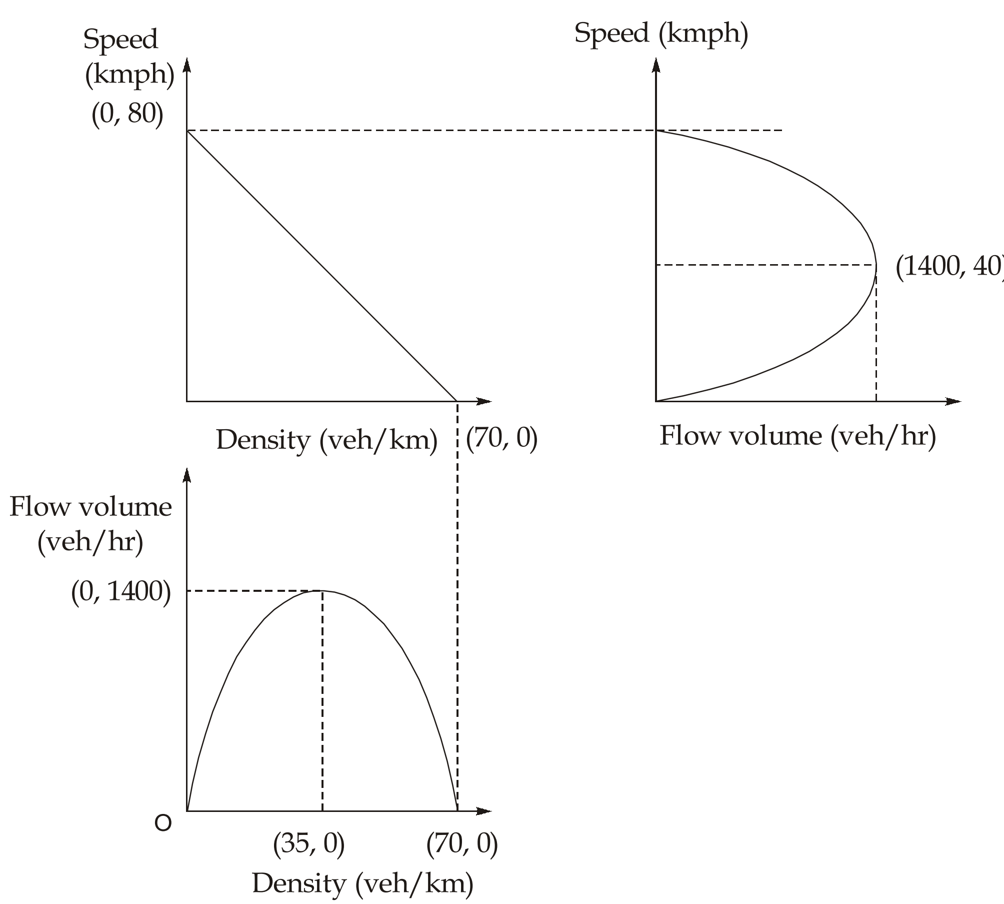
$\Rightarrow$ $k = 35$ veh/km

At maximum flow

Traffic density, $k = 35$ veh/km

Flow speed, $V = 80 - \frac{80}{70} \times 35 = 40$ kmph

Maximum flow, $q_{max} = k\,.V = 35 \times 40 = 1400$ veh/hr



Q.4 (c) Solution:

(i)

Calculation of elastic modulus, E_s for soil subgrade or single layer and rigid circular plate,

$$\Delta = 1.18\frac{pa}{E_s}F_2 \quad \Rightarrow \quad 0.5 = \frac{1.18\times1.25\times15\times1}{E_s}$$

$$F_2 = 1 \text{ (for single layer)}$$

$$\therefore \qquad E_s = 1.18\frac{1.25\times15}{0.5} = 44.25 \text{ kg/cm}^2$$

1. Calculate of elastic modulus ratio of subgrade to pavement *i.e.* $\frac{E_s}{E_p}$

$$\Delta = \frac{1.18pa}{E_s}\times F_2 \quad \Rightarrow \quad 0.5 = \frac{1.18\times5\times15}{44.25}\times F_2$$

$$\Rightarrow \qquad F_2 = \frac{0.5\times44.25}{1.18\times5\times15} = 0.25$$

Using the diagram and reading value of $\frac{E_s}{E_p}$ against $F_2 = 0.25$ and $(h/a) = (15/15) = 1.0$

$$\frac{E_s}{E_p} = \frac{1}{90} \quad \text{(by interpolation between 1/50 and 1/100)}$$

2. Design of flexible pavement for load P = 4100 kg and tyre pressure of 5 kg/cm^2

$$p = 5 \text{ kg/cm}^2$$

$$\therefore \qquad a = \sqrt{\frac{P}{\pi p}} = \sqrt{\frac{4100}{\pi\times5}} = 16.1559 \text{ cm}$$

Deflection for flexible plate (wheel load) is given by:

$$\Delta = \frac{1.5pa}{E_s}\times F_2 \quad \Rightarrow \quad 0.5 = \frac{1.5\times5\times16.1559\times F_2}{44.25}$$

$$\Rightarrow \qquad F_2 = \frac{0.5\times44.25}{1.5\times5\times16.2} = 0.182$$

For $F_2 = 0.182$ and $(E_s/E_p) = (1/90)$ using the diagram in question, $h/a = 1.6$

Therefore pavement thickness 'h' is given by:

$$h = 1.6 \text{ a} = 1.6 \times 16 = 25.6 \text{ cm}$$

(ii)

1 For plain cement concrete slab (without inforcement)

Spacing between contraction joints.

$$L_c = \frac{2S_c}{Wf}\times 10^4 = \frac{2\times 0.8\times 10^4}{2400\times 1.5} = 4.44\,\text{m}$$

2. For reinforced cement concrete slab

Total cross sectional area of steel, A_s in one direction along the slab width

$$A_s = \frac{3.5\times \pi\times 1.0^2}{0.3\times 4} = 9.16\,\text{cm}^2$$

Spacing between contraction joints,

$$L_c = \frac{200S_sA_s}{bhW_f} = \frac{200\times 1200\times 9.16}{3.5\times 20\times 2400\times 1.5} = 8.72\,\text{m}$$

Section B : Environmental Engineering

Q.5 (a) Solution:

Quantity of water to be treated = 40×10^6 liters/day

Quantity of filter alum required per day @ 18 mg/l

$$= \frac{18\times 40\times 10^6}{10^6}kg = 720\ kg.$$

Quantity of filter alum required per year = 720 × 365 = 262.8 tonnes **Ans.**

The chemical reactions that takes place are :

$$Al_2(SO_4)_3\cdot 18\,H_2O + 3\,Ca(HCO_3)_2 \longrightarrow 2Al(OH)_3\downarrow + 3CaSO_4 + 18H_2O + 6CO_2\uparrow$$

$$CaCO_3 + H_2O + CO_2 \longrightarrow Ca(HCO)_2$$

$$CaCO_3 \longrightarrow CaO + CO_2$$

Molecular weight of $Al_2(SO_4)_3\cdot 18H_2O$ = 666 g/mol

Molecular weight of $Ca(HCO_3)_2$ = 162 g/mol

Molecular weight of $CaCO_3$ = 100 g/mol

Molecular weight of CaO = 56 g/mol

It is clear from above that alum requires (3 × 162) parts of natural alkalinity as $Ca(HCO_3)_2$ for every 666 parts of alum. (3 × 162) parts of alkalinity as $Ca(HCO_3)_2$ is equivalent to (3 × 100) parts of alkalinity as $CaCO_3$

∴ Alkalinity required as $CaCO_3$ for the water containing alum as 18 mg/l

$$= \frac{3 \times 100}{666} \times 18 mg/l = 8.108\ mg/l$$

Natural alkalinity available as $CaCO_3$ = 5 mg/l

Additional alkalinity required to be added in the form of lime

$$= 8.108 - 5 = 3.108\ mg/l \text{ as } CaCO_3$$

Now, 100 parts of $CaCO_3$ is produced by 56 parts of CaO

Hence quantity of CaO required

$$= \frac{3.108 \times 56}{100} \text{mg}/l = 1.74 \text{ mg}/l$$

Since quick lime contains 85% CaO, quick lime required = $\frac{1.74}{0.85} = 2.05\ mg/l$

∴ Quantity of lime required.

$$= \frac{2.05 \times 40 \times 10^6}{10^6} kg = 82 \text{ kg/day}$$

∴ Yearly consumption of lime = 82 × 365 kg = 29.93 tonnes. **Ans.**

Q.5 (b) Solution:

1. **Trickling Filter**

Advantages:

(i) Rate of filter loading is high, as they require lesser land area and smaller quantities of filter media for their installation

(ii) Effluent obtained is sufficiently nitrified and stabilized. They can remove about 75% BOD and about 80% of suspended solids.

(iii) Working of trickling filter is simple and does not require any skilled supervision.

(iv) They are flexible in operation and can handle a variety of sewages.

(v) They are self cleaning.

(vi) Mechanical wear and tear is minimal due to less number of equipments.

(vii) Moisture content of sludge obtained is as high as 99%.

Disadvantages:

(i) The head loss through these filters is high, making automatic dosing of the filters necessary.

(ii) Cost of construction of these filters is high.

(iii) These filters cannot treat raw sewage, and primary sedimentation is must.

(iv) These filters pose a number of operational troubles such as fly nuisance, odour nuisance, ponding trouble etc.

2. **Activated sludge process**

Advantages:

(i) Lesser land area is required.
(ii) The head loss in the plant is quite low.
(iii) There is no fly or odour nuisance.
(iv) Capital cost is less
(v) Greater flexibility of operation thereby, permitting control on the quality of effluent.

Disadvantages:

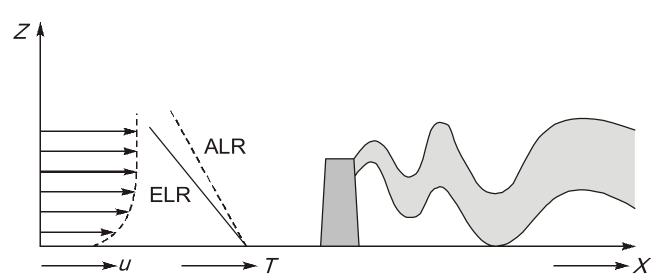
(i) High cost of operation with large power consumption
(ii) A lot of machinery to be handled.
(iii) The sudden change in the quantity and character of sewage may produce adverse effects on the process, thus producing inferior effluent.
(iv) Bulking of sludge is a common trouble, which has to be controlled, especially when industrial waste water with high carbohydrate content or antiseptic properties is present.
(v) The quantity of returned sewage has to be adjusted every time, as and when there is a change in the quantity of sewage flow thus making the operation a little cumbersome.

Q.5 (c) Solution:

Different types of plume behavior are as follows:

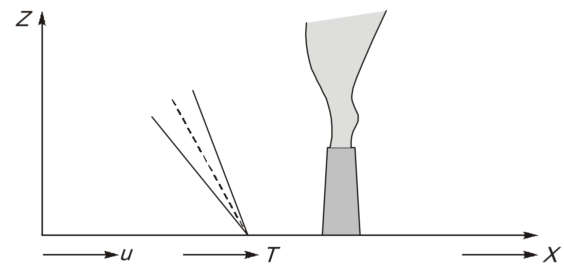
(i) Looping Plume: Under super-adiabatic condition, both upward and downward movement of the plume is possible. Large eddies of a strong wind cause a looping pattern. Although the large eddies tend to disperse pollutants over a wide region, high ground level concentrations may occur close to the stack.

ALR: Adiabatic Lapse rate
ELR : Environmental Lapse Rate



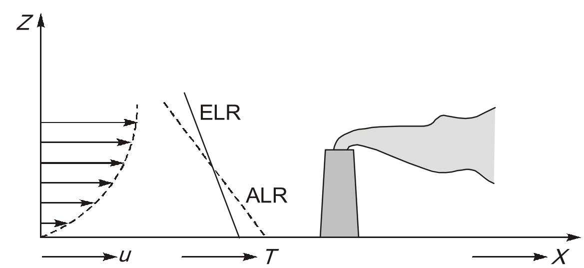
Looping plume

(ii) **Neutral Plume:** Neutral plume is the upward vertical rise of the plume from the stack, which occurs when the environmental lapse rate is equal to or very near to the adiabatic lapse rate. The upward lifting of the plume will continue till it reaches an air of density similar to that of the plume itself.



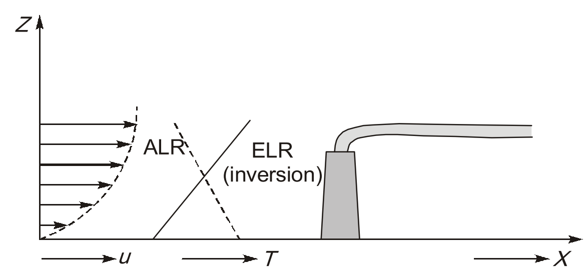
Neutral plume

(iii) **Coning Plume:** A coning plume occurs under essential neutral stability when environmental lapse rate is equal to adiabatic lapse rate and moderate to strong winds occur. The plume enlarges in the shape of a cone. A major part of pollution may be carried fairly far downwind before reaching ground.



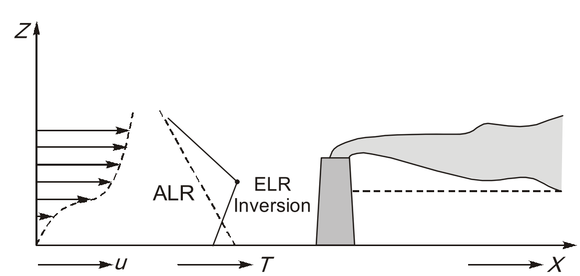
Conning plume

(iv) **Fanning Plume:** A fanning plume occurs in the presence of a negative lapse rate when vertical dispersion is restricted. The pollutants disperse at the stack height, horizontally in the form of a fanning plume.



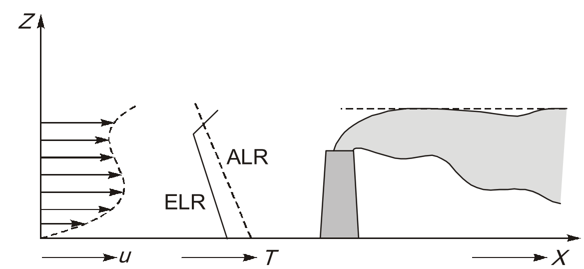
Fanning plume

(v) **Lofting Plume:** When the stack is sufficiently high and the emission is above an inversion layer mixing in the upward direction is uninhibited, but downward motion is restricted. Such lofting plumes do not result in any significant concentration at ground level. However, the pollutants are carried hundreds of kilometers from the source.



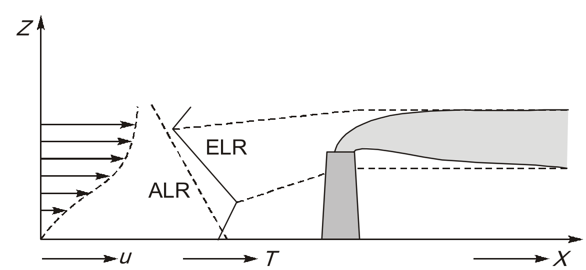
Lofting plume

(vi) Fumigating Plume: When the emission from the stack is under an inversion layer, the movement of the pollutants in the upward direction is restricted. The pollutants move downwards. The resultant fumigation can lead to a high ground level concentration downwind of the stack.



Fumigating plume

(vii) Trapping Plume: When inversion layers exist above the emission source, as well as below the source, then naturally, the emitted plume will neither go up, nor will it go down, and would remain confined between the two inversions. Such a plume is called a trapping plume, and is considered bad condition for dispersion, as the dispersion cannot go above a certain height.



Trapping plume

Q.5 (d) Solution:

$$C_aH_bO_cN_d + \frac{4a-b-2c+3d}{4}H_2O \longrightarrow \frac{4a+b-2c-3d}{8}CH_4 + \frac{4a-b+2c+3d}{8}CO_2 + dNH_3$$

The coefficients are $a = 50$

$b = 100$

$c = 40$

$d = 1$

$\therefore$ Resulting equation is

$$\underset{(1354)}{C_{50}H_{100}O_{40}N} + \underset{(103.5)}{5.75\,H_2O} \longrightarrow \underset{(434)}{27.125CH_4} + \underset{(1006.5)}{22.875CO_2} + \underset{(17)}{NH_3}$$

Mass of methane produced per tonne of waste

$$= \frac{434}{1354} \times 1000 kg/\text{tonne} = 320.5 \text{ kg/tonne}$$

Volume of methane gas produced

$$= \frac{320.5 kg / tonne}{0.7167\ kg / m^3}$$

$= 447.2\ m^3/\text{tonne of waste.}$

Since a portion of waste (15%) would be used for the synthesis of cell tissue,

Actual volume of gas produced = 0.85 × 447.2

$= 380.12\ m^3/\text{tonne of waste.}$

Q.5 (e) Solution:

(i)

- Determination of ultimate BOD

$$(K)_{20°C} = 0.23/\text{day}$$

$$(K_{30°C}) = (K_{20}) \times (1.047)^{T-20}$$

$$\Rightarrow \quad (K_{30°C}) = 0.23 \times (1.047)^{30-20}$$

$$\Rightarrow \quad (K_{30°C}) = 0.364\ \text{day}^{-1}$$

$$\therefore \quad BOD_t = L_o(1 - e^{-kt})$$

$$\Rightarrow \quad \frac{BOD_5}{1 - e^{-5K}} = L_o$$

$$\Rightarrow \quad L_o = \frac{150\ mg/l}{1 - e^{-0.364 \times 5}}$$

$$\Rightarrow \quad L_o = 179\ mg/l$$

- K value at 15°C

$$\because \quad K_T = K_{20}\ (1.056)^{T-20}$$

$$\therefore \quad K_{15°C} = 0.23\ (1.056)^{-5}$$

$$\Rightarrow \quad K_{15°C} = 0.175\ \text{day}^{-1}$$

- $$BOD_8 = L_o\ (1 - e^{-8k})$$

$$= 179\ (1 - e^{-0.175 \times 8}) = 134.86\ mg/l$$

(ii)

We know,normality of solution = $\frac{\text{No. of gram equivalent of solute}}{\text{Volume of solution in litres}}$

Number of gram equivalent in 1 ml of 0.02 N H_2SO_4 = 0.02×10^{-3}

Now, as we know that gram equivalent of two reactions will always be equal,

Hence, number of gram equivalents of alkalinity = 0.02×10^{-3}

Alkalinity as $CaCO_3$ of sample treated by 1 ml of 0.02 NH_2SO_4 = $0.02 \times 10^{-3} \times 50$g = 1 mg

$\therefore$ 30 ml of acid (H_2SO_4) $\equiv$ 30 mg of alkalinity as $CaCO_3$

$\therefore$ Concentration of alkalinity in 1000 ml = $\dfrac{30\,\text{mg}}{200\,\text{ml}} \times \dfrac{1000\,\text{ml}}{1\,l}$

$\therefore$ Total alkalinity is 150 mg/l as $CaCO_3$.

Q.6 (a) Solution:

Water required per day = 4 ML

Assuming that 4% (normally 2 to 5%) of filtered water is required for washing of the filter every day, we have

Total filtered water required per day = $\dfrac{4ML}{0.96}$ = 4.167 ML/day

Now assuming that 0.5 hour is lost everyday in washing filter, we have filtered water required per hour

$$= \frac{4.167}{23.5}\text{ML/hour} = 0.177 \text{ ML/hr}$$

Now assuming the rate of filtration to be 5000 (normally 3000 to 6000) liter/hr/m^2

We have the area of filter required

$$= \frac{0.177 \times 10^6}{5000} m^2 = 35.40 \text{ m}^2$$

Assuming length of filter to be 1.3 (normally 1.25 to 1.35) times the width of the filter bed and two filter beds, the total area provided

$$= 2 \times L \times B = 35.40$$

$$= 2 \times 1.3\, B \times B = 35.40$$

$$\therefore \quad B^2 = \frac{35.40}{2.6} = 13.62 \text{ m}$$

$$\therefore \quad B = 3.69 \text{ m}; \quad L = 1.3B = 4.8 \text{ m}$$

Hence adopt two filter units each of dimensions,

$$L = 4.8 \text{ m}$$

$$B = 3.7 \text{ m}$$

Design of under-drainage system

Let us assume that the total area of the perforations in all laterals is 0.2% of the total filter area

∴ Total area of the perforations,

$$= \frac{0.2}{100} \times 4.8 \times 3.7 = 0.03552 \text{ m}^2$$

Now, assuming the area of each lateral

= 2 times the area of perforations on it

$$\frac{\text{Total area of perforations}}{\text{Total area of laterals}} = 0.25 \text{ for 5 mm perforation and 0.5 for 13 mm perforation}$$

∴ Total area of laterals = 2 × 0.03552 ≃ 0.070 m^2

Now assuming the area of the manifold to be about twice (generally 1.75 to 2 times) the area of laterals we have.

Area of manifold = 2 × 0.070 = 0.14 m^2

∴ Dia of manifold (d) is given by

$$\frac{\pi}{4}.d^2 = 0.14 \quad \Rightarrow \quad d = \sqrt{\frac{0.14 \times 4}{\pi}} = 0.42 \text{ m}$$

Hence, use 45 cm dia manifold pipe laid length wise along centre of filter bottom.

Laterals running perpendicular to manifold may be laid at a spacing of say 15 cm (maximum 30 cm).

Number of laterals is then given by $= \frac{4.8 \times 100}{15} = 32$ on either side of manifold.

Hence, we have 64 laterals in total in each unit.

Now, length of each lateral,

$$= \frac{\text{Width of filter}}{2} - \frac{\text{Dia of manifold}}{2}$$

$$= \frac{3.7}{2} - \frac{0.45}{2} = \frac{3.25}{2} = 1.625 \text{ m}$$

Now adopting 13 mm dia perforation in the laterals,

Total area of perforations = 0.03552 m^2

$$\Rightarrow \quad 355.2 \text{ cm}^2 = x \times \frac{\pi}{4} \times 1.3^2$$ (where x = Total perforations on 64 laterals)

$$\Rightarrow \quad x = 350 \times \frac{4}{\pi} \times \frac{1}{1.3^2}$$

$$\Rightarrow \quad x = 267.6 \simeq 268$$

$$\text{No. of perforations on each lateral} = \frac{268}{64} = 4.1875 \simeq 4$$

∴ Area of perforations per lateral

$$= 4 \times \frac{\pi}{4} \times 1.3^2 = 5.31 \text{ cm}^2$$

$$\text{Allowable area of each lateral} = 2 \times \text{Area of perforations per lateral}$$

$$= 2 \times 5.31 = 10.62 \text{ cm}^2$$

$$\therefore \quad \text{Dia of each lateral} = \sqrt{\frac{10.62 \times 4}{\pi}} = 3.68 \text{ cm} \simeq 3.7 \text{ cm (say)}$$

Hence we have 64 laterals each of 3.7 cm dia @ 15 cm c/c each having 4 perforations of 13 mm dia with 45 cm dia of manifold.

$$\text{Check :} \quad \frac{\text{Length of each lateral}}{\text{Dia of lateral}} = \frac{1.625 \text{ m}}{0.037 \text{ m}} = 43.9 < 60 \quad \text{(OK)}$$

Now let us assume that the rate of washing of the filter be 60 cm rise/minute or 0.60 m/minutes (normally 0.6 to 0.8)

∴ Wash water discharge

$$= \frac{0.60 \times 4.8 \times 3.7}{60} \text{m}^3/\text{s} = 0.178 \text{ m}^3/\text{s}$$

∴ Velocity of flow in the lateral for wash water

$$= \frac{0.178}{64 \times \left(\frac{\pi}{4} \times \left(\frac{3.7}{100}\right)^2\right)} = 2.587 \text{ m/s}$$

Similarly, velocity of flow in the manifold

$$= \frac{\text{Discharge}}{\text{Area}} = \frac{0.178}{\frac{\pi}{4} \times 0.45^2} = \frac{0.178}{0.158}$$

= 1.12 m/s; which is less than 1.8 m/s to 2.4 m/s (OK)

Q.6 (b) Solution:

(i)

Requirements of good distribution system for proper functioning are as follows:

- It should be capable of supplying water at all the intended places within the city with a reasonably sufficient pressure head.
- It should be capable of supplying the requisite amount of water for fire fighting during such needs.

- It should be economical with least capital construction cost.
- It should be simple and easy to operate and repair, thereby keeping costs and troubles minimum.
- It should be safe against any future pollution of water. It is achieved by keeping pipe lines away from sewerage and drainage lines.
- It should be safe against failure by bursting etc.
- It should be fairly watertight, as to keep the "losses due to leakage" to the minimum.

Advantages of following distribution system are :

1. Dead End system

- The distribution network can be solved easily and it is possible to easily and accurately calculate the discharges and pressures at different points in the system.
- Lesser number of cut off valves are required in this system.
- Shorter pipe lengths are needed, and the laying of pipes is easier.
- It is economical and simple and can be extended or expanded easily.

2. Grid-Iron system

- Since the water reaches at different places through more than one route, the discharge to be carried by each pipe and hence friction loss and size of the pipe, get reduced.
- In case of repair, very small area will be devoid of complete supply as atleast some supply will be reaching at the point from some other route.
- Because of different inter-connections, dead ends are completely eliminated so there is no stagnation of water.
- During fire more water can be diverted towards affected point from various directions by closing and manipulating the various cutoff values.

3. Ring System

- Very suitable for towns and cities having well planned roads.
- This enhances the capacity of grid iron system and improves pressures at different point when used as a "looped feeder placed centrally around a high demand area".

(ii)

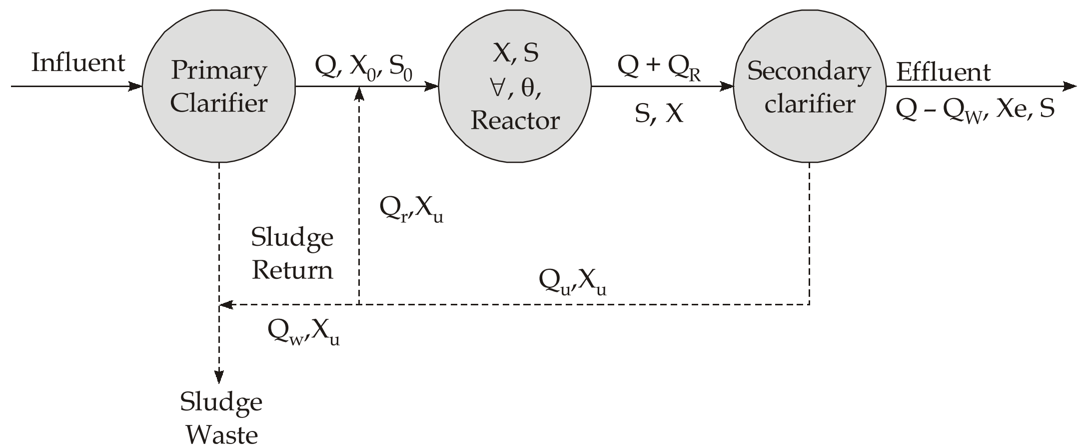
Following factors are thoroughly considered for selection of a pump:

- Capacity of pump
- Importance of water supply scheme
- Initial cost of pumping arrangement
- Maintenance cost

- Space requirement for locating the pump
- Number of units required
- Total lift of water required
- Quantity of water to be pumped

Q.6 (c) (i) Solution:

(I)



$$\theta_c = 10 \text{ days}$$

$$VX = \frac{YQ(S_o - S)\theta_c}{1 + k_D\theta_c}$$

$$\Rightarrow \quad V = \frac{0.5 \times 10000 \times (150 - 5) \times 10}{3000 \times (1 + 0.05 \times 10)}$$

$$\Rightarrow \quad V = 1611 \text{ m}^3$$

(II) At equilibrium conditions

$$\theta_c = \frac{\text{Mass of solids in reactor}}{\text{Mass of solids wasted}} = \frac{VX}{Q_w x_u}$$

$$\Rightarrow \quad Q_w X_u = \frac{VX}{\theta_c} = \frac{1611 \text{ m}^3 \times 3.0 \text{ kg/m}^3}{10\, d}$$

$$\Rightarrow \quad Q_w X_u = 483.3 \text{ kg/d}$$

Given the concentration of solids in the underflow is 10,000 mg/*l*,

$$\because \quad X_u = 10 \text{ kg/m}^3$$

$$Q_w = \frac{483.3\, kg/d}{10\, kg/m^3} = 48.3 \text{ m}^3/\text{d}$$

$$\therefore \quad Q_w = 48.3 \text{ m}^3/\text{d}$$

$$\therefore \quad X_u = \frac{Q_w X_u}{Q_w} = \frac{483.3}{48.3} \simeq 10 \text{ kg/m}^3$$

(III) A mass balance equation around the secondary clarifier can be written as follows:

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

Assuming that the solids in the effluent are negligible compared to the influent and underflow,

$$QX + Q_r X = Q_r X_u + Q_w X_u$$

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

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

$$\Rightarrow \quad Q_r = \frac{10000 \text{ m}^3/\text{day} \times 3.0 \text{ kg/m}^3 - 483.3 \text{kg/day}}{10 \text{ kg/m}^3 - 3 \text{ kg/m}^3}$$

$$\Rightarrow \quad Q_r = 4217 \text{ m}^3/\text{d}$$

$$\therefore \quad \text{Recirculation ratio} = \frac{Q_r}{Q} = \frac{4217}{10000} = 0.42$$

(ii)

$$T_a = 273 + 13 = 286 \ K$$

$$T_s = 273 + 149 = 422 \ K$$

$$\Delta T = 422 - 286 = 136 \ K$$

$$\Delta H = \frac{V_s d}{u}\left[1.5 + \left(2.68 \times 10^{-3} \times p \times \frac{\Delta T d}{T_s}\right)\right]$$

$$\Rightarrow \quad \Delta H = \frac{9.14 \times 1.07}{3.56}\left[1.5 + \left(2.68 \times 10^{-3} \times \frac{(1000 \times 136 \times 1.07)}{422}\right)\right]$$

$$\Rightarrow \quad \Delta H = 6.66 \text{ m}$$

$$\therefore \quad \text{Effective height of stack} = H + \Delta H = 203 + 6.66$$

$$= 209.66 \text{ m}$$

7. **(a) (i) Solution:**

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

Environmental Impact of Mining: In general mining activities are accompanied by a variety of environmental problems. The process of environmental degradation, which starts with the extraction of minerals resulting in land degradation and addition of pollutants in the air and water, continues even as the extracted mineral ores are further processed and developed for their ultimate uses.

The environmental impacts of mining can be broadly divided into four parts, *viz.*

1. Water pollution;
2. Air pollution;
3. Pollution of land, including land subsidence, land degradation and deforestation; and
4. Noise and ground vibrations;

Air pollution: Mining causes air pollution in two ways. Firstly, it adds *gaseous pollutants* to the air; and secondly, it emits and adds *dust particulates* to the atmosphere.

The harmful gaseous pollutants, like sulphur dioxide, oxides of nitrogen, carbon monoxide, etc. are originated in mining activities from the waste dumps; whereas, the dust particulates are produced during ore/coal handling, blasting, and transportation.

Mine fires, which are largely associated with the underground mining and also in solid waste disposals, also do pollute the atmosphere on a large scale through smokes, etc. Such pollution has been caused on a large scale near Jharia in Bihar State of our country.

(ii)

Total 5-day BOD present in sewage

$$= \frac{160 \times 4.5 \times 10^6}{10^3} \text{ g/day} = 7{,}20{,}000 \text{ g/day.}$$

Volume of the filter media required

$$V = \frac{\text{Total BOD}}{\text{Organic Loading Rate}} = \frac{7,20,000}{160}$$

$$\Rightarrow \quad V = 4500 \text{ m}^3$$

Surface area required for filter

$$A = \frac{\text{Total flow}}{\text{Hydraulic loading}} = \frac{4.5\times10^6}{2000}$$

$$\Rightarrow \quad A = 2.25 \times 10^3 = 2250 \text{ m}^2$$

$\therefore$ Depth of bed required

$$D = \frac{V}{A} = \frac{4500}{2250} = 2\text{m}$$

$$\text{Efficiency of filter unit, } \eta = \frac{100}{1+0.44\sqrt{u}}$$

where, u is in kg/m^3/day

$$\Rightarrow \quad \eta = \frac{100}{1+0.44\sqrt{0.16}}$$

$$\Rightarrow \quad \eta = 85.03\%$$

7. **(b) Solution:**

(i)

All the pollutants, which are emitted directly from the identifiable sources, either from 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. There are five primary air pollutants that contribute to about 90% of the global air pollution.

Important primary air pollutants are:

1. Oxides of sulphur, particularly the sulphur dioxide (SO_2);
2. Oxides of carbon like carbon monoxide (CO) and carbon dioxide (CO_2), particularly the carbon monoxide (CO);
3. Oxides of nitrogen, like NO, NO_2, NO_3 (expressed as NO_x);
4. Volatile organic compounds, mostly hydrocarbons; and
5. Suspended particulate matter (SPM).

1. **Carbon monoxide (CO) :** Carbon monoxide is a colourless, odourless and toxic gas produced when organic materials like natural gas, coal, or wood are incompletely burnt.

- Vehicular exhausts are the single largest source of carbon monoxide, as the number of vehicles is increasing, CO concentration is also increasing in environment.
- Poorly maintained vehicles and those having inefficient engines, without being fitted with adequate pollution control devices, release greater amount of carbon monoxide.
- Carbon monoxide possesses about 200 times more affinity for blood haemoglobin (Hb) than oxygen. Eventually, when inhaled, CO replaces O_2 from the haemoglobin, and forms what is known as carboxyl haemoglobin (CO.Hb)
- CO inhalation impairs normal oxygen transport carried out by blood. Low levels of CO inhalation produce symptoms like headache, dizziness, reduction in reaction time etc.
- In extreme cases when about half of the haemoglobin of the blood is used up in forming carboxyl haemoglobin, death becomes a certainty.

2. **Suspended particulate Matter (SPM) :** The particulate matter in air may occur largely in solid form as particles of dust, smoke, fume etc; and also in liquid form as mist and fog. The particles larger than a molecule but small enough to remain suspended in air are called aerosols.

- The SPM in the atmosphere is a variable component and is introduced either through natural phenomena like winds, volcanic eruptions, pollens and spores or either through human activities like mining, burning of fossil fuels, industrial processes etc.
- The SPM in air may prove to be harmful to human health, inspite of the fact that human respiratory system has a number of mechanisms for protecting the lungs from the entry of particulate from air.
- Very small suspended particles may reach the lungs and damage the lung tissues, causing diseases like asthma, bronchitis, and even lung cancer, when such particles bring with them carcinogenic pollutants.
- Since most important SPM are PM10 and PM2.5, considering their importance, the revised National Ambient Air Quality Standards (NAAQS)of India have specified maximum annual concentrations of PM10 and PM 2.5 to be 60 mg/m^3 and 40 mg/m^3 respectively.

(ii)

Height of the chimney will be decided based on the dispersion of particulate matter and SO_2.

- Height of chimney based on dispersion of particulate matter :

$$h = \text{height of chimney}$$
$$= 74\,(Q_p)^{0.27} \qquad (\text{where } Q_P = \text{emission of PM in t/hr.})$$

In the given case, the PM emission

$$= 2.9 \text{ t/yr/ML fuel burnt}$$

$$= 2.9 \times (12 \times 0.3) \text{ t/yr} = 10.44 \text{ t/yr}$$

$$\therefore \quad Q_P = \frac{10.44}{300 \times 24} \quad \text{(Given 300 working days in the year with 24 hr. working)}$$

$$\Rightarrow \quad Q_P = 1.45 \times 10^{-3} \text{ t/hr.}$$

$$\therefore \quad h = 74 \times (1.45 \times 10^{-3})^{0.27}$$

$$h = 12.67 \text{ m}$$

- Now we will calculate chimney height for effective disposal of SO_2:

$$h = 14(Q_s)^{0.3} \qquad \text{where } Q_s = SO_2 \text{ in kg/hr}$$

$$SO_2 \text{ emission} = 60 \text{ t/yr/ML of oil burnt}$$

$$= \frac{60 \times 1000}{300 \times 24} \text{ kg/hr/ML of oil}$$

$$= \frac{60 \times 1000}{300 \times 24} \times (12 \times 0.3) \times \text{kg/hr} = 30 \text{ kg/hr}$$

$$h = 14 \cdot (30)^{0.3} = 38.84 \text{ m}$$

$$\therefore \text{ Chimney height required} = \text{Maximum } (12.67 \text{ m}, 38.84 \text{ m}, 30 \text{ m})$$

$$\therefore \quad h = 38.84 \text{ m}$$

Q.7 (c) Solution:

(i)

Total population of the area

$$= \text{Population density} \times \text{Area}$$

$$= 185 \text{ P/ha} \times (60 \times 10^2 \text{ ha})$$

$$= 11.1 \times 10^5 \text{ persons}$$

$$\text{Average sewage flow} = 350 \; l\text{/P/day}$$

$$= 350 \times 11.1 \times 10^5 \; l\text{/d}$$

$$= 388.5 \times 10^6 \; l\text{/day}$$

$$= \frac{388.5 \times 10^6}{10^3} \times \frac{1}{24 \times 60 \times 60} \text{ cu.m/sec}$$

$$= 4.5 \text{ cumecs}$$

$$\text{Storm water flow} = \frac{(\text{Area in m}^2 \times \text{Depth of surface runoff in m})}{\text{Time of 24 hr. in sec}}$$

$$\text{Storm water flow} = 60 \times 10^6 \times \left(\frac{12}{1000}\right) \times \frac{1}{24 \times 60 \times 60} \text{ cumecs} = 8.33 \text{ cumecs}$$

Maximum sewage flow = 1.5 × Average sewage flow

= 1.5 × 4.5 = 6.75 cumecs

∴ Total maximum flow of the combined sewage

= Max. sewage flow + Storm flow

= 6.75 + 8.33 = 15.08 cumecs.

Hence sewer capacity = 15.08 cumecs

(ii)

The minimum velocity (self cleansing) is given by

$$v_S = \frac{1}{n} r^{1/6} \sqrt{kd'(G_s - 1)}$$

where $n = 0.012$, $k = 0.04$, $G_s = 2.65$

d' = Diameter of grain i.e. sand particle = 1 mm

$$r = R = D/4 = \frac{0.4\,m}{4} = 0.1\,m$$

$$v_S = \frac{1}{0.012} \times (0.1)^{1/6} \times \sqrt{0.04 \times \frac{1}{1000} \times (2.65 - 1)}$$

$\Rightarrow$ $v_S = 56.77 \times (8.12 \times 10^{-3})$m/s

$\Rightarrow$ $v_S = 0.46$ m/s

The velocity in sewer is however calculated by Manning's formula as:

$$v = \frac{1}{n} r^{2/3} s^{1/2}$$

Now assuming the sewer is designed to be running full.

$n = N = 0.012$

$r = R = D/4 = 0.1$ m

$$\therefore \quad 0.46 = \frac{1}{0 \cdot 012} \times (0.1)^{2/3} \times S^{1/2}$$

$$\Rightarrow \quad S = 6.5646 \times 10^{-4} = \frac{1}{1523}$$

Hence the required gradient for the sewer to be having self cleansing velocity is $\frac{1}{1523}$.

8. **(a) Solution:**

(i)

1. **Manholes:** Manholes are masonry or R.C.C. chambers, constructed at suitable intervals along the sewer lines, for providing access into sewers.

   The manholes thus, help in joining sewer length and also help in their inspection, cleaning and maintenance. If manhole covers are perforated, they may also assist in ventilating the sewers.

   - The manholes are generally provided at every bend, junction, change of gradient, or change of sewer diameter.

   Classification of manholes:

   - Shallow manhole : These are 0.7m to 0.9 m is depth; constructed at start of a branch sewer.
   - Normal/medium manhole : These are about 1.5m depth; provided with heavy cover at its top.
   - Deep manhole : These are more than 1.5 m in depth used at places subjected to heavy traffic.

2. **Catch Basin :** Catch basins are nothing but street inlets provided with additional small settling basins. Grits, sand, debris etc, settle in these basins and their entry into the sewer is thus prevented.

   - In addition to this, a hood is also provided which prevents the escape of foul gases, which may find its way through the sewer line.
   - Catch basins need periodical cleaning otherwise the settled organic matter may decompose, producing foul odours, and may also become a breeding place of vectors.
   - Modern well paved streets do not need catch basin as these streets offer very less grit and debris with storm run off and the same can be conveyed easily in storm water sewers laid at suitable gradient.

3. **Inverted Siphons :** Whenever a sewer pipe has to be dropped below the hydraulic gradient line for passing it beneath a valley, a road, a railway, a stream or where it passes beneath some obstructions in its path, it will be known as inverted siphon.

   - An inverted siphon is thus a sewer section constructed lower than the adjacent sewer sections and it runs full under gravity with pressure greater than atmosphere.
   - The proper design of siphons is very important; as otherwise they are likely to be clogged and become inefficient. The siphon should, therefore be designed to develop a self cleansing velocity of about 0.9 m/s.
   - The inverted siphons should be avoided as far as possible as it is most likely to get silted. Also if the inlet chamber is not properly designed the floating matter in sewage will separate out and will accumulate in this chamber.

(ii)

The presence of nitrogen in water is an indication of the presence of the organic matter, and may occur in one or more of the following forms :

- Free ammonia or ammonia nitrogen
- Albuminoid or organic nitrogen
- Nitrites
- Nitrates
- Free ammonia indicates the very first stage of decomposition of organic matter; albuminoid or organic nitrogen indicates the quantity of nitrogen present in water in the form of undecomposed organic matter; the nitrites indicate the presence of partly decomposed organic matter and nitrates indicate the presence of fully oxidised organic matter in water.
- The presence of free ammonia should not exceed 0.5 mg/l. It can be easily measured by simply boiling the water and measuring the liberated ammonia gas by distillation process.
- Presence of organic nitrogen should not be greater than 0.3 mg/l. It can be measured by adding $KMnO_4$ to already boiled water sample and again boiling the same. The sum total of ammonia nitrogen and the organic nitrogen is called the Kjeldahl nitrogen.
- Nitrites are highly dangerous and permissible limit should be nil. The nitrates should not be present too much as it adversely affects the health of infants causing "methaemoglobinemia". Nitrate concentration is to be limited to 45 mg/l.

Q.8 (b)Solution:

(i)

Year	Population	Increase in population	Percentage increase in population	Decrease in the percentage increase
1940	80,000			
		40,000	$\frac{40,000}{80,000} \times 100 = 50\%$	
1950	1,20,000			10%
		48,000	$\frac{48,000}{1,20,000} \times 100 = 40\%$	
1960	1,68,000			4%
		60,580	$\frac{60,580}{1,68,000} \times 100 = 36\%$	
1970	2,28,580			
Total				14%
Average per decade				$\frac{14}{2} = 7\%$

- Expected population at the end of year 1980

$$= 2{,}28{,}580 + \left(\frac{36-7}{100}\right)\times 2{,}28{,}580$$

$$= 294868.2 \simeq 2{,}94{,}870$$

- Expected population at the end of year 1990

$$= 2{,}94{,}870 + \left(\frac{29-7}{100}\right)\times 2{,}94{,}870$$

$$= 359741.4 \simeq 3{,}59{,}740$$

- Expected population at the end of year 2000.

$$= 3{,}59{,}740 + \frac{22-7}{100}\times 3{,}59{,}740$$

$$= 413701 \simeq 4{,}13{,}700$$

(ii)

3. Detention period of circular tank = $\dfrac{d^2(0.011d + 0.785H)}{Q}$

Where d = Dia of tank = 26 m

H = Side water depth = 2.1 m

Q = Half of total discharge as there are two tanks

$$= 13000\ \text{m}^3/\text{d} = \frac{13000}{24}\text{m}^3/\text{hr}$$

$$\therefore \quad t_d = \frac{(26)^2(0.011\times 26 + 0.785\times 2.1)}{\frac{13000}{24}} = 2.41\ \text{hr}$$

Quantity of water to be treated during detention period of 2.41 hr.

$$= \frac{13000}{24}\times 2.41 = 1305.42\ \text{m}^3$$

1. Capacity (volume) of each tank required = 1305.42 m^3

$$\therefore \quad \text{Surface area} = \frac{\text{Volume}}{\text{Depth}} = \frac{1305.42}{2.1} = 621.63\ \text{m}^2$$

2. $$\text{Overflow rate} = \frac{Q}{\text{Surface Area}} = \frac{13000}{621.63}\text{m}^3/\text{m}^2/\text{day}$$

$$= 20.91\ \text{m}^3/\text{m}^2/\text{day}$$

3. Weir loading: Length of weir along periphery = πd

$$= \pi\,(26) = 81.68\ \text{m}$$

$$\text{Weir loading per day} = \frac{\text{Discharge}}{\text{Length of weir}} = \frac{13000}{81.68}\text{m}^3/\text{m/day}$$

$$= 159.16 \text{ m}^3/\text{m/day}$$

8. (c) Solution:

Characteristics of wastewater-stream mixture

$$Q_w = 15000 \text{ m}^3/\text{d} \times \frac{1}{24\times 60\times 60}$$

$$\Rightarrow \quad Q_w = 0.17 \text{ m}^3/\text{s}$$

$$\therefore \quad Q_{mix} = 0.17 + 0.5 = 0.67 \text{ m}^3/\text{s}$$

$$(\text{BOD})_{\text{mix}} = \frac{Q_s(BOD_s)+Q_w(BOD_w)}{Q_s+Q_w} = \frac{0.5\times 3+0.17\times 40}{0.67}$$

$$\Rightarrow \quad (\text{BOD})_{\text{mix}} = 12.4 \text{ mg}/l$$

Ultimate BOD, (Given k = 0.23 day^{-1} for mix)

$$= L_o = \frac{BOD_t}{1-e^{-kt}} = \frac{12.4}{1-e^{-0.23\times 5}}$$

$$\Rightarrow \quad L_o = 18.15 \text{ mg}/l$$

- Dissolved oxygen $(DO)_{\text{mix}} = \dfrac{8\times 0.5+2\times 0.17}{0.67}$

$$\Rightarrow \quad (DO)_{\text{mix}} = 6.5 \text{ mg}/l$$

- Temperature : $T_{\text{mix}} = \dfrac{22\times 0.5+25\times 0.17}{0.67}$

$$T_{\text{mix}} = 22.8°\text{C}$$

- Reaction rate constants for mix temperature of 22.8°C

$$(K_D)_{22.8} = K_{20}\,(1.047)^{(22.8\,-\,20)}$$

$$\Rightarrow \quad (K_D)_{22.8} = 0.23\,(1.047)^{2.8} = 0.26\ d^{-1}$$

Reaeration constant, $(K_R)_{22.8} = 0.4 \times (1.016)^{(22.8\,-\,20)}$

$$\Rightarrow \quad (K_R)_{22.8} = 0.42\ d^{-1}$$

Initial dissolved oxygen deficit (D_o)

$$D_o = 8.7 - 6.5 = 2.2 \text{ mg}/l$$

- Determination of critical dissolved oxygen deficit and its location

$$t_c = \frac{1}{K_R-K_D}\log_e\left[\frac{K_R}{K_D}\left(1-D_o\frac{K_R-K_D}{K_D L_o}\right)\right]$$

$$\Rightarrow \quad t_c = \frac{1}{0.42-0.26}\log_e\left\{\frac{0.42}{0.26}\left[1-\left(2.2\frac{0.42-0.26}{0.26\times 18.15}\right)\right]\right\}$$

$$\Rightarrow \quad t_c = 2.5128 \text{ days}$$

$$D_C = \frac{K_D}{K_R}L_o e^{-K_D t_c}$$

$$\Rightarrow \quad D_C = \frac{0.26}{0.42}(18.15)e^{-0.26\times 2.5128}$$

$$\Rightarrow \quad D_C = 5.846 \text{ mg}/l$$

This condition will occur at a distance of

$$x = 0.2 \text{ m/s} \times 86{,}400 \times 2.5128 \text{ days}$$

$$\Rightarrow \quad x = 43.42 \text{ km downstream from point of discharge.}$$

- Deficit at points 20, 75 and 100 km downstream

$$t = \frac{x \text{ km}}{u \text{ km/d}}$$

$$u = 0.2 \text{ m/s} \times \frac{86400\text{s}}{\text{d}}\times\frac{1\text{km}}{1000\text{m}} = 17.28 \text{ km/day}$$

$$t_{20} = \frac{20}{17.28} = 1.16 \text{ d};\ t_{75} = \frac{75}{17.28} = 4.34\ d;\ t_{100} = \frac{100}{17.28} = 5.8\ d$$

Deficit at these times are:

$$D = \frac{K_D L_o}{K_R - K_D}\left(e^{-K_D t} - e^{-K_R t}\right) + D_o e^{-K_R t}$$

$$D_{20} = \frac{0.26\times 18.15}{0.42-0.26}\left(e^{-0.26\times 1.16} - e^{-0.42\times 1.16}\right) + 2.2e^{-0.42\times 1.16}$$

$$\Rightarrow \quad D_{20} = 5.05 \text{ mg}/l$$

Similarly $D_{75} = 5.13 \text{ mg}/l$

$$D_{100} = 4.14 \text{ mg}/l$$

$\therefore$ DO at these points are:

$$(\text{DO})_{20\text{ km}} = 8.7 - 5.05 = 3.65 \text{ mg}/l$$

$$(\text{DO})_{43.42\text{ km}} = 8.7 - 5.846 = 2.854 \text{ mg}/l$$

$$(\text{DO})_{75\text{ km}} = 8.7 - 5.13 = 3.57 \text{ mg}/l$$

$$(\text{DO})_{100\text{ km}} = 8.7 - 4.14 = 4.56 \text{ mg}/l$$

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