MADE EASY
Leading Institute for ESE, GATE & PSUs

Detailed Solutions

ESE-2024 Mains Test Series

Civil Engineering Test No : 15

Section-A

Q.1 (a) Solution:

(i)

Differential free swell test:

This test is conducted to determine the differential free swell of a soil sample which helps to identify the potential of a soil to swell.

- In this test, two samples of dry soil weighing 10 gm each, passing through 425 μ sieve are taken.
- One of these samples is poured into a 50 cm^3 graduated cylinder containing kerosene oil (non polar liquid) while other is poured in a similar cylinder containing distilled water.
- Their volumes are noted after 24 hours.

The differential free swell (DFS) is defined as

$$DFS = \frac{\text{Soil volume in water - Soil volume in kerosene}}{\text{Soil volume in kerosene}}$$

The relationship between degree of expansiveness and DFS percent is shown below in the table

Degree of expansiveness	DFS percent
Low	Less than 20
Moderate	20-35
High	35-50
Very high	Greater than 50

(ii)

The elimination of possible swelling can theoretically be brought about by following measures:

1. Pre-wetting the soil mass to a moisture content equal to the equilibrium moisture content.
2. Providing large enough external loads, which exceeds the swelling pressure.
3. Chemical stabilization with lime, as lime stabilization is effective in reducing the liquid limit and plastic limit of the soil, hence swelling potential is reduced.

Q.1 (b) Solution:

(i)

Given:

Initial volume of sludge, $V_1 = 110\ m^3$

Initial density of sludge, $\rho_1 = 1.02\ t/m^3 = 1020\ kg/m^3$

$$\text{Mass of sludge, } M_1 = V_1 \times \rho_1$$
$$= 110 \times 1020 = 112200\ kg$$

Initial moisture content of sludge, $P_1 = 96\%$

∴ 100 kg sludge contains 4 kg of solids

Hence, 112200 kg sludge contains $\frac{4}{100} \times 112200 = 4488$ kg solids.

Now, mass of solids in final sludge remains same.

Moisture content of final sludge, $P_2 = 90\%$

So, 10 kg solids results in 100 kg of sludge

So, 4488 kg solids will result in $\frac{100}{10} \times 4488 = 44880$ kg of sludge.

Now, final volume of sludge, $V_2 = \frac{44880}{\rho_2}$

where ρ_2 is final density of sludge i.e. $1040\ kg/m^3$

So, $$V_2 = \frac{44880}{1040} = 43.15 \text{ m}^3$$

So, $$\text{Savings in volume} = V_1 - V_2$$
$$= 110 - 43.15 = 66.85 \text{ m}^3$$

(ii)

There are two major differences in design of sewers and water pipe:

1. The water supply pipes carry pure water without containing any kind of solid particles, either organic or inorganic in natural. The sewage, on the other hand, does contain such particles in suspension; and the heavier of these particles may settle down at the bottom of the sewers, as and when the flow velocity reduces, thus ultimately resulting in the clogging of the sewers. In order to avoid such clogging or silting of sewers, it is necessary that the sewer pipes to be of such a size and laid at such a gradient, as to generate self-cleansing velocities at different possible discharges. The sewer material must also be capable of resisting the wear and tear caused due to abrasion of the solid particles present in the sewage, with the interior of the pipe.
2. The water supply pipes carry water under pressure and hence, within certain limits, they may be carried up and down the hills and the valleys; whereas, the sewer pipes carry sewage as gravity conduits (or open channels), and they must, therefore, be laid at a continuous gradient in the downward direction up to the outfall point, from where the sewage will be lifted up, treated and disposed of.

Q.1 (c) Solution:

(i)

$$\text{Volume of the mould} = \frac{1}{30}\text{cubic ft.} = \frac{1}{30} \times (12 \times 2.54)^3 = 943.895 \text{ cc}$$

In the loosest state,

$$\text{Bulk density} = \frac{3365.2 - 2100}{943.895} = 1.34 \text{ g / cc}$$

$$\text{Minimum dry density, } (\gamma_d)_{min} = \frac{1.34}{1+0.108} = 1.21 \text{ gm/cc}$$

$$\text{In the densest state, bulk density} = \frac{3860.5 - 2100}{943.895} = 1.865 \text{ gm/cc}$$

$$\text{Maximum dry density } (\gamma_d)_{max} = \frac{1.865}{1+0.108} = 1.683 \simeq 1.68 \text{ g/cc}$$

In-situ density of the soil, (γ) = 1.61 gm/cc

Water content = 7%

$$\text{In-situ dry density} = \frac{1.61}{1+0.07} = 1.505 \text{ gm/cc}$$

$$\text{Relative density, } R_0 = \frac{\frac{1}{\gamma_{d_{min}}} - \frac{1}{\gamma_d}}{\frac{1}{\gamma_{d_{min}}} - \frac{1}{\gamma_{d_{max}}}} = \frac{\frac{1}{1.21} - \frac{1}{1.505}}{\frac{1}{1.21} - \frac{1}{1.68}} \times 100\% = 70\%$$

(ii)

Total mass of the soil = 750 gm

Soil retained on IS 600 μ sieve = 300 gm

$$\text{Percent of soil retained on IS 600 μ sieve} = \left(\frac{300}{750}\right) \times 100 = 40\%$$

∴ Percentage finer = 60%

⇒ D_{60} = 600 μ

Soil retained on IS 500 μ sieve = 375 gm

$$\text{Percent of soil retained on 500 μ sieve} = \left(\frac{375}{750} \times 100\right) = 50\%$$

Percentage finer = 100 – (50 + 40) = 10%

⇒ D_{10} = 500 μ

$$\text{Coefficient of uniformity, } C_u = \frac{D_{60}}{D_{10}} = \frac{600}{500} = 1.2$$

Classification of soil:

Soil passing through 75 mm sieve = 0%

More than 50% of coarser fraction is passing through 4.75 mm sieve

Hence the soil is sandy

Also, $C_u < 6$ ⇒ It is poorly graded

Hence soil is classified as SP.

Q.1 (d) Solution:

The mechanism of coagulation which are thought to occur are as follows:

1. **Ionic layer compression:**

- The quantity of ions in the water surrounding a colloid has an effect on the decay function of the electrostatic potential.

- A high ionic concentration compresses the layers composed predominantly of counter ions towards the surface of colloid.
- If this layer is sufficiently compressed, then the Van-der Waals force will be predominant across the entire area of influence, so that the net force will be attractive and no energy barriers will exist.
- Although coagulants such as aluminium and ferric salts used in water treatment ionize, at the concentrations commonly used, they would not increase the ionic concentration sufficiently to affect ionic layer compression.

2. **Adsorption and charge neutralization:**
   - The nature rather than quantity of the ions is of prime importance in the theory of adsorption and change neutralization.
   - The ionization of $Al_2(SO_4)_3$ and $FeCl_3$ in water produces SO_4^{2-} and CI^- along and Al^{3+} and Fe^{3+}. The Al^{3+} and Fe^{3+} cations react immediately with water to form a variety of aquometallic ions and hydrogen ions.

$$Al^{3+} + 3H_2O \rightarrow Al(OH)_3 + 3H^+$$
$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+$$

   - The aquometallic ions thus formed become part of the ionic cloud surrounding colloid and because they have a great affinity for surfaces they are absorbed onto the surface on the colloid where they neutralize the surface charge.
   - Once the surface charge has been neutralized, the ionic cloud dissipates and the electrostatic potential disappears so that contact occurs freely.

(iii) Sweep coagulation:
- The last product formed in the hydrolysis of alum is $Al(OH)_3$.
- The $Al(OH)_3$ forms in amorphous, gelatinous form that is heavier than water and settle by gravity.
- Colloids may become entrapped in a floc as it is formed, or they may become enmeshed by its sticky surface as the flocs settle.
- The process by which colloids are swept from suspension in the manner is known as sweep coagulation.

(iv) Interparticle bridging:
- Large molecules may be formed when aluminium or ferric salts dissociate in water.
- Synthetic polymers may also be used instead of, or in addition to, metallic salts which may be linear or branched or grafted and are highly surface reactive.

- Several colloids may get attached to one polymer and several of the polymer-colloid groups may become enmeshed resulting in a settleable mass.
- In addition to the adsorption forces, charges on the polymer may assist in the coagulation process.
- Metallic polymers formed by addition of aluminium or ferric salts are positively charged while synthetic polymers may carry positive or negative charges or may be neutral.
- Judicious choice or appropriate charges may do much to enhance the effectiveness of coagulation.

Q.1 (e) Solution:

First reading of 0.720 m at station A must be the backsight reading. Since the readings were taken on a continuosly sloping ground with a 4 m staff, the largest reading that can be taken is 4 m. Therefore positions of the level must have been changed after the largest reading of each series.

By collimation method

Station	Distance (in m)	Readings (in m)			H.I. (in m)	R.L. (in m)	Remarks
		B.S.	I.S	F.S			
A	0	0.720	-	-	180.97	180.250	B.M
	30	-	1.425	-	-	179.545	-
	60	-	1.951	-	-	179.019	-
	90	-	2.412	-	-	178.558	-
	120	-	2.812	-	-	178.158	-
	150	1.12	-	3.425	178.665	177.545	C.P
	180	-	1.812	-	-	176.853	
	210	-	2.2	-	-	176.465	-
	240	0.814	-	3.540	175.939	175.125	C.P
	270	-	1.03	-	-	174.909	-
	300	-	1.421	-	-	174.518	-
B	330	-	-	2.425	-	173.514	-
Arithmetical checks		ΣB.S - ΣF.S = 2.654 – 9.39 = – 6.736 m			R.L. of last point - R.L. of first point = 173.514 – 180.250 = – 6.736 m		

There is a fall of 6.736 m in a distance of 330 m,

$$\therefore \quad \text{Gradient} = \frac{6.736}{330}$$
$$= 1 \text{ in } 49$$

Q.2 (a) Solution:

(i) Given

Radius of well, $r_w = \frac{30}{2}$ cm = 15 cm = 0.15 m

Side of equilateral triangle, B = 15 m

Radius of influence, R = 400 m

Coefficient of permeability, K = 25 m/day = 2.89×10^{-4} m/s

Thickness of aquifer, H = 16 m

Drawdown in each well, s = 2 m

1. Considering the effect of interference

Discharge through each well, $Q = \dfrac{2\pi KHs}{ln\left(\dfrac{R^3}{r_w B^2}\right)}$

$$= \frac{2\pi \times 2.89 \times 10^{-4} \times 16 \times 2}{ln\left(\dfrac{400^3}{0.15 \times 15^2}\right)}$$

$= 4.0197 \times 10^{-3}$ m^3/s

= 4.0197 litre/s

2. Neglecting the effect of inteference,

Discharge, $Q' = \dfrac{2\pi KHs}{ln\left(\dfrac{R}{r_w}\right)}$

$$= \frac{2\pi \times 2.89 \times 10^{-4} \times 16 \times 2}{ln\left(\dfrac{400}{0.15}\right)}$$

$= 7.366 \times 10^{-3}$ m^3/s = 7.37 l/s

(ii)

Methods of municipal solid wastes disposal: In general, the following scientifically managed methods can be used for disposal of municipal solid wastes (refuse):

1. **Sanitary landfilling (controlled tipping method):** In this method of refuse disposal, refuse is carried and dumped into the low lying area (marked as the landfill site) under an engineering operation, designed and operated in an environmentally sound manner, so as not to cause any public nuisance or hazard to public health or safety.

2. **Shredding and pulverisation:** The size and volume reduction of municipal solid waste (MSW) is accomplished by physical processes of shredding and pulverisation. Shredding refers to the action of cutting and tearing whereas pulverisation refers to the action of crushing and grinding. The pulverisation is achieved in hammer mill. The pulverised refuse is further disposed of by filling in trenches.

3. **Composting:** Composting of refuse is a biological method of composting (decomposing) solid wastes. This decomposition can be affected either under aerobic condition or under anaerobic condition or both. The final end product is a manure called compost or humus. Basically, composting is considered as an aerobic process because it involves piling up of refuse and its regular turning either manually or by mechanical device so as to ensure sufficient supply of air and oxygen during its decomposition by bacteria, fungi and other micro-organisms like anti-nomycetes. In India composting is practised in rural area on the mixture of right soil and refuse. Two methods which are adopted are:

   (a) Indore process (b) Banglore process

4. **Incineration and thermal pyrolysis:** Burning of refuse at high temperature in furnaces called incinerators is quite a sanitary method of refuse disposal. Normally however only the combustible matter such as garbage, rubbish and dead animals are burnt and incombustible matter like broken glass, metals etc. are either left unburnt or separated out for recycling wastes and reuse before burning the solid wastes.
   Upon heating in closed containers in oxygen free atmosphere, most of the organic substances of solid waste can be split through a combination of thermal cracking and condensation reactions into gaseous or liquid or solid fractions. This process is known as pyrolysis or thermal pyrolysis.

5. **Barging it out into the sea:** This method had been used in the past to depose of refuse by throwing it away into sea after carrying it at reasonable distance from the coast on bages.

   This method may have a limited use and that too only in few coastal towns.

Q.2 (b) Solution:

(i) Given, $\bar{\sigma}_1 = 300\,\text{kPa}$ and $\bar{\sigma}_3 = 100\,\text{kPa}$

C = 0 (for sand)

1. We know that,
$$\bar{\sigma}_1 = \bar{\sigma}_3 \tan^2\left(45° + \frac{\phi}{2}\right) + 2C\tan\left(45° + \frac{\phi}{2}\right)$$

$\Rightarrow$
$$300 = 100\tan^2\left(45° + \frac{\phi}{2}\right) + 0$$

$\Rightarrow \qquad \tan^2\left(45° + \frac{\phi}{2}\right) = 3$

$\Rightarrow \qquad 45° + \frac{\phi}{2} = 60°$

$\Rightarrow \qquad \phi = 30°$

Hence frictional angle = 30°

Inclination of slip plane to horizontal, $\theta_f = 45 + \frac{\phi}{2} = 60°$

2. Let σ_f, τ_f be the normal and shear stresses respectively on failure plane

Now,
$$\sigma_f = \left(\frac{\sigma_1 + \sigma_3}{2}\right) + \left(\frac{\sigma_1 - \sigma_3}{2}\right)\cos 2\theta_f$$

$$= \left(\frac{300+100}{2}\right) + \left(\frac{300-100}{2}\right)\cos(2\times 60°)$$

$$= 200 + 100\cos 120° = 150 \text{ kN/m}^2$$

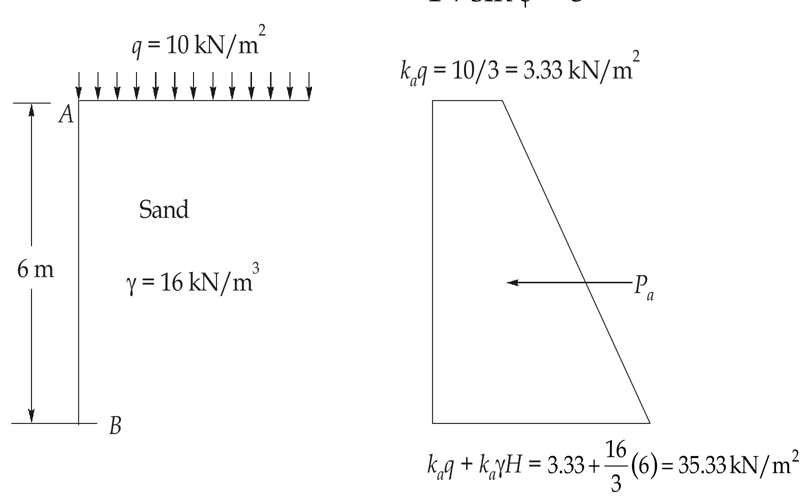
$$\tau_f = \left(\frac{\sigma_1 - \sigma_3}{2}\right)\sin 2\theta_f$$

$$= \left(\frac{300-100}{2}\right)\sin(2\times 60°) = 86.6 \text{ kN/m}^2$$

(ii) Maximum shear stress = $\frac{\bar{\sigma}_1 - \bar{\sigma}_3}{2} = \frac{300-100}{2} = 100$ kPa

(ii) $\phi = 30°$, $\gamma_b = 16$ kN/m^3

Active earth pressure coefficient, $k_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1}{3}$

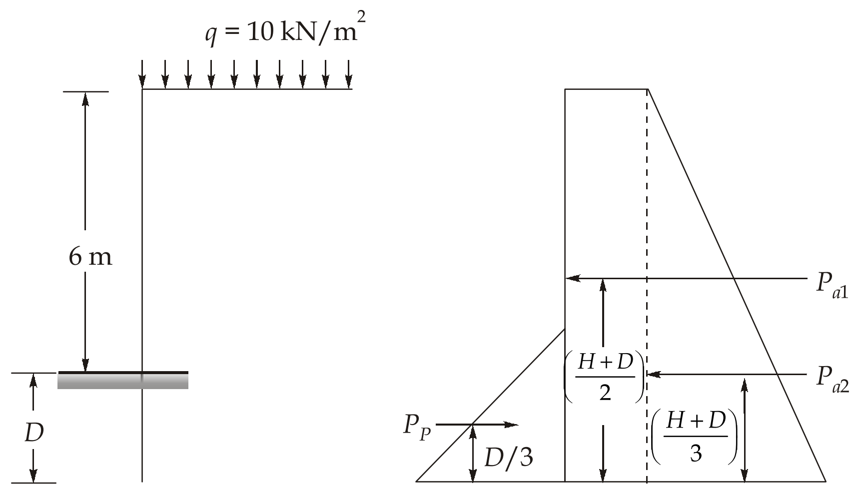


At top, $p_a = K_a q = 3.33 \text{ kN/m}^2$

At bottom, $p_b = K_a q + k_a \gamma H = 35.33 \text{ kN/m}^2$

Active thrust, $p_a = \dfrac{3.33 + 35.33}{2} \times 6 = 115.98 \text{ kN/m}$

(ii)



Let the depth of embedment = D

Now, passive earth pressure coefficient, $k_p = \dfrac{(1+\sin\phi)}{(1-\sin\phi)} = 3$

$$P_P \times \frac{D}{3} = P_{a_1}\left(\frac{H+D}{2}\right) + P_{a_2}\left(\frac{H+D}{3}\right)$$

$$\Rightarrow \quad k_p \gamma \frac{D^2}{2} \times \frac{D}{3} = \frac{k_a q}{2}(H+D)^2 + \frac{k_a \gamma}{2}(H+D)^2\left(\frac{H+D}{3}\right)$$

$$\Rightarrow \quad 3 \times 16 \times \frac{D^3}{6} = \frac{10}{3\times 2}(6+D)^2 + \frac{16}{3\times 2} \times \frac{(6+D)^3}{3}$$

On solving, we get $D = 6.1062$ m

Q.2 (c) Solution:

(i)

1. True R.L of B:

Instrument at A,

Incorrect level difference between A and B = 2.712 – 1.435 = 1.277 m

Instrument at B,

Incorrect level difference between A and B = 2.501 – 1.430 = 1.071 m

∴ True difference of levels between A and B.

$$= \frac{1.277 + 1.071}{2} = 1.174 \text{ m}$$

∴ RL of B = 100 – 1.174 = 98.826 m

2. Correction for collimation

$$\text{Collimation error} = \frac{0.003}{150} \times 1250$$

$$= 0.025 \text{ m}$$

∴ Correction for collimation = – 0.025 m

3. Correction for refraction

$$\text{Error due to curvature} = 0.0785\, D^2$$

$$= 0.0785 \times 1.25^2 \simeq 0.123 \text{ m}$$

Correction for curvature = – 0.123 m

Let the correction for refraction be C_R.

∴ Combinbed correction for curvature and refraction

$$= -0.123 + C_R$$

∴ Total correction = $-0.025 - 0.123 + C_R$

$$= -0.148 + C_R$$

True R.L of B after applying correction,

$$= 100 + 1.435 - (2.712 - 0.148 + C_R)$$

$$= 98.871 - C_R$$

∴ $98.871 - C_R = 98.826$

⇒ $C_R = 0.045$ m

(ii)

Advantages:

(a) It is very suitable for plotting small scale maps directly in the field.

(b) Since plotting is done in the field only and thus no field book is required. Furthermore, the accidental omission of any prominent detail of the area to be surveyed is avoided since surveyor has the full view of the field.

(c) The plotted map can be compared with the actual field plan on the field itself.

(d) By the provision of suitable check lines, the errors in measurement and plotting can be detected easily in the field.

(e) Because of simple instruments, not much skill is required for taking the observations.

(f) Since no angular measurements are made and thus error while reading the angles from the instruments are prevented.

(g) The biggest advantage of this method is that it can be used in magnetically affected area also where compass surveying cannot be used.

(h) Plane table surveying is usually more rapid and less expensive than other methods of surveying.

(i) Contours and other features can be plotted in the field itself and can be checked there in the field only.

Disadvantages:

(a) This method of surveying is not at all suitable for wet climates.

(b) It is not a precise method of surveying as compared to other methods.

(c) The instruments and the associated accessories of the plane table are quite heavy and bulky which the surveyor needs to carry along with.

(d) As the height of plane table is up to the waist only and thus sight distances are less than the distances measured with compass or a theodolite.

(e) In the event of omission of any field data, replotting of the plan is very difficult.

Q.3 (a) Solution:

As we know,

$$u = \frac{r^2 S}{4Tt}$$

where r is radial distance
S is storage coefficient.
T is transmissivity

Now, drawdown after 2 hour of pumping,

$$S_1 = \frac{Q}{4\pi T} W(u)$$

where Q is discharge i.e. 1500 l/m = 1.5m^3/min

$$W(u) = -0.5772 - ln(u)$$

So,
$$S_1 = \frac{Q}{4\pi T}\left[-0.5772 - \ln\left(\frac{r^2 S}{4Tt_1}\right)\right] \quad \ldots\text{(i)}$$

Similarly,
$$S_2 = \frac{Q}{4\pi T}\left[-0.5772 - \ln\left(\frac{r^2 S}{4Tt_2}\right)\right] \quad \ldots\text{(ii)}$$

Subtracting (ii) from (i), we get,

$$S_2 - S_1 = \frac{Q}{4\pi T}\ln\frac{t_2}{t_1}$$

$$\Rightarrow \quad 8.5 - 6.5 = \frac{1.5}{4\pi T}\ln\frac{24}{2}$$

$$\Rightarrow \quad T = 0.148 \text{ m}^2/\text{min}$$

Now,

$$S_1 = \frac{Q}{4\pi T}\left[-0.5772 - \ln\left(\frac{r^2 S}{4Tt_1}\right)\right]$$

$$\Rightarrow \quad 6.5 = \frac{1.5}{4\pi \times 0.148}\left[-0.5772 - \ln\left(\frac{5^2 \times S}{4 \times 0.148 \times 2 \times 60}\right)\right]$$

$$\Rightarrow \quad 8.06 = -0.5772 - ln(0.35 \times S)$$

$$\Rightarrow \quad ln(0.35 \times S) = -0.5772 - 8.06$$

$$= -8.6372$$

$$\Rightarrow \quad 0.35 \times S = 1.7738 \times 10^{-4}$$

$$\Rightarrow \quad S = 5.07 \times 10^{-4}$$

(ii)

Secondary air pollutants: The large number of primary air pollutants present in the air often react with one-another aided by sun-light and water vapours to give rise to totally new types of pollutants called as secondary air pollutants.

Various secondary air pollutants are:

(i) Sulphuric acid

(ii) Ozone

(iii) Formaldehydes

(iv) Peroxy-acyl-nitrate (PAN)

Sulphur dioxide (SO_2): SO_2 when inhaled, affects the mucous membranes of human body. It is a primary pollutant which in combination with water vapours forms a much hazardous secondary air pollutant viz. sulphuric acid (H_2SO_4). SO_2 increases the breathing rate and causes oxygen deficit in human body. SO_2 usually originates from oil refineries, chemical factories and combustion of fuels. Thermal power plants also emit SO_2 in huge proportions.

Carbon monoxide (CO): CO mainly originates from combustion of fuels in vehicles. Incomplete combustion of organic matter in limited supply of air gives rise to CO.

CO has a very high affinity towards blood haemoglobin (Hb) rather than with oxygen.

Thus when inhaled, it replaces oxygen and forms carboxy-haemoglobin which is of no use for the human respiratory system. Thus when nearly half of the blood haemoglobin gets used up to form carboxy-haemoglobin, death results.

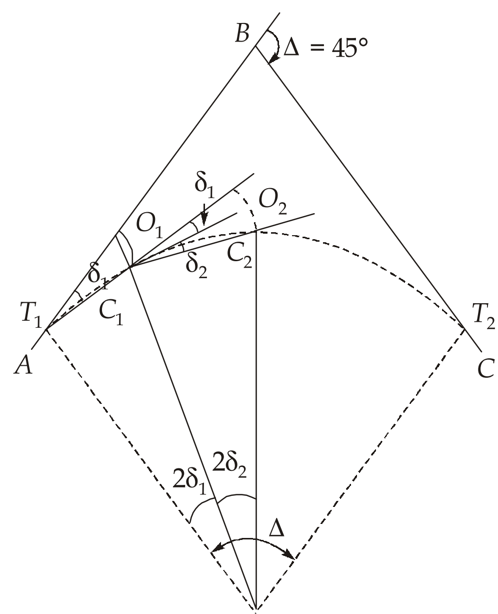
Q.3 (b) Solution:

Chain used is of 30 m length

$$\text{Degree of curve, } D = 5°$$

$$\text{Radius of curve, } R = \frac{1720}{5} = 344 \text{ m}$$

$$\text{Deflection angle, } \Delta = 180° - 135° = 45°$$



$$BT_1 = R\tan\frac{\Delta}{2}$$

$$= 344\times\tan\frac{45°}{2} = 142.49 \text{ m}$$

Chainage of intersection point B = 3850 m

$$\text{Chainage of } T_1 = 3850 - 142.49 = 3707.51 \text{ m}$$

$$\text{Length of curve} = R\times\Delta\times\frac{\pi}{180°}$$

$$= 344 \times 45° \times \frac{\pi}{180°}$$

$$= 270.18 \text{ m}$$

$$\text{Chainage of } T_2 = \text{Chainage of } T_1 + \text{Length of curve}$$

$$= 3707.51 + 270.18 = 3977.69 \text{ m}$$

Length of the chords:

$$\text{First subchord, } C_1 = 3720 - 3707.51$$

$$= 12.49 \text{ m}$$

$$\text{Last subchord, } C_n = 3977.69 - 3960$$

$$= 17.69 \text{ m}$$

$$\text{Total number of intermediate chords} = \frac{270.18 - 17.69 - 12.49}{30} = 8$$

Calculation of offsets:

$$O_1 = \frac{C_1^2}{2R} = \frac{12.49^2}{2 \times 344} = 0.227 \text{ m}$$

$$O_2 = \frac{C_2(C_1 + C_2)}{2R} = \frac{30 \times (12.49 + 30)}{2 \times 344} = 1.853 \text{ m}$$

$$O_3 = O_4 = O_5 = ... = O_{10} = \frac{C^2}{R} = \frac{30^2}{344} = 2.616 \text{ m}$$

$$O_{10} = \frac{C_{10}(C_9 + C_{10})}{2R} = \frac{17.69 \times (30 + 17.69)}{2 \times 344}$$

$$= 1.226 \text{ m}$$

(ii)

1. Bowditch's rule

- This method of traverse adjustment is suitable where linear and angular measurements are made with equal precision.
- This method is usually used for balancing a compass traverse but can be used for theodolite traverse also provided angular and linear measurements are done with same precision.
- This method assumes that the errors/mistakes are accidental in nature and the probable error in a traverse line is proportional the square root of its length.
- As per Bowditch's rule,

Error in latitude or departure of a traverse line

$$= \text{Total error in latitude or departure of traverse} \times \frac{\text{Length of traverse line}}{\text{Perimeter of traverse}}$$

- The required correction will be numerically equal to the value of error but its sign will be opposite to that of error.

  When a traverse is adjusted by Bowditch's rule, then both the lengths and bearings of the traverse get affected but here **lengths get changed less and angles get changed more.**

Advantages of Bowditch's rule:

(a) Bowditch's rule is quite easy to apply.

(b) The altered bearings of the traverse lines do not significantly affect the plotted position of the traverse points.

(c) This method is backed up by a logical mathematical reason and is not an empirical one.

2. Transit rule

- This method of traverse adjustment is used in situations where angular measurements are made with more precision as compared to linear measurements.
- In theodolite traverse, angular measurements are more precise as compared to linear measurements and thus this method is quite suitable for theodolite traverse.
- As per Transit rule,

  Error in latitude or departure of a traverse line

  = Total error in latitude or departure of traverse ×

$$\frac{\text{Numerical value of latitude or departure of traverse line}}{\text{Arithematic sum of latitudes or departures of traverse}}$$

Q.3 (c) Solution:

(i)

By Peck-Henson, equation

$$(q_a)_{net}\ \text{kN/m}^2 = 0.44\, C_w N S$$

$$S = \text{Permissible allowable settlement (in mm)} = 40 \text{ mm}$$

$$C_w = 0.5\left(1 + \frac{D_w}{D_f + 3}\right) \not> 1$$

$$= 0.5\left(1+\frac{3}{1.5+3}\right) = 0.833$$

N = Average correct SPT 'Number'

1. By overburden correction

$$N_1 = N_0 \cdot \frac{350}{\bar{\sigma}+70}$$

where $\bar{\sigma} \not> 280 \text{ kN/m}^2$

By dilatancy correction,

$$N_2 = 15+\frac{1}{2}(N_1-15)$$

S.No.	SPT No.	$\bar{\sigma}$ (kN/m^2)	N_1	N_2
1	10	18 × 1.5 = 27	36.08	25.54
2	15	27 + 15 × 1.5 = 54	42.34	28.67
3	20	54 + 10 × 1.5 = 69	50.36	32.68
4	25	69 + 8 × 1.5 = 81	57.95	36.48

Now, $$N_{avg} = \frac{25.54+28.67+32.68+36.48}{4} = 30.84$$

$$N_i \not> 1.5N_{avg} = 46.26$$

$$(q_0)_{net} = 0.44 \times 0.833 \times 30.84 \times 40$$
$$= 452.14 \text{ kN/m}^2$$

(ii)

Total BOD in raw sewage $= 3 \times 10^6 \times 250 \times 10^{-6}$
$= 750$ kg/day

BOD removed in primary tank = 25%

So, BOD entering per day in filter,

$$W_1 = (1 - 0.25) \times 750$$
$$= 562.5 \text{ kg/day}$$

BOD leaving the filter

$$= 3 \times 10^6 \times 30 \times 10^{-6} = 90 \text{ kg/day}$$

$$\therefore \quad \text{Efficiency of filter, } \eta = \frac{562.5 - 90}{562.5} = 0.84 = 84\%$$

Now,

$$\eta = \frac{100}{1 + 0.44\sqrt{\dfrac{W_1}{V}}}$$

$$\Rightarrow \quad 84 = \frac{100}{1 + 0.44\sqrt{\dfrac{562.5}{V}}}$$

$$\Rightarrow \quad \sqrt{\frac{562.5}{V}} = 0.43$$

$$\Rightarrow \quad V = 3001.556 \text{ m}^3$$

Now,

$$\frac{\pi}{4} \times D^2 \times 2 = 3001.556$$

$$\Rightarrow \quad D = 43.71 \text{ m}$$

When high rate trickling filter is used

Given

$$R = 1.5$$

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

Now,

$$\eta = \frac{100}{1 + 0.44\sqrt{\dfrac{W_1}{V_1 F_1}}}$$

$$\Rightarrow \quad 84 = \frac{100}{1 + 0.44\sqrt{\dfrac{562.5}{V_1 \times 1.89}}}$$

$$\Rightarrow \quad V_1 = 1588.125 \text{ m}^3$$

Now,

$$\frac{\pi}{4} \times D_1^2 \times 2 = 1588.125$$

$$\Rightarrow \quad D_1 = 31.8 \text{ m}$$

So, percent reduction in diameter $= \dfrac{D - D_1}{D} \times 100 = \left(\dfrac{43.71 - 31.8}{43.71}\right) \times 100$

$$= 27.25\%$$

Q.4 (a) Solution:

(i) From the modified Hiley's formula

We know that, the ultimate load on pile

$$Q_u = \frac{(\eta_h W H n_b)}{\left(S + \frac{C}{2}\right)}$$

where, η_h = Efficiency of hammer = 80% = 0.8

W = 2.5 tonne

H = 75 cm

S = average penetration under last 5 blows = 10 mm = 1 cm.

eP = 0.55 × 2 = 1.1 tonne < W(= 2.5 tonne)

$$\therefore \qquad \eta_b = \frac{W + e^2 P}{W + P} = \frac{2.5 + (0.55)^2 \times 2}{2.5 + 2} = 0.69$$

In order to find out the value of Q_u, assume as the first approximate

C = 2.5 cm

$$Q_u = \frac{(\eta_h W H \eta_b)}{\left(S + \frac{C}{2}\right)} = \frac{0.8 \times 2.5 \times 75 \times 0.69}{1 + \frac{2.5}{2}}$$

$$= 46 \text{ tonnes}$$

$$C_1 = 1.77 \frac{Q_u}{A_P}$$

$$= 1.77 \times \frac{46}{\frac{\pi}{4} \times 30^2} = 0.115 \text{ cm}$$

$$C_2 = 0.657 \left(\frac{Q_u L}{A_P}\right) = 0.657 \times \frac{46 \times 20}{\frac{\pi}{4} \times 30^2} = 0.855$$

$$C_3 = 3.55 \times \frac{Q_u}{A_P} = \frac{3.55 \times 46}{\frac{\pi}{4} \times 30^2} = 0.231$$

$$C = (C_1 + C_2 + C_3) = (0.115 + 0.855 + 0.231)$$

$$= 1.201 < 2.5 \text{ cm} \qquad \text{(OK)}$$

Let Q_u = 50 tonne $\quad C = \dfrac{1.201 \times 50}{46} = 1.306$

$$Q_u = \frac{0.8 \times 2.5 \times 75 \times 0.69}{1 + \frac{1.305}{2}} = 62.63 \text{ tonne}$$

Let Q_u = 54 tonne $\quad C = \dfrac{1.201 \times 54}{46} = 1.41$

$$Q_u = \frac{0.8 \times 2.5 \times 75 \times 0.69}{1 + \frac{1.41}{2}} = 60.7 \text{ tonne}$$

Let Q_u = 53 tonne $\quad C = \dfrac{1.201 \times 53}{46} = 1.38$

$$Q_u = \frac{0.8 \times 2.5 \times 75 \times 0.69}{1 + \frac{1.38}{2}} = 61.24 \text{ tonne}$$

Let $\quad Q_u = \dfrac{53 + 61.24}{2} = 57.12 \text{ tonne}$

$\therefore \quad C = \dfrac{1.201 \times 57.12}{46} = 1.49$

$\therefore \quad Q_u = \dfrac{0.8 \times 2.5 \times 75 \times 0.69}{1 + \frac{1.49}{2}} = 59.3 \text{ tonne}$

Let's stop our iteration and take

$$Q_u = 58.6 \text{ tonne}$$

$\therefore \quad \text{Safe load} = \dfrac{58.6}{2.5} = 23.44 \text{ tonne}$

(ii)

Pre consolidated Soils: Pre consolidated soils are those which have been subjected to effective stress in the past greater than present applied effective stress. The pre consolidated/normally consolidated soils can be differentiated using **over consolidation ratio.**

Pre consolidated soils are also called as consolidated or pre-compressed soils. Such soils are less compressible and have greater shear strength and more stability.

Some of the causes of over-consolidation or pre-consolidation are as follows:

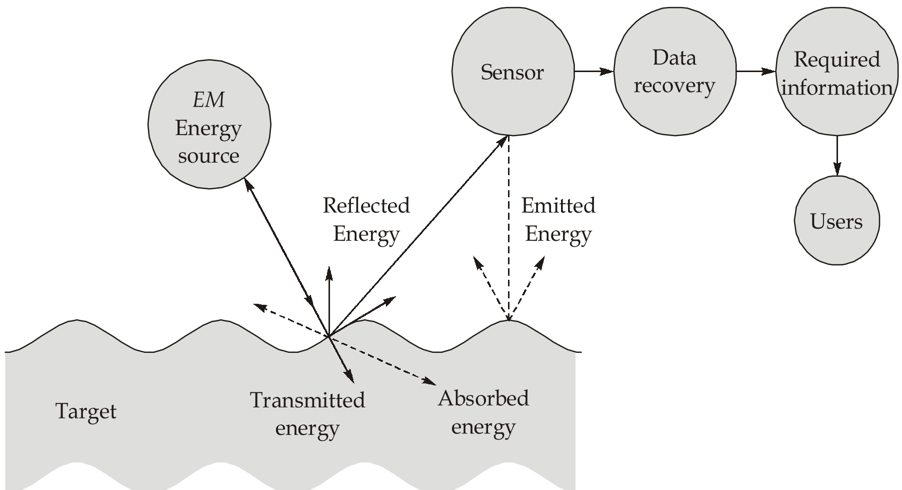
1. In the past, over burden pressure or surcharge was placed, which is removed later.
2. Continuous erosion of overburden soil.
3. Melting of glacier which covered the soil mass in past.
4. Effect of capillary pressure which is later destroyed by rise of water table.
5. During the drying of soil, effective stress reduces and soil becomes over consolidated. This process is known as '**Dessication of soil**'.
6. If initially soil was subjected to downward seepage pressure but later seepage stops, then effective stress reduces.
7. If there was no seepage but later vertically upward seepage occurs, then also the effective stress reduces.
8. Due to effects of tectonic forces.

Q.4 (b) Solution:

(i)

Remote sensing:

- Remote sensing is the science and art of acquisition of information about an object or phenomenon from a distance without making physical contact with them.
- Advantage of remote sensing is that a bird's eye perspective view can be captured from a considerable distance above the earth's surface and thus a very large area can be covered.
- The best example of remote sensing is the **human eye**.
- Human eye is able to see an object when light gets reflected from that object. Human eye acts as a sensor which detects the object by the image formation at the retina.
- But human eye is able to see only a small part of the electromagnetic spectrum called as **visible spectrum** (400 nm to 700 nm wavelength).
- In modern usage, the term remote sensing generally refers to the use of aerial sensor technologies to detect and classify objects on Earth (both on the surface, and in the atmosphere and oceans) by means of electromagnetic energy (such as light, heat, etc.).
- Remote sensors collect data by detecting the energy that is reflected from Earth. These sensors can be on satellites or mounted on aircraft.
- In remote sensing, data is acquired from highly advanced cameras, multispectral scanners and radars etc. mounted on satellite or aircraft.
- Most of the real world remote sensing processes are electromagnetic type.



An ideal sensing system

Advantages of remote sensing:

- Provides data of large areas.
- Provides data of very remote and inaccessible regions.
- Able to obtain imagery of any area over a continuous period of time through which any anthropogenic or natural changes in the landscape can be analyzed.
- Easy and rapid collection of data.
- Rapid production of maps for interpretation.
- Relatively inexpensive when compared to employing a team of surveyors.

Disadvantages of remote sensing:

- The interpretation of imagery requires a certain skill level.
- Images get distorted due to relative motion of sensors and sources.
- Data collected from multiple sources may create confusion.
- Gross verification required with ground survey data.
- Objects can be misclassified or confused.

(ii)

Pycnometer Method

- This is a quick method but it is less accurate than oven drying method.

- This method is used only when specific gravity of soil solids is known.
- A small weight of soil say 200 g to 400 g is placed in a clean pycnometer whose capacity is 900 m*l*.
- Let W_1 = Weight of empty pycnometer bottle
  W_2 = Weight of pycnometer + soil
  W_3 = Weight of pycnometer + soil + water
  W_4 = Weight of pycnometer + water

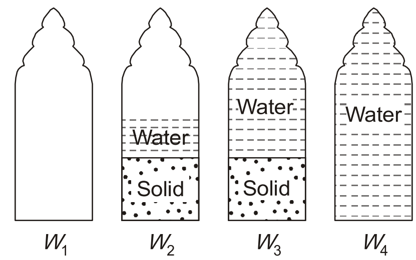


Fig. *Pycnometer method*

Let G be specific gravity of soil solids.

Now, water content, $w = \frac{W_w}{W_s} \times 100$

Weight of water = $(W_2 - W_1) - W_s$ ...(i)

If from W_3, the weight of solids W_s could be removed and replaced by the weight of an equivalent volume of water, the weight W_4 will be

$$W_4 = W_3 - W_s + \frac{W_s}{G\gamma_w} \cdot \gamma_w$$

$$\Rightarrow \quad W_s = (W_3 - W_4)\frac{G}{G-1} \quad \text{...(ii)} \quad \left[\because V_s = \frac{W_s}{\gamma_s} \text{ and } G = \frac{\gamma_s}{\gamma_w}\right]$$

From (i) and (ii),

$$w = \left[\frac{(W_2 - W_1)}{(W_3 - W_4)}\left(\frac{G-1}{G}\right) - 1\right] \times 100$$

Calcium carbide method/Rapid moisture meter method

- It is very quick method, takes only 5 to 7 minutes but may not give accurate results.
- A soil sample of weight 4 - 6 gms is placed in moisture testing equipment. The equipment consists of a closed chamber in which calibrated scale is connected to measure the pressure exerted which is directly co-related to water content.
- Calcium carbide powder (CaC_2) is added on the moist soil sample which reacts with the water and as a result acetylene gas is removed which exerts pressure.

$$CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2 \uparrow$$

- The water content recorded is expressed as a percentage of moist weight of soil, whereas actual water content is expressed as a fraction of dry weight of soil

  Let w_r = Moisture content recorded, expressed as a fraction of moist weight of soil

  w = Actual water content

Then $$w = \left(\frac{w_r}{1-w_r}\right)\times 100\%$$

Q.4 (c) Solution:

(i) For average flow conditions, the required surface area

$$A = \frac{Q}{\text{Overflow rate}} = \frac{20000\ \text{m}^3/\text{day}}{40\ \text{m}^3/\text{m}^2\text{day}} = 500\ \text{m}^2$$

Let L be the tank length and assuming two units of clarifiers having width of 6 m.

$$L = \frac{\text{Area}}{\text{Width}} = \frac{500\ \text{m}^2}{2\times 6\ \text{m}} = 41.7\ \text{m}$$

∴ Adopt surface dimensions of clarifier as 6 m × 42 m.

∴ $$\text{Tank volume} = (42\times 6\times 4)\times 2 = 2016\ \text{m}^3$$

$$\text{Overflow rate on average flow} = \frac{Q}{A} = \frac{20000\ \text{m}^3/\text{day}}{2(6\ \text{m}\times 42\ \text{m})} = 39.70\ \text{m}^3/\text{m}^2/\text{day}$$

$$\text{Detention time} = \frac{\text{Volume}}{Q} = \frac{2016\ \text{m}^3\times 24\ \text{hr}}{(20000\ \text{m}^3/\text{day})} = 2.42\ \text{hours}$$

Detention time and overflow rate at peak flow

$$\text{Overflow rate} = \frac{Q}{A} = \frac{50000\ (\text{m}^3/\text{day})}{2(6\ \text{m}\times 42\ \text{m})} = 99.2\ \text{m}^3/\text{day}/\text{m}^2$$

$$\text{Detention time, } t = \frac{\text{Volume}}{Q} = \frac{(2016\ \text{m}^3)(24\ \text{h/day})}{(50000\ \text{m}^3/\text{day})} = 0.97\ \text{hour}$$

(ii) We know,

$$\text{Scour velocity, } V_s = \left\{\frac{8k(G_s-1)gd}{f}\right\}^{\frac{1}{2}}$$

$$\Rightarrow \quad V_s = \left(\frac{8\times 0.05(1.25-1)\times 9.81\times 100\times 10^{-6}}{0.025}\right)^{\frac{1}{2}} = 0.063\ \text{m/sec}$$

$$\text{Peak flow horizontal velocity, } V_H = \frac{\text{Peak flow}}{\text{Cross-sectional area}}$$

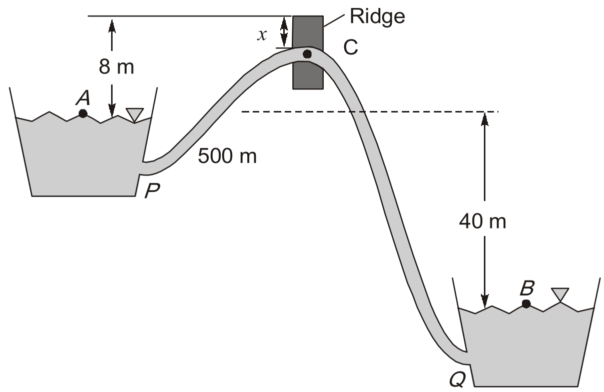
$$= \left\{\frac{50000\,m^3/d}{2(6\text{ m} \times 4\text{ m})}\right\}\left\{\frac{1}{24\,h/d \times 3600\text{ s}/h}\right\} = 0.012\text{ m/sec}$$

$$\because \quad V_H < V_S$$

Therefore, settled matter should not be resuspended.

Section-B

Q.5 (a) Solution:



Given: Diameter of siphons, (d) = 200 mm

Difference in levels of two reservior, H = 40 m

Total length of pipe = 8000 m

Height of ridge summit from water in upper reservior = 8 m

Let the depth of the pipe below the summit of ridge = x m.

∴ Height of siphon from water surface in the upper reservoir = (8 – x) m.

Minimum, pressure head at C, $\frac{P_C}{\rho g}$ = 3.0 m of water absolute

Co-efficient of friction, f = 0.006

Length of siphon from upper reservoir to the summit, L_1 = 500 m.

Apply Bernoulli's equation to points A and B, [Taking datum line passing through B]

$$\therefore \quad \frac{P_A}{\rho g} + \frac{V_A^2}{\rho g} + h_A = \frac{P_B}{\rho_g} + \frac{V_B^2}{\rho g} + Z_B + h_f$$

$$\Rightarrow \quad 0 + 0 + 40 = 0 + 0 + 0 + \frac{4fLV^2}{2gd}$$

$$\Rightarrow \quad 40 = \frac{4 \times 0.006 \times 8000 \times V^2}{2 \times 9.81 \times 0.2}$$

$$\Rightarrow \quad V = \sqrt{\frac{4\times0.2\times2\times9.81}{4\times0.006\times8000}} = 0.904 \text{ m/sec.}$$

Now applying Bernoullis's equation to points *A* and *C*,

$$\frac{P_A}{\rho g}+\frac{V_A{}^2}{2g}+Z_A = \frac{P_C}{\rho_g}+\frac{V_C{}^2}{2g}+Z_C+h_{f_1}$$

Substituting $\frac{P_A}{\rho g}$ and $\frac{P_C}{\rho g}$ in terms of absolute pressure,

$$10.3 + 0 + 0 = 3+\frac{V^2}{2g}+(8-x)+\frac{4fL_1V^2}{2gd}$$

$$\Rightarrow \quad 10.3 = 3 + \frac{0.904^2}{2\times9.81} + (8 - x) + \frac{4\times0.006\times500\times0.904^2}{2\times9.81\times0.2}$$

$$\Rightarrow \quad 10.3 = 3 + 0.0417 + 8 - x + 2.499$$

$$\Rightarrow \quad x = 3.24 \text{ m}$$

$$\text{Discharge, } Q = A \times V$$

$$= \frac{\pi}{4}\times(0.2)^2\times0.904 = 0.0284 \text{ m}^3\text{/sec.} = 28.40\ /\text{s}$$

Q.5 (b) Solution:

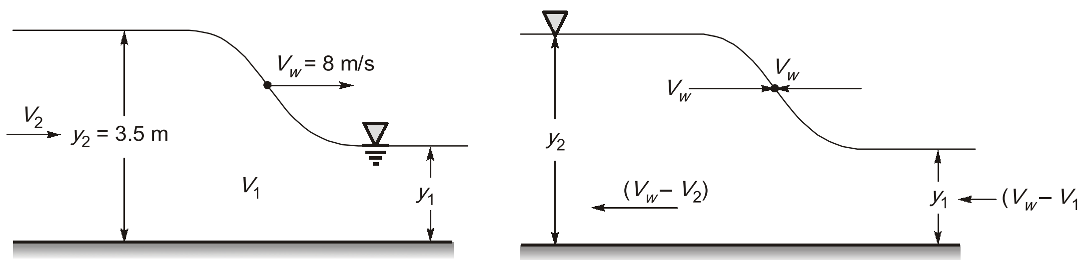
The goals and policies contained in the plan are:

1. Roads network should be developed to provide accessibility to all villages with a population of above 500 by the turn of the century.
2. Roads should be built in less industrialised areas so as to attract the growth of industries.
3. Road should be a major choice of construction programme to generate employment.
4. Long term master plan for determining the road network must be prepared at the sub-divisional, district, state and national level.
5. The national highway length should be increased so as to form a square grid of 100 km side.
6. Expressways should be constructed on major traffic corridors to provide speedy travel.
7. Energy conservation through road improvements must be given a high priority.
8. The enviornmental quality of roads and the area through which they pass must be maintained and improved.
9. Road safety measures must be undertaken to contain and bring down road accident rates.

10. Major district roads should serve and connect all towns and villages with population of 1500 and above.
11. Other district roads should serve and connect villages with a population of 1000-1500.
12. Maintenance of roads already constructed should receive attention.

Q.5 (c) Solution:

(i)



(a) (b) Simulated steady flow

Here, y_2 = 3.5 m, V_2 = 4.5 m/s and V_w = 8 m/s

By continuity equation,

$$y_1[V_w - V_1] = y_2[V_w - V_2]$$

$$\Rightarrow \quad y_1[8 - V_1] = 3.5[8 - 4.5]$$

$$\Rightarrow \quad V_1 = 8 - \frac{12.25}{y_1}$$

$$\Rightarrow \quad \frac{(V_w - V_1)^2}{gy_1} = \frac{1}{2} \times \frac{y_2}{y_1} \times \left[1 + \frac{y_2}{y_1}\right]$$

$$\Rightarrow \quad \frac{\left[8 - 8 + \frac{12.25}{y_1}\right]^2}{9.81 \times y_1} = \frac{1}{2} \times \frac{3.5}{y_1} \times \left[1 + \frac{3.5}{y_1}\right]$$

$$\Rightarrow \quad \frac{15.297}{y_1^3} = \frac{1.75}{y_1}\left[1 + \frac{3.5}{y_1}\right]$$

$$\Rightarrow \quad y_1^2 + 3.5y_1 - 8.741 = 0$$

$$\Rightarrow \quad y_1 = \frac{-3.5 \pm \sqrt{(3.5)^2 + 4 \times 8.741}}{2}$$

$$y_1 = 1.686 \text{ m}, -5.18 \text{ m}$$

$$\text{So, } y_1 = 1.686 \text{ m}$$

$$\therefore \quad V_1 = 8.0 - \frac{12.25}{1.686} = 0.734 \text{ m/sec}$$

(ii)

Given: Width of channel, b = 5 m

Specific Energy, E = 4 N-m/N

Discharge, Q = 20 m^3/sec.

Now, Specific Energy, $E = y + \frac{V^2}{2g}$

Here, $V = \frac{Q}{A} = \frac{Q}{b \times y} = \frac{20}{5 \times y} = \frac{4}{y}$

$$\therefore \quad E = y + \left(\frac{4}{y}\right)^2 \times \frac{1}{2g} = y + \frac{8}{gy^2}$$

$$\Rightarrow \quad 4 = y + \frac{8}{9.81y^2} = y + \frac{0.8155}{y^2}$$

$$4y^2 = y^3 + 0.8155$$

$$y^3 - 4y^2 + 0.8155 = 0$$

$$\Rightarrow \quad y = 3.95 \text{ m}, 0.48 \text{ m}, -0.43 \text{ m}$$

So, alternate depths are 0.48 m and 3.95 m

Q.5 (d) Solution:

The unigauge system is highly beneficial to the rail users, railway administration as well as to the nation. Some of the benefits are given below.

1. **No transport - bottlenecks:** In a unigauge system, there is no transport bottleneck. It gives improved operational efficiency and fast movement of goods and passengers.
2. **No transhipment hazards:** In unigauge system, there is no need of changing trains, hence no damage to goods and no inconvenience to the passengers.
3. **Improved utilization of track:** In unigauge system, the track can be used to the full capacity, resulting in reduction of working expenses of the railway.
4. **Provision of alternate routes:** The unigauge system, provides alternate routes for free movement of traffic, resulting in reduced pressure on the track.
5. **Better turn round:** The unigauge system provides better turn round of wagons and locomotives resulting in improved operating ratio of the railway system. This results in immense benefits to the nation.

6. **Balanced economic growth:** Due to unigauge system, the development of all areas will be uniform, resulting in balanced economic growth.

Diferent types of rails:

Rails can be classified into the following categories:

1. **Double headed rail:** Originally the rails used were double headed made of I section or dumb bell section. The idea was that when the head of the rail is worn-out during the service period, the rail could be inverted and reused without incurring any extra expenditure. Such rails have to be supported on chairs which rest on sleepers. But later it was found that during the service the bottom table of the rail was dented by the long and continous contact with the chair to such an extent that it was impossible to reuse it. This led to the development of bull headed rail.
2. **Bull headed rail:** The bull headed rail is almost similar to double headed rail. The only difference between the double headed and bull headed rail is that in bull headed rail more metal is added to the head to allow greater wear and tear.
3. **Flat footed rail:** To remove the above draw backs, Charles Vignoles developed an inverted T shaped section known as flat footed rail in 1836. Flat footed rail is also known as Vignole rail.

Q.5 (e) Solution:

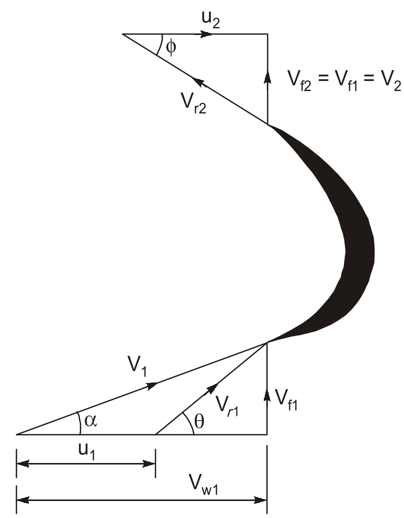
In Khosla's formula applicable to the present case, $R_M = P_M - L_M$ with, L_M = (0.48 × T°c) having a maximum value equal to corresponding P_M. The calculations are shown below.

Month	Temperature (°C)	Rainfall, P_M (cm)	L_M (cm)	Runoff, R_M (cm)
January	14	5	5	0
February	17	6	6	0
March	20	3	3	0
April	27	0	0	0
May	32	3	3	0
June	35	10	10	0
July	30	30	14.4	15.6
August	28	28	13.44	14.56
September	28	15	13.44	1.56
October	29	2	2	0
November	20	1	1	0
December	15	2	2	0

$\sum$Run off = 31.72 cm

∴ Total annual runoff = 31.72 cm

Q.6 (a) Solution:



(i) Given;

$$\text{Net head, } H = 60 \text{ m}$$
$$\text{Speed, } N = 700 \text{ rpm}$$
$$\text{Shaft power, } P = 294.3 \text{ kW}$$
$$\text{Overall efficiency, } \eta_0 = 84\%$$
$$\text{Hydraulic efficiency, } \eta_h = 93\%$$
$$\text{Flow ratio, } = \frac{V_{f_1}}{\sqrt{2gH}}$$
$$\Rightarrow \quad 0.2 = \frac{V_{f_1}}{\sqrt{2\times 9.81\times 60}}$$
$$\Rightarrow \quad V_{f1} = 0.2\times\sqrt{2\times 9.81\times 60}$$
$$= 6.86 \text{ m/s}$$
$$\text{Breadth ratio, } \frac{B_1}{D_1} = 0.1$$
$$\text{Outer diameter, } D_1 = 2 \times \text{inner diameter} = 2D_2$$
$$\text{Velocity of flow, } V_{f1} = V_{f2} = 6.86 \text{ m/s}$$

Thickness of vanes, = 5% of circumferential area of runner.

$$\therefore \quad \text{Actual area of flow} = 0.95\,\pi\, D_1 B_1$$

As discharge at outlet is radial.

$$\therefore \quad V_{w2} = 0 \text{ and } V_{r2} = V_2$$

Using relation,
$$\eta_0 = \frac{S.P}{W.P}$$
$$\Rightarrow \quad 0.84 = \frac{294.3}{W.P.}$$
$$\Rightarrow \quad W.P. = \frac{294.3}{0.84} = 350.357 \text{ kW}$$

But
$$W.P. = \frac{W.H.}{1000} = \frac{\rho.g.Q.H}{1000} = \frac{1000\times 9.81\times Q\times 60}{1000}$$
$$\Rightarrow \quad 350.357 = \frac{1000\times 9.81\times Q\times 60}{1000}$$

$\Rightarrow \quad Q = 0.5952 \text{ m}^3/\text{sec.}$

Now, $\quad Q = 0.95\pi D_1 B_1 V_{f1}$

$\Rightarrow \quad 0.5952 = 0.95 \times \pi \times D_1 \times 0.1 \times D_1 \times 6.86$

$$\Rightarrow \quad D_1 = \sqrt{\frac{0.5952}{2.047}} = 0.54 \text{ m}$$

Also, $\quad \frac{B_1}{D_1} = 0.1$

$\Rightarrow \quad B_1 = 0.1 \times 0.54 = 0.054 \text{ m}$

$= 54 \text{ mm}$

Tangential speed of the runner at inlet,

$$u_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.54 \times 700}{60}$$

$$= 19.79 \text{ m/s}$$

Using relation for hydraulic efficiency,

$$\eta_h = \frac{V_{w_1} u_1}{gH}$$

$$\Rightarrow \quad 0.93 = \frac{V_{w_1} \times 19.79}{9.81 \times 60}$$

$$\Rightarrow \quad V_{w1} = \frac{0.93 \times 9.81 \times 60}{19.79}$$

$$= 27.66 \text{ m/sec.}$$

1. Guide blade angle (α);

From inlet velocity triangle,

$$\tan \alpha = \frac{V_{f_1}}{V_{w_1}} = \frac{6.86}{27.66}$$

$$\Rightarrow \quad \alpha = \tan^{-1} 0.248$$

$$= 13.929°$$

2. Runner vane angles at inlet and outlet (θ and ϕ):

$$\tan \theta = \frac{V_{f_1}}{V_{w_1} - u_1} = \frac{6.86}{27.66 - 19.79} = 0.87$$

$$\Rightarrow \quad \theta = \tan^{-1}(0.87) = 41°$$

From outlet velocity triangle,

$$\tan\phi = \frac{V_{f_2}}{u_2} = \frac{V_{f_1}}{u_2}$$

Here,
$$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times \left(\frac{0.54}{2}\right) \times 700}{60}$$

$$= 9.896 \text{ m/sec.}$$

∴
$$\tan\phi = \frac{6.86}{9.896}$$

$$\phi = \tan^{-1} 0.6932$$

$$= 34.73°$$

3. Diameter of runner at inlet and outlet:

$$D_1 = 0.54 \text{ m}$$

$$D_2 = 0.27 \text{ m}$$

4. Width of wheel at inlet

$$B_1 = 54 \text{ mm}$$

(ii)

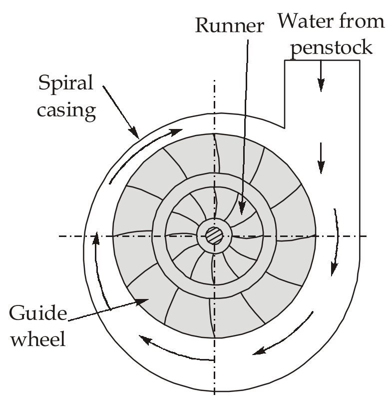
Main parts of a radial flow reaction turbine.

The main parts of a radial flow reaction turbine are:

1. Casing,
2. Guide mechanism,
3. Runner, and
4. Draft-tube.

1. **Casing**: In case of reaction turbines, casing and runner are always full of water. The water from the penstocks enters the casing which is of spiral shape in which area of cross-section of the casing goes on decreasing gradually. The casing completely surrounds the runner of the turbine. The casing as shown in figure below is made of spiral shape, so that the water may enter the runner at constant velocity throughout the circumference of the runner. The casing is made of concrete, cast iron or plate steel.
2. **Guide Mechanism**: It consists of a stationary circular wheel all round the runner of the turbine. The stationary guide vanes are fixed on the guide mechanism. The guide vanes allow the water to strike the vanes fixed on the runner without shock at inlet. Also by a suitable arrangement, the width between two adjacent vanes of guide mechanism can be altered so that the amount of water striking the runner can be varied.

3. **Runner**: It is a circular wheel on which a series of radial curved vanes are fixed. The surface of the vanes are made very smooth. The radial curved vanes are so shaped that the water enters and leaves the runner without shock. The runners are made of cast steel, cast iron or stainless steel. They are keyed to the shaft.
4. **Draft-tube**: The pressure at the exit of the runner of a reaction turbine is generally less than atmospheric pressure. The water at exit cannot be directly discharged to the tail race. A tube or pipe of gradually increasing area is used for discharging water from the exit of the turbine to the tail race. This tube of increasing area is called draft tube.



Q.6 (b) Solution:

(i) Length of,

1. National Highway (NH)

$$\text{Length of NH} = \frac{\text{Area}}{50} = \frac{3,20,000}{50} = 6400 \text{ km}$$

2. Length of state highway (SH)

- $$\text{Length of SH} = \frac{\text{Area}}{25} = \frac{3,20,000}{25} = 12800 \text{ km}$$
- $$\text{Length of SH} = \begin{pmatrix}\text{Total length of} \\ \text{SH and NH}\end{pmatrix} - (\text{length of NH})$$

$$= (62.5 \times 280) - (6400) = 11100 \text{ km}$$

Length of SH is maximum of above two i.e. (12800, 11100) i.e. 12800 km

3. Length of major district roads (MOR)

(a) $$\text{Length of MDR} = \frac{\text{Area}}{12.5} = \frac{3,20,000}{12.5} = 25,600 \text{ km}$$

(b) Length of MDR = 90 × No. of towns

= 90 × 280

= 25200 km

Length of MOR is maximum of above two i.e. (25600, 25200) i.e. 2500 km

4. Length of ODR and VR

No. of villages and towns = 280 + 42000 = 42280

Total length of all categories of roads

= 4.74 × 42280 ≃ 200408 km

Length of ODR and VR = 200408 – [6400 + 12800 + 25600]

= 155608 km

(ii)

AASHO road test was the largest and most comprehensive highway research project undertaken so far. It was the most ambitions attempt ever made to solve the perplexing problems that are faced by designers of modern highway pavements.

Objectives of the test:

1. To determine the significant relationships between the number of repetitions of specified axle loads of different magnitude and arrangement and performance of different thickness of uniformly designed and constructed asphaltic concrete, plain portland cement concrete and reinforced portland cement concrete surfaces on different thicknesses of bases and sub-bases when laid on a basement soil of known characteristics.
2. To determine the significant effects of specified vehicle axle loads and gross vehicle axle loads when applied at known frequency on bridges of known design and characteristics.
3. To make special studies dealing with such subjects as paved shoulders, base types, pavement fatigue, tyre size and pressures and heavy military vehicles and to correlate the findings of these special studies with the results of basic research.
4. To provide a record of the type and extent of effort and materials required to keep each of the test sections or portions thereof in a satisfactory condition until discontinued for test purposes.
5. To develop instrumentation, test procedures, data chart, graphs and formulae to reflect the capabilities of the various test sections, which would be helpful in future highway design, in the evaluation of the load carrying capabilities of existing highways and in determining the most promising areas for further highway research.

Q.6 (c) Solution:

(i)

$$\text{Normal width, } B_0 = 20 \text{ m}$$
$$\text{Flume width, } B_f = 12 \text{ m}$$
$$\text{Length of transition} = 24 \text{ m}$$

Let V_0, V_f, V_x be the velocities at original width, flumed width and at distance 'x' from the flumed section and B_x be the width at a distance 'x' from the flumed section.

Using Mitra's approach, rate of change of velocity per unit length of tansition is kept constant.

$$\therefore \quad \frac{V_f - V_x}{x} = \frac{V_f - V_0}{L_f} \quad \ldots(i)$$

Also, water depth, D and discharge, Q are constant.

So, $$Q = V_0 B_0 D = V_f B_f D = V_x B_x D \quad \ldots(ii)$$

From (i) and (ii)

$$\frac{\left(\frac{Q}{B_f D} - \frac{Q}{B_x D}\right)}{x} = \frac{\left(\frac{Q}{B_f D} - \frac{Q}{B_0 D}\right)}{L_t}$$

$$\Rightarrow \quad \frac{(B_x - B_f)L_f}{B_x \times B_f} = \frac{(B_0 - B_f)x}{B_f \times B_0}$$

$$\Rightarrow \quad B_x = \frac{B_0 B_f L_f}{L_0 B_0 - (B_0 - B_f)x} = \frac{20 \times 12 \times 24}{24 \times 20 - (20 - 12)x} = \frac{5760}{480 - 8x}$$

$$\Rightarrow \quad B_x = \frac{720}{60 - x}$$

So the transition width should be hyperbolic as $B_x = \dfrac{720}{60 - x}$

$x(m)$	0	3	6	9	12	15	18	21	24
$B_x(m)$	12	12.63	13.33	14.12	15	16	17.14	18.46	20

(ii)

Water lagging is a phenomena in which productivity of land gets affected due to high water table leading to the flooding of root zone of the plants and making the root zone of the plants water logged.

The water lagging affects the productivity or fertility of the land and thus leads to a reduction in the crop yield.

The water logging is usually characterized by rise of sub-soil water table.

Causes of water logging:

- Over and intensive irrigation of fields.
- Seepage of water through the canals.
- Inadequate surface drainage.
- Heavy rains
- Obstruction of natural drainage will cause flooding in the area and consequent water logging of land.
- Incorrect and defective methods of cultivation.
- Inadequate natural drainage.
- Seepage of water from adjoining high lands.
- Low permeability of soil like black cotton soil etc.

Reclamation methods of water logged area:

Land reclamation is a process by which an uncultivable land is made fit for cultivation.

- Saline and water logged lands give very less crop yields and are therefore, almost unfit for cultivation unless they are reclaimed.
- All those measures which are suggested for preventing water logging hold good for preventing salinity of land also.
- After the high water table has been lowered by suitable drainages, the soil is made from existing salts by 'leaching' process.
- 'Leaching' is a process in which land is flooded by adequate depth of water. The alkali salts present in the soil gets dissolved in this water which percolate down to the water table.
- This process is repeated till the salts in the top layer of the land are reduced to such an extent that some salt resistant crops can be grown. e.g. Bajra, fodder etc.
- If the salinity is reduced to such an extent that ordinary crop like wheat, cotton etc. can be grown, the land is said to have been reclaimed.

Q.7 (a) Solution:

(i) At the centre of the plate,

$$x = 1.25 \text{ m}$$

$$U = 1.5 \text{ m/s}$$

$$\text{Reynold's number, } Re_x = \frac{U \cdot x}{\nu} = \frac{1.5 \times 1.25}{10^{-4}} = 1.875 \times 10^4$$

This is less than $Re_{(crit)} = 5 \times 10^5$ and hence the boundary layer is laminar.

$$\therefore \quad \frac{\delta}{x} = \frac{5.0}{\sqrt{Re_x}}$$

∴ Boundary layer thickness at center of plate,

$$\delta_m = \frac{5.0 \times 1.25}{\sqrt{1.875 \times 10^4}} = 0.0456 \text{ m} = 4.56 \text{ cm}$$

$$C_f = \text{Local friction coefficient} = \frac{0.664}{\sqrt{Re_x}}$$

$$= \frac{0.664}{\sqrt{1.875 \times 10^4}} = 4.849 \times 10^{-3}$$

$$\text{Shear stress, } \tau = C_f \frac{\rho U^2}{2} = 4.849 \times 10^{-3} \times \frac{0.8 \times 1000}{2} \times (1.5)^2$$

$$= 4.364 \text{ N/m}^2$$

(ii) At the trailing edge, $x = L = 2.5$ m

$$Re_L = \frac{1.5 \times 2.50}{10^{-4}} = 3.75 \times 10^4$$

$$\therefore \quad Re_L < Re_{L(crit)} \; (= 5 \times 10^5)$$

∴ The boundary layer is laminar upto the trailing edge.

$$\therefore \quad \delta_L = \frac{5L}{\sqrt{Re_L}} = \frac{5 \times 2.50}{\sqrt{3.75 \times 10^4}} = 0.0645 \text{ m} = 6.45 \text{ cm}$$

$$\therefore \quad C_f = \frac{0.664}{\sqrt{Re_L}} = \frac{0.664}{\sqrt{(3.75 \times 10^4)}} = 3.429 \times 10^{-3} \text{ m}$$

Shear stress at trailing edge τ is

$$\tau = C_f \frac{\rho U^2}{2} = (3.429 \times 10^{-3}) \times \left(\frac{0.8 \times 1000}{2}\right) (1.5)^2$$

$$= 3.086 \text{ N/m}^2$$

Total force (on both sides of the plate)

$$F = C_f \times (\text{area}) \times \frac{\rho U^2}{2}$$

$$C_f = \frac{1.328}{\sqrt{\text{Re}_L}} = \frac{1.328}{\sqrt{3.75 \times 10^4}} = 6.858 \times 10^{-3}$$

$\therefore$ $$F = (6.858 \times 10^{-3})\,(2 \times 2.5 \times 2) \times \frac{(0.8 \times 1000) \times (1.5)^2}{2}$$

$$= 61.72 \text{ N}$$

$\therefore$ Power required to tow the plate,

$$P = F \times U = 61.72 \times 1.5 = 92.58 \text{ Nm/s} = 92.58 \text{ J}$$

Q.7 (b) (i)Solution:

For catchment *M*,

Duration of effective rainfall, t_R =6 hours

Time from beginning of rainfall excess to peak discharge, T_p = 37 hours

As we know,

$$T_p = \frac{t_R}{2} + t_p' \quad \text{where } t_p' \text{ is modified basin lag}$$

$\Rightarrow$ $$37 = \frac{6}{2} + t_p'$$

$\Rightarrow$ $$t_p' = 34 \text{ hours}$$

Now, $$t_p' = \frac{21}{22} t_p + \frac{t_R}{4}$$ where t_p is standard basin lag defined by Synder's method

$\Rightarrow$ $$34 = \frac{21}{22} t_p + \frac{6}{4}$$

$\Rightarrow$ $$t_p = 34.05 \text{ hours}$$

As we know, $$t_p = C_t(L \cdot L_{Ca})^{0.3}$$

$\Rightarrow$ $$34.05 = C_t(148 \times 76)^{0.3}$$

$\Rightarrow$ $$C_t = 2.074$$

Also, $$Q_p = 2.78 C_p \frac{A}{t_p'}$$

$$\Rightarrow \quad 200 = 2.78C_p \frac{2718}{34}$$

$$\Rightarrow \quad C_p = 0.9$$

Now, these values of C_t and C_p can be used for catchment N.

$$\text{Basin lag, } t_p = C_t(L \cdot L_{Ca})^{0.3}$$

$$= 2.074 \times (52 \times 106)^{0.3}$$

$$= 27.49 \text{ hours}$$

So,
$$t_r = \frac{27.49}{5.5} \simeq 5 \text{ hours}$$

But required duration of hydrograph is 6 hours.

So,
$$t_p' = \frac{21}{22} t_p + \frac{t_R}{4}$$

$$= \frac{21}{22} \times 27.49 + \frac{6}{4} = 27.74 \text{ hours}$$

Therefore, peak discharge,
$$Q_p = 2.78C_p \frac{A}{t_p'}$$

$$= 2.78 \times 0.9 \times \frac{1400}{27.74} = 126.27 \text{ m}^3/\text{s}$$

Now, width of unit hydrograph at 50% peak, $W_{50} = \dfrac{5.87}{q^{1.08}}$

where q is discharge per unit area.

So,
$$W_{50} = \frac{5.87}{(126.27/1400)^{1.08}}$$

$$= 78.89 \text{ hours} \simeq 79 \text{ hours}$$

Now, Width of unit hydrograph at 75% peak, $W_{75} = \dfrac{W_{50}}{1.75} = \dfrac{79}{1.75} \simeq 45$ hours

Also,
$$\text{Time base, } T_b = (72 + 3t_p') \text{ hours}$$

$$= 72 + 3 \times 27.74 \simeq 155 \text{ hours}$$

(ii)

Hydrograph: It is a continuous plot of instantaneous discharge versus time at a point in the catchment. It results from the combined interaction of various catchment and meteorological characteristics. The hydrograph is the response of a given catchment to a rainfall input. It consists of flow in all the three phases of runoff, interflow and base flow, and embodies in itself the integrated effects of a wide variety of catchment and rainfall parameters having complex integration.

Depending upon the unit of time involved, we have

1. **Annual Hydrograph**: It shows variation of daily, weekly or mean flow of any number of successive days over a year.
2. **Monthly Hydrograp**h: It shows the variation of daily mean flow over a month.
3. **Seasonal Hydrograph**: It shows the variation of the discharge in a particular season such as the monsoon season or dry season.

Q.7 (c) Solution:

(i) Streamlines are lines drawn in the flow field such that, at any given instant, they are tangent to the direction of the flow at every point.

Consequently, $$\left.\frac{dy}{dx}\right|_{\text{streamline}} = \frac{v}{u} = \frac{-Ay}{Ax} = \frac{-y}{x}$$

Separating variables and integrating, we obtain

$$\int \frac{dy}{y} = -\int \frac{dx}{x}$$

$$\Rightarrow \quad \ln y = -\ln x + \ln c$$

$$\Rightarrow \quad xy = c$$

(ii) A particle moving in the flow field has velocity which is given by

$$\vec{V} = Ax\hat{i} - Ay\hat{j}$$

Thus, $$u = \frac{dx}{dt} = Ax \text{ and } v = \frac{dy}{dt} = -Ay$$

Separating variables and integrating each will give

$$\int_{x_0}^{x} \frac{dx}{x} = \int_0^t A\,dt \text{ and } \int_{y_0}^{y} \frac{dy}{y} = -\int_0^t A\,dt$$

$$\Rightarrow \quad \ln\left(\frac{x}{x_0}\right) = At \text{ and } \ln\left(\frac{y}{y_0}\right) = -At$$

$$\Rightarrow \quad x = x_0 e^{At}$$

and $$y = y_0 e^{-At}$$

At $t = 6s$,

$$x = 2 \times e^{0.3 \times 6} = 12.1 \text{ m and } y = 8e^{-(0.3) \times 6} = 1.32 \text{ m}$$

Thus, at $t = 6s$, particle is at (12.1, 1.32) m

(iii) At the point (12.1, 1.32) m where the particle is at $t = 6$ sec

$$\vec{V} = A\left(x\hat{i} - y\hat{j}\right) = 0.3s^{-1}\left(12.1\hat{i} - 1.32\hat{j}\right)\text{m}$$

$$= 3.63\hat{i} - 0.396\hat{j} \text{ m/sec}$$

(iv) To determine the equation of the pathline, use the parametric equations:

$$x = x_0 e^{At} \text{ and } y = y_0 e^{-At} \text{ and eliminate } t \text{ from these equation.}$$

Solving for e^{At} from both equations,

$$e^{At} = \frac{x}{x_0} = \frac{y_0}{y}$$

$\therefore$ $xy = x_0 y_0 = 16 \text{ m}^2$ which is same as the equation of streamline with constant

$$c = 16 \text{ m}^2$$

Q.8 (a) Solution:

(i)

The general properties of bitumen are enumerated below:

1. Bitumen contains predominantly hydrocarbons with small quantities of sulphur, oxygen, nitrogen and metals.
2. It is predominantly soluble in carbon disulphide (CS_2). The portion insoluble in CS_2 being generally less than 0.1%.
3. Most of the bitumens are colloidal in nature.
4. Bitumen is thermoplastic i.e., it softens on heating and hardens on cooling.
5. Bitumen is insoluble in water.
6. It is highly impermeable to the passage of water.
7. It is chemically inert.
8. It oxidises slowly.

For satisfactory performance as a road material, bitumen should have the following desirable properties:

1. It should be fluid enough at the time of mixing to coat the aggregates evenly by a thin film. Fluidity is achieved either by heating or by cutting-back with a thin flux or by emulsifying the bitumen.
2. It should have low temperature susceptibility or in other words, it should exhibit little change in viscosity with change in temperature.
3. The bitumen should have a good amount of volatiles in it, and it should not lose them excessively when subjected to higher temperature. This will ensure its durability.

4. The bitumen should be ductile and not brittle.
5. The bitumen should be capable of being heated to the temperatures at which it can be easily mixed without any fire hazards.
6. The bitumen should have good affinity to the aggregates and should not be stripped off in the continued presence of water.

(ii)

$$\text{Theoretical specific gravity, } G_t = \frac{W_1 + W_2 + W_3 + W_4}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_4}{G_4}}$$

$$= \frac{820 + 1200 + 320 + 150}{\frac{820}{2.63} + \frac{1200}{2.50} + \frac{320}{2.47} + \frac{150}{2.43}}$$

$$= 2.533$$

$$\text{Mass specific gravity, } G_m = \frac{1100}{470} = 2.34$$

$$\text{Percentage air voids, } V_v = \frac{G_t - G_m}{G_t} \times 100$$

$$= \frac{2.533 - 2.34}{2.533} \times 100$$

$$= 7.62\%$$

$$\text{Percentage volume of bitumen, } V_b = \frac{G_m}{G_4} \times \frac{W}{W_{\text{mould}}} \times 100$$

$$= \frac{2.34}{1.05} \times \frac{100}{1100} \times 100 = 20.26\%$$

$$\text{Voids in mineral aggregate, } VMA = V_V\% + V_b\%$$

$$= 7.62 + 20.26$$

$$= 27.88\%$$

$$\text{Voids filled with bitumen, } VFB = \frac{V_b\%}{V_{MA}\%} \times 100 = \frac{20.26}{27.88} \times 100 = 72.67\%$$

Q.8 (b) Solution:

(i) Given, $Q = 1000\ \text{m}^3/\text{s}$, $L = 255$ m

$\therefore$ Discharge per unit length of weir, $(q) = \frac{Q}{L} = \frac{1000}{255} = 3.92\ \text{m}^3/\text{sec/m}$

Now, for discharging intensity (q), the normal depth of scour is given by Lacey's equation as,

$$R = 1.35\left(\frac{q^2}{f}\right)^{1/3} = 1.35\left(\frac{3.92^2}{1.1}\right)^{1/3} = 3.25 \text{ m}$$

Adopting downstream cutoff upto 1.5 R below the downstream level

$$1.5\,R = 1.5 \times 3.25 = 4.875 \text{ m}$$

$$\text{upstream water level} = \text{upstream HFL} = 103 \text{ m}$$

Let H = Maximum static head causing seepage = 2.4 m

∴ D/s water level = U/s HFL – H = 103 – 2.4 = 100.6 m

Hence, RL of bottom of D/s cutoff = 100.6 – 4.875 = 95.725 m

$$\text{RL of D/s floor} = 100 \text{ m (given)}$$

∴ Depth of D/s cut off = 100 – 95.725 = 4.275 m

Hence, $d = 4.275$ m

Check for exit gradient, $$G_E = \frac{H}{d} \times \frac{1}{\pi\sqrt{\lambda}}$$

$$\lambda = \frac{1+\sqrt{1+\alpha^2}}{2}$$

$$\alpha = \frac{b}{d} = \frac{\text{Length of weir floor}}{\text{Depth of D/s cutoff}}$$

$$= \frac{b}{d} = \frac{40}{4.275} = 9.357$$

$$\lambda = \frac{1+\sqrt{1+9.357^2}}{2} = 5.2$$

∴ $$G_E = \frac{2.4}{4.275} \times \frac{1}{\pi\sqrt{5.2}} = \frac{1}{12.76} < \frac{1}{6}$$ (Hence OK)

Hence, the weir is safe from exit gradient considerations of bottom of downstream cutoff at RL of 95.725 m.

(ii)

Factors to be considered for selection of site for a dam reservoir are:

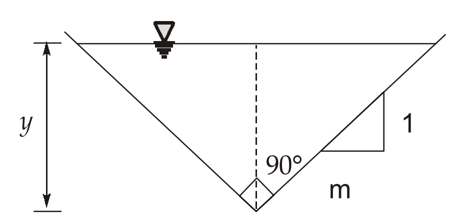
1. Geological condition of the catchment area should be such that percolation losses are minimum and maximum runoff is obtained.

2. Quantity of leakage through the reservoir site should be minimum. Reservoir site having the presence of highly permeable rocks reduce the water tightness of the reservoir. The dam should be founded on sound water tight rock base, and percolation below the dam be minimum.
3. Cost of dam is often a controlling factor in selection of a site.

   The reservoir basin should have narrow opening in the valley so that length of the dam is less.
4. The cost of real estate for the reservoir, including road, rail, dwelling re-location etc. must be as less as possible.
5. Topography of reservoir site should be such that it has adequate capacity without submerging excessive land and other properties.
6. The site should be such that a deep reservoir is formed. A deep reservoir is preferable to a shallow one because of
   (i) low submergence area
   (ii) less evaporation loss
   (iii) less likelihood of weed growth.
7. Reservoir site should be such that it avoids or excludes water from those tributaries which carry a high percentage of silt.
8. Reservoir site should be such that water stored in it is suitable for the purpose for which the project is undertaken.
9. The soil and rock mass at the reservoir site must not contain any objectionable minerals and salts.

Q.8 (c) Solution:

(i) Consider a triangular channel of side slope m horizontal : 1 vertical



$$\text{Pressure force, } P = \gamma . A . \bar{y}$$

$$= \gamma\left(my^2\right)\frac{y}{3}$$

$$= \gamma . \frac{my^3}{3}$$

$$\text{Momentum flux, } M = \frac{\rho . Q^2}{A} = \frac{\rho . Q^2}{my^2}$$

For hydraulic jump in horizontal, frictionless channel,

$$P_1 + M_1 = P_2 + M_2$$

$$\Rightarrow \quad \frac{\gamma.my_1^3}{3} + \frac{\rho.Q^2}{my_1^2} = \frac{\gamma.my_2^3}{3} + \frac{\rho.Q^2}{my_2^2}$$

where y_1 and y_2 are sequent depths

$$\therefore \quad \frac{Q^2}{m}\left[\frac{1}{y_1^2} - \frac{1}{y_2^2}\right] = \frac{gm}{3}\left[y_2^3 - y_1^3\right]$$

On simplifying,

$$\frac{Q^2}{g} = \frac{m^2}{3}\left[\frac{y_1^3(\eta^3 - 1).\eta^2 y_1^4}{(\eta^2 - 1)y_1^2}\right]$$

where, $\eta = \dfrac{y_2}{y_1}$

In the present case, $m = 1$

and, $\eta = \dfrac{y_2}{y_1} = \dfrac{1.2}{0.6} = 2$

$$\therefore \quad \frac{Q^2}{g} = \frac{1}{3} \times (0.6)^5 \left[\frac{2^3 - 1}{2^2 - 1}\right] \times 2^2 = 0.24192$$

$$\therefore \quad Q = \sqrt{0.24192 \times 9.81}$$

$$= 1.54 \text{ m}^3/\text{sec.}$$

(ii) For triangular channel, $F = \dfrac{Q}{A\sqrt{g.A/T}}$

$$\Rightarrow \quad F^2 = \frac{Q^2 T}{yA^3}$$

$$\Rightarrow \quad F^2 = \frac{Q^2(2my)}{gm^2.y^6} = \frac{2Q^2}{gm^2.y^5}$$

$$\Rightarrow \quad F_1^2 = \frac{2 \times (1.54)^2}{9.81 \times 1 \times (0.6)^5} = 6.22$$

$$\Rightarrow \quad F = 2.494$$

Froude number at the end of the jump:

Since, $F^2 = \dfrac{2Q^2}{gm^2y^5}$

$\therefore$ $\dfrac{F_1}{F_2} = \left(\dfrac{y_2}{y_1}\right)^{5/2}$

$\Rightarrow$ $\dfrac{F_1}{F_2} = \left(\dfrac{1.2}{0.6}\right)^{5/2} = 5.657$

$\therefore$ $F_2 = \dfrac{2.494}{5.657} = 0.441$

(iii) Energy loss, $E_L = E_1 - E_2$

$$= \left[y_1 + \frac{V_1^2}{2g}\right] - \left[y_2 + \frac{V_2^2}{2g}\right]$$

$$V_1 = \frac{Q}{A_1} = \frac{1.54}{(0.6)^2} = 4.28 \text{ m/sec.}$$

$$V_2 = \frac{Q}{A_2} = \frac{1.54}{(1.2)^2} = 1.070 \text{ m/sec.}$$

$$E_L = \left[0.6 + \frac{(4.28)^2}{2\times 9.81}\right] - \left[1.2 + \frac{(1.070)^2}{2\times 9.81}\right]$$

$$= 1.534 - 1.258 = 0.276 \text{ m}$$

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