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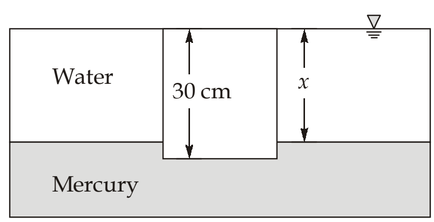
Detailed Solutions

ESE-2019 Mains Test Series

Civil Engineering Test No : 13

Section A

Q.1 (a) Solution:



Let the top edge of the cube be at a distance x from the water-mercury interface.

Thus, the force of buoyancy is given by

F_B = Volume of cube in water × $\rho_w g$ + Volume of cube in mercury × ρ_{Hg} × g

$$F_B = \left(\frac{30}{100}\times\frac{30}{100}\times x\right)\times 1000\times 9.81+\frac{30}{100}\times\frac{30}{100}\times\left(\frac{30}{100}-x\right)\times 13600\times 9.81$$

$\Rightarrow \quad F_B = 882.9x + 12007.44\,(0.3 - x)$

Given, Weight of cube, $W = 500$ N

$\therefore \quad W = F_B$

$\Rightarrow \quad 500 = 882.9x + 12007.44\,(0.3 - x)$

$\Rightarrow \quad 500 = 882.9x + 3602.232 - 12007.44\,x$

$\Rightarrow \quad 11124.54x = 3102.232$

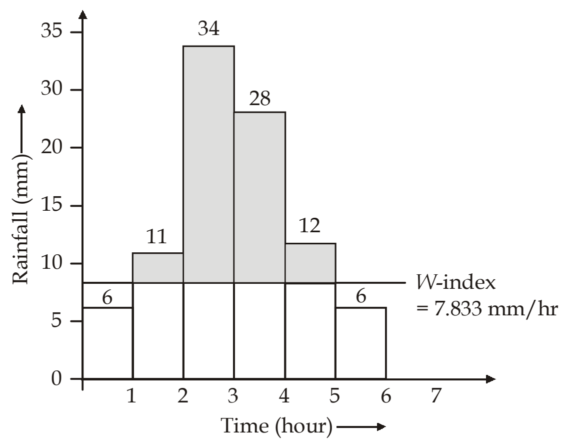
$\Rightarrow \quad x = 0.2789$ m

$= 27.89$ cm [From the top edge of the block]

Q.1 (b) Solution:

(i)

Time	0	1	2	3	4	5	6	7
Rainfall (mm)	0	6.0	11.0	34.0	28.0	12.0	6.0	0.0



$$\text{Total precipitation,} \quad P = 97 \text{ mm}$$

$$\text{Total runoff,} \quad R = \frac{25000}{50 \times 10^4} = 0.05 \text{ m} = 50 \text{ mm}$$

$$\therefore \quad \text{Total infiltration, } I = P - R$$

$$= 97 - 50 = 47 \text{ m}$$

$$\therefore \quad W\text{-index} = \frac{P-R}{t} = \frac{97-50}{6}$$

$$= 7.833 \text{ mm/hr}$$

$$\because \quad \phi\text{-index} \geq W\text{-index}$$

$$\therefore \quad \phi\text{-Index} = \frac{\text{(Total infiltration – infiltration during period when no excess rain occurs)}}{\text{Period of excess rainfall}}$$

$$= \frac{47-6-6}{4} = 8.75 \text{ mm/hr}$$

Check :

Total runoff (R) = $[(11-8.75)+(34-8.75)+(28-8.75)+(12-8.75)] \times 1 = 50$ mm which is same as given.

(ii)

$$\Sigma p = 100 + 120 + 190 + 95 + 125 = 630 \text{ cm}$$

$$\therefore \quad \bar{p} = \frac{\Sigma p}{5} = \frac{630}{5} = 126 \text{ cm}$$

Optimum number of stations can be calculated as

$$N = \left(\frac{C_v}{E}\right)^2$$

where C_v is coefficient of variation of rainfall and E is allowable degree of error in %

Now, $$C_v = \frac{\sigma_{m-1} \times 100}{\bar{p}}$$

where $$\sigma_{m-1} = \sqrt{\frac{\sum_{i=1}^{m}(p_i - \bar{p})^2}{m-1}}$$

$\therefore$ $$\sigma_{m-1} = \sqrt{\frac{(100-126)^2 + (120-126)^2 + (190-126)^2 + \left(95-126^2\right) + (125-126)^2}{5-1}}$$

$\Rightarrow$ $$\sigma_{m-1} = 37.98 \text{ cm}$$

$\therefore$ $$C_v = \frac{37.98 \times 100}{126} = 30.14\%$$

$\Rightarrow$ $$N = \left(\frac{30.14}{10}\right)^2 = 9.09 \approx 10 \text{ stations}$$

So, 9 non-recording type and 1 recording type rain gauge may be provided for this watershed.

Q.1 (c) Solution:

Given data: $Q = 1500$ litres per minute $= 0.025\ \text{m}^3/\text{s}$, $r_1 = 6$ m, $s_1 = 6$ m, $r_2 = 16$ m, $s_2 = 2$ m, $H = 120$ m

$\therefore$ $$h_1 = H - s_1 = 120 - 6 = 114 \text{ m}$$

$$h_2 = H - s_2 = 120 - 2 = 118 \text{ m}$$

Using Thiem's equation for unconfined aquifer, we have

$$Q = \frac{\pi k\left(h_2^2 - h_1^2\right)}{2.303\log_{10}\left(\frac{r_2}{r_1}\right)}$$

$\Rightarrow$ $$0.025 = \frac{\pi k\left(118^2 - 114^2\right)}{2.303\log_{10}\left(\frac{16}{6}\right)}$$

$$k = 8.4123 \times 10^{-6} \text{ m/s}$$

Thus, the coefficient of permeability, $k = 8.4123 \times 10^{-6}$ m/s

Radius of gravity well, $$r_w = \frac{0.6}{2} = 0.3 \text{ m}$$

Using Theim's equation again, we get

$$Q = \frac{\pi k\left(h_i^2 - h_w^2\right)}{2.303\log_{10}\left(\frac{r_1}{r_w}\right)}$$

$$0.025 = \frac{\pi \times 8.4123 \times 10^{-6} \times \left(114^2 - h_w^2\right)}{2.303\log_{10}\left(\frac{6}{0.3}\right)}$$

$\Rightarrow$ $h_w = 100.805$ m

$\therefore$ Drawdown in the pumped well = $H - h_w$

$= 120 - 100.805$

$= 19.195$ m

Q.1 (d) Solution:

Impacts of disposal of waste water into fresh water:

(i) Nutrients: Eutrophication arises from the oversupply of nutrients, which leads to overgrowth of plant algae. After such organisms die, the bacterial degradation of their biomass consumes the oxygen from the water thereby creating the state of hypoxia.

Eutrophication is almost always induced by the discharge of nitrates or phosphates containing detergents, fertilizers or sewage into the aquatic system.

(ii) Heavy metals: Major industrial sources of wastewater include surface treatment processes with metals like As, Co, Cu, Zn, Ni, Cd, Pb, Hg and Cr as well as industrial products that at the end of their use are discharged into waste water treatment plants (WWTP's) facilities.

Toxic metals in wastewater are one of the main causes of river or fresh water pollution. Heavy metals are often released into the aquatic environment through atmospheric deposition or anthropogenic sources. The impacts of heavy metals on aquatic ecosystems are well documented.

(iii) Oil and grease: With the excessive discharge of oil and grease to sewerage system, problems may occur with clogging of sewers and pumping plants and with the interference of biological treatment processes.

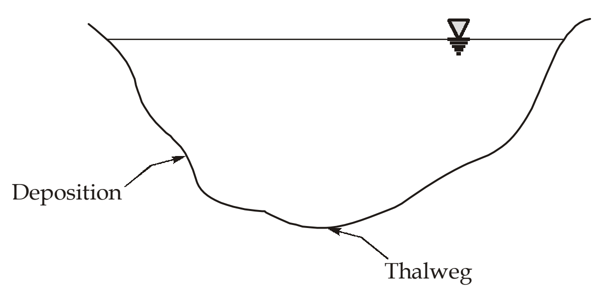
(iv) Suspended solids: There is considerable effect of suspended and dissolved solids in the irrigation water on the growth of plants. The salts increase the osmotic potential of the soil water and increase in osmotic pressure of the soil solution increases the amount of energy which plants must expend to take up water from the soil.

Q.1 (e) Solution:

(i) **River bed aggradation :** When the sediment transporting capacity of a river at a point becomes less than the sediment load being carried, as a result of reduction in the velocity due to an increase in cross-section or reduction in slope of the river, the excess sediment gets deposited on the river bed. As a result, the riverbed rises and this phenomenon is being termed as aggradation. Often this phenomenon is noticed on the upstream of the dam.

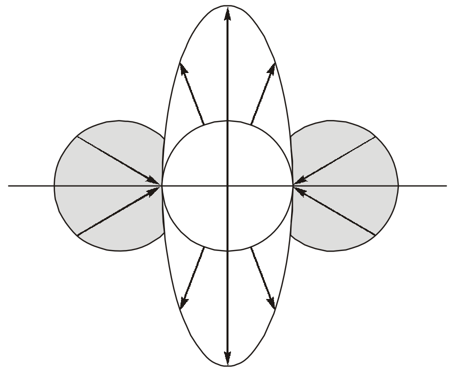
(ii) **Armouring :** A phenomenon related to stream bed degradation is called armouring, where the coarsening of the bed material size results during degradation as finer particles get washed away. When the applied bed shear stress is sufficiently large to mobilize the large bed particles, degradation continues. When the bed shear stress cannot mobilize the coarse bed particles, an armour layer forms on the bed surface. The armour layer becomes coarser and thicker as the bed degrades until it is sufficiently thick to prevent any further degradation.

(iii) **Thalwegs :** The locus of the deepest point of the river along the length is called as thalweg. Most thalwegs pass through a succession of pools in the channel bed that are separated by riffles which might be sedimentary bed forms or bed rock ledger.



Cross sectional view of a river

Q.2 (a) Solution:



$U = 30$ m/s, $P_0 = 101$ kN/m^2

On the surface of cylinder,

$$U_\theta = -2U\sin\theta$$

$$U_r = 0$$

$\therefore$ At $\theta = 90°$

$$U_\theta = -2U \times 1$$

$$U_\theta = -2 \times 30 = -60 \text{ m/s}$$

Applying Bernoulli's equation,

$$\frac{P_0}{\rho g} + \frac{U^2}{2g} = \frac{P}{\rho g} + \frac{V^2}{2g}$$

$$\Rightarrow \quad \frac{P_0}{\rho g} + \frac{U^2}{2g} = \frac{P}{\rho g} + \frac{[-2U\sin\theta]^2}{2g}$$

$$\Rightarrow \quad \frac{P - P_0}{\rho} = \frac{U^2}{2}\left(1 - 4\sin^2\theta\right)$$

$$C_p = \frac{P - P_0}{\frac{1}{2}\rho U^2} = \left(1 - 4\sin^2\theta\right)$$

At stagnation point, $\theta = 0°$ and $180°$

$$\therefore \quad C_p = 1$$

$$\therefore \quad P - P_0 = \frac{1}{2}\rho U^2$$

$$\Rightarrow \quad P = 101 \times 10^3 + \frac{1}{2} \times 1.2 \times 30^2$$

$$= 101540 \text{ N/m}^2$$
$$= 101.54 \text{ kN/m}^2$$

At 90° from flow direction, $\theta = 90°$

$\therefore \quad C_p = 1 - 4\sin^2 90° = 1 - 4 = -3$

$$\Rightarrow \quad \frac{P - P_0}{\frac{1}{2}\rho U^2} = -3$$

$$\Rightarrow \quad P = P_0 - \frac{3}{2}\times\rho U^2 = 101\times10^3 - \frac{3}{2}\times1.2\times30^2$$
$$= 99380 \text{ N/m}^2 = 99.38 \text{ kN/m}^2$$

Q.2 (b) Solution:

(i) Classification of turbines on the basis of head available:

(a) High head turbines

- These are capable of working under very high heads ranging from several hundred metres to few thousand metres.
- These turbines require relatively less quantity of water.
- Pelton wheel is an example of high head turbine.

(b) Medium head turbines

- These are capable of working under medium heads ranging from about 60 m to 250 m.
- These turbines require relatively large quantity of water.
- Modern Francis turbine may be classified as medium head turbine.

(c) Low head turbines

- These are capable of working under the heads less than 60 m.
- Kaplan turbine is an example of low head turbine.

(ii) Classification of turbines on the basis of action of water:

(a) Impulse turbine

- In an impulse turbine, all the available energy of water is converted into kinetic energy.
- As the water flows over the vanes, the pressure is atmospheric from inlet to outlet of the turbine.
- Example of the impulse turbines are Pelton wheel, Girard turbine, Turgo turbine, etc.

(b) Reaction turbine

- In a reaction turbine, at the entrance to of runner, only a part of the available energy of water is converted into kinetic energy and a substantial part remains in the form of pressure energy.
- As the water flows through runner, the water is under pressure and the pressure energy goes on changing into kinetic energy.
- The runner is completely enclosed in an air-tight casing and the runner and casing is completely full of water.
- Thomson, Francis, Propeller, Kaplan turbines, etc. are some examples of reaction turbines.

(iii) Classification of turbines on the basis of specific speed in SI units:

(a) Low specific speed turbines

- Specific speed varies from 8.5 to 30.
- Example is Pelton wheel with single jet.

(b) Medium specific speed turbines

- Specific speed varies from 50 to 340.
- Example is Francis turbine.

(c) High specific speed turbines

- Specific speed varies from 255 to 860.
- Example is Kaplan turbine.

Derivation of the expression for unit speed

It is defined as the speed of the turbine working under a unit head. It is denoted by N_u.
Let N is the speed of a turbine under a head H and 'u' is the tangential velocity.

The tangential velocity, absolute velocity of water and head on the turbine are related as:

$$u \propto V \text{ and } V \propto \sqrt{H}$$

$$\therefore \quad u \propto \sqrt{H}$$

But $$u = \frac{\pi D N}{60} \text{ where } D \text{ is diameter of turbine}$$

For a given turbine, D is constant

$$\therefore \quad u \propto N$$

$$\Rightarrow \quad N \propto \sqrt{H}$$

$$\Rightarrow \quad N = k_1\sqrt{H} \text{ where } k_1 \text{ is a constant of proportionality}$$

If head on the turbine becomes unity, the speed N becomes unit speed

i.e. when $H = 1, N = N_u$

$\therefore \quad N_u = k_1\sqrt{1}$

$\Rightarrow \quad k_1 = N_u$

$\therefore \quad N = N_u\sqrt{H}$

$\Rightarrow \quad N_u = \dfrac{N}{\sqrt{H}}$ **(Ans.)**

Derivation of expression for unit discharge

It is defined as the discharge passing through a turbine, which is working under a unit head. It is denoted by Q_u.

Let H = Head of water on turbine

Q = Discharge passing through turbine when head is H

a = Area of flow of water

The discharge passing through a given turbine under a head 'H' is given by

$$Q = a \times V$$

If a is constant, then

$$Q \propto V$$

But $V \propto \sqrt{H}$

$\therefore \quad Q \propto \sqrt{H}$

$\Rightarrow \quad Q = k_2\sqrt{H}$

If $H = 1$ then $Q = Q_u$

$\therefore \quad Q_u = k_2\sqrt{1}$

$\Rightarrow \quad k_2 = Q_u$

$\therefore \quad Q = Q_u\sqrt{H}$

$\Rightarrow \quad Q_u = \dfrac{Q}{\sqrt{H}}$ **(Ans.)**

Derivation of expression for unit power

It is defined as the power developed by a turbine, working under a unit head. It is denoted by P_u.

Let H = Head of water on the turbine

P = Power developed by the turbine under a head of H

Q = Discharge through turbine under a head H

The overall efficiency (η_o) is given by

$$\eta_o = \frac{\textit{Power developed}}{\textit{Water power}} = \frac{P}{\dfrac{\rho \times g \times Q \times H}{1000}}$$

$$\Rightarrow \quad P = \eta_o \times \frac{\rho \times g \times Q \times H}{1000}$$

$$\Rightarrow \qquad P \propto Q \times H$$

But $\qquad Q \propto \sqrt{H}$ (as obtained above)

$$\therefore \qquad P \propto \sqrt{H} \times H$$

$$\Rightarrow \qquad P \propto H^{3/2}$$

$$\Rightarrow \qquad P = k_3 H^{3/2}$$

If $\qquad H = 1$ then $P = P_u$

$$\therefore \qquad P_u = k_3(1)^{3/2}$$

$$\Rightarrow \qquad k_3 = P_u$$

$$\therefore \qquad P = P_u \times H^{3/2}$$

$$\Rightarrow \qquad P_u = \frac{P}{H^{3/2}}$$ **(Ans.)**

Q.2 (c) Solution:

(i)

Let τ_o is the average shear stress at the channel boundary and it may be written as

$$\tau_o = \gamma RS \qquad \text{... (i)}$$

where γ is unit weight of water, R is hydraulic radius and S is the slope of channel bottom.

But the shear stress (τ_o) has been related to mass density (ρ) and average velocity (V) by the equation,

$$\tau_o = \frac{f}{8}\rho V^2 \qquad \text{... (ii)}$$

Equating (i) and (ii), we get

$$\gamma RS = \frac{f}{8}\rho V^2$$

$$\Rightarrow \qquad V^2 = \left(\frac{\gamma}{\rho}\right) \times \frac{8}{f} \times RS$$

$$\Rightarrow \qquad V = \sqrt{\frac{8g}{f}}\sqrt{RS} \qquad [\because \gamma = \rho g]$$

$$\Rightarrow \qquad V = C\sqrt{RS} \qquad \text{...(iii)}$$

where C is called Chezy's coefficient and it is given by

$$C = \sqrt{\frac{8g}{f}}$$

Now from **Manning's equation**, we have

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

$$\Rightarrow \quad V = \frac{1}{n} \times R^{2/3} \times \frac{R^{1/2}}{R^{1/2}} \times S^{1/2}$$

$$\Rightarrow \quad V = \left(\frac{1}{n}\right) R^{1/6} \times (RS)^{1/2} = \frac{1}{n} \times R^{1/6} \sqrt{RS} \qquad \text{...(iv)}$$

Comparing equations (iii) and (iv) we get

$$C = \frac{1}{n} \times R^{1/6} \qquad \left[\because C = \sqrt{\frac{8g}{f}}\right]$$

$$\Rightarrow \quad \sqrt{\frac{8g}{f}} = \frac{1}{n} \times R^{1/6}$$

$$\Rightarrow \quad \frac{8g}{f} = \frac{1}{n^2} \times R^{1/3}$$

$$\Rightarrow \quad f = \frac{8gn^2}{R^{1/3}} \qquad \textbf{(Ans.)}$$

(ii)

$$\text{Bed slope, } S = \frac{1}{2500}; \text{ Discharge, } Q = 0.60 \text{ m}^3/\text{s}$$

$$\text{Area of flow, } A = (1.5 \times 0.25) + \left[\frac{\pi}{2} \times (0.75)^2\right] = 1.2586 \text{ m}^2$$

$$\text{Wetted perimeter, } P = 2 \times 0.25 + \frac{1}{2}[2\pi \times (0.75)] = 2.8562 \text{ m}$$

$$R = \frac{A}{P} = \frac{1.2586}{2.8562} = 0.4407$$

Using Chezy's formula,

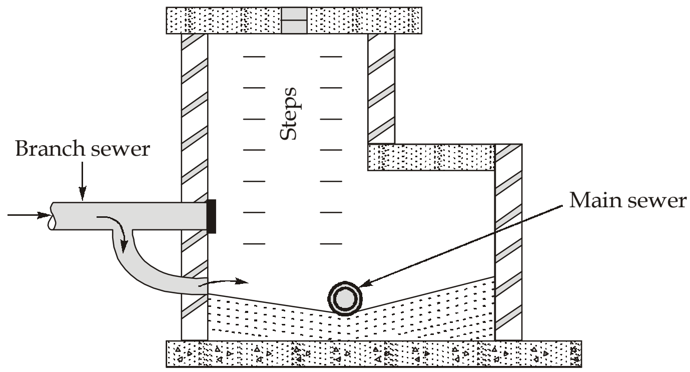
$$Q = AC\sqrt{RS}$$

$$\Rightarrow \quad 0.60 = 1.2586 \times C\sqrt{0.4407 \times \frac{1}{2500}}$$

$$\Rightarrow \quad C = 35.9056$$

Q.3 (a) Solution:

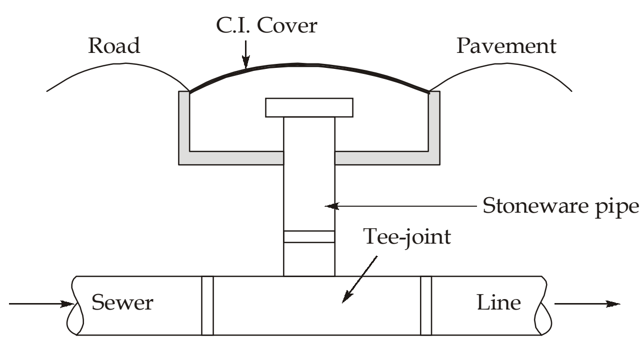
(i) **Drop manhole :** A manhole which is constructed to connect the high level branch sewer to the low level main sewer by vertical dropping pipe is known as drop manhole. As shown in figure below, a branch sewer passes at higher level and the main sewer runs at lower level.



Drop manhole

So the sewage will fall in the main sewer in the form of a spring. This will cause much inconvenience to the workers in the working chamber. So, the end of the branch pipe is plugged and a vertical dropping pipe is taken from the branch pipe and connected to the manhole near the bottom to allow the sewage to fall in main sewer smoothly. Steps are provided in zigzag manner for the entry and exit of the workers.

(ii) **Lamp hole :** A hole or opening which is provided in a sewer line for lowering a lamp inside is known as lamp hole. It is a vertical pipe made of stoneware which is connected to the sewer by a Tee-joint. At the top a box-line compartment is made which carries a cast-iron cover. The cover may be solid or perforated as shown in figure below.



Lamp hole

The construction of lamp hole is advisable for the following conditions:

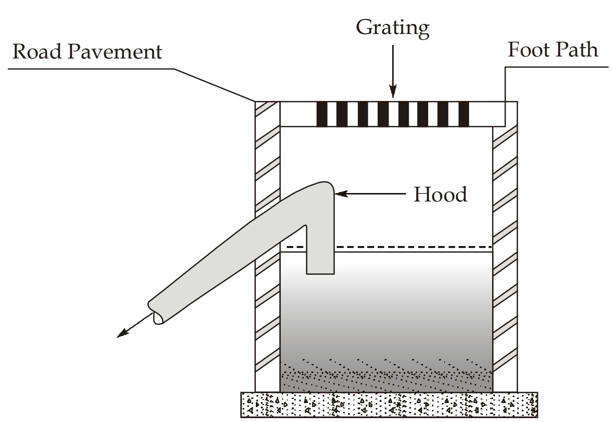
- When the spacings of regular manholes are at longer interval.
- When it is difficult to construct a regular manhole.
- When a change of direction or change of grade is encountered in the sewer line.

The following are the functions of lamp hole:

- By removing the C.I. cover, an electric lamp is inserted into the sewer. If the sewer is clear, the light will be visible from the adjacent manholes. If there is any obstruction, the light will not be visible from the manholes. Then the operation of clearing will be done accordingly.

- For clearing the obstruction, the flushing devices may be applied through the lampholes.
- If the C.I. cover is made perforated, then it will serve the purpose of ventilation of sewer or the removal of obnoxious and other gases.

(iii) Catch basin : A catch basin is a rectangular chamber constructed along the sewer line to allow the storm water to enter the sewer by eliminating the silt, grit, etc. at the bottom of the basin. The basin is constructed with brick masonry with a perforated C.I. cover at the top. The storm water on the pavement directly enters the basin through the C.I. cover. Moreover, the road curb is provided with grating for the entry of storm water into the basin. The basin is connected to the sewer by a pipe having its hood within the basin as shown in figure below.

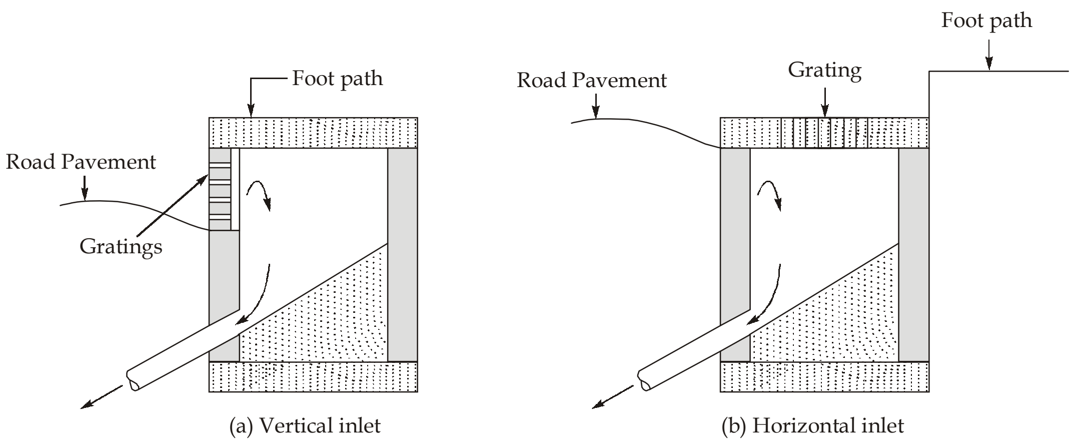


Catch basin

This prevents the sewer gas to escape to atmosphere through the basin. The clear storm water is allowed to enter the sewer and the sediments are arrested at the bottom of the basin which is cleared at a regular interval or when required.

(iv) Street inlet : The street inlets are the openings provided by the side of roads to allow the storm water to enter the sewer directly without accumulating on the road pavement. The spacing of inlets should be 20 m and should be provided on both sides of the road.

The inlets may be vertical or horizontal. A box-like compartment is constructed with brick masonry. In vertical type, a grating is provided on the road curb just at the ege of foot path, as shown in figure (a). In horizontal types, a perforated cover is placed on the top of the chamber, as shown in figure (b).



Steel inlet

Q.3 (b) Solution:

(i) Disc unit

$$\text{Disc cover required} = \frac{54 \times 1000}{20} = 2700 \text{ m}^2$$

$$\text{Total area of disc of 3 m diameter} = 2\,\text{sides} \times \frac{\pi d^2}{4}$$

$$= 2 \times \frac{\pi \times 3^2}{4} = 14.137 \text{ m}^2$$

$$\therefore \quad \text{Number of discs required} = \frac{2700}{14.137} = 190.988 \simeq 191$$

As discs are 5 cm apart on centres, the tank for housing the discs will have

$$\text{Length} = \text{Number of discs} \times \text{Spacing between the discs} = \frac{191 \times 5}{100} = 9.55 \text{ m}$$

Width = 3 m diameter + 0.2 m clearance

= 3.2 m

Depth = 2 m

$\therefore$ Tank volume = 9.55 × 3.2 × 2 = 61.12 m^3

(ii) Hydraulic loading rate

$$= \frac{200 \times 1000}{\left(\frac{\pi}{4} \times 3^2 \times 2 \times 191\right)} = 74.0686 \text{ litres/m}^2\text{-day}$$

(iii) Surface loading rate

$$= \frac{200 \times 1000 \times 10^{-3}}{9.55 \times 3.2} = 6.544 \text{ m}^3/\text{m}^2\text{-day}$$

(iv) Efficiency

$$\text{Influent BOD} = \frac{54 \times 1000}{200} = 270 \text{ mg}/l$$

$$\text{Effluent BOD} = 49 \text{ mg}/l \text{ (given)}$$

$$\therefore \quad \eta\,(\%) = \frac{270 - 49}{270} \times 100 = 81.85\%$$

(v) Excess sludge at 0.6 kg/kg BOD removed

$$\text{Total BOD removed} = (270 - 49)\frac{mg}{l} \times 200 \text{ lts} \times 10^3$$

$$= 44.2 \times 10^6 \text{ mg} = 44.2 \text{ kg}$$

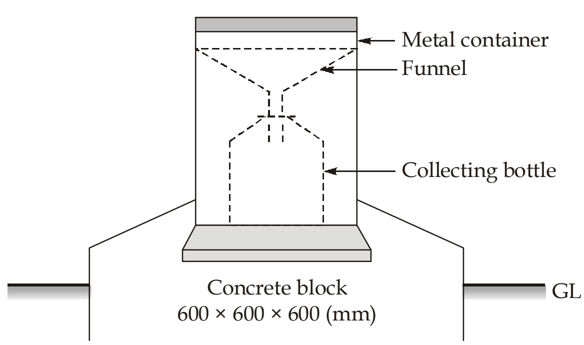
$$\therefore \quad \text{Excess sludge removal} = 0.6 \times 44.2 = 26.52 \text{ kg/day}$$

Q.3 (c) Solution:

Rainfall is measured and collected in a raingauge. A raingauge is a cylindrical vessel assembly kept in open to collect rain.

Raingauge are primarily of two types.

1. **Non recording gauge:** It is also called as 'Symon's gauge.



Non-recording raingauge (Symon's)

2. **Recording gauge:** It gives continuous plot of rainfall against time and provides valuable data of intensity and duration of rainfall.

To measure rainfall from raingauge, it has to be setup via adopting standard settings which are as follows:

(a) The ground must be level and in open and instrument must present a horizontal catch surface.
(b) The gauge must be set as near the ground as possible to reduce wind effects but should be adequately high enough to avoid flooding, splashing etc.
(c) The instrument must be surrounded by an open fenced area of atleast 5.5 m × 5.5 m. No object should be nearer to instrument than 30 m or twice the height of obstruction.

3. **Telemetering raingauge:** It is recording type raingauge and contains electronic units to transmit data on rainfall to a base station. Used in mountainous and inaccessible locations.
4. **Radar measurement of rainfall:** Good degree of accuracy, used to measure rainfall over large areas. Even Doppler type radar measure velocity and distribution of raindrops.

Snowfall: A graduated stick/staff is used to measure depth of snow at a selected place. Average of several measurements in an area is taken as depth of snow in a snowfall event. *Snow stakes* are graduated permanent posts used to measure total depth of accumulated snowfall at a place.

Snow boards: 40 cm side square boards used to collect snow samples. These boards are placed horizontally on a pervious accumulation of snow and after a snowfall event, the snow samples are cut off from board and depth and water equivalent of snow are derived and recorded.

Water equivalent of snowfall: Depth of water that would result in melting of a unit of snow.

It is obtained/measured by following two ways

Snow gauges: Large cylindrical receiver (without funnel and collecting bottle), 203 mm in diameter. Used to collect snow as it falls. After collecting snow, it is brought in a warm room and snow is melted by adding premeasured quantity of hot water.

Snow tubes: A set of telescopic metal tubes provided with a cutter edge for easy penetration as well as to enable extraction of core sample. 40 mm dia. in normal size.

Consistency of rainfall data is determined by deploying "Double mass curve technique". It is based on principle of consistency of recorded data which comes from same parent population.

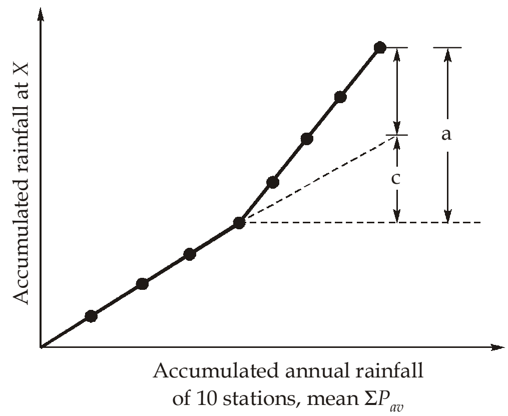
Let problem station is denoted as X

The rainfall average at other 10 stations is taken annually and a graph is plotted by keeping former as ordinate and later on abscissa (x-axis).

Records are arranged and placed on graph in reverse chronological order.

Corrected value

$$P_{cx} = P_x \times \frac{M_c}{M_a} \quad \begin{matrix} \rightarrow \text{Corrected slope} \\ \rightarrow \text{Original slope} \end{matrix}$$



Q.4 (a) Solution:

$$\text{BOD of wastewater} = \frac{7.2\,\text{M}l \times 300\,\text{mg}/l + 4\,\text{M}l \times 1500}{7.2\,\text{M}l + 4\,\text{M}l} = 728.57\ \text{mg}/l$$

$$Q_s = \text{Wastewater discharge with 8\% expansion}$$

$$= \frac{1.08 \times (240 \times 30000 + 4 \times 10^6)}{24 \times 3600} = 140\ l/\text{s}$$

$$\text{Initial DO of saturated stream} = 7\ \text{mg}/l$$

$$\text{D.O. of mixture at starting point} = \frac{7 \times 4500 + 0 \times 140}{4500 + 140} = 6.789\ \text{mg}/l$$

$$\text{Initial D.O. deficit, } D_0 = 7 - 6.789 = 0.211\ \text{mg}/l$$

$$\text{Critical D.O. deficit, } D_C = 7 - 4 = 3\ \text{mg}/l$$

Using following equation, we get

$$\left[\frac{L}{D_c f}\right]^{f-1} = f\left[1 - (f-1)\frac{D_0}{L}\right]$$

where, $$f = \frac{k_R}{k_D} = \frac{0.3}{0.1} = 3$$

$$\therefore \quad \left[\frac{L}{3 \times 3}\right]^{(3-1)} = 3\left[1 - \frac{2 \times 0.211}{L}\right]$$

$$\Rightarrow \qquad \frac{L^2}{81} = 3\left[1-\frac{0.422}{L}\right]$$

$$\Rightarrow \qquad \frac{L^2}{81} = 3-\frac{1.266}{L}$$

$$\Rightarrow \qquad L^2 = 243-\frac{102.546}{L}$$

$$\Rightarrow \qquad L^3 = 243L - 102.546$$

$$\Rightarrow \qquad L^3 - 243L + 0 = 10$$

$$L = 15.371 \text{ mg}/l$$

Maximum permissible BOD_5 of mix at mix temperature

$$y_5 = L\left[1-(10)^{-0.1\times 5}\right]$$

$\because \quad k_D$ at mixture temperature $= 0.1$

$$y_5 = 0.684\,L = 0.684 \times 15.371 = 10.51 \text{ mg}/l$$

Using equation

$$(\text{BOD})_{\text{mix}} = \frac{C_S \times Q_S + C_R Q_R}{Q_S + Q_R}$$

$$\Rightarrow \qquad 10.51 = \frac{C_S \times 140 + 0 \times 4500}{140 + 4500}$$

$$\Rightarrow \qquad C_S = 348.66 \text{ mg}/l$$

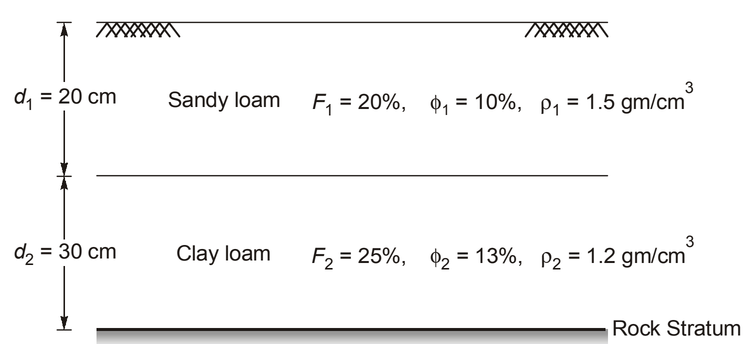
Degree of treatment required to be given to wastewater having BOD of 728.57 mg/l

$$= \frac{728.57 - 348.66}{728.57} \times 100 = 52.14\%$$

Q.4 (b) Solution:

(i)

The soil profile can be shown as in the figure:



Let F be the field capacity, ϕ be the wilting point, d be the depth of soil, ρ be the density of soil and γ be the unit weight of soil.

Moisture storing capacity of sandy loam is given by

$$d_s = \frac{\gamma_1 d_1}{\gamma_w}[F_1 - \phi_1]$$

$$= \frac{\rho_1 d_1}{\rho_w}[F_1 - \phi_1] = \frac{1.5 \times 20}{1}\left[\frac{20}{100} - \frac{10}{100}\right]$$

$$= 3 \text{ cm}$$

Moisture storing capacity of clay loam is given by

$$d_c = \frac{\rho_2 d_2}{\rho_w}[F_2 - \phi_2] = \frac{1.2 \times 30}{1}\left[\frac{25}{100} - \frac{13}{100}\right] = 4.32 \text{ cm}$$

$\therefore$ Total moisture storing capacity of the soil = $d_s + d_c$ = 3 + 4.32 = 7.32 cm

It is given that consumptive use requirement of crop = 0.5 mm per day

$\therefore$ Maximum number of days in which the entire moisture storing capacity will be utilized

$$= \frac{\text{Moisture storing capacity of soil in cm}}{\text{Consumptive use requirement of crop in cm per day}}$$

$$= \frac{7.32}{0.05} = 146.4 \text{ days}$$

Thus, the crop can survive for a maximum of 146.4 days without irrigation.

(ii)

Using Gumbel's equation, we have

$$X_{(T)} = \overline{X} + K\sigma$$

where K is given by general equation

$$K = \frac{y_T - \overline{y}_n}{s_n}$$

where $\overline{y}_n$ and s_n remain the same for one analysis, because n is fixed in one analysis.

$$\therefore \quad X_{100} = \overline{X} + \left[\frac{y_{100}}{s_n} - \frac{\overline{y}_n}{s_n}\right]\sigma = 485 \text{ m}^3/\text{s (given)} \quad \text{...(i)}$$

$$\text{and} \quad X_{50} = \overline{X} + \left[\frac{y_{50}}{s_n} - \frac{\overline{y}_n}{s_n}\right]\sigma = 445 \text{ m}^3/\text{s (given)} \quad \text{...(ii)}$$

Subtracting (ii) from (i), we get

$$\left[\frac{y_{100}}{s_n} - \frac{y_{50}}{s_n}\right]\sigma = 40 \text{ m}^3/\text{s} \quad \text{...(iii)}$$

y_T is given by equation as

$$y_T = -\ln\ln\left(\frac{T}{T-1}\right)$$

$$\therefore \quad y_{100} = -\left[\ln\ln\cdot\frac{100}{99}\right] = 4.60015$$

$$\text{and} \quad y_{50} = -\left[\ln\ln\cdot\frac{50}{49}\right] = 3.90194$$

$\therefore$ Substituting y_{100} and y_{50} in (iii), we get

$$(4.60015 - 3.90194)\cdot\frac{\sigma}{s_n} = 40$$

$$\Rightarrow \quad \frac{\sigma}{s_n} = 57.2894$$

Also, for given 1000 years return period, we have

$$y_{1000} = -\left[\ln\ln\frac{1000}{999}\right] = 6.90726$$

$$\therefore \quad [y_{1000} - y_{100}]\frac{\sigma}{s_n} = X_{1000} - X_{100}$$

Substituting the values, we get

$$[6.90726 - 4.60015]\ 57.2894 = X_{1000} - 485$$

$$\Rightarrow \quad 132.17 = X_{1000} - 485$$

$$\Rightarrow \quad X_{1000} = 617.17 \text{ m}^3/\text{s}$$

Q.4 (c) Solution:

Given : for prototype $\rightarrow L_p = 10$ km; $B_p = 920$ m; $Q_p = 3000$ m/s; $H_p = 6$ m; for model $\rightarrow Q_m < 150$ $l$ps;

$B_m < 2$ m; $L_m < 20$ m; $H_m < 70$ cm

Depth scale, $(L_r)_v = 10$

$$\therefore \quad \frac{H_p}{H_m} = 10$$

$$H_m = \frac{6}{10} = 0.6 \text{ m} = 60 \text{ cm} < 70 \text{ cm} \quad \text{(Hence OK)}$$

Using Froude Model law $\quad (F_e)_m = (F_e)_p$

$$\frac{V_m}{\sqrt{g(L_m)_v}} = \frac{V_p}{\sqrt{g(L_p)_v}}$$

$$\frac{V_p}{V_m} = \sqrt{\left(\frac{L_p}{L_m}\right)} = \sqrt{(L_r)_v}$$

$$V_r = \sqrt{(L_r)_v}$$

$$\frac{Q_p}{Q_m} = \frac{A_p}{A_m} \times \frac{V_p}{V_m}$$

$$Q_r = (L_r)_H \times (L_r)_v \times \sqrt{(L_r)_v}$$

$$Q_r = (L_r)_H \times (L_r)_v^{3/2}$$

$$\therefore \quad \frac{3000}{150 \times 10^{-3}} = (L_r)_H \times 10^{3/2}$$

$$(L_r)_H = 632.455$$

As given, horizontal scale should be multiple 10

$\therefore$ Let us assume, $(L_r)_H = 640$

Checking for discharge,

$$Q_r = (L_r)_H \times (L_r)_v^{3/2}$$

$$\frac{Q_p}{Q_m} = 640 \times 10^{3/2}$$

$$Q_m = \frac{3000}{640 \times 10^{3/2}} = 0.14823 \text{ m}^3/\text{s}$$

$$= 148.23\ l\text{ps} < 150\ l\text{ps}$$

$\therefore$ okay

Checking for length $\quad (L_r)_H = \frac{L_p}{L_m}$

$$L_m = \frac{10 \times 10^3}{640} = 15.625 \text{ m} < 20 \text{ m}$$

Checking for width $\quad (L_r)_H = \frac{B_p}{B_m}$

$$B_m = \frac{920}{640} = 1.4375 \text{ m} < 2 \text{ m}$$

So we can safely take $(L_r)_H = 640$

Hence, $\quad (L_r)_v = 10$

$$(L_r)_H = 640$$

$$Q_m = 148.23\ l\text{ps}$$

$$H_m = 60 \text{ cm}$$
$$L_m = 15.625 \text{ m}$$
$$B_m = 1.4375 \text{ m}$$

Section B

Q.5 (a) Solution:

Bowditch's Rule (Compass Rule)	Transit Rule
1. The correction of an error in latitude by Bowditch's rules affects all lines and angle in the traverse.	1. The correction of the some error by the transit rule only affect lines in the direction of the error because line of at right angles to these have no latitudes.
2. Balancing the traverse by Bowditch's rule distort the angle from the observed values.	2. In balancing by transit rules the angle are unaltered.
3. The Bowditch rule is particularly used for compass traverse where the angles are susceptible to considerable error.	3. The transit rule is more suited for a theodolite traverse where the possibility of error is more in the linear rather than in the angular measurements.
4. Bowditch rule alters the bearings.	4. Transit rule alters the distances more.
5. It is used to balance a traverse when linear and angular measurements are equally precise. • Errors in linear measurements $\propto \sqrt{l}$. • Error in angular measurements $\propto \frac{1}{\sqrt{l}}$	5. It is employed when the angular measurements are more precise as compared to the linear measurements (theodolite traversing)
6. Corrections magnitude is proportional to the length of the line.	6. Correction magnitude is proportional to the latitude and departure.

Q.5 (b) Solution:

Given: $e_{max} = 0.82, e_{min} = 0.38$

$$G = 2.66, w = 10\%$$

Bulk unit weight, $\gamma_b = 19 \text{ kN/m}^3$

$$\because \quad \gamma_b = \frac{G\gamma_w(1+w)}{1+e}$$

$$\Rightarrow \quad 19 = \frac{2.66 \times 9.81(1+0.1)}{1+e}$$

$$\Rightarrow \quad e = 0.511$$

$$\therefore \quad \text{Relative density } (R_D) = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100$$

$$= \frac{0.82 - 0.511}{0.82 - 0.38} \times 100 = 70.23\%$$

$\because$ The relative density obtained is 70.23%. Thus the granular soil deposit is dense in nature. Hence it will have high shear strength and low compressibility.

Q.5 (c) Solution:

Stone column method is used to increase the load-bearing capacity of shallow foundations on soft clay layers.

Principle : The stabilization of soils by displacing the soil radially, with the help of a deep vibrator, refilling the resulting space with granular material and compacting the same with the vibrator.

Merits:

(i) Cost effective.

(ii) It improves the bearing capacity and reduces the settlement of weak soil strata.

(iii) It accelerate the dissipation of excess pore water pressure.

(iv) It improve stiffness of subsoil.

(v) There is no waiting period after installation unlike PVD.

Demerits:

(i) Stone column method cannot be used in clays having sensitivity greater than 4 because these soils cannot adequately regain their shear strength.

(ii) Stone column when installed at a distance less than 3.5 m can cause high lateral pressures and displacement of adjacent structures.

(iii) Stone column installation in extremely cohesive clays and silts is suitable only if pre-loading facility is available.

Q.5 (d) Solution:

$\because$ $$k = \frac{Ql}{Ah} = \frac{V \cdot l}{Ath}$$

$$A = \frac{\pi}{4} \times 7.5^2 = 44.18 \text{ cm}^2$$

$\therefore$ $$k = \frac{626 \times 18}{44.18 \times 60 \times 24.7} = 0.172 \text{ cm/s} \qquad [\because \; 1 \text{ m}l = 1 \text{ cm}^3]$$

Discharge velocity, $$v = ki = 0.172 \times \frac{24.7}{18} = 0.236 \text{ cm/s}$$

Seepage velocity, $$v_s = \frac{v}{n} = \frac{0.236}{0.44} = 0.536 \text{ cm/s}$$

$\because$ $$n_1 = 44\%$$

$$\therefore \quad e_1 = \frac{n_1}{1-n_1} = 0.79, \quad \therefore \quad \frac{e_1^3}{1+e_1} = 0.275$$

$$n_2 = 39 = 0.39\%$$

$$e_2 = \frac{n_2}{1-n_2} = 0.64, \quad \therefore \quad \frac{e_2^3}{1+e_2} = 0.16$$

At 25°C, viscosity of water $\mu_1 = 8.95$ millipoise

At 20°C, $\mu_2 = 10.09$ millipoise

$$k = C\left(\frac{\gamma_w}{\mu}\right)\left(\frac{e^3}{1+e}\right)D^2$$

$$\therefore \quad \frac{k_{25°C}}{k_{20°C}} = \frac{\frac{1}{\mu_{25°C}}\left(\frac{e^3}{1+e}\right)_{25°C}}{\frac{1}{\mu_{20°C}}\left(\frac{e^3}{1+e}\right)_{20°C}}$$

$$= \frac{\frac{1}{8.95}(0.275)}{\frac{1}{10.09}(0.16)} = 1.9377$$

$$\therefore \quad k_{20°C} = \frac{k_{25°C}}{1.9377} = \frac{0.172}{1.9377} = 0.0888 \text{ cm/s} = 8.88\times10^{-2}\text{cm/s}$$

Q.5 (e) Solution:

(i)

$$\text{Thickness of pavement, } t = \sqrt{\frac{1.75P}{CBR} - \frac{P}{p\pi}}$$

$$t = \sqrt{\frac{1.75\times4100}{6} - \frac{4100}{7\pi}} = 31.771 \text{ cm}$$

(ii)

$$\text{Coefficients, } x = 1$$

$$a = 1.4, b = 1.4, n = \frac{1}{1.4}$$

Existing pavement thickness, h_e = 10 cm

Design thickness, h_d = 20 cm

Rigid overlay thickness, $h_0 = \left(h_d^a - xh_e^b\right)^n$

$$= \left(20^{1.4} - 1 \times 10^{1.4}\right)^{\frac{1}{1.4}} = 14.23 \text{ cm}$$

Q.6 (a) Solution:

(i)

Since the error is in seconds only the degrees and minutes of the quantities have not been included in the tabulation. The computations are arranged in the tabular form below:

S.No.	Value	Weight(w)	V	V^2	wV^2
1.	20″	2	1	1	2
2.	18″	2	–1	+1	2
3.	19″	3	0	0	0
		$\Sigma w = 7$			$\Sigma wv^2 = 4$

Weighted arithmetic mean of the seconds readings of the observed angles

$$= \frac{20'' \times 2 + 18'' \times 2 + 19'' \times 3}{2+2+3} = 19''$$

∴ Weighted arithmetic mean of the angle = 30° 24′ 19″

∴ $v_1 = 20'' - 19'' = 1''$

$v_2 = 18'' - 19'' - 1''$

$v_3 = 19'' - 19'' = 0$

1. Probable error of single observation unit weight is given by

$$E_s = \pm 0.6745\sqrt{\frac{\Sigma wv^2}{n-1}}$$

$$= \pm 0.6745\sqrt{\frac{4}{3-1}} = \pm 0.95'' \qquad \text{...(i)}$$

2. Probable error of the arithmetic mean is given by

$$E_m = \pm 0.6745\sqrt{\frac{\Sigma wv^2}{\Sigma w\,(n-1)}} = \pm 0.6745\sqrt{\frac{4}{7(3-1)}} = \pm 0.36''$$

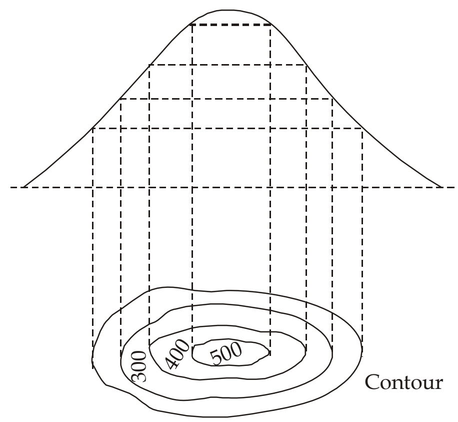
3. Probable error of single observation of weight 3 is given by

$$E_w = \frac{E_s}{\sqrt{w}} = \pm 0.6745\sqrt{\frac{\Sigma wv^2}{w(n-1)}}$$

$$= \pm \frac{0.95}{\sqrt{3}} \text{(substuting } E_S \text{ from (i))} = \pm 0.55''$$

(ii)

Contours: A contour may be defined as an imaginary line passing through points of equal elevation. Thus, the contour lines on a plan illustrate the conformation of the ground. A contour line may also be defined as intersection of a level surface with the surface of the earth.



Characteristics of contours: The characteristics are listed below:

1. All the points on a contour line have the same elevation. The elevations are indicated either by inserting the figure in a break in the respective contour or printed closed to contour. When no value is present, it indicates a flat terrain. A zero metre contour line represents the coastline.
2. Two contour lines do not intersect each other except in the cases of an overhanging cliff or cave penetrating a hillside.
3. A contour line must close onto itself but not necessarily within the limits of the maps.
4. Equally spaced contour represents a uniform slope and contours that are well apart indicate a gentle slope.
5. A set of close contours with higher figures inside and lower figures outside indicate a hillock whereas in the case of depressions like, lakes etc., the higher figures are outside and the lower figures are inside.
6. Irregular contours represent uneven ground.
7. The direction of the steepest slope is along the shortest distance between the contours. The direction of the steepest slope at a point on a contour is therefore at right angles to the contour.

Q.6 (b) Solution:

(i)

High mast lighting: It is a tall pole with lighting attached to the top pointing towards ground generally used for lighting a highway or recreational fields. The pole on which lighting is mounted on is generally at least 30 metres tall. While the lighting consists of a luminare ring surrounding the pole with one or several independent lighting fixtures are mounted around it. Some units have the lighting surround by a circular shield to prevent or reduce the light pollution or light trespass from affecting neighbourhoods adjacent to the high most light.

Maintenance of these systems are done by lowering the luminare ring from the mast head to the base using a winch and motor to the ground at a height accessible by a cherry picker and located in areas to allow for easier access without disrupting traffic.

Advantages of high mast lighting:

(i) Installation cost of high mast lighting for interchanges is considerably less than conventional lighting system due to reduced complexibility of conduit.

(ii) Maintenance of high mast lighting system is easier and cheaper than conventional lighting system.

(iii) High mast lighting reduces light pollution or light trespass to house adjacent to high most light.

(ii)

Given, Speed, $V = 100$ kmph

Degree of curve $= 2°$

$\therefore$ Radius of curve, $R = \dfrac{1720}{D} = \dfrac{1720}{2} = 860$ m

Superelevation, $e_{th} = \dfrac{GV^2}{1.27R}$

$$e_{th} = \frac{1.676 \times (100)^2}{1.27 \times 860} \text{ cm} = 15.35 \text{ cm}$$

$\because$ $e_{th} = e_{act} + \text{C.D.}$ [Assume C.D. = 7.6 cm]

$\therefore$ $e_{act} = 15.35 - 7.6$

$= 7.75$ cm

$\because$ $e_{act} < 16.5$ cm

Hence accepted $e_{act} = 7.75$ cm

$\therefore$ Length of transition curve, L_c is maximum of the following :

(i) $L = 7.2e = 7.2 \times 7.75 = 55.8$ m

(ii) $L = 0.073\, eV_{max} = 0.073 \times 7.75 \times 100 = 56.6$ m

(iii) $L = 0.073 \times (CD) \times V_{max} = 0.073 \times 7.6 \times 100 = 55.5$ m

$\therefore$ L_C is maximum of (i), (ii), (iii) = 56.6 m $\simeq$ 57 m

Q.6 (c) Solution:

$$\sigma_{1f} = 250 + 100 = 350 \text{ kN/m}^2$$

$$\sigma_{3f} = 100 \text{ kN/m}^2$$

$$\sin\phi' = \frac{\sigma_{1f} - \sigma_{3f}}{\sigma_{1f} + \sigma_{3f}} = \frac{350 - 100}{350 + 100}$$

$$\phi' = 33.75°$$

Inclination of failure plane with horizontal,

$$\beta = 45 + \frac{\phi'}{2} = 45 + \frac{33.75}{2} = 61.875°$$

Normal stress on failure plane

$$\sigma'_{ff} = \sigma_{1f}\cos^2\beta + \sigma_{3f}\sin^2\beta$$

$$= 350\cos^2 61.875° + 100\sin^2 61.875$$

$$= 155.55 \text{ kN/m}^2$$

$\therefore$

$$\tau_{ff} = c + \sigma'_{ff}\tan\phi' = 0 + 155.55\tan 33.75°$$

$$\tau_{ff} = 103.94 \text{ kN/m}^2$$

$$\tau_{max} = \frac{\sigma_{1f} - \sigma_{3f}}{2} = \frac{350 - 100}{2} = 125 \text{ kN/m}^2$$

Orientation of τ_{max} plane is 45° to the horizontal

Obliquity of the failure plane = $\dfrac{\tau_{ff}}{\sigma_{ff}} = \dfrac{103.93}{155.55} = 0.668$

$$\sigma_n \text{ at } \tau_{max} \text{ plane} = \frac{350 + 100}{2} = 225 \text{ kN/m}^2$$

The obliquity of the plane of maximum shear stress = $\dfrac{\tau_{max}}{\sigma_{(at\ \tau_{max,plane})}} = \dfrac{125}{225} = 0.56$

Thus the plane of maximum obliquity governs failure.

FOS on the plane of maximum shear stress = $\dfrac{\tau}{\tau_{max}} = \dfrac{225\tan 33.75°}{125} = 1.2 > 1$ OK

Q.7 (a) Solution:

$$k_{a_1} = \frac{1-\sin\phi}{1+\sin\phi};\ k_{a_1} = \frac{1}{3} \qquad (\because\ \phi = 30°)$$

$$k_{a_2} = \frac{1-\sin 10}{1+\sin 10} = 0.704$$

p_a-diagram for top soil (1)

$$p_a = k_{a_1}q + k_{a_1}\gamma_1 z_1 = P_1 + P_2$$

$$p_1 = \frac{1}{3}\times 10 = 3.33\ \text{kN/m}^2;\ P_2 = \frac{1}{3}\times 15\times 3 = 15\ \text{kN/m}^2$$

$$p_a = 18.33\ \text{kN/m}^2$$

p_a-diagram for bottom soil (2)

$$p_a = k_{a_2}(q+\gamma_1 H_1) + k_{a_2}\gamma_2 z_2 - 2c\sqrt{k_{a_2}}$$

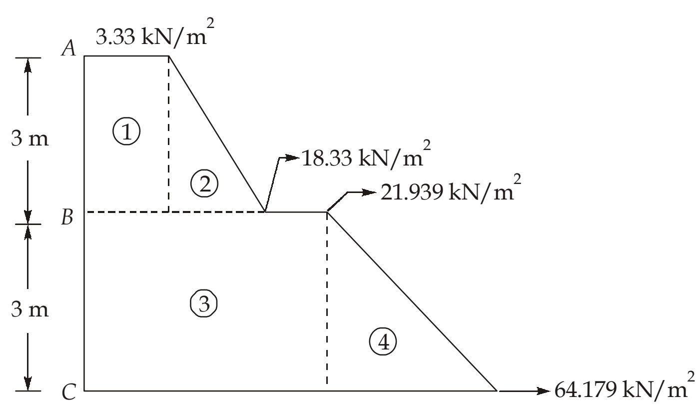
$$= 21.939 + 14.08z_2$$

At B, $z_2 = 0$; $\therefore$ $p_a = P_3 = 21.939\ \text{kN/m}^2$

At C, $z_2 = 3$ m; $\therefore$ $p_a = 21.939 + 14.08 \times 3$

$$= 21.939 + 42.24$$

$$= 64.179\ \text{kN/m}^2$$



p_a - diagram

$$P_1 = 3.33 \times 3 = 10\ \text{kN/m}$$

$$\text{Acting at } Z_1 = 3 + \frac{3}{2} = 4.5\ \text{m above base}$$

$$P_2 = \frac{1}{2}\times 15\times 3 = 22.5\ \text{kN/m at } Z_2 = 3 + \frac{3}{3} = 4\ \text{m above base}$$

$$P_3 = 21.939 \times 3 = 65.817 \text{ kN/m acting at } Z_3 = \frac{3}{2} = 1.5 \text{ m above base}$$

$$P_4 = \frac{1}{2} \times 42.24 \times 3 = 63.36 \text{ kN/m acting at } Z_4 = \frac{3}{3} = 1 \text{ m above base}$$

$$\therefore \quad \text{Total } P_a = 10 + 22.5 + 65.817 + 63.36 = 161.677 \text{ kN/m}$$

$$Z = \frac{10 \times 4.5 + 22.5 \times 4 + 65.817 \times 1.5 + 63.36 \times 1}{161.677}$$

$$= 1.837 \text{ m above base}$$

Q.7 (b) Solution:

(i)

Let h be the height of radio tower.

$$\therefore \quad \text{Scale of photograph, } S = \frac{x}{X} = \frac{f}{H - h_{avg}}$$

$$\Rightarrow \quad \frac{0.1023}{300} = \frac{0.1524}{H - 553}$$

$$\Rightarrow \quad H - 553 = 446.92$$

$$H = 999.92 \text{ m}$$

Now, $$d = \frac{rh}{H - h_{avg}}$$

where, $$d = r - r_1$$

$$= 0.08 - 0.07 = 0.01 \text{ m}$$

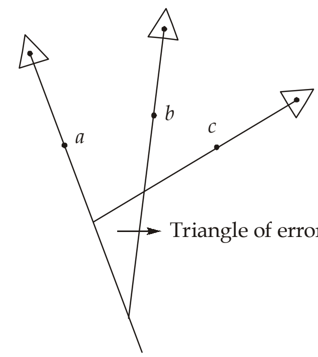
$$\therefore \quad 0.01 = \frac{0.08 \times h}{999.92 - 553}$$

$$\Rightarrow \quad h = 55.865 \text{ m} \simeq 55.87 \text{ m}$$

(ii)

Three point problem : (Resection after orientation by three points): The three-point problem consists of locating the position of the plane table station on the drawing sheet by means of the observation of three well-defined points, whose positions have already been plotted on the plan. Let A, B and C be three well defined points and let their plotted positions be a, b and c. It is required to fix ground station T on the plan as t.

Lehmann's Method or (Trial and Error Method): This method is very commonly used in the field measurements as it is very accurate. The position of plane table is estimated by judgement. Let it be t'. The alidade is kept against $t'a$ and table is oriented. Pivot the alidade on b and sight B. Draw the back ray. If the orientation is correct, the three rays will intersect at one point t, otherwise a triangle of error is formed. This triangle is reduced to a point by trial and error.



Trial and Error Method

Lehmann's Rules: The adjustment in orientation is facilitated by **Lehmann's rules** for estimating the exact position of t from triangle of error.

1. The distance of the point t to be fixed from each of the rays aA, bB and cC is proportional to the respective distances of the stations A, B and C from station T.
2. While looking towards the station, the point t to be fixed will either be to the left or the right of each of the ray.

From the above two rules it follows that the plotted position of the instrument station t lies within triangle of error only when the ground station T lies within the triangle ABC. These two rules are sufficient to reduce the triangle of error to one point.

1. When T is outside the great circle ABC, t is always on the same side of the ray drawn to the most distant station as the intersection of the other two rays.
2. When T falls within any of three segments of the great circle ABC, formed by the side of triangle ABC, the ray towards the middle station lies between t and intersection of other two rays.
3. If plane table station T lies on great circle (passing through the points A, B, C) the correct station is not possible because the three rays will always meet at a point even if the table is not oriented.

Q.7 (c) Solution:

(i)

Given, Design speed, $V = 80 \text{ kmph} = 22.22 \text{ m/s}$

Deflection angle, $N = \frac{1}{20} + \frac{1}{40} = 0.075$

- Length of valley curve, $L_v = 2 \times \sqrt{\frac{NV^3}{C}} = 2\sqrt{\frac{0.075 \times (22.22)^3}{0.6}}$

$$= 74.06 \text{ m}$$

- Assuming the length of the valley curve to be greater than the stopping distance i.e. $L > S$.

$$L = \frac{NS^2}{1.5 + 0.035S} = \frac{0.075 \times (120)^2}{1.5 + 0.035 \times 120}$$

$$= \frac{0.075 \times (120)^2}{1.5 + 4.2} = 189.47 \text{ m} \simeq 190 \text{ m}$$

Since this value is greater than stopping sight distance of 120 m, hence the assumption is correct and 190 m length of valley curve is essential for safe driving at night.

- Check for impact,

$$\text{Impact factor, } I = \frac{1.59NV^2}{L} \text{ percent}$$

$$= \frac{1.59 \times 0.075 \times 80^2}{190} = 4.017\%$$

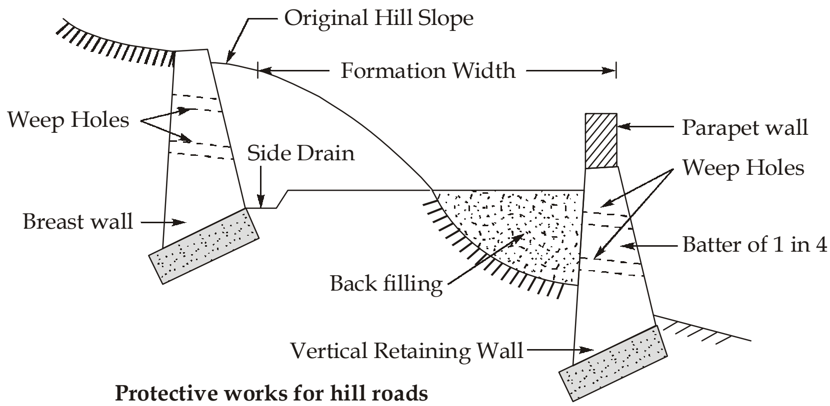
which is less than the maximum allowable impact factor of 17% (as per IRC). Hence provide valley curve of length 190 m.

(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; and
- 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.8 (a) Solution:

(i)

Apparatus Required (Common for both methods):

Consolidometer: A device to hold the sample in a ring either fixed or floating with porous stones (or ceramic discs) on each face of the sample. A consolidometer shall also provide means for submerging the sample, for applying a vertical load and for measuring the change in the thickness of the specimen.

Dial gauge: To record the vertical expansion of the specimen precisely.

Specimen Diameter: The specimen shall be 60 mm in diameter (specimens of diameters 50, 70 and 100 mm may also be used in special case) precisely.

Specimen Thickness: The specimen shall be at least 20 mm thick in all cases. However, the thickness shall not be less than 10 times the maximum diameter of the grain in the soil specimen. The diameter to thickness ratio shall be a minimum of 3.

Porous Stones: The stones shall be of silicon carbide or aluminium oxide and of medium grade. The stones shall have a high permeability compared to that of the soil being tested.

Water Reservoir: To keep the soil sample submerged.

1. **Consolidometer Method:**

   Preparation of specimen from undisturbed soil sample: The container ring shall be cleaned and weighed empty. From one end of the undisturbed soil sample about 30 mm, or more if desired, of the soil sample shall be cut off and rejected. The consolidation ring should be gradually inserted in the sample by pressing with hands and carefully removing the material around the ring. The soil specimen so cut shall project as far as 10 mm on either side of the ring.

   The specimen shall then be trimmed smooth and flush with the top and bottom of the ring. Any voids in the specimen caused due to removal of gravel or limestone pieces, shall be filled back by pressing lightly the loose soil in the voids, care being taken to see that the specimen is not affected. The container ring shall be wiped clear of any soil sticking to the outside and weighed again with the soil. The whole process should be quick to ensure minimum loss of moisture and if possible shall be carried out in the moist room. Three representative specimens from the soil trimming shall be taken in moisture content cans and their moisture content determined.

   Preparation of specimen from disturbed soil sample: In case where it is necessary to use disturbed soil samples, the soil sample shall be compacted to the desired (field) density and water content in a standard compaction Proctor mould. Samples of suitable sizes are cut from it as described above.

   Procedure: All surfaces of the consolidometer which are to be enclosed shall be moistened. The porous stones shall be saturated by boiling in distilled water for at least 15 minutes. The consolidometer shall be assembled with the soil specimen (in the ring) and porous stones at top and bottom of the specimen, providing a filter paper rendered wet between the soil specimen and the porous stone. The loading block shall then be positioned centrally on the top porous stone.

   An initial setting load of 50 gram-force/cm^2 (this includes the weight of the porous stone and the loading pad) shall be placed on the loading hanger and the initial reading of the dial gauge shall be noted.

   The system shall be connected to a water reservoir with the level of water in the reservoir being at about the same level as the soil specimen and water allowed to flow in the sample. The soil shall then be allowed to swell.

The free swell readings shown by the dial gauge under the seating load of 5 kN/m^2 (0.05 kgf/cm^2) shall be recorded at different time intervals.

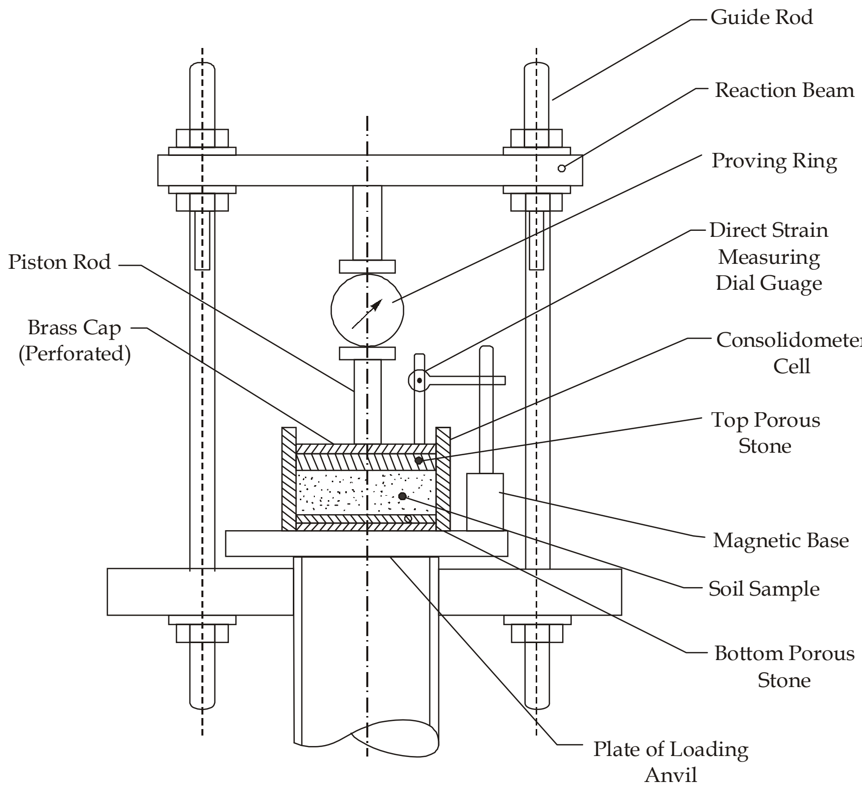
The dial gauge readings shall be taken till equilibrium is reached. This is ensured by making a plot of swelling dial reading versus time in hours, which plot becomes asymptotic with abscissa (time scale). The equilibrium swelling is normally reached over a period of 6 to 7 days in general for all expansive soils.

The compression dial readings shall be recorded till the dial readings attain a steady state for each load applied over the specimen. The consolidation loads shall be applied till the specimen attains its original volume.

2. **Constant Volume Method:**

The consolidation specimen ring with the specimen shall be kept between two porous stones saturated in boiling water providing a filter paper between the soil specimen and the porous stone. The loading block shall then be positioned centrally on the top of the porous stone.

This assembly shall then be placed on the plate of the loading unit as shown in figure. The load measuring proving ring tip attached to the load frame shall be placed in contact with the consolidation cell without any eccentricity. A direct strain measuring dial gauge shall be fitted to the cell. The specimen shall be inundated with distilled water and allowed to swell.

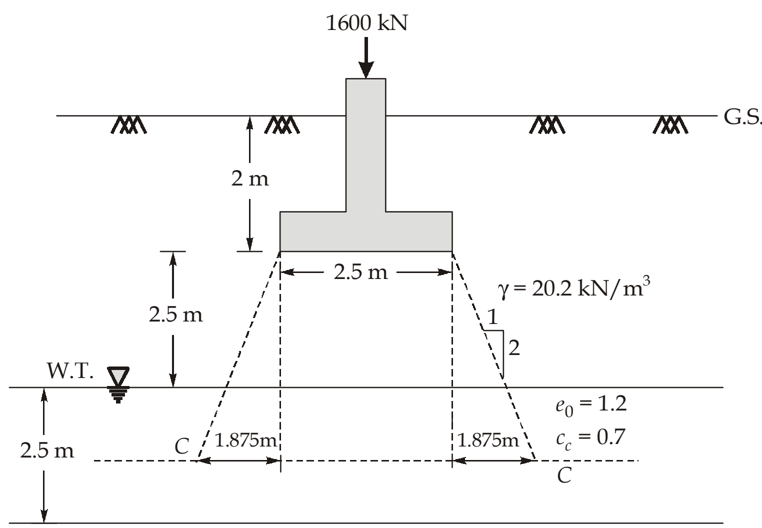


Set up for measuring Swelling Pressure in the Constant Volume Method

Procedure:

The initial reading of the proving ring shall be noted. The swelling of the specimen with increasing volume shall be obtained in the strain measuring load gauge. To keep the specimen at constant volume, the platen shall be so adjusted that the dial gauge always show the original reading. This adjustment shall be done at every 0.1 mm of swell or earlier. The duration of test shall conform to the requirements given in previous method. The assembly shall then be dismantled and the soil specimen extracted from the consolidation ring to determine final moisture content in accordance with IS : 2720 (Part IX)-1973.

(ii)



Stress area at the centre of clay

Stress area at the middle of clay

$$\text{Layer (A)} = \{2.5 + 2 \times 1.875\}^2 = 39.062 \text{ m}^2$$

$$\gamma_{\text{sat clay}} = \frac{G+e}{1+e}\gamma_w = \frac{2.7+1.2}{1+1.2} \times 9.81 = 17.39 \text{ kN/m}^3$$

Initial effective overburden pressure at middle of clay layer, ($c - c$)

$$\bar{\sigma}_0 = 20.2 \times 4.5 + 1.25\,(17.39 - 9.81)$$

$$\Rightarrow \quad \bar{\sigma}_0 = 100.375 \text{ kN/m}^2$$

Now, increase in over burden pressure,

$$\Delta\sigma = \frac{P}{A} = \frac{1600}{39.0625} = 40.96 \text{ kN/m}^2$$

$$\therefore \quad \Delta H = \frac{H_0 c_c}{1+e_0}\log_{10}\left(\frac{\bar{\sigma}_0 + \Delta\sigma}{\bar{\sigma}_0}\right)$$

$$= \frac{2.5 \times 0.7}{1+1.2}\log_{10}\frac{100.375 + 40.96}{100.375}$$

$$= 0.1182 \text{ m}$$

$\therefore$ Settlement of footing, ΔH = 11.82 cm

Q.8 (b) Solution:

Minimum elevation of line of sight = 220 + 3 = 223 m

Let us take this elevation of 223 m as datum,

∴ Height of station A above this datum,

$$h_1 = 240 - 223 = 17 \text{ m}$$

The tangent distance D_1 corresponding to h_1 is given as,

$$D_1 = 3.855\sqrt{h_1}$$

$$= 3.855\sqrt{17} = 15.89 \text{ km}$$

Distance of B from point of tangency,

$$D_2 = 60 - 15.89 = 44.11 \text{ km}$$

The elevation of h_2 (of B above datum) is computed as below

h_2 corresponding to the distance D_2 is given by

$$h_2 = 0.06729\ D_2^2$$

$$= 0.06729 \times (44.11)^2 = 130.93 \text{ m}$$

$$\text{Elevation of line sight at } B = 223 + 130.93$$

$$= 353.93 \text{ m}$$

$$\text{Ground level at } B = 340 \text{ m}$$

∴ Maximum height of signal above ground at B

$$= 353.93 - 340$$

$$= 13.93 \text{ m}$$

Q.8 (c) Solution:

(i)

The pore water pressure can be classified in two stages:

(i) Consolidation stage or cell pressure stage

(ii) Shear stage or deviator stress stage

The value of B can be given as

$$B = \frac{\Delta u_c}{\Delta \sigma_c} = \frac{\Delta u_c}{\Delta \sigma_3}$$

Here B is the ratio of pore pressure developed to the change in confining pressure. Δu_c represents increase in pore pressure due to increase in cell pressure, $\Delta\sigma_c$. For a fully saturated soil, B =1 and for a fully dried soil B = 0. The value of B can also be determined by using soil properties. Thus, the value of B can be given as

$$B = \frac{1}{1 + n\dfrac{C_v}{C_c}}$$

where n is porosity, C_v is coefficient of consolidation, C_c is coefficient of compression.

A is defined as $\bar{A} = AB$

where $\bar{A}$ is related to change in pore water pressure due to change in deviator stress i.e.

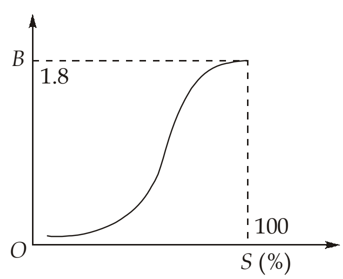
$$\bar{A} = \frac{\Delta u_d}{\Delta \sigma_d} = \frac{\Delta u_d}{\Delta \sigma_1 - \Delta \sigma_3}$$

where Δu_d is change in pore water pressure due to change in deviator stress.

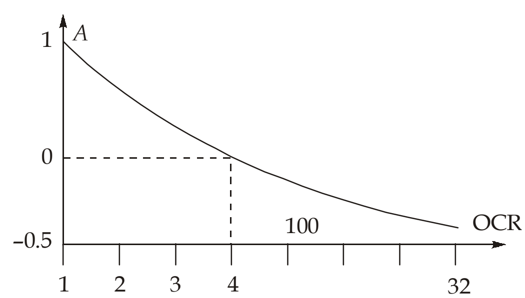
Now $\Delta u = \Delta u_c + \Delta u_d = B \cdot \Delta \sigma_3 + \bar{A} \cdot \Delta \sigma_d = B \cdot \Delta \sigma_3 + AB \cdot \Delta \sigma_d = B \cdot \Delta \sigma_3 + AB(\Delta \sigma_1 - \Delta \sigma_3)$

$\therefore$ $\Delta u = B[\Delta \sigma_3 + A(\Delta \sigma_1 - \sigma_3)]$

The value of A may be as high as 2 to 3 for saturated fine sand and may be as low as –0.5 for heavily over consolidated clays. For a given soil A depends upon the strain, anisotropy, sample disturbance and the over consolidation ratio.



Variation of B with S (%)



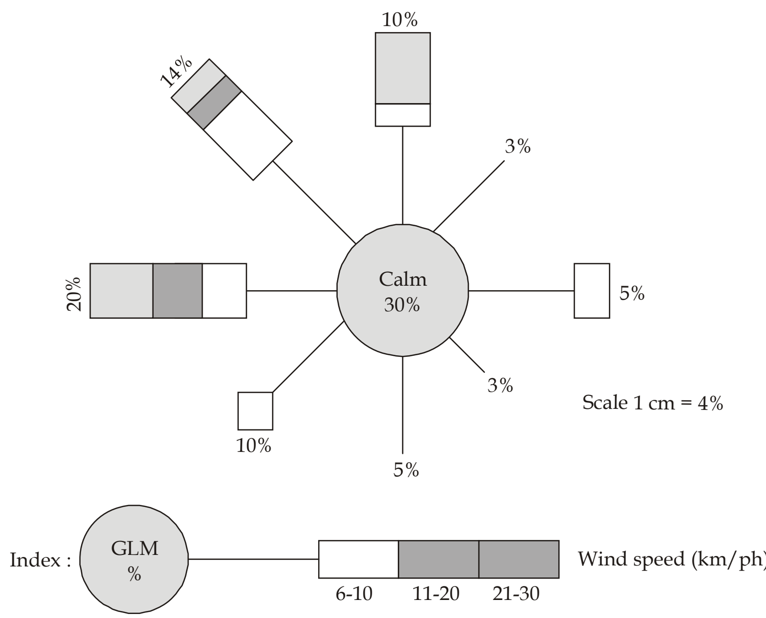
Variation of A (at failure) with OCR

(ii)

Wind rose diagram : The wind data pertaining to a particular area is presented in the form of geometrical diagram called as wind rose diagram. It indicates the direction, intensity and duration of wind component. It is correlated with meteorological data to predict most suitable orientation of runway. It gives warning of the bad weather and inform the aircrafts about the feasibility of the check landing or take off. The windrose diagram is shown below which shows the prevailing direction of wind.

Construction of wind rose diagram : Wind roses may be constructed from the data obtained over a given time period such as particular month or season or a year. The convention used is wind direction refers to the direction from which the wind is blowing. A line or bar extending to the north on the wind rose diagram indicates the frequency of winds blowing from the north.

The wind rose diagram is prepared using an appropriate scale to represent percentage frequencies of wind directions and appropriate index shades, lines etc. to represent various speeds. Observations corresponding to wind speed below 1 km/hr are recorded as calm.



Wind Rose Construction

Significance in Runway Orientation: Runways are oriented in the direction of the prevailing wind. The reason behind that is to utilize it fully to get the maximum force of wind at the time of take off and landing of an aircraft. According to FAA standards, runways should be oriented so that the aircraft can take off and/or land atleast 95% of time without exceeding the allowable crosswinds.

Wind data is required in many dimensions i.e. in terms of duration, intensity of wind in the vicinity of the airport and this is required for development of windrose diagram which is finally used to identify the orientation of runway based on wind coverage area.

Wind direction is studied from wind rose diagram to examine whether the wind will attack aircraft from the headside or tailside or from lateral sides. Also direction of wind is not necessarily same throughout the year. It will keep on changing.