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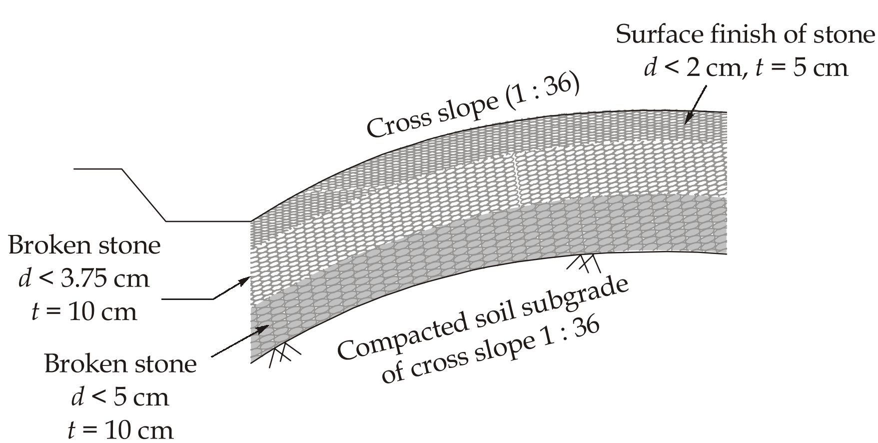
Detailed Solutions

ESE-2022 Mains Test Series

Civil Engineering Test No : 2

Q.1 (a) Solution:

(i) **Macadam Roads:** Macadam's method is first method based on scientific thinking i.e., stresses due to wheel load of traffic gets decreased at the lower layer of pavement therefore it is not necessary to provide large and strong boulder stone as foundation at lowest layer of pavement.



- In order to provide subgrade drainage, subgrade was compacted and was prepared with a cross slope of 1 in 36. Compacted layer of smaller size broken stones placed at bottom.
- Broken stone of strong variety, all passing through 5 cm size were compacted to thickness of 10 cm.
- In the second layer, strong broken stones of size 3.75 cm were compacted to 10 cm thickness.

- Top layer consisted of stones of size less than 2 cm compacted to a thickness of about 5 cm and finished so that cross slope of pavement surface was also 1 in 36.
- The total thickness of construction was less than all previous methods like Roman road, Tresaguet, Telford construction etc. and due to better load dispersion characteristics of compacted broken stone aggregate of smaller size.
- The size of broken stone for the top layer was decided based on stability under animal drawn vehicle.

(ii) **A.** **Pot holes:** These are bowl shaped holes of varying size in surface layer extending upto base course.

Pot holes may occur due to penetration of water into pavement through surface course, or may be due to lack of bond between bituminous surface and the underlined aggregate or due to insufficient bitumen.

B. **Rutting:** It is longitudinal depression or groove due to wheel of heavy vehicle. It occurs due to heavy channelised traffic and due to inadequate construction of mix at surfaces.

Width of ruts are usually same as width of wheel path.

C. **Streaking:** Alternate heavy and lean line of bitumen in longitudinal and transverse direction.

It occurs due to improper compaction, improper application of bitumen and mechanical fault.

D. **Ravelling:** It is progressive disintegration of surface due to failure of binds to hold the material together. It occurs due to inadequate compaction, overheating of mix, wet weather during construction etc.

Q.1 (b) Solution:

(i) **A.** **The hour angle:** The hour angle of a heavenly body is the angle between the observer's meridian and the declination circle passing through the body. The hour angle is always measured westwards.

B. **Solastices:** Solastices are the points at which the north and south declination of the sun is maximum. In Northern hemisphere, the point at which the north declination of the sun is maximum is called the summer solastice, while the point at which south declination of the sun is maximum is known as the winter solastice. The case is just the reverse in the southern hemisphere.

C. **The Ecliptic:** Ecliptic is the great circle of the heavens which the sun appears to describe on the celestial sphere with the Earth as a centre in the course of a year.

The plane of the ecliptic is inclined to the plane of the equator at an angle (called the obliquity) of about 23° 27′, but is subjected to a diminution of about 5″ in a century.

D. The Terrestrial Poles: The terrestrial poles are the two points in which the earth's axis of rotation meets the Earth's sphere.

(ii)

Station	Chainage	*BS*	*IS*	*FS*	Rise (m)	Fall (m)	RL(m)
1		0.650					100.000
2		2.155		2.455		1.805	98.195
3		1.405		1.305	0.850		99.045
4		2.655		0.555	0.850		99.895
5	0	2.435		2.405	0.250		100.145
6	10		2.385		0.050		100.195
7	20		2.335		0.050		100.245
8	30			2.285	0.050		100.295
		Σ = 9.3		Σ = 9.005	Σ = 2.1	Σ = 1.805	

$$\text{Rise per 10 m} = \frac{1}{200} \times 10 = 0.05 \text{ m}$$

Check:

$$\Sigma BS - \Sigma FS = 9.3 - 9.005 = 0.295 \text{ m}$$

$$\text{Last } RL - \text{First } RL = 100.295 - 100 = 0.295 \text{ m}$$

$$\Sigma\text{Rise} - \Sigma\text{Fall} = 2.1 - 1.805 = 0.295 \text{ m}$$

$$\therefore \quad \Sigma\text{Rise} - \Sigma\text{Fall} = \text{Last RL} - \text{First RL} \quad \text{(OK)}$$

Q.1 (c) Solution:

Let us assume that *e* value is incorrect and remaining all are correct.

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

$$\Rightarrow \quad 15 = \frac{2.72 \times 9.81}{1+e}(1+2)$$

$$\Rightarrow \quad e = 4.34$$

Then

$$Se = wG$$

$$S \times 4.34 = 2 \times 2.72$$

$$\Rightarrow \quad S = 1.253 > 1, \text{ which is not possible means } e \neq 4.34$$

$$\therefore \quad e \neq 4.34$$

∴ Given e value can't be incorrect.

Now assume w to be incorrect and remaining all are correct.

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

$$\Rightarrow \quad 15 = \frac{9.81\times 2.72}{1+5.8}(1+w)$$

$$\Rightarrow \quad w = 2.82$$

Then, $Se = wG$

$$\Rightarrow \quad S(5.8) = 2.82 \times 2.72$$

$$\Rightarrow \quad S = 1.322 > 1,$$

which is not possible means $w \neq 2.82$

∴ Given w value cannot be incorrect.

Now, assume G to be incorrect and remaining all are correct.

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

$$\Rightarrow \quad 15 = \frac{G\times 9.81}{1+5.8}(1+2)$$

$$\Rightarrow \quad G = 3.466$$

Then, $Se = wG$

$$\Rightarrow \quad S \times 5.8 = 3.466 \times 2$$

$\Rightarrow \quad S = 1.195 > 1$, which is not possible,

∴ Given, G value cannot be incorrect.

Now, assume γ is incorrect and remaining all are correct.

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

$$\Rightarrow \quad \gamma = \frac{2.72\times 9.81}{1+5.8}\times(1+2) = 11.772 \text{ kN/m}^3$$

Then, $Se = wG$

$$\Rightarrow \quad S \times 5.8 = 2 \times 2.72$$

$\Rightarrow \quad S = 0.938 < 1$, which is possible.

So, given γ value is incorrect and $\gamma = 11.772 \text{ kN/m}^3$ is correct.

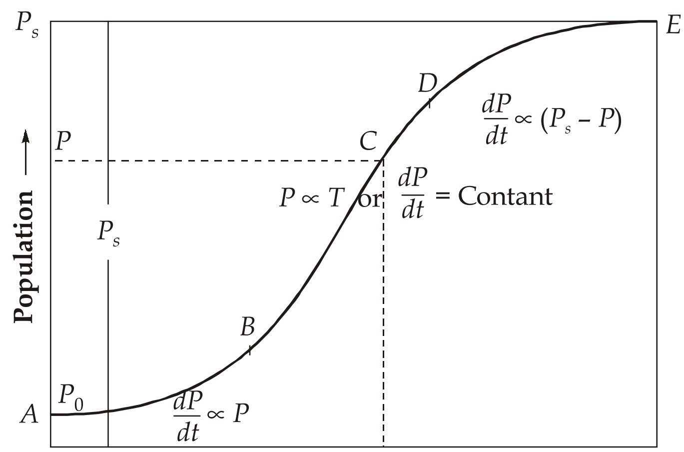
Q.1 (d) Solution:

(i) (a) **Factors affecting water consumption:** The rate of water consumption depends on many factors, which can be summerised as given below:

1. **Climatic condition:** Climatic condition has great influence on water consumption rate. The water consumption rate in hot and arid regions will tend to increase as compared to wet and colder places.
2. **Standard of living:** For cities with high standard of living, the water consumption will be higher. For poor class people, the per capita demand of water is low.
3. **Industries:** Water requirement not only directly depends on the nature, number and size of industries, but also their indirect relation to overall development. For industrial areas water demand also should be properly linked with fire demand. In general, with the increase of industries, water demand will increase.
4. **Quality of water:** If the quality of water is good, people will consume more water. Otherwise, they may avoid and try to use minimum quantity of water. So for safe and good quality water, water consumption will be higher.
5. **Pressure in the distribution system:** If the pressure in the distribution system is high, that will cause not only high rate of flow, but leakages also will be high, thus increases per capita demand of water.
6. **System of sanitation:** If the towns are provided with water carriage system of sanitation, the per capita water demand increases.
7. **Use of meters:** If the metering system is introduced for the purpose of charging for consumed water, the consumer will be cautious in using water and there will be less wastage of water. So per capita demand may lower down.

(ii) **Logistic curve method**

When the growth rate of population due to births, deaths and migrations takes place under normal situation and it is not subjected to extraordinary changes due to unusual situation like war, epidemic, earthquake, exodus of refugees etc., the population would probably follow the growth curve characteristics of living things within limited space or with limited economic opportunity. This curve is S-shaped as shown in figure and is known as logistic curve.



Logistic Curve, *T*

This curve represents early growth AB at an increasing rate i.e., geometric growth or log growth, $\frac{dP}{dt} \propto P$ and late growth (DE) at an increasing rate i.e., first order curve $\frac{dP}{dt} \propto (P_s - P)$, as the saturation population value P_s is approached. The transitional middle curve BD follows arithmetic increase i.e., $\frac{dP}{dt} = \text{constant}$. Forecasting of future population is made on the basis of the above equation. Verhulst has put forward a mathematical solution for this logistic curve. According to him, the entire curve AE (in figure) can be represented by an auto catalytic first order equation, given by

$$\log_e\left(\frac{P_s - P}{P}\right) - \log_e\left(\frac{P_s - P_o}{P_o}\right) = KP_s t$$

where, P_o = Population at the start point *A*

P_s = Saturation population at point *E*

P = Population at any time, *t*

K = Constant

(b) $P_0 = 50{,}000$ at $t = 0$

$P_1 = 1{,}00{,}000$ at $t = 10$ years

$P_2 = 1{,}35{,}000$ at $t = 20$ years

$$\therefore \quad P_S = \frac{2P_0P_1P_2 - P_1^2(P_0 + P_2)}{P_0P_2 - P_1^2}$$

$$\Rightarrow \quad P_S = \frac{2(50000)(100000)(135000) - (100000^2)(50000 + 135000)}{(50000)(135000) - (100000)^2}$$

$$\Rightarrow \quad P_S = 153846.15$$

Q.1 (e) Solution:

Given: $P_1 = 1$ atm, $P_2 = 2.5$ atm

$T_1 = 273$ K, $T_2 = 30°C = 303$ K

$V_1 = 22.4\ l/\text{mol}$, $V_2 = ?$

(i)

$$1\ \mu g/m^3 = \frac{1 \text{ ppm} \times \text{molecular mass in g/mol}}{l/\text{mol of gas at given temp. and pressure}} \times 10^3 l/m^3$$

By Avogadro's law, we know that

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\Rightarrow \quad V_2 = \left(\frac{P_1 V_1}{T_1}\right)\left(\frac{T_2}{P_2}\right) = \left(\frac{1 \times 22.4}{273}\right)\left(\frac{303}{2.5}\right) = 9.945\ l/\text{mol}$$

Also, 200 ppb = 0.2 ppm

Molecular wt. of $SO_2 = 32 + 2 \times 16 = 64$ g/mol

$$\text{Concentration of } SO_2 \text{ in } \mu g/m^3 = \frac{0.2 \times 64}{9.945} \times 10^3 = 1287.08\ \mu g/m^3$$

(ii) Scale of motion represents the interaction of the four elements of all meteorological phenomena i.e., heat, pressure, wind and moisture. All weather parameters, including pressure systems, wind speed and direction, humidity, temperature and precipitation ultimately results from variable relationships of heat, pressure, wind and moisture.

Scales of motion are related to mass movement of air which may be global, continental, regional or local in scope.

According to their geographic range of influence, the scales of motion may be designated as macroscale, mesoscale and microscale.

A. Macroscale: Atmospheric motion on the macroscale involves the planetary patterns of circulation, the grand sweep of air current over hemispheres. These phenomena occur on scale of thousands of kilometers and creates semipermanent high and low pressure areas over oceans and continents.

B. **Mesoscale:** Circulation patterns develop over regional geographic units, primarily because of influence of regional or local topography. These phenomena occur on scales of hundreds of kilometers.

C. **Microscale:** Microscale phenomena occurs over area of less than 10 km^2 and can be exemplified by the meandering and dispersion of smoke plumes from industrial stacks.

Q.2 (a) Solution:

(i) Objective of providing extra widening of pavements on horizontal curve are as follows:

(a) An automobile has a rigid wheel base and only the front wheels can be turned using steering wheel so, when this vehicle takes a turn to negotiate a horizontal curve, the rear wheels do not follow the same path as that of the front wheels. This phenomenon is called *off tracking*. If inner front wheel takes a path on the inner edge of a pavement at a horizontal curve, inner rear wheel will be off the pavement on the inner shoulder. The off-tracking depends on the length of the wheel base of the vehicle and the turning angle or the radius of the horizontal curve being negotiated.

(b) At speeds higher than the design speed, when the superelevation and lateral friction developed are not fully able to counteract the outward thrust due to the centrifugal force, some transverse skidding may occur and the rear wheels may take paths on the outside of those traced by the front wheels on the horizontal curves.

(c) In order to take curved path with larger radius and to have greater visibility at curve, the drivers have tendency not to follow the central path of the lane, but to use the outer side at the beginning of a curve.

(d) While two vehicles cross or overtake at horizontal curve there is a psychological tendency to maintain a greater clearance between the vehicles, than on straights for increased safety.

Thus, the required extra widening of the pavement at the horizontal curve, W_e depends on the length of wheel base of the vehicle, radius of the curve negotiated R, and the psychological factor which is a function of the speed of the vehicle and the radius of the curve.

(ii) For rolling terrain, minimum design speed for National Highway is 65 kmph i.e., V = 65 kmph, radius of curve (R) = 250 m (given), No. of lanes (n) = 2, length of wheel base (l) = 6.1 m.

Allowable rate of introduction of superelevation (if pavement is rotated about centre line) is 1 in N = 1 in 50.

Length of Transition curve (L_{TC}):

A. On the basis of change of centrifugal acceleration

$$L = \frac{V^3}{CR}$$

where, V = design speed (m/s)

R = Radius of curve (m) = 250 m

$$\therefore \quad V = \frac{65}{3.6} = 18.055 \text{ m/s}$$

C = Rate of change of centrifugal acceleration

$$\Rightarrow \quad C = \frac{80}{75 + V(\text{kmph})}$$

$$\Rightarrow \quad C = \frac{80}{75 + 65} = 0.5714 \text{ m/s}^3$$

$$\therefore \quad L = \frac{(18.055)^3}{0.5714 \times 250} = 41.20 \text{ m}$$

B. On the basis of introduction of superelevation

$$L = e(W + W_e)N \quad \text{(when rotated about inner edge)}$$

Extra widening, $$W_e = \frac{nl^2}{2R} + \frac{V(\text{kmph})}{9.5\sqrt{R}}$$

$$= \frac{2 \times 6.1^2}{2 \times 250} + \frac{65}{9.5\sqrt{250}} = 0.5816 \text{ m}$$

W = Width of pavement = 7 m (two lane)

Superelevation, $$e = \frac{V^2}{225R}$$

V = Design speed (kmph)

R = Radius = 250 m

$$\therefore \quad e = \frac{65^2}{225 \times 250} = 0.0751 > 0.07$$

Since e is more than maximum recommended value by IRC, so we will provide

$$e = 0.07 \text{ and check for } f.$$

$$\therefore \quad e + f = \frac{V^2}{127R}$$

$$\Rightarrow \quad 0.07 + f = \frac{65^2}{127 \times 250}$$

$$\Rightarrow \quad f = 0.063 < 0.15 \quad \text{(OK)}$$

∴ Take $e = 0.07$

$$\therefore \quad L = 0.07\,(7 + 0.5816) \times 150 = 79.6068 \text{ m}$$

C. For plain and rolling terrain, using empirical formula

$$L = \frac{2.7V^2}{R}$$

$$V = \text{Design speed (kmph)}$$

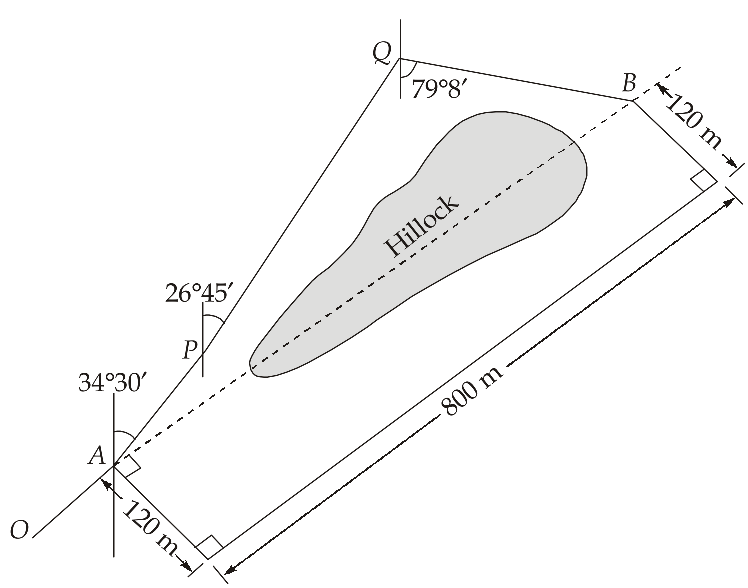
$$\therefore \quad L = \frac{2.7 \times 65^2}{250} = 45.63 \text{ m}$$

Adopt the highest value of above three criteria i.e.,

$$L_{TC} = 79.6068 \text{ m} \simeq 80 \text{ m}$$

Q.2 (b) Solution:

(i)



Line	Length (m)	Bearing	Latitude (m)	Departure (m)
AP	165.8	N34°30′W	136.64	-93.91
PQ	600	N26°45′E	535.78	270.06
QB	269.63	S79°08′E	- 66.37	346.06
BA	—	—	—	—

$$\text{Latitude of } BA = -(136.64 + 535.78 - 66.37) = -606.05 \text{ m}$$

$$\text{Departure of } BA = -(-93.91 + 270.06 + 346.06) = -522.21 \text{ m}$$

$$\therefore \quad \text{Length of } BA = \sqrt{(-606.05)^2 + (-522.21)^2} = 799.999 \text{ m} \simeq 800 \text{ m}$$

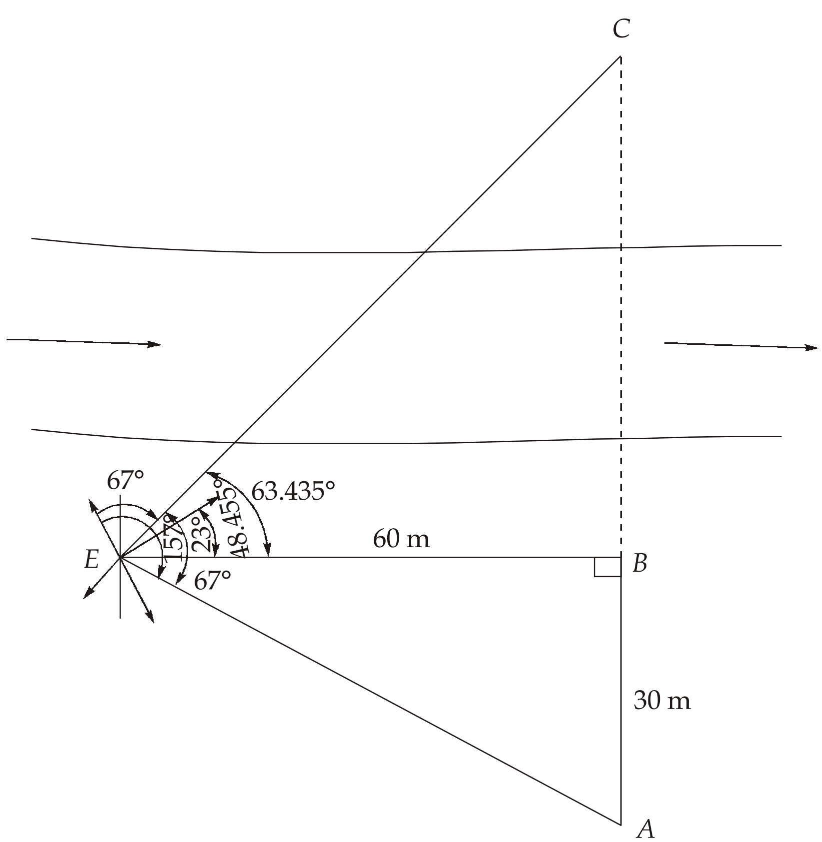
Bearing of BA: $\tan\theta = \left(\dfrac{-522.21}{-606.05}\right)$

$$\theta = 40.7502°$$

$\therefore$ Bearing of BA = S40°45′W

$\therefore$ Bearing of AB = N40°45′E (Hence verified)

(ii) Given:

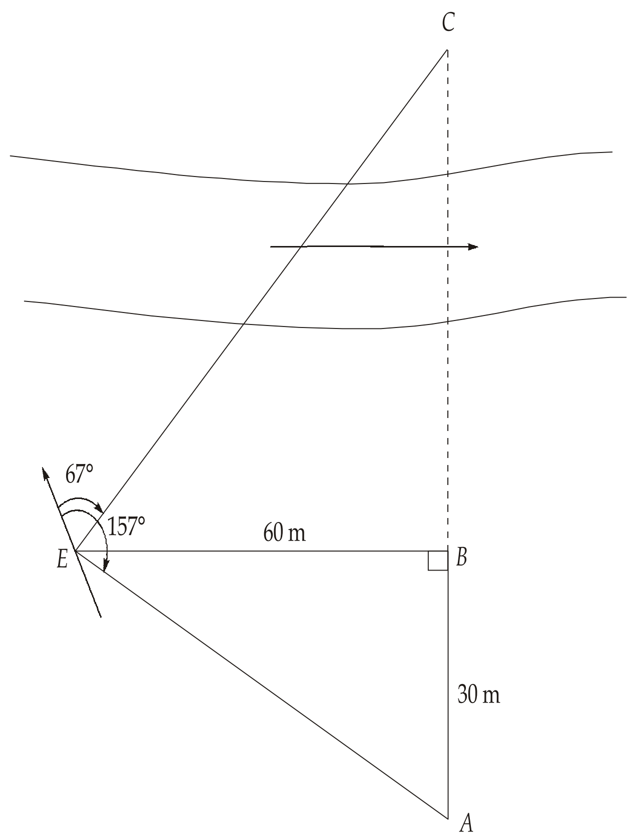


$$\therefore \quad \tan 63.435° = \frac{CB}{60}$$

$$\Rightarrow \quad CB = 120 \text{ m}$$

$$\therefore \quad \text{Chainage of } C = 270.5 + 120 = 390.5 \text{ m}$$

Alternatively:



$$\angle CEA = \text{Bearing of } A - \text{Bearing of } C$$

$$= 157° - 67° = 90°$$

$\therefore \angle AEC$ is a right angled triangle with right angle at E i.e., $\angle AEC = 90°$.

Now in ΔAEC and ΔABE,

$$\angle A = \angle A$$

$$\angle E = \angle B = (90°)$$

$$\therefore \quad \Delta AEC \sim \Delta ABE$$

$$\therefore \quad \frac{AE}{AB} = \frac{EC}{BE} = \frac{AC}{AE}$$

$$\Rightarrow \quad \frac{AE}{30} = \frac{EC}{60} = \frac{30+BC}{AE}$$

$$\therefore \quad AE^2 = 30\,(30 + BC)$$

and
$$EC = \frac{60}{AE}(30+BC) = \frac{60(30+BC)}{\sqrt{30}\sqrt{30+BC}}$$

$$= \frac{60}{\sqrt{30}}\sqrt{30+BC}$$

Also from ΔAEC,
$$AC^2 = AE^2 + EC^2$$

$$\Rightarrow \quad (30 + BC)^2 = 30\,(30+BC) + \left[\frac{60}{\sqrt{30}}\sqrt{30+BC}\right]^2$$

$$\Rightarrow \quad (30 + BC)^2 = 30(30+BC) + \frac{3600}{30}(30+BC)$$

$$\Rightarrow \quad 30 + BC = 30 + 120$$

$$\Rightarrow \quad BC = 120 \text{ m}$$

$$\therefore \quad \text{Chainage of } C = \text{Chainage of } B + BC$$

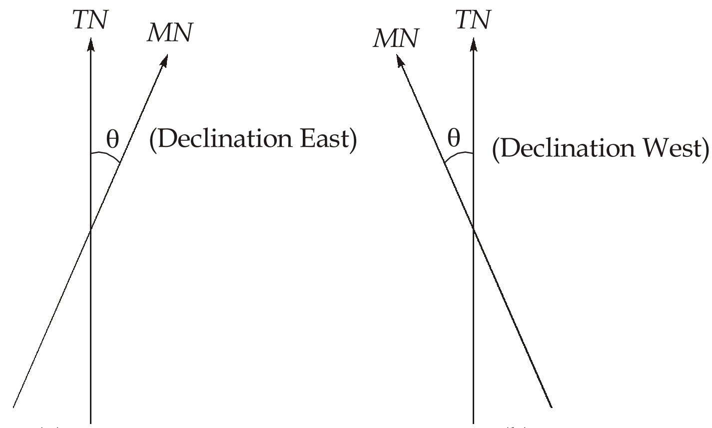
$$= 270.5 + 120 = 390.5 \text{ m}$$

(iii)

- **Magnetic Declination** : The horizontal angle between the magnetic meridian and true meridian is known as 'magnetic declination'.

  When the north end of the magnetic needle is pointed towards the west side of the true meridian, the position is termed as Declination West (θW) or negative declination.

  When the north end of the magnetic needle is pointed towards the east side of the true meridian, the position is termed as Declination East ($\theta\, E$) or positive declination.



(a) (b)

- **Variation of Magnetic Declination**: The magnetic declination at a place is not constant. It varies due to the following reasons:
  - **(a) Secular Variation** : The magnetic meridian behaves like a pendulum with respect to the true meridian. After every 100 years or so, it swings from one direction to the opposite direction, and hence the declination varies. This variation is known as 'secular variation'.
  - **(b) Annual Variation** : The magnetic declination varies due to the rotation of the earth, with its axis inclined, in an elliptical path around the sun during a year. This variation is known as 'annual variation'. The amount of variation is about 1 to 2 minutes.
  - **(c) Diurnal Variation** : The magnetic declination varies due to the rotation of the earth on its own axis in 24 hours. This variation is known as 'diurnal variation'. The amount of variation is found to be about 3 to 12 minutes.

Q.2 (c) Solution:

(i) 45.5% of micro-organisms are killed in 8 minutes

$\Rightarrow$ Micro-organisms surviving after 8 minutes is 54.5%.

$$N_8 = 54.5\%$$

$$\because \quad N_t = \frac{N_0}{1+k(t)}$$

$$\therefore \quad \frac{N_8}{N_0} = \frac{1}{1+k(8)}$$

$$\Rightarrow \quad 0.545 = \frac{1}{1+k(8)}$$

$$\Rightarrow \quad k = 0.104 \text{ min}^{-1}$$

To calculate time required to kill last 40% of micro-organisms in order to achieve 90% efficiency, we need to determine time required in killing of organisms from 50% to 90%.

Time required in killing of 50% micro-organisms,

$$\because \quad N_t = \frac{N_0}{1+kt}$$

where $N_t = 0.5\, N_0$

$$\therefore \quad 0.5 = \frac{1}{1+0.104 \times t}$$

$$\Rightarrow \quad t = 9.615 \text{ minutes}$$

Time required in killing of 60% micro-organisms,

After killing 60% of micro-organisms,

$$N_t = 0.4\, N_0$$

$$\because \quad N_t = \frac{N_0}{1+kt}$$

$$\Rightarrow \quad \frac{N_t}{N_0} = \frac{1}{1+kt}$$

$$\Rightarrow \quad 0.4 = \frac{1}{1+0.104 \times t}$$

$$\Rightarrow \quad t = 14.423 \text{ min}$$

Now, rate of kill is doubled,

$$\therefore \quad k' = 2 \times 0.104 \text{ min}^{-1} = 0.208 \text{ min}^{-1}$$

$N_t' = (0.1\, N_0)$, as 90% overall efficiency is required.

$$N_0' = 0.4\, N_0$$

$$\therefore \quad N_t' = \frac{N_0'}{1+k't}$$

$$\Rightarrow \qquad (0.1\,N_0) = \frac{0.4N_0}{1+(0.208\times t)}$$

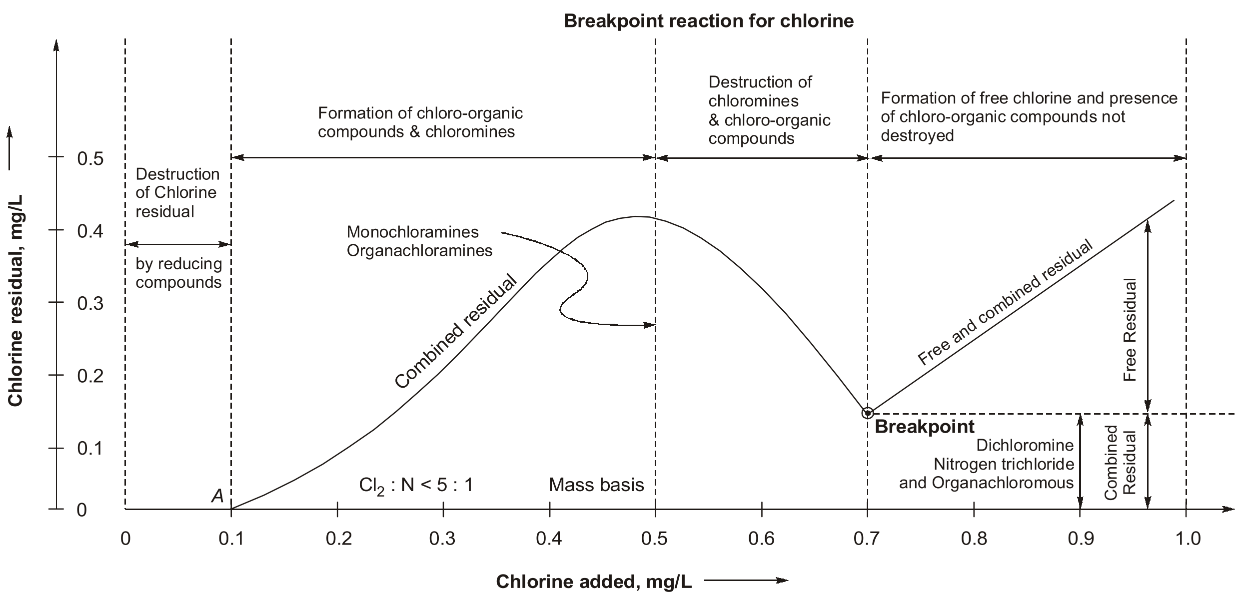
$$\Rightarrow \qquad t = 14.423 \text{ minutes}$$

Time to kill micro-organisms from 50% to 60% = (14.423 – 9.615)

= 4.808 min

Time to kill micro-organisms from 60% to 90% = 14.423 min

(ii)



Chlorine is added to the water supply in two ways. It is mostly added as a gas i.e., $Cl_2(g)$. However, it can also be added as a salt such as sodium hypochlorite (NaOCl) or bleach. Chlorine gas dissolves in water following Henry's law.

$$Cl_2(g) \rightarrow Cl_2(aq) \qquad k_H = 6.2 \times 10^{-2}$$

Once dissolved, the following reaction occurs forming hypochlorous acid (HOCl),

$$Cl_2(aq) + H_2O \rightarrow HOCl + H^+ + Cl^-$$

Hypochlorous acid and hypochlorite ion are collectively called as the free chlorine residual. These free chlorine compounds can react with many other organic and inorganic compounds to form chlorinated compounds. If the products of these reactions possess oxidizing potential, they are considered the combined chlorine residual. A common compound in drinking water systems that reacts with chlorine to form combined residual is ammonia. Reaction between ammonia and chlorine forms chloramines, which is mainly monochloromine (NH_2Cl), although some dichloramines ($NHCl_2$) and trichloramine (NCl_3) can also form. Many drinking water utilities use monochloramine as disinfectant. The overall reactions of the free chlorine and nitrogen can be represented by two simplified reactions as follows:

Monochloramine formation reaction: The reaction occurs rapidly when ammonia nitrogen is combined with free chlorine upto molar ratio of 1 : 1.

$$HOCl + NH_3 \rightarrow NH_2Cl + H_2O$$

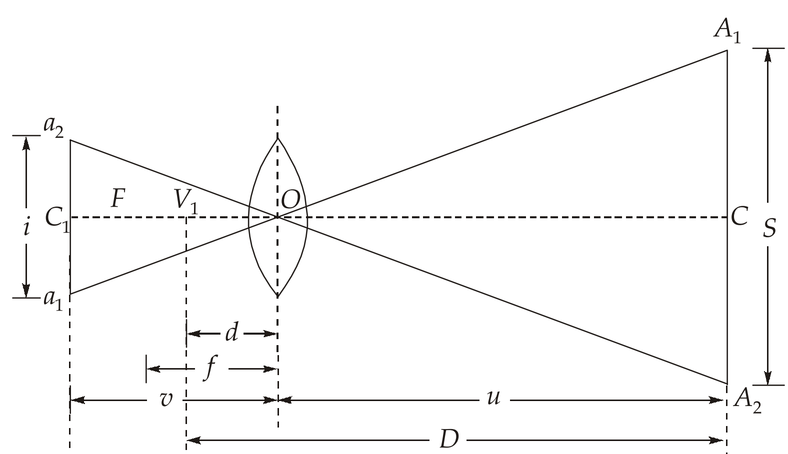
Breakpoint reaction: When excess free chlorine is added beyond the 1 : 1 initial molar ratio, the monochloramine is removed as follows:

$$2NH_2Cl + HOCl \rightarrow N_2(g) + 3H^+ + 3Cl^- + H_2O$$

The formation of chloramines and the breakpoint reaction creates a unique relationship between chlorine dose and amount of chlorine.

Q.3 (a) Solution:

(i) Derivation of tacheometric distance equation



Let O = Optical centre of object glass

A_1, A_2, C = Readings on staff cut by three hairs.

a_1, a_2, C_1 = Bottom, top and central hairs of diaphragm

a_1a_2 = i = Length of image

A_1A_2 = S = Staff intercept

F = Focus

V = Vertical axis of instrument

f = Focal length of object lens

d = Distance between optical centre and vertical axis of instrument

u = Distance between optical centre and staff

v = Distance between optical centre and image

From similar triangles $a_1 Oa_2$ and $A_1 OA_2$,

$$\frac{i}{S} = \frac{v}{u}$$

$$\Rightarrow \quad v = \frac{iu}{S}$$

From the property of lens (also called as 'lens formula')

$$\frac{1}{v}+\frac{1}{u} = \frac{1}{f} \quad \text{...(i)}$$

Putting the value of v in eq. (i),

$$\frac{1}{iu/S}+\frac{1}{u} = \frac{1}{f}$$

$$\Rightarrow \quad \frac{S}{iu}+\frac{1}{u} = \frac{1}{f}$$

$$\Rightarrow \quad \frac{1}{u}\left(\frac{S}{i}+1\right) = \frac{1}{f}$$

$$\Rightarrow \quad u = \left(\frac{S}{i}+1\right)f$$

But $\quad D = u + d$

$$\Rightarrow \quad D = \left(\frac{S}{i}+1\right)f+d$$

$$= \frac{S}{i}\times f+f+d=\left(\frac{f}{i}\right)\times S+(f+d)=kS+C$$

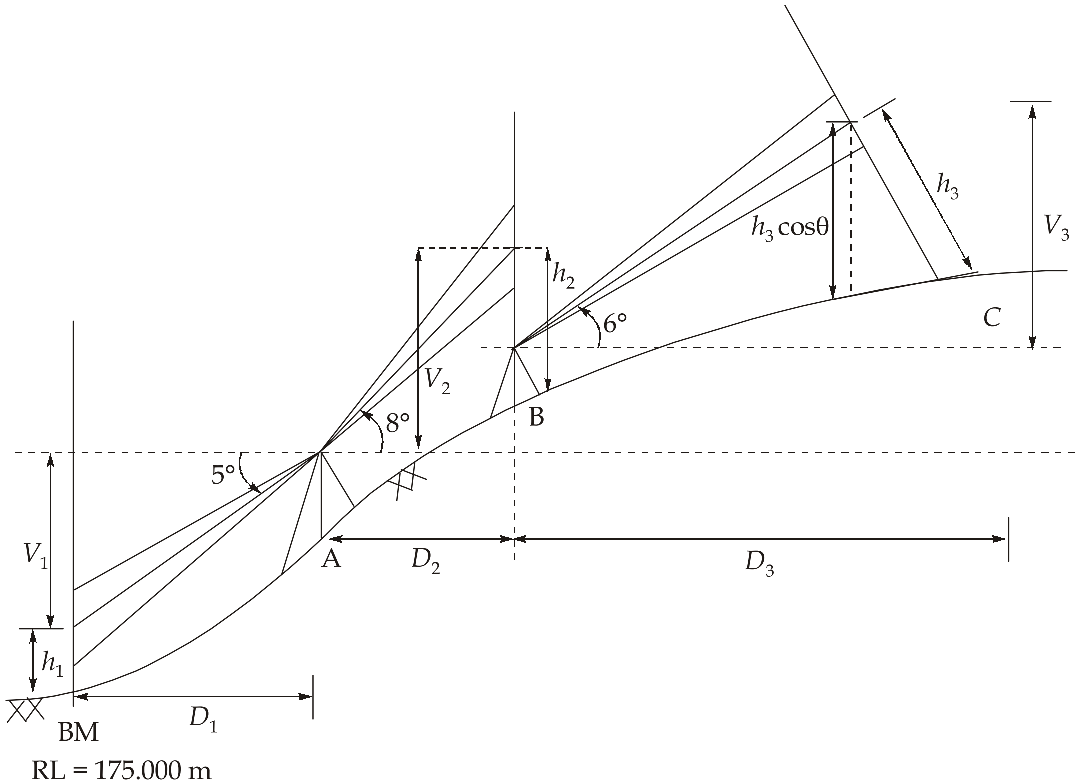
where, $\quad k = \frac{f}{i} =$ Multiplying constant

$C = (f + d)$ = Additive constant

(ii) $\quad h_1 = 1.450$ m, $\theta_1 = 5°$

$h_2 = 1.650$ m, $\theta_2 = 8°$

$h_3 = 2.303$ m, $\theta_3 = 10°$



$\therefore \quad D_1 = (kS\cos\theta_1 + C)\cos\theta_1$

$\Rightarrow \quad D_1 = 100(2.000 - 0.905)\cos^2 5° + 0$

$\Rightarrow \quad D_1 = 108.67 \text{ m}$

Similarly for D_2,

$D_2 = (kS\cos\theta_2 + C)\cos\theta_2$

$\Rightarrow \quad D_2 = 100(2.250 - 0.750)\cos^2 8° = 147.09 \text{ m}$

Similarly for D_3, $\quad D_3 = (kS + C)\cos\theta_3 + h_3\sin\theta_3$

$\Rightarrow \quad D_3 = 100(3.400 - 1.500)\cos 6° + 2.300\sin 6°$

$\Rightarrow \quad D_3 = 189.20 \text{ m}$

Total distance from BM to C $= D_1 + D_2 + D_3$

$= 108.67 + 147.09 + 189.20$

$= 444.96 \simeq 445 \text{ m}$

RL of C $= RL_{BM} + h_1 + V_1 + V_2 - h_2 + (HI)_B + V_3 - h_3\cos\theta$

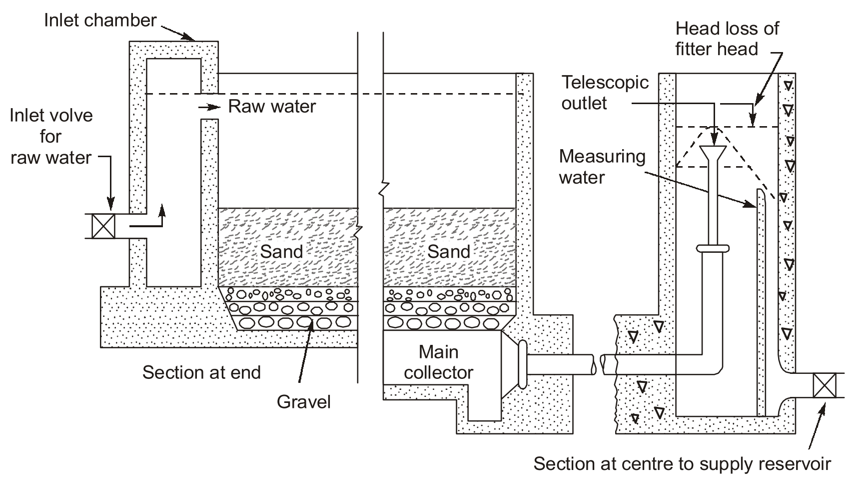
where, $\quad V_1 = [kS\cos\theta_1 + C]\sin\theta_1$

$= [100(2.000 - 0.905)\cos 5°]\sin 5° = 9.51 \text{ m}$

$$V_2 = [kS\cos\theta_2 + C]\sin\theta_2$$
$$= [100(2.25 - 0.750)\cos 8°]\sin 8° = 20.67 \text{ m}$$
$$V_3 = (kS + C)\sin\theta_3$$
$$= [100(3.400 - 1.500)]\sin 6° = 19.86\text{m}$$
$$\therefore \quad RL_C = 175.000 + 1.450 + 9.51 + 20.67 - 1.650 + 1.505 + 19.86 - 2.303\cos 10°$$
$$\Rightarrow \quad RL_C = 224.08 \text{ m}$$

Q.3 (b) Solution:

(i)



Construction: Slow sand filters are constructed of fine sand with an effective grain size of 0.2 to 0.3 mm. The depth of sand is kept between 90 and 110 cm and sand layer is rested upon the gravel layer in the filter. Gravel layer is provided only to support the sand medium.

Total height of filter is in the range of 2.5 to 3.5 m and height of gravel layer is about 60 to 90 cm. The bed slope is kept at about 1 in 100 towards central drain. Filter medium used in this filter can be of the sand, anthracite, geotextile, garnet or activated carbon. Filter medium particles are well graded and very fine having coefficient of uniformity (C_u) in the range of 3 to 5 and effective size (D_{10}) of about 0.2-0.3 mm. Area of each filter unit comes out in the range of 100-2000 m^2.

The base gravel layer is provided in three layers, which are as follows:

(a) Top layer of size 3-6 mm

(b) Middle layer of size 20-40 mm

(c) Bottom layer of size 40-65 mm

Design period of a slow sand filter is 10 years.

The top 15-30 cm of sand is generally kept of finer variety than that of the rest, which is generally kept uniform in grain size.

The finer the sand used, the purer will be the obtained water as more bacteria and impurities will be removed.

Working:

The treated water from the sedimentation tank is allowed to enter the inlet chamber of the filter unit and water gets distributed uniformly over the filter bed. The height of water above medium is equal to the height of medium itself, and under this water head, water percolates through the sand and gravel layer and in-turn gets purified.

Initial loss of head through freshly cleaned filter is in the range of 10-15 cm which goes on increasing during filtration as more and more impurities are entrapped in the voids of the filter media. Hence, the height of telescopic tube is adjusted according to the head loss to obtain the constant discharge through filter.

The filtered water percolating from gravel layer gets collected in lateral through open joints, which discharge into main drain, and finally water gets discharged in filtered water well from main drain from where it is taken to storage tank for supplies.

Cleaning of filter:

When the head loss through filter reaches about 0.7 to 0.8 times the depth of sand in filter layer, filter unit is put out of service and filter is cleaned.

Cleaning of filter is done by scrapping and removing the 1.5 to 3 cm of top sand layer. The top surface is finally racked, roughed, cleaned and washed. The amount of wash water used is generally 0.2 to 0.6% of total filtered water.

Advantages and Limitations:

Advantages: Slow sand filters are highly efficient in removing bacteria and other suspended solids from raw water. The extent of bacteria removal is upto 98-99% or even higher. This filter will also remove the odour and taste.

Limitation: However, these filters are less efficient in removing colours of raw water. Moreover, they remove turbidity only upto 50 mg/l or so, and are, therefore, not suitable for turbidities greater than 50 to 60 mg/l.

(ii) **Formation of Schmutzdecke Layer:** Certain micro-ogranisms and bacteria are generally present in the voids of the filter. They may either reside initially as coating over sand grains, or they may be caught during the initial process of filtration. Nevertheless, these organisms require organic impurities (such as algae, plankton, etc.) as their food for their survival. These organisms, therefore, utilise such organic impurities and convert them into harmless compounds by the process of biological metabolisms. The harmless compounds so formed, generally form a layer on the top, which is called Schmutzdecke or dirty skin. This layer further helps in absorbing and straining out the impurities.

Q.3 (c) Solution:

(i) Practical capacity is the maximum number of vehicles that can pass a given point on a lane or roadway during one hour, without traffic density being so great so as to cause unreasonable delay, hazard or restriction to driver's freedom to manoeuvre under the prevailing roadway and traffic conditions.

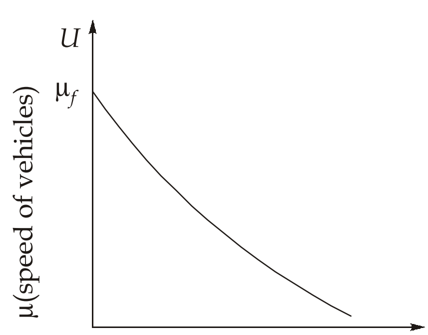
Factor affecting practical capacity are as follows:

- Lane width
- Lateral clearance
- Width of shoulder
- Commercial vehicles
- Alignment of road
- Presence of intersection at grade
- Stream speed
- Number of traffic lane
- Vehicular and driver characteristics
- Composition of traffic
- Traffic volume

(ii) Underwood's Exponential Model:

- This model is a modification of Greenberg model which was unable to represent velocity of stream at lower density.
- Underwood proposed exponential model which is given by

$$U = U_f e^{-K/K_0}$$



$\because \quad U = U_{sf} e^{-K/K_0}$

where U_{sf} = Free flow speed

q = Traffic flow

K_0 = Optimum density

U = Speed of vehicle

K = Density of vehicle

$$q = KU_{sf} e^{-K/K_0}$$

For $q = q_{max}$, $\frac{dq}{dK} = 0$

$$\Rightarrow \quad \frac{dq}{dK} = \frac{d}{dK}\left[KU_{sf} e^{-K/K_0}\right]$$

$$\Rightarrow \quad 0 = U_{sf}\left[e^{-K/K_0} + Ke^{-K/K_0}\left(-\frac{1}{K_0}\right)\right]$$

$$\Rightarrow \quad U_{sf} e^{-K/K_0}\left[1 + K \times \left(\frac{-1}{K_0}\right)\right] = 0$$

$$\Rightarrow \quad e^{-K/K_0}\left[1 - \frac{K}{K_0}\right] = 0$$

$$\Rightarrow \quad K = K_0$$

$\therefore$ At $K = K_0$, $U = U_0$ = Optimum speed

$$\therefore \quad U_0 = U_{sf} e^{-K_0/K_0}$$

$$\Rightarrow \quad U_0 = \frac{U_{sf}}{e}$$

(Hence proved)

(iii) Given: q_A = 500 PCU/hour

q_B = 350 PCU/hour

S_A = 1500 PCU/hour

S_B = 1100 PCU/hour

L = Total lost time = $2n + R$

where, n = No. of phases = 2

R = All red time = 2s

$\therefore \quad L = 2n + R = 2(2) + 8 = 12$ sec

Now, $y_A = \frac{q_A}{S_A} = \frac{500}{1500} = \frac{1}{3}$

and, $y_B = \frac{q_B}{S_B} = \frac{350}{1100} = \frac{7}{22}$

$$y = y_A + y_B = \frac{1}{3} + \frac{7}{22} = \frac{43}{66}$$

$\therefore$ Optimum cycle time, $C_0 = \frac{1.5L+5}{1-y} = \frac{1.5(12)+5}{1-\frac{43}{66}} = 66 \text{ sec}$

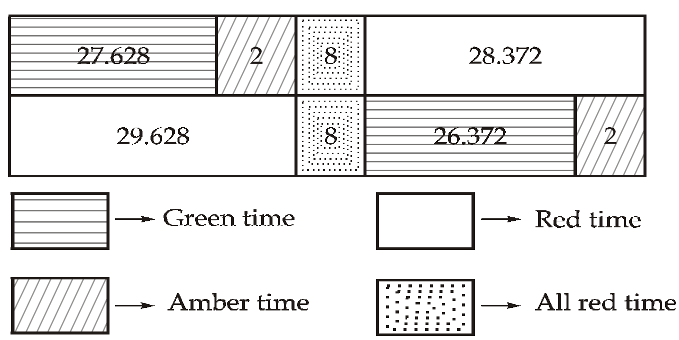
$\therefore$ $G_A = \frac{y_A}{y}(C_0 - L) = \frac{1}{3} \times \frac{66}{43}(66-12) = 27.628 \text{ sec}$

$\therefore$ $G_B = \frac{y_B}{y}(C_0 - L) = \frac{7}{22} \times \frac{66}{43} \times (66-12) = 26.372 \text{ sec}$

Providing amber time of 2*s* for each phase as clearance time,

Total cycle time = 27.628 + 26.372 + 8 + 4 = 66 sec

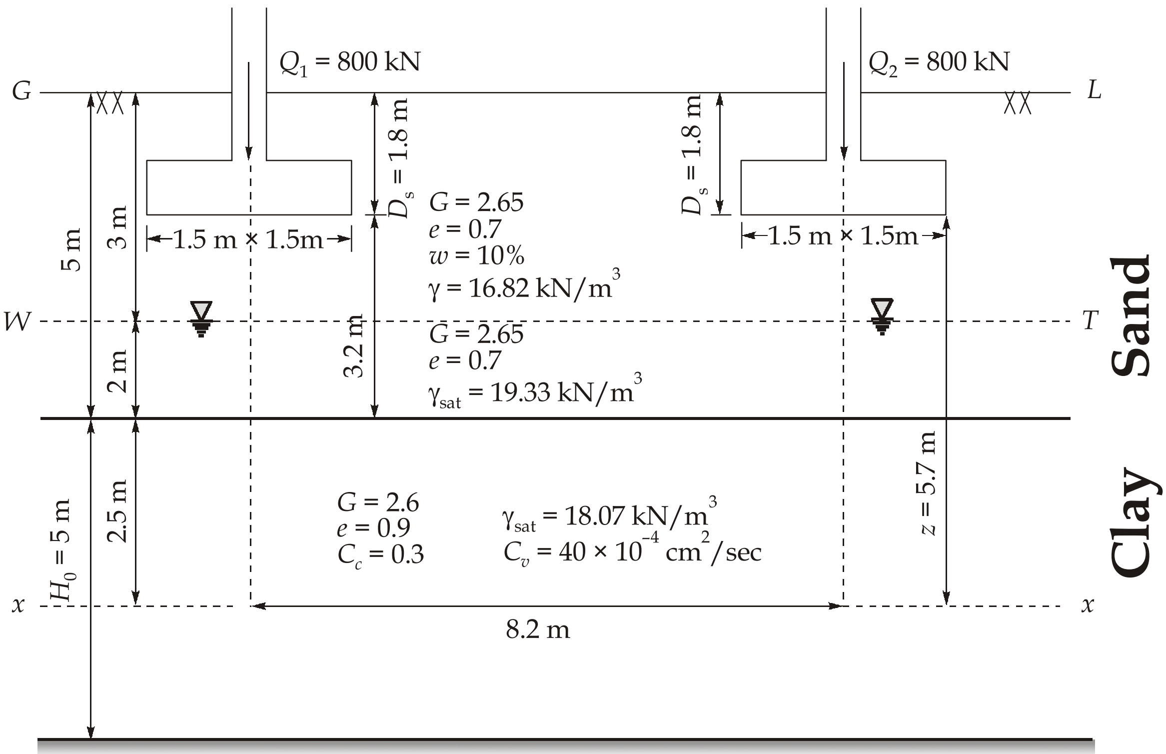
Phase diagram:



All dimension are in seconds

Q.4 (a) Solution:

A.



$$\therefore \quad \gamma_{sand} = \frac{G\gamma_w}{1+e}(1+w) = \frac{2.65\times 9.81}{1+0.7}\times(1+0.10) = 16.82 \text{ kN/m}^3$$

$$\therefore \quad (\gamma_{sat})_{sand} = \frac{G+e}{1+e}\gamma_w = \frac{2.65+0.7}{1+0.7}\times 9.81 = 19.33 \text{ kN/m}^3$$

$$\therefore \quad (\gamma_{sat})_{clay} = \frac{G+e}{1+e}\gamma_w = \frac{2.6+0.9}{1+0.9}\times 9.81 = 18.07 \text{ kN/m}^3$$

$$\therefore \quad (\gamma')_{sand} = (\gamma_{sat})_{sand} - \gamma_w = 19.33 - 9.81 = 9.52 \text{ kN/m}^3$$

$$\therefore \quad (\gamma')_{clay} = (\gamma_{sat})_{clay} - \gamma_w = 18.07 - 9.81 = 8.26 \text{ kN/m}^3$$

Initial effective stress at center of clay layer,

$$\sigma_0' = \gamma_{sand}(3) + \gamma'_{sand}(2) + \gamma'_{clay}(2.5)$$

$$\Rightarrow \quad \sigma_0' = 16.82(3) + 9.52(2) + 8.26\,(2.5)$$

$$\Rightarrow \quad \sigma_0' = 90.15 \text{ kN/m}^2$$

Since the largest dimension of load area i.e. 1.5 m is less than 0.3z i.e. 0.3 × 5.7 = 1.71 m, hence we can consider the footing loads as point load.

So, $\Delta\sigma'$ or σ_z can be calculated by using Boussinesq's equation.

$$\sigma_z = \sigma_{z1} + \sigma_{z2}$$

$$\Rightarrow \quad \sigma_z = k_{B1}\frac{Q_1}{z^2} + k_{B2}\frac{Q_2}{z^2}$$

$$\Rightarrow \quad \sigma_z = \frac{3}{2\pi}\left[\frac{1}{1+\left(\frac{r_1}{z}\right)^2}\right]^{5/2}\frac{Q_1}{z^2} + \frac{3}{2\pi}\left[\frac{1}{1+\left(\frac{r_2}{z}\right)^2}\right]^{3/2}\frac{Q_2}{z^2}$$

Now, given, $Q_1 = Q_2 = 800$ kN

$z = 5.7$ m

$r_1 = 8.2$ m, $r_2 = 0$ m {For max. change in pressure}

$$\frac{r_1}{z} = \frac{8.2}{5.7} = 1.44 < 1.52$$

$$\frac{r_2}{z} = 0 < 1.52$$

$$\therefore \quad \sigma_z = \frac{3}{2\pi}\left[\frac{1}{1+1.44^2}\right]^{5/2} \times \frac{800}{5.7^2} + \frac{3}{2\pi}\left[\frac{1}{1+0}\right]^{5/2} \times \frac{800}{5.7^2}$$

$$\Rightarrow \quad \sigma_z = 0.7098 + 11.7566$$

$$\Rightarrow \quad \sigma_z = \Delta\sigma' = 12.4664 \text{ kN/m}^2 \simeq 12.47 \text{ kN/m}^2$$

$$\therefore \quad \Delta H = \frac{C_C H_0}{1+e_0}\log_{10}\left[\frac{\sigma_0' + \Delta\sigma'}{\sigma_0'}\right]$$

$$\Rightarrow \quad \Delta H = \frac{0.3\times 5}{1+0.9}\log_{10}\left[\frac{90.15+12.47}{90.15}\right]$$

$$\Rightarrow \quad \Delta H = 0.04442 \text{ m} \simeq 4.44 \text{ cm}$$

B. Time required for 65% consolidation.

Now, $U = 65\% = 0.65$

$d = H_0 = 5$ m (One way drainage)

$$\therefore \quad T_v = \frac{C_v t}{d^2}$$

For $U > 60\%$, $T_v = -0.0851 - 0.9332 \log_{10}(1 - U)$

$$\Rightarrow -0.9332\log_{10}(1 - 0.65) - 0.0851 = \frac{C_v t}{d^2}$$

$$\Rightarrow -0.9332\log_{10}(1-0.65) - 0.0851 = \frac{(40\times10^{-4}\times10^{-4})\times t}{5^2}$$

$$\Rightarrow \quad t = 21273481.31 \text{ sec}$$

$$\Rightarrow \quad t = 246.22 \text{ days}$$

C. Secondary settlement

$$\Delta H_s = \frac{C_s H_{100}}{1+e_{100}}\log_{10}\left(\frac{t'}{t_{100}}\right)$$

$$H_{100} = H_0 - \Delta H = 5 - 0.04442 = 4.95558 \text{ m}$$

$$\therefore \quad \frac{\Delta H}{H_0} = \frac{e_0 - e_{100}}{1+e_0}$$

$$\Rightarrow \quad \frac{0.04442}{5} = \frac{0.9 - e_{100}}{1+0.9}$$

$$\Rightarrow \quad e_{100} = 0.88312$$

$$t' = 5 \text{ years}, \quad C_s = 0.03$$

t_{100} = time taken for 90% consolidation (as given)

For 90% consolidation, $T_v = 0.0851 - 0.9332 \log_{10}(1-0.9) = 0.8481$

$$\therefore \quad T_v = \frac{C_v t_{100}}{d^2}$$

$$\Rightarrow \quad 0.8481 = \frac{40\times10^{-8}\times t_{100}}{5^2}$$

$$\Rightarrow \quad t_{100} = 53006250 \text{ sec}$$

$$\Rightarrow \quad t_{100} \simeq 613.498 \text{ days} \quad \simeq 1.681 \text{ years}$$

$$\therefore \quad \Delta H_s = \frac{0.03\times4.9558}{1+0.88312}\log_{10}\left(\frac{5}{1.681}\right)$$

$$\Delta H_s = 0.037375 \text{ m} = 3.74 \text{ cm}$$

$$\text{Total settlement} = (\Delta H)_{PS} + (\Delta H)_{SS}$$
$$= 4.44 + 3.74 = 8.18 \text{ cm}$$

Q.4 (b) Solution:

Specimen No. 1:

Load dial reading at 2.5 mm penetration = 34 divisions

$$\therefore \quad \text{Load at 2.5 mm penetration} = 34\times\frac{190}{100} = 64.6 \text{ kg}$$

$\therefore$ CBR value at 2.5 mm penetration = $\frac{64.6}{1370} \times 100 = 4.7\%$

Load at 5 mm penetration = $\frac{48 \times 190}{100} = 91.2$ kg

$\therefore$ CBR value at 5 mm penetration = $\frac{91.2}{2055} \times 100 = 4.44\%$

$\therefore$ CBR value of Specimen No. 1 = 4.7%

Specimen No. 2:

Load dial reading at 2.5 mm penetration = 35.5 division

$\therefore$ Load at 2.5 mm penetration = $35.5 \times \frac{190}{120} = 67.45$ kg

$\therefore$ CBR value at 2.5 mm penetration = $\frac{67.45}{1370} \times 100 = 4.92\%$

Load at 5 mm penetration = $\frac{45 \times 190}{100} = 85.5$ kg

$\therefore$ CBR value at 5 mm penetration = $\frac{85.5}{2055} \times 100 = 4.16\%$

$\therefore$ CBR value of specimen No. 2 = 4.92%

Therefore mean CBR value of soil sample = $\frac{4.7 + 4.92}{2} = 4.81\%$

Thickness for pavement as per CBR method

$$T\,(\text{cm}) = \sqrt{\frac{1.75P}{\text{CBR}} - \frac{P}{p\pi}}$$

$\therefore$ Thickness of pavement required over subgrade

$$= \sqrt{\frac{1.75 \times 4100}{4.81} - \frac{4100}{7 \times \pi}} = 36.13 \text{ cm}$$

Thickness of pavement required over sandy soil whose CBR is given as 6.5%

$$= \sqrt{\frac{1.75 \times 4100}{6.5} - \frac{4100}{7\pi}} = 30.29 \text{ cm}$$

∴ Thickness of sandy soil = 36.13 – 30.29 = 5.84 cm.

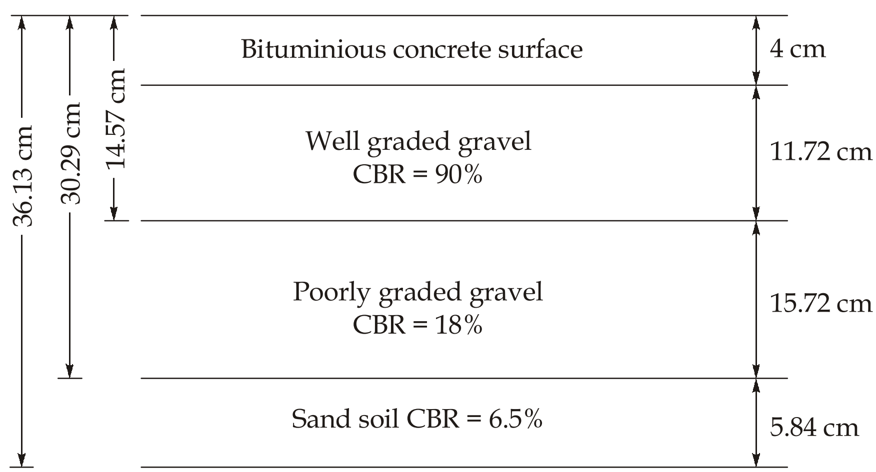
Thickness of pavement required over poorly graded gravel whose CBR is given as 18%

$$= \sqrt{\frac{1.75(4100)}{18} - \frac{4100}{7\pi}} = 14.57 \text{ cm}$$

∴ Thickness of poorly graded gravel = 30.29 – 14.57 = 15.72 cm

∴ Thickness of bitumen layer at top = 4 cm

∴ Thickness of well graded gravel = 15.72 – 4 = 11.72 cm



Subgrade, CBR = 4.81%

Q.4 (c) Solution:

(i) When weight of observations are not given directly, then if V is difference between the mean observed value and the observed value of an angle, the weight of angle is given by

$$W = \frac{\frac{1}{2}n^2}{\Sigma V^2}$$

$$\text{Mean value of } A = \frac{10+13+16+9}{4} = 12'' \text{ i.e. } 34°22'12''$$

$$\text{Mean value of } B = \frac{45+48+42}{3} = 45'' \text{ i.e. } 69°32'45''$$

$$\text{Mean value of } C = \frac{12+16}{2} = 14'' \text{ i.e. } 76°03'14''$$

Discrepancy, $d = 180° \, 0' \, 0'' - [34°22'12'' + 69°32'45'' + 76°03'14'']$

$= 0° \, 1' \, 49''$

$\therefore \quad \Sigma V_A^2 = \Sigma(m_A - L_A)^2 = [(12-10)^2 + (12-13)^2 + (12-16)^2 + (12-9)^2] = 30$

$\Sigma V_B^2 = \Sigma(m_B - L_B)^2 = [(45-45)^2 + (45-48)^2 + (45-42)^2 = 18$

$\therefore \quad \Sigma V_C^2 = \Sigma(m_C - L_C)^2 = [(14-12)^2 + (14-16)^2 = 8$

$n_A = 4; \; n_B = 3, \; n_C = 2$

Now, $$W_A = \frac{\left(\frac{1}{2}\right)(4)^2}{30} = 0.267$$

$$\therefore \quad W_B = \frac{\left(\frac{1}{2}\right)(3)^2}{18} = 0.25$$

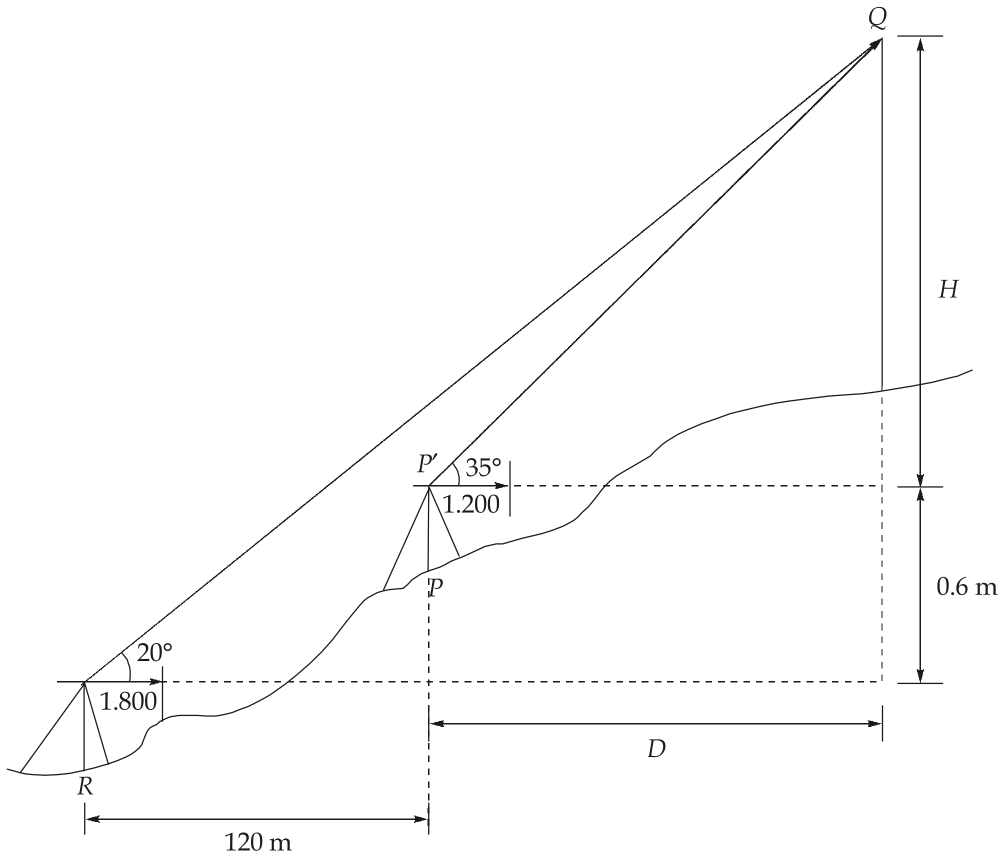
$$\therefore \quad W_C = \frac{\left(\frac{1}{2}\right)(2)^2}{8} = 0.25$$

Now, $$C_A = \frac{\frac{1}{W_A} \times d}{\frac{1}{W_A} + \frac{1}{W_B} + \frac{1}{W_C}} = \frac{\frac{1}{0.267} \times 1'49''}{\frac{1}{0.267} + \frac{1}{0.25} + \frac{1}{0.25}} = 34.76''$$

$$\therefore \quad C_B = \frac{\frac{1}{W_B} \times d}{\frac{1}{W_A} + \frac{1}{W_B} + \frac{1}{W_C}} = \frac{\frac{1}{0.25} \times 1'49''}{\frac{1}{0.267} + \frac{1}{0.25} + \frac{1}{0.25}} = 37.12''$$

$$C_C = \frac{\frac{1}{W_B} \times d}{\frac{1}{W_A} + \frac{1}{W_B} + \frac{1}{W_C}} = \frac{\frac{1}{0.25} \times 1'49''}{\frac{1}{0.267} + \frac{1}{0.25} + \frac{1}{0.25}} = 37.12''$$

(ii)



$$\frac{H}{D} = \tan 35°$$

$\Rightarrow$ $$H = D\tan 35° \quad ...(i)$$

Also, $$\frac{H+0.6}{D+120} = \tan 20° \quad ...(ii)$$

$\Rightarrow$ $$\frac{D\tan 35° + 0.6}{D+120} = \tan 20° \quad \text{(From (i))}$$

$\Rightarrow$ $$D\tan 35° - D\tan(20°) = 120\tan 20° - 0.6$$

$\Rightarrow$ $$D = 128.113 \text{ m}$$

Put D in eq. (1),

$\therefore$ $$H = 128.113\tan 35° = 89.706 \text{ m}$$

$\therefore$ $$RL_{P'} = RL_R + 1.800 + 0.6$$

$$= 100.000 + 1.800 + 0.600 = 102.400 \text{ m}$$

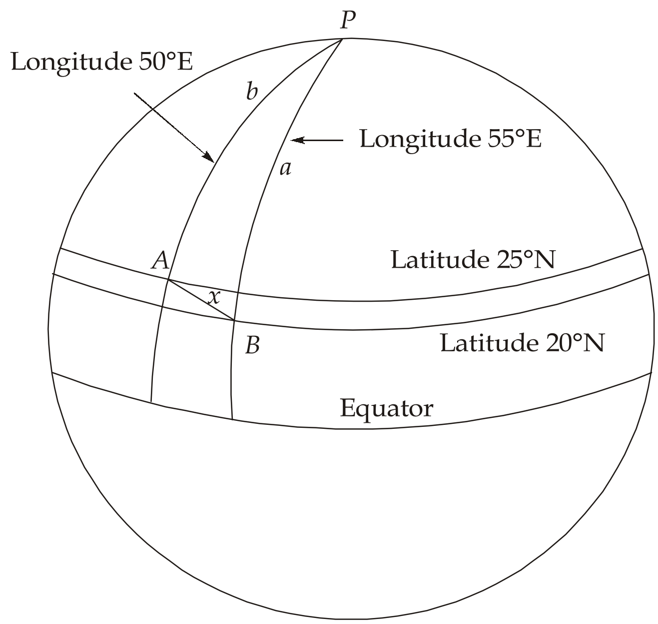
$\therefore$ $$RL_Q = RL_{P'} + H$$

$$= 102.4 + 89.706 = 192.106 \text{ m}$$

∴ Distance between Q and R = $120 + D = 120 + 128.113 = 248.113$ m

Q.5 (a) Solution:

(i)



In the spherical triangle ABP

$$b = AP = 90° - 25° = 75°$$

$$a = BP = 90° - 20° = 70°$$

$$\angle P = 55° - 50° = 5°$$

Now $AB = x$, can be computed as follows.

$$\cos P = \frac{\cos x - \cos a \cos b}{\sin a \sin b}$$

$$\Rightarrow \quad \cos 5° = \frac{\cos x - \cos 70° \cos 75°}{\sin 70° \sin 75°}$$

$$\Rightarrow \quad x = 6°54'28.51''$$

Now, $\quad$ Arc = Radius × Central angle

$$\Rightarrow \quad \text{Distance } AB = 6370 \times (6°54'28.51'') \times \frac{\pi}{180°} = 768.005 \text{ km} \simeq 768 \text{ km}$$

(ii) $H = 3000$ m, $h_a = 500$ m, $h_b = 300$ m

$$F = 15 \text{ cm}$$

$$\therefore \quad X_a = \frac{H - h_a}{f} x_a = \frac{3000 - 500}{0.15} \times (+2.5 \times 10^{-2}) \text{ m} = +416.67 \text{ m}$$

$$X_b = \frac{H-h_b}{f}x_b = \frac{3000-300}{0.15}\left(-1.9\times10^{-2}\right)\text{ m} = -342\text{ m}$$

$$Y_a = \frac{H-h_a}{f}y_a = \frac{3000-500}{0.15}\left(+1.4\times10^{-2}\right)\text{ m} = +233.33\text{ m}$$

$$Y_b = \frac{H-h_b}{f}y_b = \frac{3000-300}{0.15}\left(+3.7\times10^{-2}\right)\text{m} = +666\text{ m}$$

$$\therefore \quad L_{AB} = \sqrt{(X_a-X_b)^2+(Y_a-Y_b)^2}$$

$$= \sqrt{(416.67+342)^2+(233.33-666)^2} = 873.37\text{ m}$$

Q.5 (b) Solution:

(i) Road development has started in India from 1927, in which Jaykar Committee had established to examine situation and development of roads in India. After establishment of this committee, road development was considered as a subject of National Importance. Then, in the following manner road development, has started in India:

- An extra tax was levied on petrol from user for development of roads named "Central Road Fund" in 1929.
- A semi-official technical body should be formed which can provide a forum for regular pooling of experience and idea on all matters regarding planning, construction, maintenance, standard specification etc. known as Indian Road Congress (IRC) in 1934.
- In 1939, Motor Vehicle Act came into effect of regulate the road traffic in the form of traffic laws, ordinances and regulation.
- In 1943, 1st 20 year road plan was prepared in Nagpur for collective development of roads, which achieved its target in 1961 only.
- In 1950, a research organisation "Central Road Research Institute (CRRI)" was established to carry-out research and development of new techniques of road development.
- In 1956, National Highway Act was passed regarding the responsibility of development and maintenance of NH under central government and also regarding acquisition of land and take possession for the development of highways.
- Due to early completion of first 20 year plan in 1961, second 20 year plan was initiated in Bombay (1961-1981) for development of 32 km/100 km^2 road density.
- In 1973, Highway Research Board (HRB) of IRC was set-up to give direction and guidance for research activities in India.

- In 1978, National Transport Policy Committee (NTPC) was set-up to prepare a comprehensive national transport policy for the country for next decade or so keeping in view the objective and priorities set out in five year plan.
- In 1981, third road development plan was prepared (1981-2001) in Lucknow for constructing roads with density of 82 km/100 km^2.
- In 1988, National Highway Authority of India (NHAI) was established.
- In 2000, "Pradhan Mantri Gram Sadak Yojana" was launched by government of India to increase the connectivity of rural roads.

(ii) Coats in flexible pavement

1 **Prime coat:** Bituminous prime coat is the first application of a low viscosity liquid bituminous material over an existing porous absorbent pavement surface like the WBM base course. The main object of priming is to plug in the capillary voids of the porous surface and to bond the loose mineral particles on the existing surface, using a binder of low viscosity which can penetrate into the voids. Usually MC or SC cutbacks of suitable grade or viscosity is chosen depending on the porosity of the surface to be treated. The bituminous primer is sprayed uniformly using a mechanical prayer. The primed surface is allowed to cure for atleast 24 hours, during that period no traffic is allowed.

2 **Tack coat:** B ituminous tack coat is the application of bituminous material over an existing pavement surface which is relatively impervious like an existing bituminous surface or a cement concrete pavement or a pervious surface like the WBM which has already been treated by a prime coat. Tack coat is usually applied by spraying bituminous material of higher viscosity like the hot bitumen. However in some special circumstances, a tack out of bituminous emulsion may also be applied in cold state.

3 **Seal coat:** Seal coat is usually recommended as top coat over certain bituminous pavements which are not impervious, such as open graded bituminous construction like pre-mixed carpet and grouted Macadam. Seal coat is also provided over an existing bituminous pavement which is worn out. The seal coat is a very thin surface treatment or a single coat surface dressing which is usually applied over an existing black top surface. A pre-mixed sand bitumen (hot mix) seal coat is also commonly used over the pre-mixed carpet. The main functions of seal coat are:

(a) to seal the surfacing against the ingress of water
(b) to develop skid resistant texture
(c) to enliven an existing dry or weathered bituminous surface

Q.5 (c) Solution:

Uniform pumping rate = 1.3 cumecs (i.e., 1.3 m^3/sec)

= $1.3 \times 60 \times 60 \times 1000$ liters/hr (∵ 1000 lit. = 1 m^3)

$$= \frac{1.3 \times 36}{10} \text{ million litres/hr} = 4.68 \text{ million litres/hr}$$

The given data is now analysed in table below, which is self-explanatory.

Time (hr)	Demand (ML)	Cumulative demand (ML)	Pumping (ML)	Cumulative pumping (ML)	Excess of demand (ML) Col.(3) - Col.(5) (+ve value only)	Excess of supply (ML) Col.(5) - Col.(3) (+ value only)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	2.5	2.5	4.68	4.68	Nil	2.18
2	2.3	4.8	4.68	9.66	Nil	4.86
3	2.2	7.0	4.68	14.04	Nil	7.04
4	2.1	9.1	4.68	18.72	Nil	9.62
5	2.3	11.4	4.68	23.40	Nil	12.00
6	2.5	13.9	4.68	23.08	Nil	9.18
7	3.0	16.9	4.68	32.76	Nil	15.868
8	4.5	21.4	4.68	37.44	Nil	16.04
9	5.9	27.3	4.68	42.12	Nil	14.82
10	6.3	33.6	4.68	46.80	Nil	13.2
11	6.4	40.0	4.68	51.48	Nil	11.48
12	6.3	46.3	4.68	56.16	Nil	9.86
13	6.3	52.6	4.68	60.84	Nil	8.24
14	6.3	58.9	4.68	65.52	Nil	6.62
15	6.2	65.1	4.68	70.20	Nil	5.10
16	6.3	71.4	4.68	74.88	Nil	3.48
17	6.4	77.8	4.68	79.56	Nil	1.76
18	6.7	84.5	4.68	84.24	0.26	Nil
19	7.0	91.5	4.68	88.92	2.58	Nil
20	7.0	98.5	4.68	93.60	4.90	Nil
21	6.7	105.2	4.68	98.28	6.92	Nil
22	5.8	111	4.68	102.96	8.04	Nil
23	4.2	115.2	4.68	107.64	7.56	Nil
24	3.5	118.7	4.68	112.32	6.38	Nil

From the above table, it can be observed that:

The maximum excess of demand = 8.04 million litres

and, the maximum excess of supply = 16.04 million litres

Hence, the total storage required = 8.04 + 16.04 = 24.08 million litres

$$= \frac{24.08 \times 10^6}{10^3} = 24080 \text{ m}^3 \text{ (or cu.m)}$$

Q.5 (d) Solution:

(i) Sound power, $P_w = 0.005$ W

Assuming sound radiates from the source in all directions, hence area of propagation at 6 m distance will be area of sphere.

i.e., $A = 4\pi r^2$

$\Rightarrow$ $A = 4\pi(6^2)$

$\Rightarrow$ $A = 452.39 \text{ m}^2$

A. Sound power level,

$$L_w = 10\log\frac{P_w}{10^{-12}} \text{dB} = 10\log\left(\frac{0.005}{10^{-12}}\right) = 96.99 \text{ dB}$$

B. Intensity of sound,

$$I = \frac{P}{A} = \frac{0.005}{452.39} = 11.05 \times 10^{-6} \text{ W/m}^2$$

C. Sound level intensity,

$$L_I = 10\log\frac{I}{10^{-12}} = 10\log\left(\frac{11.05 \times 10^{-6}}{10^{-12}}\right) = 70.43 \text{ dB}$$

D. Given, $L_I = L_P$

$$L_P = 10\log\frac{\Delta P_{rms}^2}{4 \times 10^{-10}}$$

$$\Rightarrow \quad 70.43 = 10\log\frac{\Delta P_{rms}^2}{4 \times 10^{-10}}$$

$$\Rightarrow \quad \Delta P_{rms} = 0.0665 \text{ N/m}^2$$

Maximum differential pressure

$$\Delta P_m = \Delta P_{rms} \times \sqrt{2}$$

$$\Rightarrow \quad \Delta P_m = 0.09405 \text{ N/m}^2$$

(ii) A. The power of sound

The presence of the faintest sound that can be heard by a normal healthy individual is about 20 micropascal (μP_a). The sound level (L) is represented as

$$L = \log_{10}\frac{Q}{Q_0}(\text{bels}) \quad ...(i)$$

where, Q = Measured quantity of sound pressure or sound intensity

Q_0 = Reference standard quantity of sound pressure or sound intensity, as the case may be

L = Sound level in bel (B)

Bel is large unit, and thus a smaller unit decibel is used

$$L = 10\log_{10}\frac{Q}{Q_0}\,dB \quad ...(ii)$$

The reference standard quantity Q_0 in the above equation is taken to be equal to 20 μPa, when sound pressure is measured.

B. The sound intensity

Sound pressure level,

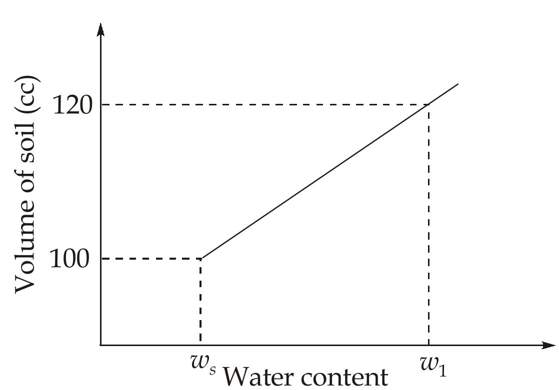
$$L_P = 10\times\log_{10}\left(\frac{P_{rms}}{20\ \mu\text{Pa}}\right)^2$$

$$\Rightarrow \quad L_P = 20\log_{10}\left(\frac{P_{rms}}{20\ \mu\text{Pa}}\right) \quad ...(i)$$

The sound pressure levels so measured are reported as dB_{re} : 20 μPa.

Q.5 (e) Solution:

(i)



$$M_{solid} = 209 \text{ gm}$$

$$\gamma_d = \frac{M_{solid}}{V_{soil}}$$

$$\Rightarrow \quad \gamma_d = \frac{209}{100} = 2.09 \text{ g/cc}$$

$$M_{soil} = 252 \text{ gm}$$

$$M_{solid} = 209 \text{ gm}$$

$$\therefore \quad M_W = M_{soil} - M_{Solid} = 43 \text{ gm}$$

Water content, $$w_1 = \frac{M_W}{M_{solid}}$$

$$\Rightarrow \quad w_1 = \frac{43}{209} = 0.2057 = 20.57\%$$

$$\therefore \quad G_D = \frac{\gamma_d}{\gamma_w} = \frac{2.09}{1} = 2.09 = R(\text{shrinkage ratio})$$

But $$R = \frac{\dfrac{V_1 - V_s}{V_s}}{w_1 - w_s}$$

$$\Rightarrow \quad 2.09 = \frac{\dfrac{120-100}{100}}{0.2057 - w_s}$$

$$\Rightarrow \quad w_s = 0.11 = 11\%$$

Now, $$w_s = \frac{1}{G_D} - \frac{1}{G}$$

$$\Rightarrow \quad 0.11 = \frac{1}{2.09} - \frac{1}{G}$$

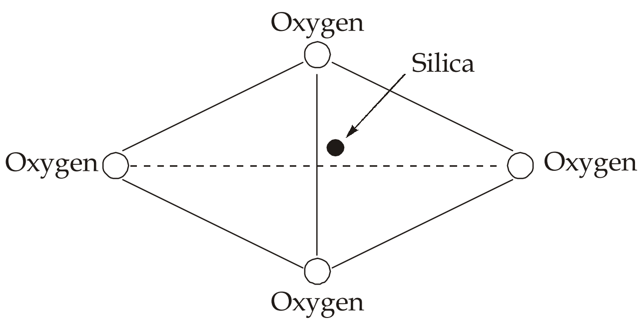
$$\Rightarrow \quad G = 2.714$$

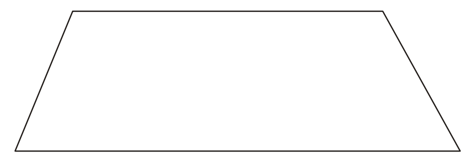
(ii) A. Building blocks of clay minerals:

There are two types of building blocks of clay mineral viz:

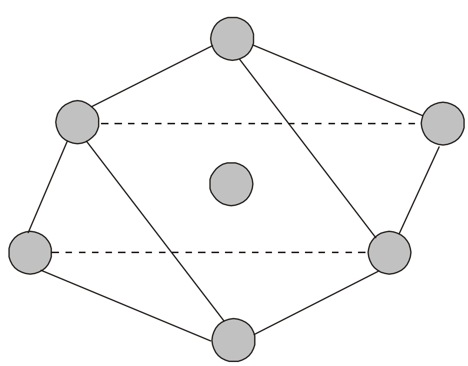
1. Silica tetrahedral unit.
2. Octahedral unit.

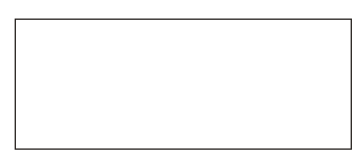
1. **Silica tetrahedral unit**:
   - In this unit, 4 oxygen atoms enclose silica at center of tetrahedron with all the oxygen at base of tetrahedron lying in same common plane and is shared by 2 tetrahedron units.
   - Net charge over tetrahedron unit is – 1.
   - It is represented as a trapozoid.





2. **Octahedral unit**
   - In this unit, 6 hydroxyl(OH^-) molecules enclose Al, Mg or Fe at centre of octahedral geometry. Each hydroxyl molecule is shared between 3 units.
   - If Al^{+3} is at center, it is termed as gibbsite unit, similarly for Mg and Fe it is known as brucite and ferrite unit respectively and is represented as rectangular symbol.
   - Net charge present over octahedral unit is +1.





B. Effect of water content on compaction:

As the water content is increased, the soil particles get lubricated. The soil mass becomes more workable and the particles have closer packing. The dry density of the soil increases with an increase in the water content till the optimum water content is reached. At that stage, the air voids attain approximately a constant volume. With further increase in water content, the air voids do not decrease, but the total voids (air plus water) increase and the dry density decreases. Thus the higher dry density is achieved upto the optimum water content due to forcing air out from the soil voids. After the optimum water content is reached, it becomes more difficult to force air out to further reduce the air voids.

Q.6 (a) Solution:

For effect of local attraction (*LA*)

$$|FB - BB| \neq 180°$$

$$\text{for } AB = 305°00' - 125°30' = 179°\ 30° \text{ (LA)}$$

$$\text{for } BC = 75°30' - 254°30' = -179°\ 0'\ 0'' + 360° = 181° \text{ (LA)}$$

$$\text{for } CD = 115°30' - 302°00' = -186°\ 30' + 360° = 173°30' \text{ (LA)}$$

$$\text{for } DE = 165°30' - 345°30' = -180° + 360° = 180° \text{ (No LA)}$$

$$\text{for } EA = 225° - 44° = 181° \text{ (LA)}$$

It means the lines starts from *D* and *E* has no correction, remaining all are locally attracted.

Line	Bearing	Correction	Corrected bearing
AB	305°	+1°	306°00′
BA	125°30′	+30′	126°00′
BC	75°30′	+30′	76°00′
CB	254°30′	+1°30′	256°00′
CD	115°30′	+1°30′	117°00′
DC	302°	0	302′
DE	165°30′	0	165°30′
ED	345°30′	0	345°30′
EA	225°00′	0	225°30′
AE	44°00′	+1°	45°00′

$$EA - AE = 180°$$

$\Rightarrow$ $225° - AE = 180°$

$\Rightarrow$ $AE = 45°$ i.e. +1° correction is required at station *A*.

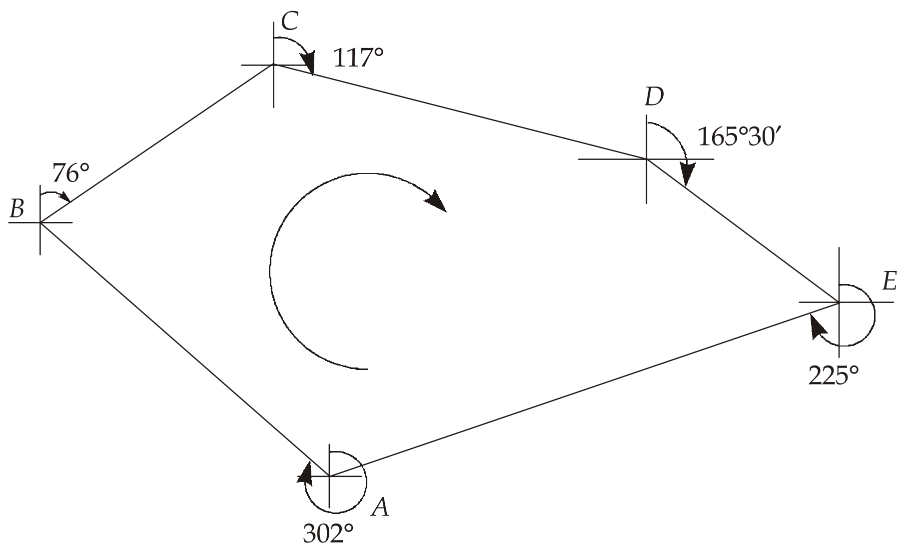
$$AB - BA = 180°$$

$\Rightarrow$ $306° - BA = 180°$

$\Rightarrow$ $BA = 126°$ i.e. + 30′ correction is required at station *B*.

$$BC - CB = 180°$$

$\Rightarrow$ $76°\ 00' - CB = 256°$ i.e. + 1° 30′ correction is required at station *C*.



$$\angle A = AE - AB = 45° - 306° + 360° = 99°$$

$$\angle B = BA - BC = 126° - 76° = 50°$$

$$\angle C = CB - CD = 256° - 117° = 139°$$

$$\angle D = DC - DE = 302° - 165° 30' = 136°30'$$

$$\angle E = ED - EA = 345° 30' - 225° = 120°30'$$

$$\text{Sum of interior angle} = 545° = (2n - 4) \times 90°$$

Sum of interior angle should be 540° i.e. –1° correction should be applied.

$$\therefore \quad \angle A = 98°, \angle B = 49°, \angle C = 138°, \angle D = 135°30'$$

$$\angle E = 119°30'$$

Accordingly all the bearing should be corrected again.

Let's assume DC to be correct, accordingly all other remaining bearing will be changed.

$$\angle D = DC - DE$$

$$\Rightarrow \quad 135° 30' = 302° - DE \quad \text{i.e.} \quad DE = 166°30'$$

$$\because \quad DE - ED = 180° \quad \therefore \quad ED = 346°30'$$

$$\angle E = ED - EA$$

$$\Rightarrow \quad 119°30' = 346°30' - EA \quad \text{i.e.} \quad EA = 227°$$

$$\because \quad EA - AE = 180° \quad \therefore \quad AE = 47°$$

$$\Rightarrow \quad \angle A = AE - AB$$

$\Rightarrow \quad 98° = 47° - AB \quad$ i.e. $\quad AB = 309°$

$\because \quad AB - BA = 180° \quad \therefore \quad BA = 129°$

$\angle B = BA - BC$

$\Rightarrow \quad 49° = 129° - BC \quad$ i.e. $\quad BC = 80°$

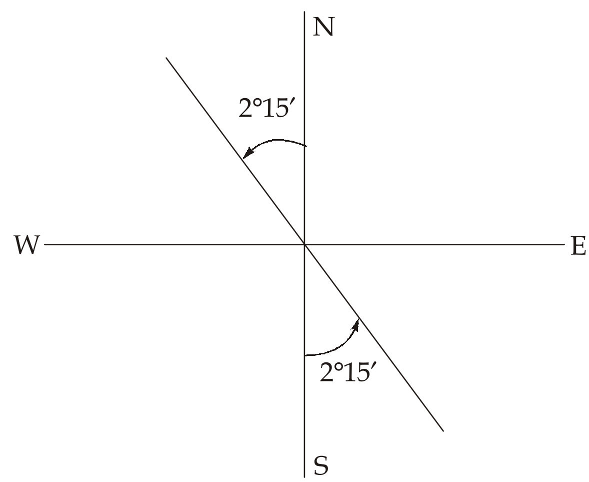
$\because \quad BC - CB = 180° \quad \therefore \quad CB = 260°$

$\angle C = CB - CD$

$\Rightarrow \quad 138° = 260° - CD \quad$ i.e. $\quad CD = 122°$

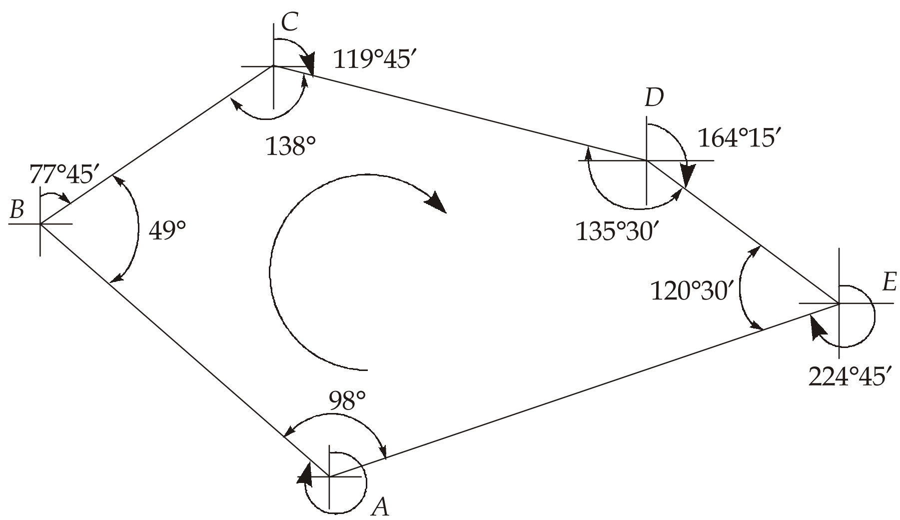
$\because \quad CD - DC = 180° \quad \therefore \quad DC = 302°$ (OK)

As at noon magnetic declination of sun is 2° 15′ i.e. 2°15° W declination.



True bearing = Magnetic bearing – Declination

Line	Corrected bearing	West declination	True bearing
AB	309°	2°15′	306°45′
BA	129°	2°15′	126°45′
BC	80°	2°15′	77°45′
CB	260°	2°15′	257°45′
CD	122°	2°15′	119°00′
DC	302°	2°15′	299°45′
DE	166°30′	2°15′	164°15′
ED	346°30′	2°15′	347°15′
EA	227°	2°15′	224°45′
AE	47°	2°15′	44°45′



Q.6 (b) Solution:

(i) **Test-1** **Test-2**

$\sigma_3 = 150\ kN/m^2$ $\sigma_3 = 300\ kN/m^2$

$\sigma_d = 350\ kN/m^2$ $\sigma_d = 500\ kN/m^2$

$\therefore\ \sigma_1 = \sigma_3 + \sigma_d = 500\ kN/m^2$ $\sigma_1 = \sigma_3 + \sigma_d = 800\ kN/m^2$

$$\because \quad \sigma_1 = \sigma_3 \tan^2\theta_c + 2C\tan\theta_c$$

$$\therefore \quad 500 = 150\tan^2\theta_c + 2C\tan\theta_c \quad ...(1)$$

$$800 = 300\tan^2\theta_c + 2C\tan\theta_c \quad ...(2)$$

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

$$500 = 150\tan^2\theta_c + 2C\tan\theta_c$$

$$800 = 300\tan^2\theta_c + 2C\tan\theta_c$$

$$-300 = -150\tan^2\theta_c$$

$$\Rightarrow \quad \tan^2\theta_c = 2$$

$$\Rightarrow \quad \theta_c = \tan^{-1}\sqrt{2}$$

i.e. $\theta_c = 54.7356°$

$$\therefore \quad \theta_c = 45 + \frac{\phi}{2}$$

$$\Rightarrow \quad 45 + \frac{\phi}{2} = \tan^{-1}\sqrt{2}$$

$$\Rightarrow \quad \phi = 19.47°$$

Put θ_c in equation (1)

$$\therefore \quad 500 = 150\tan^2(54.7356°) + 2C\tan(54.7356°)$$

$$C = 70.710 \text{ kPa}$$

Now,

$$\gamma_d = 17 \text{ kN/m}^2$$

$$\Rightarrow \frac{G\gamma_w}{1+e} = 17$$

$$\Rightarrow e = 0.5581$$

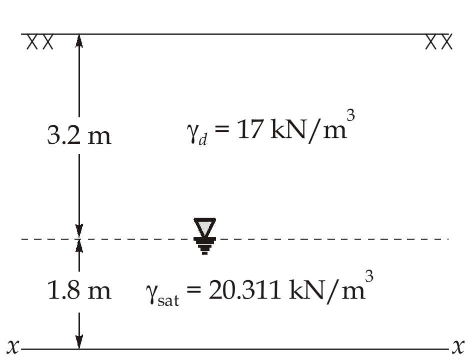
$$\gamma_{sat} = \frac{G+e}{1+e}\gamma_w = \frac{2.7+0.5581}{1+0.5581}\times 9.81$$

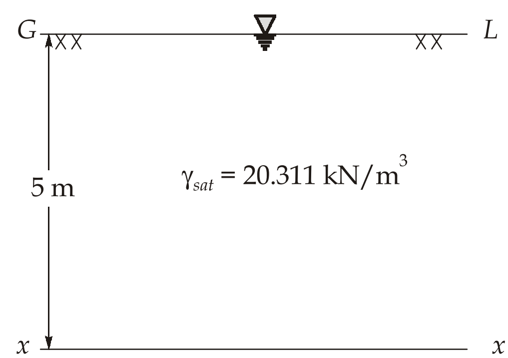
$$\gamma_{sat} = 20.311 \text{ kN/m}^3$$

$$\therefore \quad \gamma' = \gamma_{sat} - \gamma_w$$

$$= 20.311 - 9.81$$

$$= 10.501 \text{ kN/m}^3$$





$$\sigma' = \gamma_d(3.2) + \gamma'(1.8)$$

$$\Rightarrow \sigma' = 17(3.2) + 10.501\,(1.8)$$

$$\Rightarrow \sigma' = 73.3 \text{ kN/m}^2$$

$$\tau = C + \sigma'\tan\phi$$

$$\Rightarrow \tau = 70.71 + 73.3\tan(19.47°)$$

$$\Rightarrow \tau = 96.62 \text{ kN/m}^2$$

$$\sigma' = \gamma'(5)$$

$$\Rightarrow \sigma' = 10.501\,(5)$$

$$\Rightarrow \sigma' = 52.505 \text{ kN/m}^2$$

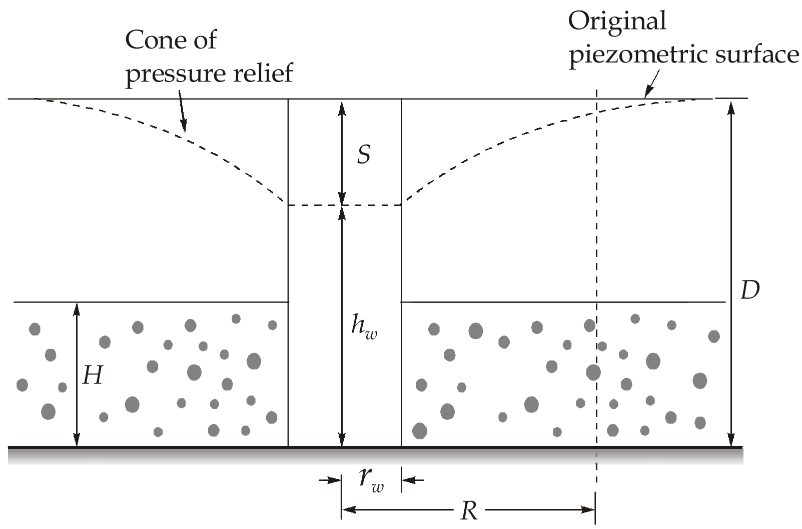
$$\tau = C + \sigma'\tan\phi'$$

$$\Rightarrow \tau = 70.71 + 52.505\tan(19.47°)$$

$$\Rightarrow \tau = 89.27 \text{ kN/m}^2$$

$$\text{Percentage change in shear strength} = \frac{96.62 - 89.27}{96.62}\times 100 = 7.607\%$$

(ii)



$$Q = kiA$$

$$\Rightarrow \quad Q = k\frac{dh}{dr}2\pi(rH)$$

$$\Rightarrow \quad \frac{dr}{r} = \frac{2\pi rH}{Q}dh$$

Integrating between r_w and R, we get

$$\int_{r_w}^{R}\frac{dr}{r} = \frac{2\pi k}{Q}H\int_{h_w}^{D}dh$$

$$\Rightarrow \quad |\ln r|_{r_w}^{R} = \frac{2\pi k}{Q}H|h|_{h=h_w}^{h=D}$$

$$\Rightarrow \quad 2.303\log_{10}\frac{R}{r_w} = \frac{2\pi kH}{Q}[D-h_w]$$

$$\Rightarrow \quad Q = \frac{2\pi kH(D-h_w)}{2.303\log_{10}\left(\frac{R}{r_w}\right)}$$

H = Total depth of confined aquifer

h_w = Artesian pressure in well

r_w = Radius of the well

D = Initial artesian pressure at bottom of aquifer or initial height of piezometric surface from bottom of well

s = Drawdown = $D - h_w$

Q.6 (c) Solution:

(i) The product sum of EWL is calculated as follows:

No. of axle	AADT	EWL Constant	Product
2	4000	330	1320000
3	400	1070	428000
4	300	2460	738000
5	50	4620	231000

Total year EWL = 2717000

Taking the average increase for 10 year period,

$$EWL_{10} = \left(\frac{1+1.75}{2}\right)\times 10\times 2717000 = 37358750$$

Traffic index, $TI = 1.35\ (\text{EWL})^{0.11}$

$= 1.35\ [37358750]^{0.11}$

$= 9.19$

Thickness of pavement $= \dfrac{k(TI)(90-R)}{C^{1/5}}$

Where, k = Numerical constant = 0.166

$TI = 9.19$

$R = 40$

$C = 70$

$$\therefore \quad T = \frac{0.166\times 9.19\times(90-40)}{70^{1/5}}$$

$\Rightarrow \quad T = 32.6117$ cm

(ii) For $\Delta = 1.25$ cm, load value will be

$$P = 1490+\left[\frac{1580-1490}{1.40-1.15}\times(1.25-1.15)\right] = 1526 \text{ kg}$$

$$k = \text{Modulus of subgrade reaction} = \frac{p}{\Delta} = \frac{P}{A\Delta}$$

$$\Rightarrow \quad k = \frac{1526}{\frac{\pi}{4}\times 30^2\times 0.125} = 17.27 \text{ kg/cm}^3$$

Modulus of subgrade reaction for 75 cm plate,

$$k_{75}\, a_1 = k_{30}\, a_2$$

$$\Rightarrow \quad k_{75} \times \frac{75}{2} = 17.27 \times \frac{30}{2}$$

$$\Rightarrow \quad k_{75} = 6.908 \text{ kg/cm}^3$$

Now, radius of relative stiffness,

$$l = \left[\frac{Eh^3}{12k\left(1-\mu^2\right)}\right]^{1/4}$$

$$\Rightarrow \quad l = \left[\frac{3 \times 10^5 \times 20^3}{12 \times 6.908 \times \left(1-0.15^2\right)}\right]^{1/4}$$

$$\Rightarrow \quad l = 73.77 \text{ cm}$$

Now, radius of equivalent distribution of pressure

$$\frac{a}{h} = \frac{15}{20} = 0.75 < 1.724$$

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

$$\Rightarrow \quad b = \sqrt{1.6(15)^2 + 20^2} - 0.675(20)$$

$$\Rightarrow \quad b = 14.068 \text{ cm}$$

Now stress at the interior (δ_i)

$$\delta_i = \frac{0.316P}{h^2}\left[4\log\frac{l}{b} + 1.069\right]$$

$$= \frac{0.316 \times 5100}{20^2}\left[4\log\frac{73.77}{14.068} + 1.069\right]$$

$$= 15.905 \text{ kg/cm}^2$$

Stress at edge,

$$\delta_e = \frac{0.572P}{h^2}\left[4\log\left(\frac{l}{b}\right) + 0.359\right]$$

$$= \frac{0.572 \times 5100}{20^2}\left[4\log\frac{73.77}{14.068} + 0.359\right]$$

$$= 23.612 \text{ kg/cm}^2$$

Stress at corner, $\delta_c = \frac{3P}{h^2}\left[1-\frac{a\sqrt{2}}{l}\right]$

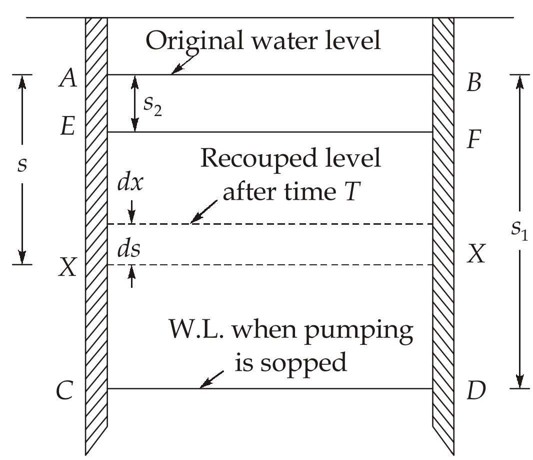
$$= \frac{3\times 5100}{20^2}\left[1-\frac{15\sqrt{2}}{73.77}\right]$$

$$= 27.25\ \text{kg/cm}^2$$

Q.7 (a) Solution:

(i) **Recuperation test:** Although the pumping test gives accurate value of safe yield, it sometimes becomes very difficult to adjust the rate of pumping, so as to keep the well water level constant. In such circumstances, recuperating test is adopted.

In this method, the water is first of all drained from the well at a fast rate so as to cause sufficient drawdown. The pumping is then stopped. The water level in the well will start rising. The time taken by the water to come back to its normal level or some other measured level is then noted. The discharge can then be worked out as below (shown in figure).



Let

AB = Static water level in the well before the pumping was started

CD = Water level in the well when the pumping was stopped.

s_1 = Depression head in the well at the time the pumping was stopped.

EF = Water level in the well at the noted time (say after a time T from when the pumping was stopped)

s_2 = Depression head in the well at time T after the pumping was stopped.

Let X-X be the position of water level at any time t after the pumping was stopped, and let the corresponding depression head be s. Let ds be the decrease in depression head in a time dt after the time T. Hence, in a time t after the pumping is stopped, the water level recuperates by $(s_1 - s)$. It again recuperates by ds in a time dt after this.

$\therefore$ Volume of water entering the well in the small interval of time (dt)

$$= dV = Ads \quad \text{...(i)}$$

where A is the cross-sectional area of the well at the bottom

Also, if Q is the rate of recharge into the well at the time t under a depression head s, then the volume of water entering the well in this small time interval is

$$= dV = Qdt$$

But, $$Q \propto s$$

$\therefore$ $$Q = C's \quad \text{...(ii)}$$

where C' is a constant depending on the soil through which the water enters the well

$\therefore$ $$dV = C'sdt \quad \text{...(iii)}$$

Equating eq. (i) and (iii)

$$-Ads = C'sdt$$

(The –ve sign indicates that s decreases at t increases)

$\therefore$ $$\frac{C'dt}{A} = -\left(\frac{ds}{s}\right)$$

Integrating between the limits

$$t = 0$$
$$t = T'$$
$$s = s_1$$
$$s = s_2$$

We get, $$\frac{C'}{A}\int_0^T dt = -\int_{s_1}^{s_2} \frac{ds}{s}$$

$\Rightarrow$ $$\frac{C'}{A}|t|_0^T = -|\log_e s|_{s_1}^{s_2}$$

$\Rightarrow$ $$\frac{C'}{A}(T) = -\log_e \frac{s_2}{s_1}$$

$$= -2.3\log_{10}\frac{s_2}{s_1} = 2.3\log_{10}\frac{s_1}{s_2}$$

$\therefore$ $$\frac{C'}{A} = \frac{2.3}{T}\log_{10}\frac{s_1}{s_2}$$

Knowing the value of s_1, s_2 and T from the above test, the value of $\frac{C'}{A}$ can be calculated. $\frac{C'}{A}$ is called the specific yield or the specific capacity of the open well in cumecs per sq.m of area under a unit depression head. Knowing the value of $\frac{C'}{A}$, the discharge Q for a well under a constant depression head H can be calculated as follows:

$$Q = C's$$

$$\Rightarrow \quad Q = \left(\frac{C'}{A}\right) As$$

$$\Rightarrow \quad Q = \left(\frac{2.3}{T}\log_{10}\frac{s_1}{s_2}\right) As$$

As A and s are known, the discharge for any amount of drawdown (s) can be easily worked out.

(ii) Given,

$$s_1 = \text{Initial drawdown} = 3.0 \text{ m}$$

$$s_2 = \text{Final drawdown} = 3 - 1.9 = 1.1 \text{ m}$$

$$T = \text{Time} = 76 \text{ minutes} = 1.267 \text{ hours}$$

Now,

$$\frac{C'}{A} = \frac{2.303}{T}\log_{10}\frac{s_1}{s_2}$$

$$\Rightarrow \quad \frac{C'}{A} = \frac{2.303}{1.267}\log_{10}\left(\frac{3.0}{1.1}\right) = 0.792 \text{ m}^3/\text{h}/\text{m}^2/\text{m}$$

∴ Yield from the well,

$$Q = \frac{C'}{A} As$$

$$\Rightarrow \quad Q = 0.792\left(\frac{\pi}{4}\times 2.5^2\right)(3)$$

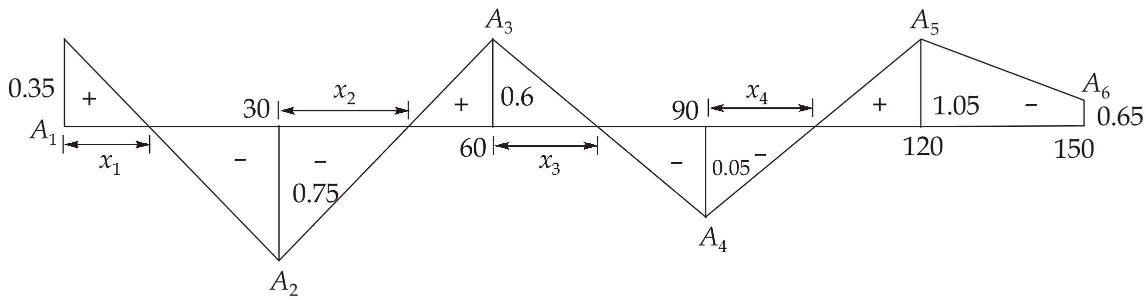
$$\Rightarrow \quad Q = 11.66 \text{ m}^3/\text{hr}$$

$$\Rightarrow \quad Q = 3.24\ l/\text{sec}$$

Q.7 (b) Solution:

$$\text{Rise per 30 m} = \frac{30}{120} = 0.25 \text{ m}$$

Chainage (m)	GL (m)	FL (m)	Cutting (+)(m)	Filling (–)(m)	Section
0	115.35	115.00	0.35		A_1
30	114.50	115.25		0.75	A_2
60	116.10	115.50	0.6		A_3
90	115.70	115.75		0.05	A_4
120	117.05	116.00	1.05		A_5
150	116.90	116.25	0.65		A_6



$$\frac{0.35}{x_1} = \frac{0.75}{30 - x_1}$$

$\Rightarrow$ $10.5 - 0.35x_1 = 0.75x_1$

$\Rightarrow$ $x_1 = 9.55$ m

$$\frac{0.75}{x_2} = \frac{0.6}{30 - x_2}$$

$\Rightarrow$ $22.5 - 0.75x_2 = 0.6x_2$

$\Rightarrow$ $x_2 = 16.7$ m

$$\frac{0.6}{x_3} = \frac{0.05}{30 - x_3}$$

$\Rightarrow$ $18 - 0.6x_3 = 0.05x_3$

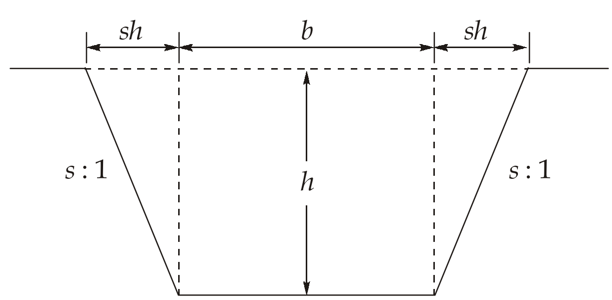
$\Rightarrow$ $x_3 = 27.69$ m

$$\frac{0.05}{x_4} = \frac{1.05}{30 - x_4}$$

$\Rightarrow$ $1.5 - 0.05x_4 = 1.05x_4$

$\Rightarrow$ $x_4 = 1.36$ m

Ground is level along transverse direction.



Cross-sectional area, $$A = \frac{b + b + 2sh}{2} \times h$$

$$A = (b + sh)h$$

Given $b = 6$ m, $s = 2:1$

$$A_1 = [6 + 2(0.35)] \times 0.35 = 2.345 \text{ m}^2$$
$$A_2 = [6 + 2(0.75)] \times 0.75 = 5.625 \text{ m}^2$$
$$A_3 = [6 + 2(0.6)] \times 0.6 = 4.32 \text{ m}^2$$
$$A_4 = [6 + 2(0.05)] \times 0.05 = 0.305 \text{ m}^2$$
$$A_5 = [6 + 2(1.05)] \times 1.05 = 8.505 \text{ m}^2$$
$$A_6 = [6 + 2(0.65)] \times 0.65 = 4.745 \text{ m}^2$$

Calculation of volume,

(a) From chainage 0 to 30 m

$$\text{Cutting} = \frac{2.345 + 0}{2} \times 9.55 = 11.197 \text{ m}^3$$
$$\text{Filling} = \frac{0 + 5.625}{2} \times (30 - 9.55) = 57.516 \text{ m}^3$$

(b) From chainage 30 m to 60 m

$$\text{Cutting} = \frac{4.32 + 0}{2} \times (30 - 16.7) = 28.728 \text{ m}^3$$
$$\text{Filling} = \frac{5.625 + 0}{2} \times 16.7 = 49.969 \text{ m}^3$$

(c) From chainage 60 m to 90 m

$$\text{Cutting} = \frac{4.32 + 0}{2} \times (27.69) = 59.81 \text{ m}^3$$
$$\text{Filling} = \frac{0 + 0.305}{2} \times (30 - 27.69) = 0.352 \text{ m}^3$$

(d) From chainage 90 m to 120 m

$$\text{Cutting} = \frac{0 + 8.505}{2} \times (30 - 1.36) = 121.792 \text{ m}^3$$
$$\text{Filling} = \frac{0.305 + 0}{2} \times (1.36) = 0.2074 \text{ m}^3$$

(e) From chainage 120 m to 150 m

$$\text{Cutting} = \frac{8.505 + 4.745}{2} \times 30 = 198.75 \text{ m}^3$$
$$\text{Total cutting} = 11.197 + 28.728 + 59.81 + 121.792 + 198.75$$

$$= 420.277 \text{ m}^3$$

$$\text{Total Filling} = 57.516 + 49.969 + 0.352 + 0.2074$$

$$= 108.044 \text{ m}^3$$

Q.7 (c) Solution:

(i)

Speed range (kmph)	Mid speed (kmph)	Number of vehicles	Frequency (%)	Cumulative frequency
0 – 10	5	88	2.52	2.52
10 – 20	15	175	5.00	7.52
20 – 30	25	205	5.87	13.39
30 – 40	35	720	20.60	33.99
40 – 50	45	878	25.12	59.11
50 – 60	55	1205	34.48	93.59
60 – 70	65	212	6.07	99.66
70 – 80	75	12	0.34	100
		3495		

$$\text{Design speed} = \text{98th percentile speed}$$

$$\text{For 98th percentile speed} = 55 + \frac{65-55}{99.66-93.59} \times (98-93.59) = 62.27 \text{ kmph}$$

$$\text{Upper safe limit, 85th percentile} = 45 + \frac{55-45}{93.59-59.11} \times (85-59.11) = 52.51 \text{ kmph}$$

(ii) As per given condition

$$\frac{V^2}{2g(f+n)} = \frac{V^2}{2g(f-n)} - 12$$

$$\Rightarrow \quad \frac{(80/3.6)^2}{2 \times 9.81(0.5+n)} = \frac{(80/3.6)^2}{2 \times 9.81(0.5-n)} - 12$$

$$\Rightarrow \quad \frac{25.17}{0.5+n} = \frac{25.17}{0.5-n} - 12$$

$$\Rightarrow \quad \frac{25.17}{0.5+n} = \frac{25.17 - 12(0.5-n)}{0.5-n}$$

$$\Rightarrow \quad \frac{25.17}{0.5+n} = \frac{19.17+12n}{0.5-n}$$

$$\Rightarrow \quad 12.585 - 25.17\,n = 9.585 + 6\,n + 19.17\,n + 12\,n^2$$

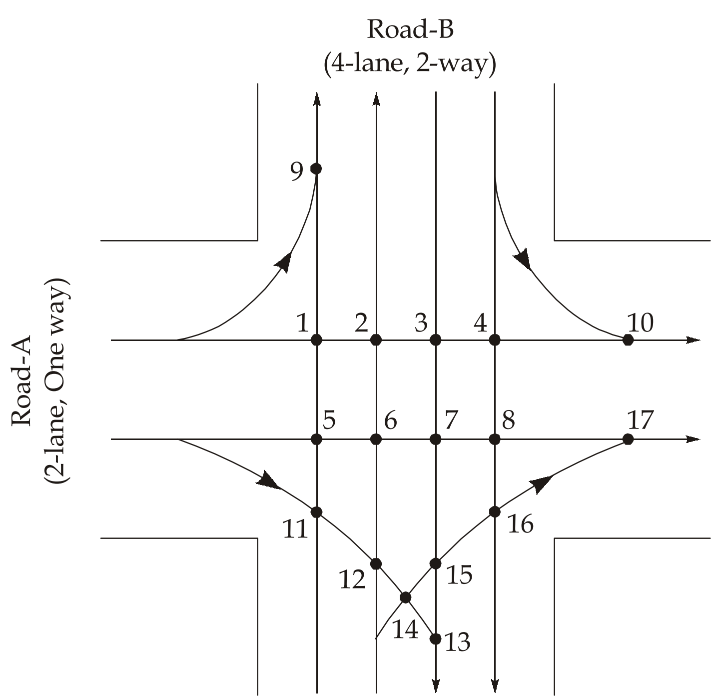
$$\Rightarrow \quad 12\,n^2 + 50.34\,n - 3 = 0$$

$$n = 0.05877 \text{ i.e., } 5.877\%$$

∴ Braking distance down the grade

$$= \frac{(80/3.6)^2}{2\times 9.81\times(0.5-0.05877)} = 57.04 \text{ m}$$

(iii)



8- Crossing (1, 2, 3, 4, 5, 6, 7, 8)

4-Merging (9, 10, 13, 17)

5-Weaving (11, 12, 14, 15, 16)

∴ Total conflict points are 17.

Q.8 (a) Solution:

Given: $\Delta H = 6 - 2 = 4$ m, $k = 7 \times 10^{-5}$ m/s

$N_f = 3$, $N_D = 6$

A. Total rate of seepage, $Q = \frac{N_f}{N_D} k(\Delta H)$

$$\Rightarrow \quad Q = \frac{3}{6} \times 7 \times 10^{-5} \times 4 = 1.4 \times 10^{-4} \text{ m}^3/\text{s/m}$$

B. Piezometric head

$$\Delta h = \frac{\Delta H}{N_D} = \frac{4}{6} = 0.67 \text{ m}$$

i.e., equipotential drop is 0.67 m.

$\therefore$ Piezometric head A = 6 – 1 (0.67) = 5.33 m

Piezometric head B = 6 – 2 (0.67) = 4.66 m

Piezometric head C = 6 – 5 (0.67) = 2.65 m

C. FOS against piping failure,

$$\text{FOS} = \frac{i_c}{i}$$

$$i_c = \frac{G-1}{1+e} = \frac{2.7-1}{1+0.8} = 0.944$$

$$i = \frac{\Delta h}{l} = \frac{0.67}{1} = 0.67$$

$$\therefore \quad \text{FOS} = \frac{i_c}{i} = \frac{0.944}{0.67} = 1.409$$

D. Effective stress,

$$\gamma' = \frac{G-1}{1+e}\gamma_w = \frac{2.7-1}{1+0.8} \times 9.81 = 9.265 \text{ kN/m}^3$$

$$\gamma_{sat} = \gamma' + \gamma_w = 9.265 + 9.81 = 19.075 \text{ kN/m}^3$$

Total stress at A = $\gamma_w(6) + \gamma_{sat}(3)$

= $9.81(6) + 19.075(3)$

= 116.085 kN/m^2

Pressure head at A (down ward flow at A)

= H_1 + z -head loss

$$= 6 + 3 - \left(\frac{4}{6} \times 1\right) = 8.33 \text{ m}$$

$\therefore$ Pore water pressure at A = $\gamma_w(\Delta H)$

= $9.81 \times 8.33 = 81.72$ kN/m^2

$\therefore$ Effective stress at A = $116.085 - 81.72 = 34.365$ kN/m^2

Total stress at C = $\gamma_w(2) + \gamma_{sat}(1.5)$

= $9.81\ (2) + 19.075(1.5) = 48.2325$ kN/m^2

Pressure head at C = $H_1 + z$ + head loss

$\because$ Flow is upward and thus pressure head at C

$$= 2+1.5+\frac{4}{6}(1) = 4.17 \text{ m}$$

Pore water pressure at C = $9.81 \times 4.17 = 40.9077$ kN/m^2

Effective stress at C = $48.2325 - 40.9077 = 7.3248$ kN/m^2

(ii) $h_1 = 60$ cm, $h_2 = 30$ cm, $t = 70$ min., a = 1.25 cm^2

Cross-sectional area of soil sample,

$$A = \frac{\pi}{4}\times 9^2 = 63.62 \text{ cm}^2$$

Height of soil sample, l = 10 cm

For falling head permeability test,

$$k = 2.303\frac{al}{At}\log_{10}\frac{h_1}{h_2}$$

$$= 2.303\times\frac{1.25\times 10}{63.12\times 70}\log_{10}\frac{60}{30}$$

$$= 1.961 \times 10^{-3} \text{ cm/min}$$

$$= 1.1766 \times 10^{-3} \text{ m/s}$$

Now, $$t = 2.303\frac{al}{Ak}\log\frac{h_1}{h_2}$$

$\Rightarrow$ $$t = 2.303\times\frac{1.25\times 10}{63.62\times 1.961\times 10^{-3}}\times\log\frac{60}{20}$$

$\Rightarrow$ t = 110.07 min.

$\therefore$ Δt = 110.07 – 70 = 40.07 minutes

Q.8 (b) Solution:

(i) Cutback bitumen is defined as the bitumen, the viscosity of which has been reduced by a volatile dilutant. For use in surface dressing, some type of bitumen macadam and soil bitumen stabilisation, it is necessary to have a fluid binder which can be mixed relatively at low temperatures. Hence, to increase fluidity of the bituminous binder at low temperatures, the binder is blended with a volatile solvent. After the cutback mix is used in construction work, the volatile solvent gets evaporated and the cutback develops the binding properties. The viscosity of the cutback and rate at which it hardens on the road depends on the characteristics and quantity of both bitumen and volatile oil used as the dilutant. Cutback bitumens are available in three types, namely,

(a) Rapid Curing (RC)

(b) Medium Curing (MC)

(c) Slow Curing (SC)

The classification is based on the rate of curing or hardening after the application.

The cutback with the lowest viscosity is designated by numerical 0, such as RC-0, MC-0 and SC-0. Suffix numericals 0, 1, 2, 3, 4 and 5 designate progressively thicker or more viscous cutbacks as the numbers increase. This number indicates a definite and the same initial viscosity at a specified temperature.

Rapid curing cutbacks are bitumens, fluxed or cutback with a petroleum distillate such as nephta or gasoline which will rapidly evaporate after using in construction, leaving the bitumen binder. The grade of the RC cutback is governed by the proportion of the solvent used. The penetration value of residue from distillation up to 360°C of RC cutback bitumen is 80 to 120.

Medium curing cutback are bitumen fluxed to greater fluidity by blending with a intermediate-boiling-point solvent like kerosene or light diesel oil. MC cutback evaporate relatively at slow rate because the kerosene range solvents will not evaporate rapidly as the gasoline-range solvents used in the manufacture of RC cutbacks. Hence the designation 'medium curing' is given to this cutback type. MC products have good wetting properties and so satisfactory coating of fine grained aggregates and sandy soils is possible.

Slow curing cutbacks are obtained either by blending bitumen with high-boiling-point gas oil, or by controlling the rate of flow and temperature of the crude during the first cycle of refining. SC cutbacks or wood soils harden or set away slowly as it is a semi-volatile material.

Bituminous Emulsion:

A bitumen emulsion is a liquid product in which a substantial amount of bitumen is suspended in a finely divided condition in an aqueous medium and stabilized by means of one or more suitable materials. An emulsion is a two phase system consisting of two immiscible liquids; the one being dispersed as fine globules in the other.

The function of this emulsifier is to form a protective coating around the globules of binder resisting the coalescence of the globules. Emulsifiers usually adopted are soaps, surface active agents and colloidal powder. Half to one percent emulsifier by weight of finished emulsion are usually taken while preparing normal road emulsions. The bitumen/tar content of emulsions range from 40 to 60 percent and the remaining portion is water.

When the emulsion is applied on the road, it breaks down and the binder start binding the aggregates, though the full binding power develops slowly as and when the water evaporates. If the bitumen emulsion is intended to break rapidly, the emulsion is said to possess rapid-set quality. Emulsions which do not break spontaneously on contact with stone, but break during mixing or by fine mineral dust are medium-set-grades. When special types of emulsifying agents are used to make the emulsion relatively stable, they are called slow setting grades.

Emulsions are used in bituminous road constructions, especially in maintenance and patch repair works. The main advantages of emulsion is that it can be used in wet weather even when it is raining. Also emulsions have been used in soil stabilisation, particularly for the stabilisation of sands in desert areas.

Three types of bituminous emulsion are prepared viz. (i) Rapid Setting (RS), (ii) Medium Setting (MS) and (iii) Slow Setting (SS) types. Rapid Setting type emulsion is suitable for surface dressing and penetration macadam type of construction. Medium Setting type is used for pre-mixing with coarse aggregates and Slow Setting type emulsion is suitable for fine aggregate mixes.

(ii) A. Bulk density of specimen by uncoated specimen,

$$= \frac{W_{air}}{W_{air} - W_w} = \frac{1170}{1170 - 670} = 2.340$$

B. Bulk density from paraffin coated specimen,

$$G_m = \frac{W_{air}}{(W_{air})_{with\ wax} - (W_w)_{with\ wax} - \frac{(W_{air})_{with\ wax} - W_{air}}{G_{wax}}}$$

$$= \frac{1170}{1220 - 663 - \frac{1220 - 1170}{0.9}} = 2.333$$

C. Maximum theoretical density

$$G_t = \frac{100}{\frac{W_{CA}\%}{G_{CA}} + \frac{W_{FA}\%}{G_{FA}} + \frac{W_{Filler}}{G_{Filler}} + \frac{W_{Bitumen}}{G_{Bitumen}}}$$

$$= \frac{100}{\frac{55}{2.60} + \frac{32}{2.72} + \frac{7}{2.7} + \frac{6}{1.01}} = 2.4124$$

D. Percentage air voids,

$$V_a = \frac{G_t - G_m}{G_t} \times 100 = \frac{2.4124 - 2.333}{2.4124} \times 100 = 3.291\%$$

E. Voids in mineral aggregate (VMA)

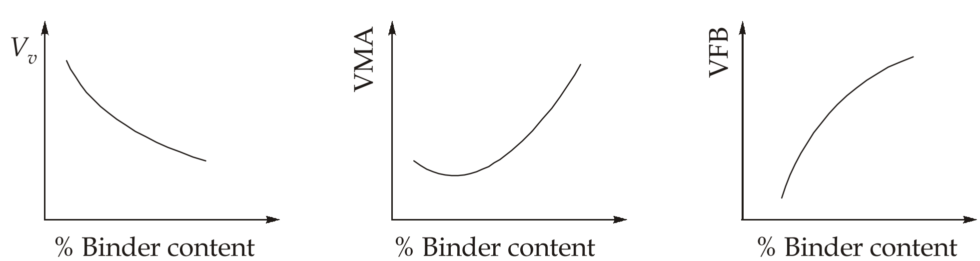
$$VMA = V_v + V_b$$

where, $$V_b = \frac{W_b}{G_b} \times G_m \times 100 = \frac{0.06}{1.01} \times 2.333 \times 100 = 13.859\%$$

∴ $$VMA = 3.291 + 13.859 = 17.15\%$$

F. Voids filled with bitumen (VFB)

$$VFB = \frac{V_b}{VMA} \times 100 = \frac{13.859}{17.15} \times 100 = 80.81\%$$



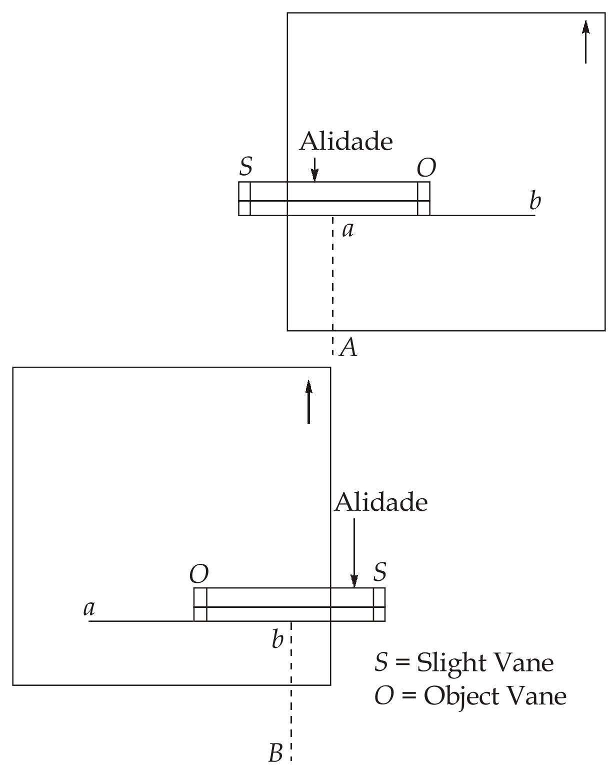
Q.8 (c) Solution:

(i) A. Orientation by back sighting:

(a) Suppose A and B are two stations. The plane table is set up over A. The table is levelled by spirit level and centered by U-fork so that the point *a* is just over station A. The north line is marked on the right-hand top corner of the sheet by trough compass.

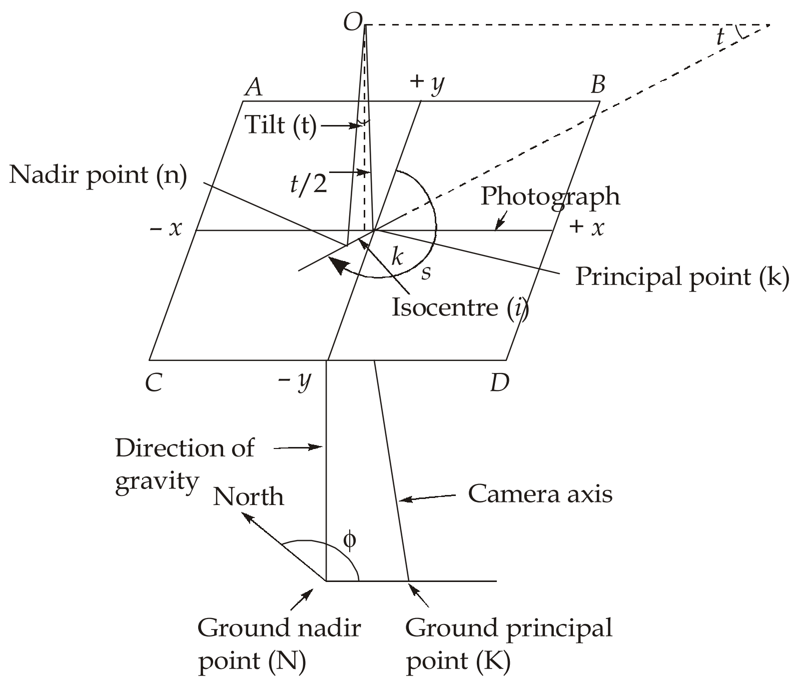
(b) With the alidade is touching *a*, the ranging rod at *B* is bisected and a ray is drawn. The distance *AB* is measured and plotted to any suitable scale. So, the point *b* represents station *B*.

(c) The table is shifted and set up over *B*. It is levelled and centered so that *b* is just over *B*. Now the alidade is placed along the line *ba*, and the ranging rod at A is bisected by turning the table clockwise or anticlockwise. At this time the centering may be disturbed, and should be adjusted immediately if required. When the centering, levelling and bisection of the ranging rod at A are perfect then the orientation is said to be perfect (as shown in figure).



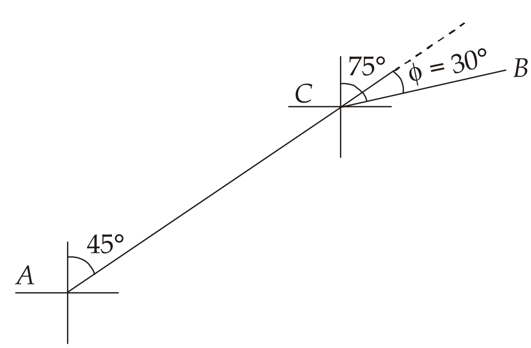
B. Tilt and tip of vertical photograph:

- **Tilt**: It is the rotation of the aerial camera about the line of flight. In the figure shown below, angle kOn (t) is the vertical angle obtained by the intersection of the optical axis with the plumb line at the exposure station. It lies in the principal plane.



- **Tip**: It is the rotation of the aerial camera about a horizontal axis normal to the line of flight. This is also known as swing. In the figure shown below, the angle 's' measured in the plane of the photograph from the positive Y-axis clockwise to the nadir point is the swing.

(ii)



Deflection angle, ϕ = $75° - 45° = 30°$

Degree of curve, D = $2°$

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

Tangent length = $R\tan\dfrac{\phi}{2} = 860\tan 15° = 230.435\,\text{m}$

$$\text{Curve length} = \frac{\pi R\phi}{180} = \frac{\pi\times 860\times 30}{180} = 450.295 \text{ m}$$

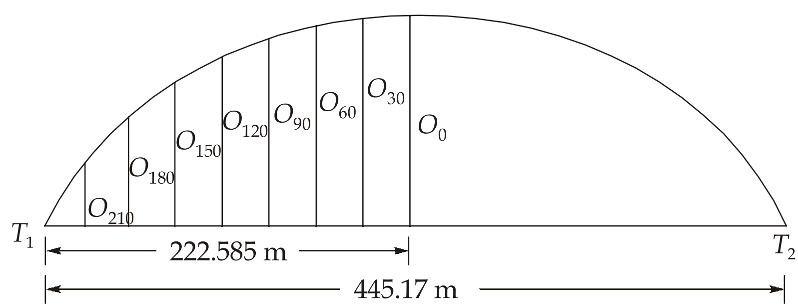
$$\text{Length of long chord} = 2R\sin\frac{\phi}{2} = 2\times 860\sin\left(\frac{30°}{2}\right) = 445.17 \text{ m}$$

$$\text{Chainage of point of curve} = 2560 - 230.436 = 2329.564 \text{ m}$$

$$\text{Chainage of point of tangency} = 2329.564 + 450.295 = 2779.859 \text{ m}$$

The long chord is divided into two equal parts (i.e. left half and the right half)

i.e. $\frac{445.17}{2} = 222.585$ m



The ordinates for left half portion are calculated at 30 m interval as follows:

$$O_0 = R-\sqrt{R^2-\left(\frac{L}{2}\right)^2} = 860-\sqrt{860^2-222.585^2}$$

$$= 29.304 \text{ m}$$

$$O_{30} = \sqrt{(R^2-x^2)}-(R-O_0) = \sqrt{860^2-30^2}-(860-29.304)$$

$$= 28.781 \text{ m}$$

$$O_{60} = \sqrt{(R^2-x^2)}-(R-O_0) = \sqrt{860^2-60^2}-(860-29.304)$$

$$= 27.208 \text{ m}$$

$$O_{90} = \sqrt{(R^2-x^2)}-(R-O_0) = \sqrt{860^2-90^2}-(860-29.304)$$

$$= 24.582 \text{ m}$$

$$O_{120} = \sqrt{(R^2-x^2)}-(R-O_0) = \sqrt{860^2-120^2}-(860-29.304)$$

$$= 20.891 \text{ m}$$

$$O_{150} = \sqrt{(R^2-x^2)}-(R-O_0) = \sqrt{860^2-150^2}-(860-29.304)$$

$$= 16.122 \text{ m}$$

$$O_{180} = \sqrt{(R^2 - x^2)} - (R - O_0) = \sqrt{860^2 - 180^2} - (860 - 29.304)$$

$$= 10.256 \text{ m}$$

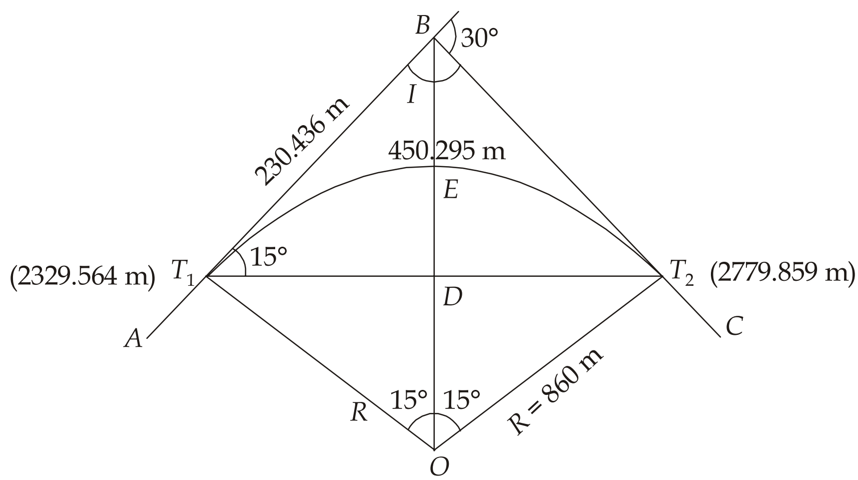
$$O_{210} = \sqrt{(R^2 - x^2)} - (R - O_0) = \sqrt{860^2 - 210^2} - (860 - 29.304)$$

$$= 3.270 \text{ m}$$

$$O_{222.585} = \sqrt{(R^2 - x^2)} - (R - O_0) = \sqrt{860^2 - 222.585^2} - (860 - 29.304)$$

$$\simeq 0 \text{ m}$$

The ordinates for the right half portion are similar to those for the left half.



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