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Detailed Solutions

ESE-2024 Mains Test Series

Civil Engineering Test No : 2

Section A : Highway Engineering + Surveying and Geology

Q.1 (a) Solution:

(i) Kerbs: Kerb indicates the boundary between the pavement and median or footpath or island or shoulder. It is desirable to provide kerbs on urban roads. Kerbs may be mainly divided into three groups based on their functions as below:

(1) Low kerb or mountable type kerb: The height of this type of kerb is about 100 mm above the pavement edge with a slope or batter to enable vehicles to climb the kerb at slow speed. It is provided at medians and also in longitudinal drainage system.

(2) Semi-barrier type kerb: The height of kerb stone is about 150 m above the pavement edge with a batter of 1 : 1 on the top 75 mm.

(3) Barrier type kerb. The height of kerb stone is about 200 mm above the pavement edge with a batter of 1V : 0.25 H.

(ii) Camber : Camber is the slope provided to the road surface in the transverse direction to drain off the rain water from the road surface are as follows:

Recommended values of camber for different types of road surfaces.

S. No.	Types of road surface	Range of camber in areas	
		Heavy rainfall	Low rainfall
1.	Cement concrete and high type bituminous surface	2%	1.7%
2.	Thin bituminous surface	2.5%	2%
3.	WBM and gravel pavement	3%	2.5%
4.	Earth road	4%	3%

(iii) Pavement uneveness: The longitudinal profile of the road pavement has to be 'even' in order to provide good riding comfort to fast moving vehicles and to minimise the vehicle operation cost. Presence of undulations on the pavement surface is called 'pavement uneveness' which results in:

(i) increase in discomfort and fatigue to road users.

(ii) increase in fuel consumption and tyre wear.

(iii) increase in vehicle maintenance cost.

(iv) reduction in vehicle operating speed.

(iv) Shoulders:

- Shoulders are provided on both sides of the pavement all along the road in the case of undivided carriageway. Shoulders are provided along the outer edge of the carriageway in the case of divided carriageway.
- The minimum shoulder width recommended by the IRC is 2.5 m.

The important functions of shoulder are:

(a) Shoulders provide structural stability and support to the edges of the flexible pavements particularly to the granular pavement layers.

(b) The capacity of the carriageway and the operating speeds of vehicles increase if the shoulders are laid and maintained in good conditions.

Q.1 (b) Solution:

(i)

Stopping sight distance: It is the distance available on highway that is sufficient for a vehicle traveling at design speed to come to a stop/halt safely without collision with any other obstruction.

Intermediate sight distance : It is always desirable to have sufficient overtaking sight distance available on roads. However under certain circumstances particularly on horizontal curves, safe overtaking sight distance requirements cannot be complied with. In such cases, overtaking is prohibited by regulatory signs. Thus in road stretches where overtaking sight distance cannot be provided, intermediate sight distance is provided which is generally equal to twice the stopping sight distance.

(ii)

Given data: Reaction time, t_r = 2.5 sec

Speed of car-1, V_1 = 80 km/h

Speed of car-2, V_2 = 60 km/h

Effective friction coefficient, with 60% brake efficiency during stopping

$$f = 0.60 \times 0.35 = 0.21$$

Now, stopping sight distance for car-1,

$$S_{D1} = 0.278V_1 \cdot t_r + \frac{V_1^2}{254f}$$

$$= 0.278 \times 80 \times 2.5 + \frac{80^2}{254 \times 0.21} = 175.59 \text{ m}$$

Stopping sight distance for car-2, $S_{D2} = 0.278V_2 \cdot t_r + \frac{V_2^2}{254f}$

$$= 0.278 \times 60 \times 2.5 + \frac{60^2}{254 \times 0.21} = 109.19 \text{ m}$$

Total sight distance required to avoid head-on collision of the two approaching cars

$$= SD_1 + SD_2$$

$$= 175.59 \text{ m} + 109.19 = 284.78 \text{ m} \simeq 285 \text{ m (say)}$$

Q.1 (c) Solution:

Apparent difference in elevations with the two instrument settings are the following:

With the instrument at P,

Difference of elevations = 2.427 – 1.701 = 0.726 m

With the instrument at Q,

Difference of elevations = 1.285 – 0.805 = 0.48 m

$$\text{True difference of elevations} = \frac{0.726 + 0.48}{2} = 0.603 \text{ m}$$

Given reading shows a fall from P to Q,

$$\therefore \quad \text{RL of } Q = \text{RL of P} - 0.603$$
$$= 203.135 - 0.603 = 202.532 \text{ m}$$
$$\text{Error due to curvature} = 0.0785\, D^2$$
$$= 0.0785(1.2)^2 = 0.113 \text{ m}$$
$$\text{Collimation error} = 0.002 \text{ m}/100 \text{ m for } 1200 \text{ m}$$
$$= \frac{0.002}{100} \times 1200 = 0.024 \text{ m}$$

Let R is error due to refraction with the instrument at P,

$$\text{Correct reading at } Q = 2.427 - \underbrace{(0.113 - R)}_{\text{Net due to curvature and refraction}} - \underbrace{0.024}_{\text{due to collimation}}$$

Now, true difference in elevations

$$= 2.427 - 0.113 + R - 0.024 - 1.701$$
$$= R + 0.589$$
$$\therefore \quad 0.603 = R + 0.589$$
$$\Rightarrow \quad R = 0.014 \text{ m}$$ {-ve sign of error due to refraction already considered in calculation}

Q.1 (d) Solution:

(i) Electromagnetic remote sensing involves the following basic elements:

- **Source of energy** which provides the requisite electromagnetic energy to the object under consideration.
- **Atmosphere** for propagating energy from the source to the object.
- **Interaction with earth's surface** features which depends on the characteristics of the object and the incident energy.

(ii)

Difference between passive and active remote sensing	
Passive remote sensing	**Active remote sensing**
• Passive sensors respond to external stimuli. • They record natural energy that is reflected or emitted from the Earth's surface. The most common source of radiation detected by passive sensors is reflected sunlight. • Ex. RADAR - RAdio Detection And Ranging, and LiDAR (Light + RADAR).	• Active sensors use internal stimuli to collect data about Earth. • For example, a laser-beam remote sensing system projects a laser onto the surface of Earth and measures the time that it takes for the laser to reflect back to its sensor. • Ex. Film photography, infrared, charge-coupled devices, and radiometers.

(iii)

Disadvantages of remote sensing

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

Q.1 (e) Solution:

Frequency distribution and cumulative frequency values of spot speed data are given below:

Speed range (kmph)	Mid speed (kmph)	Frequency (f)	Cumulative frequency	Cumulative frequency (%)
0 to 10	5	10	10	1.18
10 to 20	15	20	30	3.53
20 to 30	25	68	98	11.53
30 to 40	35	90	188	22.12
40 to 50	45	205	393	46.24
50 to 60	55	250	643	75.65
60 to 70	65	120	763	89.76
70 to 80	75	40	803	94.47
80 to 90	85	30	833	98
90 to 100	95	17	850	100

(i) Upper speed limit for regulation = 85^{th} percentile speed

85th percentile speed is calculated with the help of interpolation as below.

$$\frac{89.765-75.647}{65-55} = \frac{85-75.647}{V_{85}-55}$$

$$\Rightarrow \quad V_{85} = 61.62 \text{ kmph}$$

Lower speed limit for regulation = 15^{th} percentile speed

15th percentile speed is calculated with the help of interpolation

$$\frac{22.12-11.53}{35-25} = \frac{15-11.53}{V_{15}-25}$$

$$\Rightarrow \quad V_{15} = 28.28 \text{ kmph}$$

(ii) Speed to check geometric design elements

$$= 98^{th} \text{ percentile speed}$$
$$= 85 \text{ kmph}$$

Q.2 (a) Solution:

(i)

Station	B.S.	I.S.	F.S.	Rise	Fall	R.L.	Remarks
1	2.285	–	–	–	–	232.46	B.M No. 1
2	1.650	–	2.265	0.020	–	232.48	
3	–	2.105	–	–	0.455	232.025	
4	1.625	–	1.960	0.145	–	232.17	
5	2.050	–	1.925	–	0.300	231.87	
6	–	1.665	–	0.385	–	232.255	B.M. No. 2
7	1.690	–	1.325	0.340	–	232.595	
8	2.865	–	2.100	–	0.410	232.185	
9		–	1.625	1.240	–	233.425	B.M. No. 3
	Σ=12.165		Σ=11.2	Σ=2.13	Σ=1.165		

Formula used:

$$\text{Rise/fall} = (\text{Previous reading}) - (\text{Current reading})$$
(+ve rise and – ve fall)

$$\text{RL of any point} = \text{R.L. of previous point + Rise/Fall}$$
(+ve rise and – ve fall)

Calculations:

1. At station 2, as the rise of 0.02 m is given, so fore sight reading will be (2.285 – 0.02) i.e. 2.265 m.
2. At station 3, backsight and foresights are given as 1.65 m and 2.105 respectively and so fall will be (1.65 – 2.105) i.e. – 0.455 m. (Here, negative sign indicates fall).
3. At station 4, intermediate and foresights are given as 2.105 m and 1.960 m respectively and so rise will be (2.105 – 1.96) i.e. 0.145 m.
4. At station 5, fore sight and fall are given as 1.925 m and 0.3 m respectively and so backsight will be (1.925 – 0.3) i.e. 1.625 m.
5. At station 5, R.L. is calculated as 231.87 m. Now at station 6, R.L is given as 232.255 m. So, there will be a rise of (232.255 – 231.87)i.e. 0.385 m. Now, backsight is also

given as 2.05 m. So, intermediate sight will be (2.05 – 0.385) i.e. 1.665 m.

6. At station 7, previous intermediate sight is given as 1.665 m and rise is given as 0.34 m. So, foresight will be (1.665 – 0.34)i.e. 1.325 m.
7. At station 8, backsight and foresights are given as 1.69 and 2.1 m respectively and so fall will be (1.69 – 2.1) i.e. 0.41 m.
8. At station 8, R.L. is calculated as 232.185 m. At station 9, R.L. is given as 233.425 m. So, rise will be (233.425 – 232.185) i.e. 1.24 m.

Arithmetical checks:

$$\Sigma BS - \Sigma FS = 12.165 - 11.2 = 0.965 \text{ m}$$

$$\Sigma \text{Rise} - \Sigma \text{Fall} = 2.13 - 1.165 = 0.965 \text{ m}$$

$$\text{Last RL} - \text{First RL} = 233.425 - 232.46 = 0.965 \text{ m}$$

(ii)

$$\text{Shrinkage factor} = \frac{\text{Shrunk scale}}{\text{Original scale}}$$

$$\Rightarrow \quad \frac{9.78}{10} = \frac{\text{Shrunk scale}}{\frac{1\,\text{cm}}{20\,\text{m}}}$$

$$\Rightarrow \quad \text{Shrunk scale} = \frac{1\,\text{cm}}{20.45\,\text{m}}$$

Now, length of line AB on paper = 18.7 cm

So, length of line AB on ground = 18.7 × 20.45 m = 382.415 m

Now, actual length of chain = 20.015 m

Designated length of chain = 20 m

$$\text{Length to be measured on ground} = 382.415 \times \frac{20}{20.015}$$

$$= 382.128 \simeq 382.13 \text{ m}$$

Q.2 (b) Solution:

The mean values of journey time, stopped delay, number of vehicles overtaking, overtaken and in opposite direction for north -south and south-north directions are given below in the table below:

Trip No.	Direction	Journey time min-sec	Stopped delay min-sec	No. of vehicles overtaking	No. of vehicles overtaken	No. of vehicles from opposite direction
1	$N-S$	$6-30$	$1-40$	4	7	270
3		$6-40$	$1-50$	4	2	280
5		$6-10$	$1-30$	3	5	230
7		$6-40$	$1-40$	2	5	300
	Mean	$6-30$	$1-40$	3.25	4.75	270
2	$S-N$	$7-16$	$1-40$	5	3	180
4		$7-50$	$2-10$	2	1	200
6		$8-24$	$2-20$	3	4	170
8		$7-30$	$1-10$	2	2	150
	Mean	$7-45$	$1-50$	3	2.5	175

(a) North-South direction

n_y = Average number of vehicles overtaking minus overtaken

= 3.25 – 4.75 = – 1.5 vehicles

n_a = Average number of vehicles during trip in opposite direction (for S-N trips)

= 175 vehicles

t_w = Average journey time with the stream,

= 6 min 30 sec = 6.5 min

t_a = Average journey time during trips against the stream.

= 7 min 45 sec = 7.75 min

Now, Average volume, $q = \frac{n_a + n_y}{t_a + t_w} = \frac{175+(-1.5)}{7.75+6.5} = 12.175$ veh/min.

Average journey time, $\bar{t} = t_w - \frac{n_y}{q} = 6.5 - \frac{(-1.5)}{12.175} = 6.62$ min.

Average journey speed $= \frac{4\times 60}{6.62}$ kmph $= 36.25$ kmph

Average stopped delay = 1 min 40 sec = 1.67 min.

Average running time = Average journey time – average stopped delay

= 6.62 – 1.67 = 4.95 min.

$$\text{Average running speed} = \frac{4\times 60}{4.95}\text{kmph} = 48.48 \text{ kmph}$$

(b) South-North direction

$$n_y = 3 - 2.5 = 0.5 \text{ vehicles}$$

$$n_a = 270 \text{ vehicles} \quad (\text{N} - \text{S trips})$$

$$t_w = 7 \text{ min. } 45 \text{ sec} = 7.75 \text{ min}$$

$$t_a = 6 \text{ min. } 30 \text{ sec} = 6.5 \text{ min}$$

Now,

$$\text{volume, } q = \frac{n_a + n_y}{t_a + t_w} = \frac{270+0.5}{6.5+7.75} = 18.98 \text{ veh/min.}$$

$$\text{Average journey time, } \bar{t} = t_w - \frac{n_y}{q} = 7.75 - \frac{0.5}{18.98} = 7.72 \text{ min.}$$

$$\text{Average journey speed} = \frac{4\times 60}{7.72} = 31.09 \text{ kmph}$$

$$\text{Average stopped delay} = 1 \text{ min. } 50 \text{ sec} = 1.83 \text{ min.}$$

$$\text{Average running time} = 7.72 - 1.83 = 5.89 \text{ min.}$$

$$\text{Now, average running speed} = \frac{4\times 60}{5.89} = 40.75 \text{ kmph}$$

Q.2 (c) Solution:

(i)

1. The Los Angeles abrasion test evaluates the resistance of aggregate to abrasion and impact. It involves placing a sample of the aggregate in a rotating drum along with steel balls, causing abrasion and impact. After a specified number of revolutions, the material is sieved, and the percentage loss in weight is calculated.
   - For pavement construction, lower Los Angeles values indicate better resistance to mean and degradation.
   - The Los Angeles abrasion value of good aggregate acceptable for bituminous concrete and other high quality pavement material should be less than 30 percent, for cement concrete pavement and dense bituminous macadam (DBM) binder course the maximum acceptable value is 35 percent, values upto 40 percent are allowed in granular base course (like WBM and WMM).
2. The aggregate impact test is carried out to evaluate the resistance to impact of aggregates to fracture under repeated impacts. The test has been standardized by Bureau of Indian Standards (BIS).

Procedure: Aggregate specimen passing 12.5 mm sieve and retained on 10 mm sieve is filled in the cylindrical measure in three layers by tamping each layer by 25 blows by the tamping rod. The sample is weighed and transferred from the measure to the cup of the aggregate impact testing machine and compacted by tamping 25 times. The hammer is raised to a height of 380 mm above the upper surface of the aggregate in the cup and is allowed to fall freely on the specimen. After subjecting the test specimen to 15 blows, the crushed aggregate is sieved through 2.36 mm sieve.

Based on test result, the toughness property of the aggregate may be reported as given below:

Aggregate impact value (%)	Toughness property
Less than 10	Exceptionally tough/strong
Above 35	Weak for pavement surface

(ii)

Given data:

Theoretical specific gravity, G_t = 2.45

Measured specific gravity, G_m = 2.35

Specific gravity of bitumen, G_b = 1.02

Bitumen content, w_b = 5%

- Percentage of air voids (V_a) $= \dfrac{G_t - G_m}{G_t} \times 100 = \dfrac{2.45 - 2.35}{2.45} \times 100 = 4.082\%$
- Percentage bitumen by volume, $V_b = \dfrac{w_b(\%)}{G_b} \times G_m = \dfrac{5}{1.02} \times 2.35 = 11.52\%$
- Percentage voids in mineral aggregate

$$\text{VMA} = V_a + V_p$$
$$= 4.082 + 11.52 = 15.602\%$$

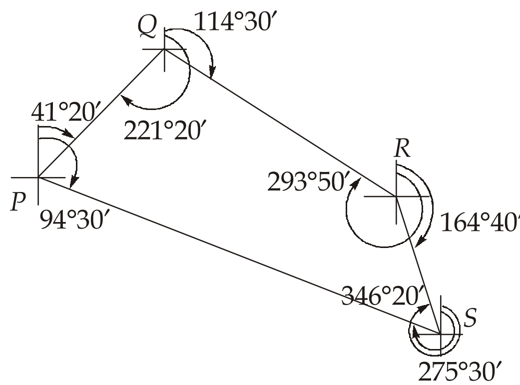
Now, percent voids in mineral aggregate filled with bitumen (VFB)

$$= \frac{V_b}{VMA} \times 100 = \frac{11.52}{15.602} \times 100 = 73.837\%$$

Q.3 (a) Solution:

(i)

A rough sketch of the traverse is shown below.



$$\angle P = 94°30' - 41°20' = 53°10'$$

$$\angle Q = 221°20' - 114°30' = 106°50'$$

$$\angle R = 293°50' - 164°40' = 129°10'$$

$$\angle S = 346°20' - 275°30' = 70°50'$$

Sum of all interior angles $= 53°10' + 106°50' + 129°10' + 70°50' = 360°$

So, there is no error in sum of angles, i.e. all internal angles measured are correct.

Now, the fore bearing and back bearing of traverse PQ differs by 180°. So, stations P and Q are free of local attraction.

$\therefore$ Bearing of PS is correct,

$\therefore$ Bearing of $SP = 94°30' + 180° 00' = 274°30'$

$\therefore$ Bearing of SR = Bearing of $SP + \angle S$

$= 274°30' + 70° 50' = 345°20'$

$\therefore$ Bearing of $RS = 345°20' - 180° 00' = 165°20'$

$\therefore$ Bearing of $RQ = 165°20' + 129° 10' = 294°30'$

Bearing of $QR = 294°30' - 180° = 114°30'$

Line	Fore bearing	Back bearing
PQ	41°20′	221°20′
QR	114°30′	294°30′
RS	165°20′	345°20′
SP	274°30′	94°30′

(ii)

Surveyor's compass v/s Prismatic compass			
S. No.	**Characteristic**	**Surveyor's compass**	**Prismatic compass**
1.	Magnetic needle	Edge bar needle is used and it acts as an index	Broad needle is used which is hidden below the aluminum ring. It does not act as an index.
2.	Graduation	Graduated ring is attached to the box and ring rotates with the box. Graduations are embrossed from 0° to 90° in the four quadrants. Zero points are marked with *N* and *S*.	Graduated ring is attached to the needle and remains stationary when the box is rotated. Graduations are embrossed from 0° to 360° clockwise from zero at the south end.
3.	Sighting vanes	Object vane consists of a metal frame with vertical hair. Eye vane also consists of a metal frame with a fine slit. Readings are taken by directly looking down through the glass and reading the north end of the needle.	Object vane consists of a metal frame with vertical hair. Eye vane also consists of a small frame with a fine slit near the prism. Readings are taken through the vertical side of the prism provided at the eye vane.
4.	Reading	Sighting and reading are done separately and that too from different positions. After sighting the object, the observer moves around and takes the reading at the north end of the needle.	Sighting and reading are done simultaneously from the same position of the observer.
5.	Support requirement	This cannot be used without a support like tripod etc.	This can be held in hand while taking the observation but it is better to use tripod with it.

Q.3 (b) Solution:

(i)

Radius of relative stiffness is given by

$$l = \left[\frac{Eh^3}{12k\left(1-\mu^2\right)}\right]^{1/4} = \left[\frac{3\times10^5\times(20)^3}{12\times6\times\left(1-0.15^2\right)}\right]^{1/4}$$

$$= 76.42 \text{ cm}$$

Equivalent radius of resisting section is given by,

$$b = \sqrt{1.6a^2+h^2}-0.675h \qquad [\because a < 1.724\text{ h}]$$

$$= \sqrt{1.6\times(15)^2+20^2}-0.675\times20$$

$$= 14.1 \text{ cm}$$

(a) Stress at interior

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

$$= \frac{0.316\times 5000}{(20)^2}\left[4\log_{10}\left(\frac{76.42}{14.1}\right)+1.069\right]$$

$$= 15.82 \text{ kg/cm}^2$$

(b) Stress at the edge

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

$$= \frac{0.572\times 5000}{(20)^2}\left[4\log_{10}\left(\frac{76.42}{14.1}\right)+0.359\right]$$

$$= 23.56 \text{ kg/cm}^2$$

(c) Stress at the corner

$$S_c = \frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]$$

$$= \frac{3\times 5000}{(20)^2}\left[1-\left(\frac{15\times\sqrt{2}}{76.42}\right)^{0.6}\right] = 20.12 \text{ kg/cm}^2$$

(d) Location where corner load crack develops:

Location where the crack is likely to develop due to corner loading, the distance from the corner of the slab is,

$$X = 2.58\sqrt{al}$$

$$= 2.58\sqrt{15\times 76.42} = 87.35 \text{ cm}$$

(ii)

Attribute/Item	Flexible pavement	Rigid pavement
Material composition	Consists of multiple layers of materials.	Made of a single layer of concrete
Load distribution	Distributes loads through the entire structure.	Transfer loads directly to the subgrade.
Flexibility	Can accommodate sight movement and deformations.	Has limited flexibility and tends to crack under movement.
Maintenance	Generally requires more frequent maintenance.	Often has lower maintenance requirements
Cost	Often more cost-effective initially.	May have higher initial construction cost.
Construction time	Quick construction time	Typically takes longer to construct.

Q.3 (c) Solution:

(i)

1. **Face Right:** When vertical circle of the theodolite is on the right of the observer, then the theodolite is said to be in face right condition and the corresponding measurements are called as **face right measurements.**
2. **Face Left:** When vertical circle of the theodolite is on the left of the observer, then the theodolite is said to be in face left condition and the corresponding measurements are called as **face left measurements.**

   By taking mean of measurements of face left and face right readings, the collimation error is eliminated.
3. **Swing the telescope:** It is the operation of revolving the telescope in the horizontal plane about the vertical axis. Clockwise rotation is called as **right swinging** and anticlockwise rotation is called as **left swinging.**

   By taking mean of observations of both the swinging, the error due to friction or backlash in the moving parts can be eliminated.
4. **Line of collimation**: It is the (imaginary) line passing through the intersection of cross hairs on the diaphragm and the optical center of the objective. It is also known as line of sight.

5. **Telescope inverted:** The telescope is said to be in inverted position when vertical circle is on the right of the observer.

(ii)

Standard length of tape, $l_0 = 30$ m

Standard temperature, $T_0 = 16°C$

Standard pull, $P_0 = 50$ N

Total weight of tape, $W = 20$ N

Field temperature, $T_m = 28°C$

Applied pull, $P_m = 120$ N

$$\text{Correction for pull, } C_p = \frac{(P - P_0)l_0}{AE}$$

$$= \frac{(120 - 50) \times 30}{7.5 \times 2 \times 10^5} = +\ 0.0014 \text{ m}$$

$$\text{Correction for temperature, } C_t = \alpha l_0 (T_m - T_0)$$

$$= 12 \times 10^{-6} \times 30 \times (28 - 16)$$

$$= 0.0043 \text{ m}$$

$$\text{Correction for sag, } C_s = \frac{-W^2 l_0}{24P^2}$$

$$= -\frac{20^2 \times 30}{24 \times 120^2} = -\ 0.0347 \text{ m}$$

$\therefore$ Total correction $= C_p + C_t + C_s$

$= 0.0014 + 0.0043 - 0.0347 = (-)0.029$ m

$\therefore$ Correct length of tape $= 30 + 0.029 = 29.971$ m

Correct length of measured 640 m base line.

$$= \frac{29.971}{30} \times 640 = 639.38 \text{ m}$$

Q.4 (a) Solution:

(i)

Principle of triangulation:

- In triangulation, the whole area under consideration is covered with a framework of triangles. It is based on the principle that:

"If the length and direction of one side and all the three angles of the triangle are measured precisely then the lengths and directions of the remaining two sides can be determined. The precisely measured first line is called as "base line."

- Furthermore, the other two sides of the triangle (whose lengths and directions are now known) act as base lines of the other interconnected triangles. This process goes on further which gives rise to a network of triangles throughout the area to be surveyed.
- When the whole area has been covered with triangles, then at last, as a check, the length of one of the sides of the last triangle is also measured directly and compared with the computed value. This side is called as check base.

Triangulation Systems:

- A system consisting of triangulation stations connected by a chain of triangles is called as triangulation system or triangulation figure.
- Most commonly used figures in triangulation system are:
  (1) Triangles (2) Quadrilaterals (3) Polygons

All these triangulation figures must satisfy the required geometrical conditions.

- But it is not possible to satisfy all the geometrical conditions due to errors involved in observations and calculations until the field measurements have been adjusted.

1. Triangulation Figure: Triangle (Δ)

- When a narrow strip of chain is to be surveyed then a chain of triangles is very economical and rapid. e.g. Survey of a railway line or a highway. For well-conditioned triangles, the angles must not be less than 30° or greater than 120°.
- Well-conditioned Triangle: A triangle is said to be well-conditioned if its shape is such that any error in the measurement of an angle has a minimum effect on the computed lengths.

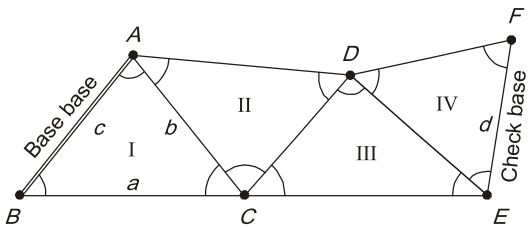
2. Triangulation Figure : Quadrilateral (◇)

- It is a better system as compared to triangles due to the availability of various combinations of sides and angles that can be used to compute the lengths of required sides and checks can be made frequently.
- Among all the quadrilaterals, the best quadrilateral is the square.

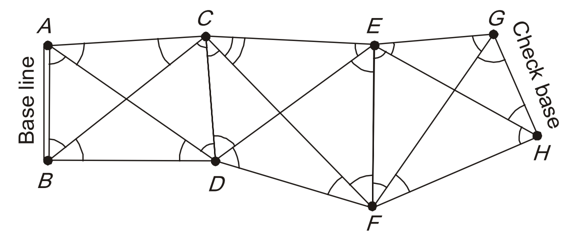
3. Triangulation Figure : Polygons (⬠, ⬡ etc.)

- When the wide area is to be surveyed then a pentagon or a hexagon is more economical.

- However the pace of work reduces due to more number of settings of the instrument required.
- This system provides the desired checks on the calculations.



(1) Chain of simple triangles



(2) Braced quadrilaterals

(ii)

For a closed traverse *ABCDA*,

Algebraic sum of latitudes, $\Sigma L = 0$

Algebraic sum of departures, $\Sigma D = 0$

Let length and bearing of line BC be l and θ respectively.

Now, $\Sigma L = 0$

$\Rightarrow 156.5\cos(78°40') + l\cos\theta + 234.8\cos 251°18' + 203.1\cos(3°45') = 0$

$\Rightarrow \quad l\cos\theta = -158.14$ ...(1)

Also, $\Sigma D = 0$

$\Rightarrow \quad 156.5\sin(78°40') + l\sin\theta + 234.8\sin(251°18') + 203.1\sin(3°45') = 0$

$\Rightarrow \quad l\sin\theta = 55.67$ ...(2)

From (1) and (2),

$$l^2 = (-158.14)^2 + (55.67)^2$$

$\Rightarrow \quad l = 167.65$ m

Also, $\tan\theta = \dfrac{55.67}{-158.14}$

$\Rightarrow \quad \theta = -19°23'37''$

As latitude of BC is negative and departure of *BC* is positive, the quadeant is SE.

$\therefore \quad l = 167.65$ m

and $\quad \theta = S19°23'37''E$

Q.4 (b) Solution:

(i)

Given data:

Stopping sight distance, SSD = 150 m

Overtaking sight distance, OSD = 650 m

Maximum length of summit curve, L = 500 m,

$$\text{Deviation angle, } N = +\frac{1}{50} - \left(-\frac{1}{60}\right) = \frac{11}{300}$$

(1) Requirements of stopping sight distance,

Assume length of curve, $L > \text{SSD}$

$$\therefore \quad L = \frac{NS^2}{4.4} = \frac{11}{300} \times \frac{150^2}{4.4} = 187.5 \text{ m} \simeq 188 \text{ m (say)}$$

As this length is greater than SSD, hence assumption is correct.

The length of summit curve required is 188 m which is less than prescribed maximum limit of 500 m.

(2) Requirement of overtaking sight distance as the length, L of summit curve is to be restricted to 500 m which is less than the required OSD of 650 m.

Assume $L < \text{OSD}$

$$\therefore \quad L = 2S - \frac{9.6}{N}$$

$$= 2 \times 650 - \frac{9.6}{11/300} = 1038.18 \text{ m}$$

As the length of summit curve obtained is higher than the OSD of 650 m, the assumption is not correct. Also in this problem, it is specified that the length of the summit curve is restricted to a value less than 500 m. Therefore it is not possible to provide an OSD of 650 m.

Therefore attempt may be made to design the summit curve, to provide intermediate sight distance (ISD) equal to twice the SSD (200 × 2) = 400 m.

Assume $L > \text{SD of 300 m}$

$$\therefore \quad L = \frac{NS^2}{9.6} = \frac{11}{300} \times \frac{(300)^2}{9.6} = 343.75 \text{ m} \simeq 344 \text{ m (Say)}$$

As this value is greater than the assumed SD of 300 m, the assumption is correct. Hence provide length of summit curve of 344 m.

(ii)

Given data

$$\text{Speed, } V = 90 \text{ kmph} = 25 \text{ m/s}$$

$$\text{Gradient, } n_1 = -\frac{1}{30} \text{ and } n_2 = +\frac{1}{40}$$

$$\therefore \quad \text{Deviation angle, } N = \left|-\frac{1}{30} - \frac{1}{40}\right| = \frac{7}{120}$$

(1) Valley curve length, L for comfort condition is:

$$L = 2\left[\frac{Nv^3}{C}\right]^{1/2}$$

$$= 2\left[\frac{7}{120} \times \frac{25^3}{0.6}\right]^{1/2} = 77.95 \text{ m} \simeq 78 \text{ m (say)}$$

(2) Valley curve length, L for head light sight distance.

- Stopping sight distance (S) is given by

$$S = V \cdot t_r + \frac{v^2}{2gf}$$

$$\text{Assume reaction time, } t_r = 2.5 \text{ sec}$$

and $\quad$ friction, $f = 0.35$

$$\therefore \quad S = 25 \times 2.5 + \frac{25^2}{2 \times 9.81 \times 0.35}$$

$$\Rightarrow \quad S = 153.51 \text{ m}$$

Now, $\quad$ assume $L >$ SSD of 153.51 m

$$\therefore \quad L = \frac{NS^2}{1.5 + 0.035S} = \frac{\frac{7}{120} \times (153.51)^2}{(12.5 + 0.035 \times 153.51)}$$

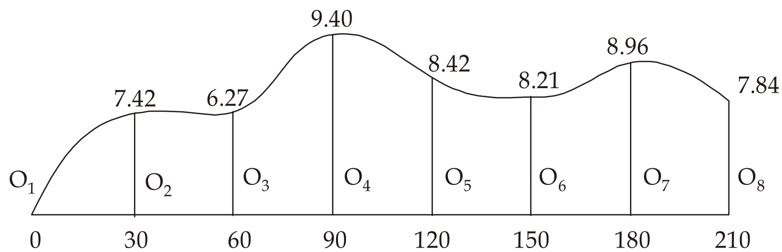
$$= 200 \text{ m}$$

As this value of L is higher than the SSD of 153.51 m, the assumption is correct.

$$\text{Length of valley curve} = \max.\begin{cases} (i)\, 78\text{m} \\ (ii)\, 200\,\text{m} \end{cases} = 200 \text{ m}$$

Q.4 (c) Solution:

(i)



Total number of offsets, n = 8

Number of divisions = 7

Offset internal, d = 30 m

Here, number of offsets (n) = 8 which is even

So, Simpson's rule can be applied from O_1 to O_7, and area of last segment i.e., from offset O_7 to O_8 can be determined from average ordinate method.

$$\therefore \quad A = A_1 + A_2$$

$$A_1 = \frac{d}{3}\left[(O_1 + O_7) + 4(O_2 + O_4 + O_6) + 2(O_3 + O_5)\right]$$

$$= \frac{30}{3}\left[0 + 8.96 + 4(7.42 + 9.40 + 8.21) + 2(6.24 + 8.42)\right]$$

$$= 1384.6 \text{ m}^2$$

$$A_2 = \left(\frac{O_7 + O_8}{2}\right)d$$

$$= \left(\frac{8.96 + 7.84}{2}\right) \times 30 = 252 \text{ m}^2$$

$$\therefore \quad A = A_1 + A_2$$

$$= 1384.6 + 252 = 1636.6 \text{ m}^2$$

(ii)

For the datum elevation, $B = \frac{H}{f} \cdot b$

$$= \frac{600}{150 \times 10^{-3}} \times 6.5 \times 10^{-2} = 260 \text{ m}$$

Parallaxes for the top and bottom of chimney are calculated as,

$$p = \frac{Bf}{H-h}$$

For the bottom of chimney, $p_1 = \dfrac{260 \times 150}{600} = 65\,\text{mm}$

For the top of chimney, $p_2 = \dfrac{260 \times 150}{600 - 100} = 78\,\text{mm}$

Hence, difference in parallax,

$$\Delta p = p_2 - p_1$$
$$= 78 - 65 = 13 \text{ mm}$$

Section B : Geo-technical & Foundation Engg. - 1 + Environmental Engg. -1

Q.5 (a) Solution:

Initial water content, w_0 = 12%

Required water content, w_1 = 20%

Weight of soil = 100 kN

Degree of saturation, S = 42%

Specific gravity, G = 2.65

Void ratio, $e = \dfrac{wG}{S} = \dfrac{0.12 \times 2.65}{0.42} = 0.76$

Bulk density of soil, $\gamma_b = \left(\dfrac{G + eS}{1+e}\right) \times \gamma_w$

$$= \left(\frac{2.65 + 0.76 \times 0.42}{1 + 0.76}\right) \times 9.81$$

$$= 16.55 \text{ kN/m}^3$$

Volume of the soil $= \dfrac{100\,\text{kN}}{16.55 \text{ kN/m}^3} = 6.04 \text{ m}^3$

Dry density, $\gamma_d = \left(\dfrac{G}{1+e}\right) \times \gamma_w = \dfrac{2.65 \times 9.81}{1 + 0.757} = 14.77 \text{ kN/m}^3$

Weight of soil solids, W_s = 14.77 × 6.04 = 89.21 kN

Weight of water, W_w = 100 kN – 89.21 kN = 10.79 kN

Weight of water corresponding to 20% water content,

W_{w2} = 0.2 × 89.21 kN = 17.84 kN

∴ Additional water required = (17.84 – 10.79) kN = 7.05 kN

Q.5 (b) Solution:

Height of chimney (H) for effective dispersion of particulate matter emission is given as,

$$H \text{ (in meters)} = 74\ (Q)^{0.27}$$

where, Q = Particulate emission in tonnes per hour

The particulate emission is equal to 3.0 tonnes per million litres of oil per year.

Consumption of oil is equal to 4,00,000 × 12 litre

= 48,00,000 litre/year

= 4.8 million litre/year

Therefore, total particulate emission = 4.8 × 3 = 14.4 tonnes per year

$$= \frac{14.4}{300 \times 24} \text{ tonnes per hour}$$

Now,
$$H = 74 \times \left(\frac{14.4}{300 \times 24}\right)^{0.27} = 13.82 \text{ m}$$

The height of the chimney (H) for effective dispersion of SO_2 is to be calculated as,

$$H\text{(in meters)} = 14(Q)^{0.3}$$

where, Q = SO_2 emission in kg/hr

Now, Q = 59.7 × 4.8 = 286.56 tonnes per year

$$= \left(\frac{286.56 \times 10^3}{300 \times 24}\right) = 39.8 \text{ kg/hr}$$

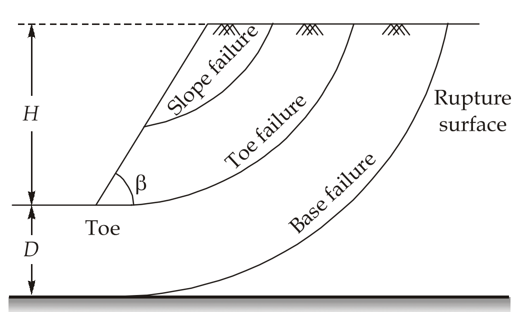
Therefore, $H = 14 \times [39.8]^{0.3} = 42.28$ m

So, adopt a height of 42.28 m.

Q.5 (c) Solution:

(i)

There are three basic modes of failure of slopes:

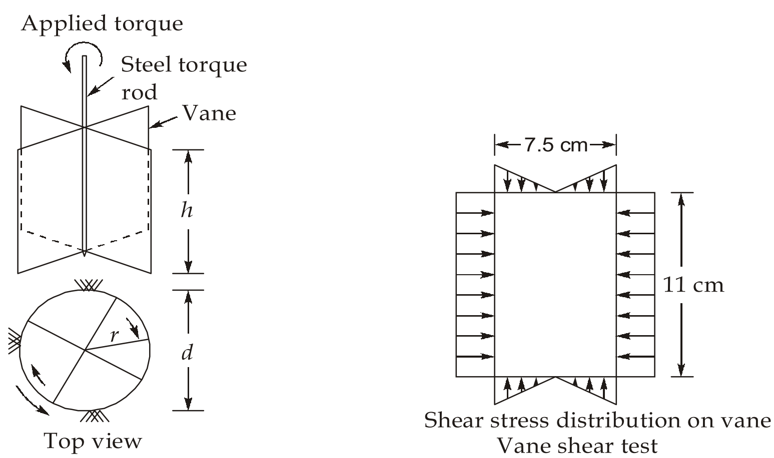


Types of failure of finite slope

In figure, H is the height of the slope and DH is the depth of the lowest point of the failure surface, 'D' is called the depth factor.

1. **Slope failure** is when the failure surface intersects the slope above the toe. This can occur when the slope angle 'β' is very high and soil close to the toe is quite strong or the soil in the upper part of the slope is relatively weak.
2. **Toe failure** is when the failure surface passes through the toe. Toe failure occurs in steep slopes when the soil mass above the base and below the base is homogenous. This is the most common mode of failure.
3. **Base failure** is when the failure surface passes below the toe. This can occur when the soil below the toe is relativey weak and soft and the slope is flat.

(ii)



Vane shear test

It is difficult to determine the shearing resistance of soft, saturated clay deposits in the field as obtaining undisturbed sample is not an easy task. The shear strength of such sensitive clays may be significantly altered during the process of sampling and handling. Vane shear test offers a method of overcoming this problem.

The shear vane consists of four steel blades called vanes welded at right angles to a steel rod. The vane is pushed gently into the soil upto the required depth or at the bottom of a borehole and torque is applied gradually to the upper end of the torque rod until the soil fails in shear, due to the rotation of the vanes. The torque is measured by noting the angle of the two shear failure that occur over the surface and the ends of a cylinder having a diameter 'd' equal to the diameter of the vane.

The shearing resistance of the soil at failure

$$= \pi dh C_u + 2\int_0^{d/2} (2\pi r dr) C_u$$

where C_u is the unit undrained shearing resistance and r is radius of the sheared surface.The moment of the total shear resistance about the centre is torque T at failure.

Now, $$T = \pi dh C_u \times \frac{d}{2} + \int_0^{d/2} (2\pi r dr) C_u \times r$$

$\Rightarrow$ $$T = C_u \pi \left(\frac{d^2 h}{2} + \frac{d^3}{6}\right)$$

$\Rightarrow$ $$C_u = \frac{T}{\pi\left(\frac{d^2 h}{2} + \frac{d^3}{6}\right)}$$

If the test is carried out such that the top end of the vane does not shear the soil then,

$$T = C_u \pi \left(\frac{d^2 h}{2} + \frac{d^3}{12}\right)$$

$\Rightarrow$ $$C_u = \frac{T}{\pi\left(\frac{d^2 h}{2} + \frac{d^3}{12}\right)}$$

Q.5 (d) Solution:

The total settlement will be the sum of the settlement of the top clay layer and the settlement of the bottom clay layer.

For clay

Submerged unit weight of clay, $\gamma'_{clay} = \frac{G-1}{1+e} \times \gamma_w$

where $$e = \frac{wG}{S} = \frac{0.4 \times 2.7}{1} = 1.08$$

$\therefore$ $$\gamma'_{clay} = \frac{(2.7-1) \times 9.81}{1+1.08} = 8.02 \text{ kN/m}^3$$

Submerged unit weight of sand, $\gamma'_{sand} = 21 - 9.81 = 11.19 \text{ kN/m}^3$

- Settlement of top clay layer (S_1)

  Effective stress at centre of top clay layer,

$$\bar{\sigma}_0 = 11.19 \times 4 + 8.02 \times 1 = 52.78 \text{ kN/m}^2$$

Now,

$$S_1 = \frac{C_c H}{1+e_0} \log\left(\frac{\bar{\sigma}_0 + \Delta\bar{\sigma}}{\bar{\sigma}_0}\right)$$

$$= \frac{0.24 \times 2}{1+1.08} \log\left(\frac{52.78+160}{52.78}\right) = 0.1397 \text{ m} = 139.7 \text{ mm}$$

- Settlement of bottom layer (S_2)

  Effective stress at centre of bottom clay layer,

$$\bar{\sigma}_0 = 11.19 \times 4 + 8.02 \times 2 + 11.19 \times 5 + 8.02 \times 1.5$$

$$= 128.78 \text{ kN/m}^2$$

Now,

$$S_2 = \frac{0.24 \times 3}{1+1.08} \log\left(\frac{128.78+160}{128.78}\right)$$

$$= 0.1214 \text{ m} = 121.4 \text{ mm}$$

$\therefore$ Total settlement $= S_1 + S_2 = 139.7 + 121.4 = 261.1$ mm

Q.5 (e) Solution:

(i) Alum: [$Al_2(SO_4)_3 \cdot 18H_2O$]

- Alum reacts with HCO_3^- alkalinity to form gelatinous precipitate (floc) of $Al(OH)_3$. The chemical attracts other fine particles and suspended matter, becomes bigger in size and finally settle down to bottom of tank. The chemical reaction of alum with alkalinity is given as

$$Al_2(SO_4)_3 \cdot 18H_2O + 3Ca(HCO_3)_2 \longrightarrow \underset{\text{Permanent Hardness}}{3\,CaSO_4} + \underset{\text{ppt}}{2\,Al(OH)_3 \downarrow} + 6CO_2 \uparrow + 18\,H_2O$$

- This reaction introduces permanent hardness in water in the form of calcium sulphate as evident from the reaction and the carbon dioxide gas, which is evolved, causes corrosiveness. The turbidity and colour of raw water determines the dose of coagulant (alum) and this amount is estimated with the help of Jar test. Normal alum dose is 10-30 mg/litre of water and is very effective in the pH range of 6.5 to 8.5.

(ii) Copperas: [$FeSO_4 \cdot 7\,H_2O$]

Copperas is generally added to raw water in conjunction with lime. Lime may be added earlier to copperas or vice-versa. When lime is added first, the following reaction takes place:

- $\underset{\text{Copperas}}{FeSO_4 \cdot 7H_2O} + \underset{\text{Hydrated lime}}{Ca(OH)_2} \longrightarrow CaSO_4 + \underset{\text{Ferrous hydroxide}}{Fe(OH)_2} + 7\,H_2O$

Similarly, when copperas is added earlier to lime, the reactions that take place are:

- $FeSO_4 \cdot 7H_2O + \underset{\text{Alkalinity present in raw water}}{Ca(HCO_3)_2} \longrightarrow Fe(HCO_3)_2 + CaSO_4 + 7\,H_2O$
- $Fe(HCO_3)_2 + 2\underset{\text{Hydrated lime}}{Ca(OH)_2} \longrightarrow \underset{\text{Ferrous hydroxide}}{Fe(OH)_2} + 2\,CaCO_3 + 2\,H_2O$

The ferrous hydroxide formed in either case, further gets oxidised forming ferric hydroxide as given below:

- $4Fe(OH)_2 + O_2 + 2H_2O \longrightarrow 4Fe(OH)_3$

The ferric hydroxide forms the floc, and thus helps in sedimentation.

(iii) Sodium aluminate: [$Na_2\,Al_2O_4$]

Sodium aluminate when dissolved and mixed with water, reacts with the salts of calcium and magnesium present in raw water, resulting in the formation of precipitate of calcium or magnesium aluminate. The chemical reactions that are involved are:

- $Na_2Al_2O_4 + Ca(HCO_3)_2 \longrightarrow \underset{\text{Calcium aluminate}}{CaAl_2O_4 \downarrow} + Na_2CO_3 + CO_2 \uparrow + H_2O$
- $Na_2\,Al_2O_4 + CaCl_2 \longrightarrow CaAl_2O_4 \downarrow + 2\,NaCl$
- $Na_2\,Al_2O_4 + CaSO_4 \longrightarrow CaAl_2O_4 \downarrow + Na_2SO_4$

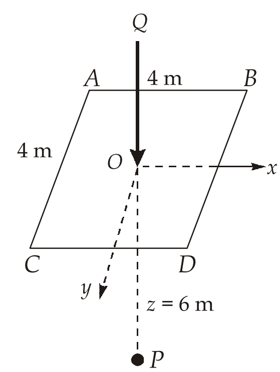
This coagulant is about $1\frac{1}{2}$ times costlier than alum, and is therefore, generally avoided for treating ordinary public water supplies, but however, it is very useful for treating water which does not have the natural desired alkalinity. It removes hardness from water.

Q.6 (a) Solution:

(i)

Size of raft is 4 m × 4 m and loading intensity 'q' is 300 kN/m^2.

1. Using Boussinesq's method



Total load, $Q = 300 \times 4 \times 4 = 4800$ kN

Now, vertical stress at 6 m depth,

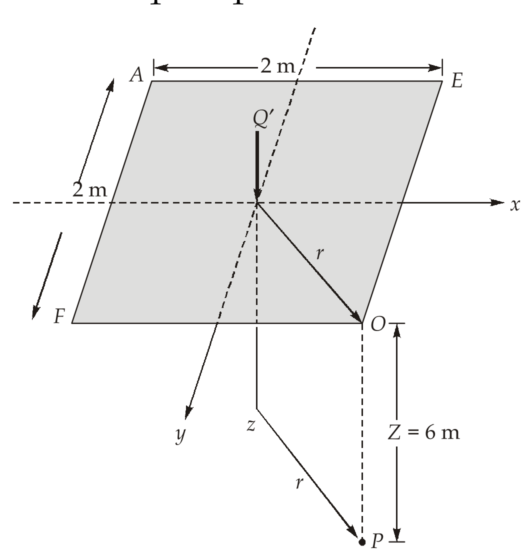
$$\sigma_6 = k_B \frac{Q}{z^2} = \frac{3}{2\pi}\left(\frac{1}{1+\left(\frac{r}{z}\right)^2}\right)^{5/2} \times \frac{Q}{z^2}$$

$$\Rightarrow \quad \sigma_z = \frac{3}{2\pi}\left(\frac{1}{1+0}\right)^{5/2} \times \frac{4800}{6^2} = 63.66 \text{ kN/m}^2$$

2. Equivalent load method

Dividiing the area into 4 equal rafts of size 2 m × 2 m

$$Q' = \frac{Q}{4} = \frac{4800}{4} = 1200\,\text{kN}$$



$$r = \sqrt{1^2 + 1^2} = \sqrt{2} \text{ m}$$

$$z = 6 \text{ m}$$

Vertical stress at detph z, $\sigma_z = 4 \times k_B \times \dfrac{Q'}{z^2}$

$$= 4 \times \frac{3}{2\pi} \times \left(\frac{1}{1 + \left(\frac{\sqrt{2}}{6} \right)^2} \right)^{5/2} \times \frac{1200}{6^2}$$

$$= 55.61 \text{ kN/m}^2$$

Result obtained by equivalent point load method is lower as compared to that obtained by Boussinseq's method.

(ii)

1. For homogeneous earth dam, we prefer the compaction to be done on dry of optimum side to achieve higher soil density with lower permeability.
2. For core of an earth dam, we want to reduce the permeability of the soil and prevent the cracking in the core. Hence, we prefer compaction to be done on the wet of optimum side.
3. For subgrade of pavement, volume change has to be limited. Hence we prefer the comapction to be done on wet of optimum side.

Q.6 (b) Solution:

(i)

Disposal of refuse by sanitary land filling method:

- Disposal on or in the earth's surface (mantle) is at present the only variable method for the long term handling of:
  1. Solid wastes that are collected and are of no further use.
  2. The residual matter remaining after solid wastes have been processed.
  3. The residual matter remaining after the recovery of conversion products and/or energy has been accomplished.

  Land filling is the method of disposal used most commonly for municipal wastes. Land farming and deep well injection have been used for industrial wastes. Although incineration is often considered a disposal method, it is in reality, a processing method.

- In this method of refuse disposal, refuse is carried and dumped into the low lying area (marked as land fill site) under an engineered operation, designed and operated in an environmentally sound manner so as not to cause any public nuisance or hazards to public health or safety.
- The refuse is dumped and compacted in layers of about 0.5 m thickness, and after the day's work when the depth of filling becomes about 1.5 m, it is covered by good earth of 15 cm thickness. This cover of good earth is called daily cover.
- The refuse is well compacted with bulldozers, trucks, rollers etc. and is well covered daily with good earth, so that it does not cause any public nuisance.
- The filling of refuse is actually done in sanitary land filling by dividing the entire land fill area into smaller portion called cells.
- These cells are initially filled with daily compacted refuse about 1.5 m depth. After filling all the cells with first lift, the second lift is laid in about 1.5 m height and covered with good earth cover of about 0.15 m depth called intermediate cover.
- The process will continue till the top most lift is piled up, over which the final cover of good earth of about 0.6 m depth shall be laid and well compacted to prevent the rodents from burrowing into the surface.
- A **cap system** may also be installed over the top of the final cover.
- The filled up refuse gets stabilized due to the decomposition of organic matter in due course of time and subsequently gets converted into stable compounds.

Advantages of sanitary land filling:

1. This method is most simple and economical. No costly plant or equipment is required in this method, as is required in other methods of incineration or pulverization.
2. Separation of different kinds of refuse, as required in incineration method is also not required in this method.
3. There are no residues or by-products left out/evolved in this method and hence no further disposal is required, thus being a complete method in itself.
4. Low lying waterlogged areas and odd quarry pits can be easily reclaimed and put to better use. The mosquito breeding places are thus, eliminated.

Disadvantages of sanitary land filling:

1. Low lying depressions or dumping sites may not always be available. They may become scarce or unavailable in future.

2. There is a continuous evolution of foul gases near the fill site, especially during the times the refuse is being dumped there. These gases may often be explosive in nature and are produced by the decomposing or evaporating organic matter. These gases are known as land fill gases.
3. Since the dumped garbage may contain harmful and sometimes carcinogenic non-biodegradable substances such as plastic, unused medicines, paint etc. They may start troubling on a later date, particularly during rainy season, when excess water seeping through the area, may come out of the dump as a coloured liquid called leachate which is highly poisonous in nature.

(ii)

Depending upon the concentration of suspended matter and the characteristics of particles, sedimentation process (settling processes) can be classified in following four categories.

1. **Type I settling (Discrete particles in dilute suspension):** In this, particle have little or no tendency to flocculate in a dilute suspension. Such particles are known as **discrete particles**. They settle as individual entities and there is no significant interaction with neighbouring particles. This type of settling occurs in case of inorganic **sand particles.**

   Example: Settling in grit chamber.
2. **Type II settling (Flocculent particle in dilute suspension):** In the second type, there is settling of flocculent particles in a dilute suspension. Particles agglomerate during settling which causes increase in size, shape and density resulting in settlement at a faster rate. It is also known as **hindered settling.**

   Example: Settling of flocs in primary sedimentation tank.
3. **Type III or zone settling (Flocculent particles in dilute suspension):** The third type of sedimentation occurs when flocculent particles settle in a suspension of an intermediate concentration. Due to proximity of particles with each other, they tend to remain in fixed positions with respect to each other and settle as a large mass rather than as individuals. It is known as **zone settling.**

   Example: Settling of sludge in SST after treatment in ASP.
4. **Type IV or compression settling (Flocculent particles in concentrated suspension):** The fourth type is settlement of flocculent particles in a very high concentration. Due to high concentration, particles come into physical contact and form a structure and further settling occur due to compression of the structure. The process is also known as **compression settling.**

   Example: Settling of sludge in SST after treatment in the trickling filter.

Q.6 (c) Solution:

(i)

Given:

Unconfined compressive strength of soil, q_u = 130 kN/m^2

In unconfined compressive test,

$$q_u = 2C_u \tan\left(45° + \frac{\phi}{2}\right)$$

where C_u is undrained cohesion.

$$\therefore \qquad 130 = 2C_u \tan\left(45° + \frac{\phi}{2}\right) \qquad \text{...(i)}$$

In triaxial compression test,

Cell pressure, $\sigma_c = \sigma_3 = 40$ kN/m^2

Deviator stress, $\sigma_d = 150$ kN/m^2

$\therefore$ Major principle stress, $\sigma_1 = \sigma_3 + \sigma_d$

$= 40 + 150 = 190$ kN/m^2

As we know,
$$\sigma_1 = \sigma_3 \tan^2\left(45° + \frac{\phi}{2}\right) + 2C_u \tan\left(45° + \frac{\phi}{2}\right)$$

$$\Rightarrow \qquad 190 = 40\tan^2\left(45° + \frac{\phi}{2}\right) + 2C_u \tan\left(45° + \frac{\phi}{2}\right) \qquad \text{...(ii)}$$

Putting eq. (i) in (ii) we get

$$190 = 40\tan^2\left(45° + \frac{\phi}{2}\right) + 130$$

$$\Rightarrow \qquad 1.5 = \tan^2\left(45° + \frac{\phi}{2}\right)$$

$$\Rightarrow \qquad \phi = 11.54°$$

Putting value of ϕ in eq. (i) we get

$$C_u = 53.07 \text{ kN/m}^2$$

Now, the given condition is shown in figure.

$$G = 2.65$$

Dry unit weight of soil, $\gamma_d = 16 \text{ kN/m}^3$

Now, $$\gamma_d = \frac{G\gamma_w}{1+e}$$

$$\Rightarrow \quad 16 = \frac{2.65 \times 9.81}{1+e}$$

$$\Rightarrow \quad e \simeq 0.62$$

Submerged unit weight of the soil,

$$\gamma_{sub} = \frac{(G-1)}{1+e}\gamma_w = \frac{2.65-1}{1+0.62} \times 9.81 = 9.99 \text{ kN/m}^3$$

Now effective stress at a depth of 5 m,

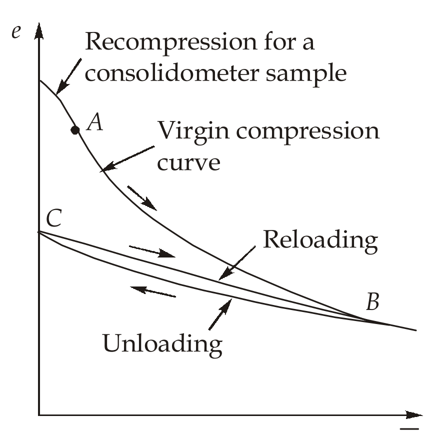
$$\bar{\sigma} = (16 \times 2.5 + 9.99 \times 2.5) = 64.975 \text{ kN/m}^2$$

Hence shearing resistance at 5 m depth,

$$\tau = C_u + \bar{\sigma}\tan\phi$$
$$= 53.07 + 64.975 \times \tan 11.54°$$
$$= 66.34 \text{ kN/m}^2$$

(ii)

Soil tends to retain the effect of stress change that have taken place in their geological history, in the form of their structure. When a soil is stressed to a level greater than maximum stress to which it was ever subjected in the past, some kind of breakdown in the soil occurs, resulting in a much higher compressibility indicated by a steep void-effective stress curve ($e - \bar{\sigma}$).



The initial flatter portion of the e – $\bar{\sigma}$ curve is called recompression curve and the steeper portion after the break in the curve is called virgin compression curve, because the soil is experienceing first time stresses in this part. Somewhere, between these two parts of the curve lies point *A* corresponding to the maximum value of stress the soil has ever experienced, called the preconsolidation pressure.

Q.7 (a) Solution:

Magnesium bicarbonate reacts with lime in two steps with equation as

$$Mg(HCO_3)_2 + 2Ca(OH)_2 \rightarrow 2CaCO_3 + Mg(OH)_2 + 2H_2O$$

Above reaction shows that magnesium bicarbonate needs two equivalents of lime as against one equivalent of lime needed by others like calcium bicarbonate, magnesium chloride and Magnesium sulphate whereas calcium sulphate does not need any lime.

(i) Requirement of hydrated lime:

1. To react with $CaCO_3$ of 280 ppm:

100 ppm $CaCO_3$, needs hydrated lime = 74 ppm

$\therefore$ 280 ppm of $CaCO_3$ will need = $\frac{74}{100} \times 280$

= 207.2 ppm of hydrated lime

2. To react with $Mg(HCO_3)_2$ of 100 ppm:

146 ppm of $Mg(HCO_3)_2$ needs hydrated lime = 2 × 74 ppm

100 ppm of $Mg(HCO_3)_2$ will need hydrated lime = $\frac{2 \times 74 \times 100}{146}$ = 101.4 ppm

3. To react with $MgCl_2$ of 138 ppm:

95 ppm of $MgCl_2$ needs hydrated lime = 74 ppm

138 ppm of $MgCl_2$ will need hydrated lime = $\frac{74 \times 138}{95}$ = 107.5 ppm

4. To react with $MgSO_4$ of 80 ppm:

120 ppm of $MgSO_4$ needs hydrated lime = 74 ppm

80 ppm of $MgSO_4$ will need hydrated lime = $\frac{74 \times 80}{120}$ = 49.3 ppm

$\therefore$ Total lime = 207.2 + 101.4 + 107.5 + 49.3 = 465.4 ppm

Daily lime required = $465.4 \times 10^{-6} \times 50000$ = 23.27 kg/day

Since the purity of lime is 86% hence, daily lime requirement = $\frac{23.27}{0.86}$ = 27.06 kg/day

(ii) **Requirement of soda (Na_2CO_3)**: Soda is required for reacting with $CaSO_4$, $MgCl_2$ and $MgSO_4$.

1. To react with $CaSO_4$ of 110 ppm:
   136 ppm of $CaSO_4$ needs Na_2CO_3 = 106 ppm

   110 ppm of $CaSO_4$ will need $Na_2CO_3 = \frac{106}{136}\times 110$ = 85.7 ppm of Na_2CO_3

2. To react with $MgCl_2$ of 138 ppm ($MgCl_2$ has been converted into equivalnet $CaCl_2$ by lime)
   95 ppm of $MgCl_2$ needs 106 ppm of Na_2CO_3.

   $\therefore$138 ppm of $MgCl_2$ will need = $\frac{106}{95}\times 138$ = 154 ppm of Na_2CO_3

3. To react with $MgSO_4$ of 80 pm (After $MgSO_4$ has been reduced in equivalent $CaSO_4$ by lime)
   120 ppm of $MgSO_4$ needs 106 ppm of Na_2CO_3

   80 ppm of $MgSO_4$ will need $\frac{106}{120}\times 80$ = 70.7 ppm of Na_2CO_3.

Total soda required = 85.7 + 154 + 70.7

= 310.4 ppm = 310.4 mg/lt

Daily soda requirement to react 50,000 litres of water the soda having 98% purity

$$= \frac{310.4\times 50,000}{10^6}\times\frac{1}{0.98} = 15.84 \text{ kg/day}$$

Q.7 (b) Solution:

Lateral earth pressure refers to the force exerted by soil or other materials against a retaining structure, such as a wall or a foundation.

Unlike fluids, soil solids do not transfer pressure equally in all directions. Hence lateral pressure in soils depends on lateral strain conditions and the nature of the soil. It is related to the magnitude of vertical pressure as:

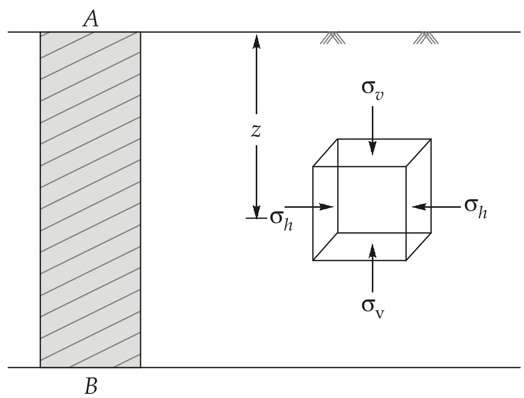
$$\sigma_h = k\sigma_v$$

Lateral earth pressure acting on the retaining structures is divided into three categories depending upon the movement of retaining structure with respect to backfill soil.

1. Earth pressure at rest – Wall does not move at all.

2. Active earth pressure –Wall moves away from the backfill.
3. Passive earth pressure –Wall moves towards the backfill.

1. **Earth pressure at rest**: When the wall is rigid and unyielding, the soil mass is in the state of rest and there are no deformations and displacement. The earth pressure corresponding to this state is called earth pressure at rest.



Let, σ_v = Vertical earth pressure

σ_h = Horizontal earth pressure

Coefficient of earth pressure at rest,

$$k_0 = \frac{\sigma_h}{\sigma_v}$$

At rest condition:

Lateral strain, $(\in_h) = 0$

$$\Rightarrow \quad \in_h = \frac{\sigma_h}{E} - \mu\frac{\sigma_h}{E} - \mu\frac{\sigma_v}{E} = 0$$ where μ is Poisson's ratio.

$$\Rightarrow \quad \sigma_h(1-\mu) = \mu\sigma_v$$

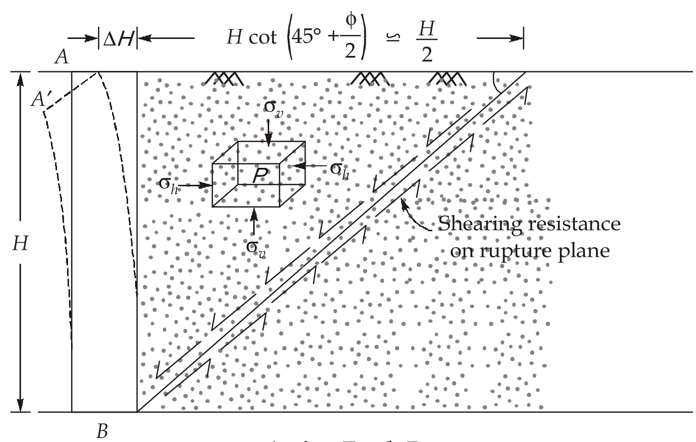
$$\Rightarrow \quad \frac{\sigma_h}{\sigma_v} = \frac{\mu}{(1-\mu)}$$

Thus, coefficient of lateral earth pressure at rest condition is,

$$k_0 = \frac{\mu}{(1-\mu)}$$

2. **Active earth pressure**: During the active stage, wall moves away from the backfill and the portion of the backfill just behind the wall leaves the rest of the soil mass and moves along with wall.

The resistance of the soil due to its shear resistance is mobilized in upward and outward direction on the rupture plane which decreases the pressure on the wall. This decrease in pressure takes place upto an extent when entire shear resistance is mobilized. The minimum pressure acting on the wall in this stage is termed as active earth pressure.



Active Earth Pressure

At plastic equilibrium

$$\sigma_1 = \sigma_3 \tan^2\left(45° + \frac{\phi}{2}\right) + 2C \tan\left(45° + \frac{\phi}{2}\right)$$

For cohesionless soil $C = 0$

So, $$\sigma_1 = \sigma_3 \tan^2\left(45° + \frac{\phi}{2}\right)$$

For active stage, $\sigma_1 = \sigma_v$ and $\sigma_3 = \sigma_v$

$\therefore$ $$\sigma_v = \sigma_h \tan^2\left(45° + \frac{\phi}{2}\right)$$

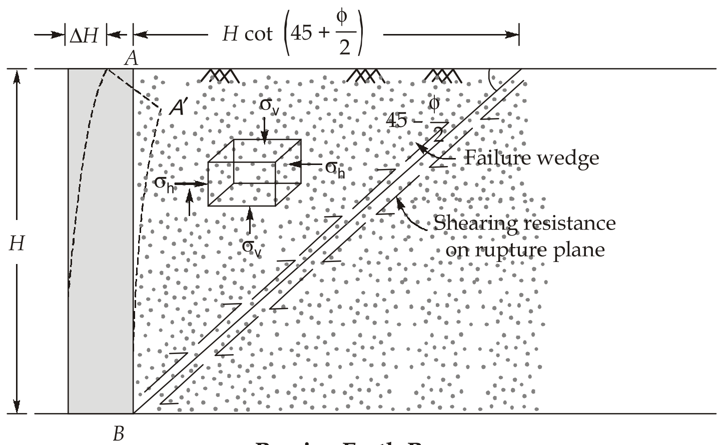
$\Rightarrow$ $$\frac{\sigma_h}{\sigma_v} = \frac{1}{\tan^2\left(45° + \frac{\phi}{2}\right)}$$

$\Rightarrow$ $$k_a = \frac{1 - \sin\phi}{1 + \sin\phi}$$

where k_a is active earth pressure coefficient.

3. **Passive earth pressure**: In passive stage, wall moves towards the backfill. The shearing resistance on the wall builds up against the wall, which results in increase of pressure on the wall.

This increase in pressure takes place upto an extent when entire shear resistance is mobilized. The maximum pressure acting on the wall in this stage is termed as passive earth pressure.



Passive Earth Pressure

For passive stage:

$$\sigma_1 = \sigma_h, \quad \sigma_3 = \sigma_v$$

$$\therefore \quad \sigma_h = \sigma_v \tan^2\left(45^\circ + \frac{\phi}{2}\right)$$

$$\Rightarrow \quad \frac{\sigma_h}{\sigma_v} = \tan^2\left(45^\circ + \frac{\phi}{2}\right)$$

$$\Rightarrow \quad k_p = \tan^2\left(45^\circ + \frac{\phi}{2}\right) = \frac{1+\sin\phi}{1-\sin\phi}$$

where k_p is passive earth pressure coefficient.

Q.7 (c) Solution:

$$\text{Supply} = \text{Mean monthly flow} \times \text{Days} \times 86400 \times 10^{-6} \text{ Ml}$$

Mean monthly flow	Supply (Ml)	Cumulative Supply (CS)	Demand (Ml)	Cumulative demand (CD)	CS – CD
15	40.176	40.176	68.49	68.49	– 28.314
10	24.192	64.368	68.49	136.98	– 72.612
8	21.427	85.795	68.49	205.47	– 119.675
6	15.552	101.347	68.49	273.96	– 172.613
5	13.392	114.739	68.49	342.45	– 227.711
12	31.104	145.843	68.49	410.94	– 265.097
25	66.96	212.803	68.49	479.43	– 266.627
40	107.136	319.939	68.49	547.92	– 227.981
71	184.032	503.971	68.49	616.41	– 112.449
60	160.704	664.675	68.49	684.90	– 20.225
40	103.680	768.355	68.49	753.39	+ 19.965
20	53.568	821.923	68.49	821.88	0.043
	Σ = 821.923		Σ = 821.88		

$$\text{Rate of demand/month} = \frac{\text{Total supply}}{\text{Number of months}}$$

$$= \frac{821.923}{12} = 68.49 \text{ Ml/month}$$

$$\text{Maximum supply} = 184.032 \text{ million litres}$$

$$\text{Balancing storage} = (CS - CD)_{max.} + (CD - CS)_{max}$$

$$\text{Minimum capacity of reservoir} = [19.965 + 266.627] \times 10^6 \times 10^{-4}$$

$$= 28659.2 \text{ ha.m.}$$

As the number of days in month of february is less and supply is same irrespective of the month, so 28 days will be used to calculate capacity of conduit.

$$\text{Capacity of conduit} = \frac{68.49 \times 10^6 \times 10^3}{28 \times 86400} = 28.31 \text{ m}^3/\text{sec}$$

Q.8 (a) Solution:

(i)

When water flows through saturated soil mass, it exerts pressure over the soil skelton by virture of frictional drag. This pressure is termed as seepage pressure. The seepage pressure is exterted by the water on the soil in the direction of the flow.

When the flow takes place from downwards to upwards direction, water exerts seepage pressure in upwards direction and hence results in a decrease of effective stress of the soil mass. If the seepage pressure is such that it equals the submerged weight of the soil mass, then effective stresses at that location reduces to zero. Under such conditions, cohesionless soil mass looses all its shear strength and the soil mass has a tendency to move along the flowing water in the upward direction. This process in which soil particles are lifted over along with water is called quick sand condition.

In "quick sand" condition, $\bar{\sigma} = 0$

$$\Rightarrow \quad \bar{\sigma} = \gamma' z - iz\gamma_w = 0$$

$$\Rightarrow \quad i = \frac{\gamma'}{\gamma_w} = i_{cr}$$

$$\Rightarrow \quad i_{cr} = \frac{\gamma'}{\gamma_w} = \left(\frac{G-1}{1+e}\right)$$

'i_{cr}' is the gradient at which quick sand condition occurs, hence it is called as critical hydraulic gradient, piping gradient or floating gradient. To avoid the piping, hydraulic gradient should be less than i_c critical hydraulic gradient.

Quick sand condition occurs mainly in fine sand because in clay, shear strength does not reduce to zero, even if effective stress reduces to zero and particles are bounded due to their inherent cohesion.

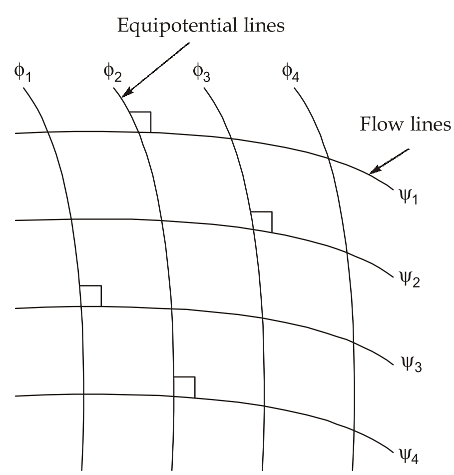
This condition does not arise in gravels and coarse sand as discharge required to generate critical hydraulic gradient is very large and practically impossible.

(ii)

When flow takes place in 2-D then Darcy's equation cannot be used. In such case of seepage, Laplace equations are used which represent the loss of energy head in any resistive medium like soil. The graphical solution of Laplace's equation for relevant boundary conditions is a pattern of flow lines and equipotential lines referred as flow net.

Properties of flow net:

- Flow lines (ψ lines) and equipotential lines (ϕ-lines) meet each other orthogonally.
- Flow lines and equipotential lines are smooth continous curves, being either elliptical or parabolic in shape.
- Flow takes place parallel to the flow line and velocity vector is perpendicular to equipotential line.
- The area between two flow lines is termed as flow channels and discharge through each flow channel (Δq) remains same.
- Loss of head between two equipotential lines and two flow lines is called flow field, which are approximately square in isotropic medium, which may be linear or curvilinear whereas as in non-isotropic medium, flow field is rectangular which may be linear or curvilinear.



Flow Nets

Application of flow nets:

Flow nets can be used to determine:

1. Seepage discharge.
2. Seepage pressure.
3. Pore water pressure or uplift pressure.
4. Exit gradient.

1. Seepage discharge can be found out using relation.

$$q = kH\frac{N_f}{N_d}$$

where q is discharge, k is permeability, H is head available, N_f is number of flow channels and N_d is number of equipotential drops.

For non-isotropic medium, $k_{eq} = \sqrt{k_x k_y}$

2. Determination of seepage pressure

   Let 'h' be the seepage head after equipotential drop. Then, seepage pressure (p_s)
   = seepage head (h) × γ_w

   $$\therefore \quad p_s = h\,\gamma_w$$

   After n equipotential drops

   $$h = H - n\Delta h$$

3. Determination of pore pressure

   Let h_w is the pressure head after 'n' equipotential drops.

   Then, pore water pressure = $h_w\,\gamma_w$

4. Determination of exit gradient

   $$i_{exit} = \frac{\Delta h}{l}$$

   where l is the length of flow.

Q.8 (b) Solution:

$$\text{Average daily demand} = \text{Population} \times \text{Per capita demand}$$
$$= 2{,}75{,}000 \times 200$$
$$= 55 \times 10^6\ l/\text{d} \quad = 55\ \text{MLD}$$
$$\text{Maximum daily demand} = 1.8 \times 55 = 99\ \text{MLD}$$

Filtered water required for backwashing = 5%

$$= 5\%\ \text{of}\ 99\ \text{MLD} = 4.95\ \text{MLD}$$

∴ Daily water demand of filtered water = 99 + 4.95 = 103.95 MLD

Since 30 minutes is lost daily in back washing the filters, the effective time left for working of filter units.

$$= 24 - 0.5 = 23.5\ \text{hr}$$

∴ Filtered water required per hour = $\frac{103.95}{23.5}$ = 4.42 ML/hr.

Now, filtration rate = $15\ \text{m}^3/\text{m}^2/\text{h}$

$$\therefore \quad \text{Area of filter required} = \frac{\left[\frac{4.42 \times 10^6}{10^3}\right]\text{m}^3/\text{hr}}{15\ \text{m}^3/\text{m}^2/\text{hr}} = 294.67\ \text{m}^2$$

Given, Size of filter = 10 m × 4 m

Area of one filter unit = 40 m^2

$$\text{Number of filter units required} = \frac{294.67}{40} = 7.37 \simeq 8$$

Using one filter unit as stand by unit, total number of filter units required = 9

$$\text{Now, settling velocity, } V_s = \sqrt{\frac{\frac{4}{3}g.d.(G-1)}{C_D}}$$

$$= \sqrt{\frac{\frac{4}{3}\times 9.81\times(0.6\times 10^{-3})\times(2.5-1)}{5.02}} = 0.048 \text{ m/sec.}$$

Now,

$$\frac{D_e}{D} = \frac{1-\eta}{1-\eta_e}$$

where η and η_e are porosity of unexpanded and expanded bed respectively.

$$\therefore \quad \frac{0.66}{0.60} = \frac{1-0.5}{1-\eta_e}$$

$$\Rightarrow \quad (1 - \eta_e) = \frac{0.5\times 0.6}{0.66} = 0.455$$

$$\Rightarrow \quad \eta_e = 0.545$$

Now,

$$\eta_e = \left(\frac{V_b}{V_s}\right)^{0.22}$$

$$\Rightarrow \quad 0.545 = \left(\frac{V_b}{0.048}\right)^{0.22}$$

$$\Rightarrow \quad V_b = 3.04 \times 10^{-3} \text{ m/s} = 0.304 \text{ cm/sec}$$

$$= 18.2 \text{ cm/min}$$

Hence the backwash upflow velocity of water = 18.2 cm/min.

Head loss through the expanded medium is,

$$h_{Le} = D_e(1 - \eta_e)(G - 1)$$

$$= (1 - 0.545) \times 0.66 \times (2.5 - 1)$$

$$= 0.455 \times 0.66 \times 1.5 = 0.45 \text{ m}$$

Q.8 (c) Solution:

(i) As per Dupuit's equation:

$$\text{Discharge, } q = \frac{\pi k\left[H_1^2 - H_2^2\right]}{2.303\log\left[\frac{r_2}{r_1}\right]}$$

Now,

$$q = 1500 \text{ lt/min}$$
$$H_1 = 100 - 5 = 95 \text{ m}$$
$$H_2 = 100 - 1.5 = 98.5 \text{ m}$$
$$r_1 = 6 \text{ m}$$
$$r_2 = 16 \text{ m}$$

$$\therefore \quad \frac{1500\times10^{-3}\ \text{m}^3}{60\,\text{sec.}} = \frac{\pi\times k\times[98.5^2 - 95^2]}{2.303\times\log\left[\frac{16}{6}\right]}$$

$$\Rightarrow \quad k = 1.15\times10^{-5} \text{ m/sec.}$$

So, permeability coefficient ofmMedium = 1.15×10^{-5} m/sec.

(ii) Drawdown in the pumped well:

$$q = \frac{\pi k\left[h_1^2 - h_0^2\right]}{2.303\log\left[\frac{R_1}{r_w}\right]}$$

Here,

$$r_w = \text{Radius of well} = 0.25 \text{ m}$$
$$h_0 = \text{Depth of water in the pumped well}$$

$$\therefore \quad \frac{1.5\,\text{m}^3}{60\,\text{sec.}} = \frac{\pi\times1.15\times10^{-5}\times\left[95^2 - h_0^2\right]}{2.303\log\left[\frac{6}{0.25}\right]}$$

$$h_0 = 82.62 \text{ m}$$

$\therefore$ Drawdown in the pumped well = 100 – 82.62 = 17.38 m

(iii) For specific capacity, discharge should be corresponding to unit drawdown.

$$\therefore \quad Q_{sc} = \frac{\pi k\left[H^2 - H_{sc}^2\right]}{2.303\log\left(\frac{R}{r_w}\right)}$$

where R is radius of influence

Here, $H = 100$ m

$H_{sc} = 100 - 1 = 99$ m

$r_w = 0.25$ m

Now to find R,

$$Q = \frac{\pi k\left[H^2 - h_0^2\right]}{2.303\log\left(\frac{R}{r_w}\right)}$$

$$\Rightarrow \quad \frac{1.5\,\text{m}^3}{60\,\text{sec.}} = \frac{\pi\times 1.15\times 10^{-5}\times\left(100^2 - 82.62^2\right)}{2.303\log_{10}\left[\frac{R}{0.25}\right]}$$

$$\Rightarrow \quad R = 24.52 \text{ m}$$

$$\therefore \quad Q_{sc} = \frac{\pi\times 1.15\times 10^{-5}\times\left(100^2 - 99^2\right)}{2.303\log_{10}\left[\frac{24.52}{0.25}\right]}$$

$$\Rightarrow \quad Q_{sc} = 94.05\ l/\text{min.}$$

For maximum discharge, drawdown in test well should be maximum.

$$\therefore \quad S_0 = 100 \text{ m}$$

$$\Rightarrow \quad H_0 = 0$$

$$Q_{\text{max.}} = \frac{\pi k\left[H^2 - H_0^2\right]}{2.303\log\left(\frac{R}{r_w}\right)}$$

$$\Rightarrow \quad Q_{\text{max.}} = \frac{\pi\times 1.15\times 10^{-5}\times\left[100^2 - 0^2\right]}{2.303\log\left[\frac{24.52}{0.25}\right]}$$

$$\Rightarrow \quad Q_{\text{max.}} = 7.88\times 10^{-2}\ \text{m}^3/\text{sec} = 4728 \text{ litre/min.}$$

(iv) Drawdown in the observation well cooresponding to the maximum discharge.

$$Q_{\text{max.}} = \frac{\pi k\left[H_1^2 - H_0^2\right]}{2.303\log\left[\frac{R_1}{r_w}\right]}$$

$$\Rightarrow \qquad 7.88 \times 10^{-2} = \frac{\pi \times 1.15 \times 10^{-5} \left(H_1^2 - 0\right)}{2.303 \times \log\left[\frac{6}{0.25}\right]}$$

$$\Rightarrow \qquad H_1 = 83.26 \text{ m}$$

Drawdown in first observation well, S_1 = 100 – 83.26 = 16.74 m

Also,
$$Q_{max.} = \frac{\pi k\left[H_2^2 - H_0^2\right]}{2.303 \log\left[\frac{R_2}{r_w}\right]}$$

$$\Rightarrow \qquad 7.88 \times 10^{-2} = \frac{\pi \times 1.15 \times 10^{-5} \times \left[H_2^2 - 0\right]}{2.303 \times \log\left[\frac{16}{0.25}\right]}$$

$$\Rightarrow \qquad H_2 = 95.25 \text{ m}$$

$$\therefore \qquad S_2 = 100 - 95.25 = 4.75 \text{ m}$$

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