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ESE 2024

Main Exam Detailed Solutions

Civil Engineering

PAPER-II

EXAM DATE : 23-06-2024 | 02:00 PM to 05:00 PM

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ANALYSIS

Civil Engineering Paper-II
ESE 2024 Main Examination

Sl.	Subjects	Marks
1.	Fluid Mechanics & Hydraulic Machines	59
2.	Engineering Hydrology	12
3.	Water Resource Engineering	30
4.	Environmental Engineering	139
5.	Soil Mechanics & Foundation Engg.	114
6.	Surveying and Geology	42
7.	Transportation Engineering	84
		Total 480

Scroll down for detailed solutions

SECTION : A

Q.1 (a) A rectangular plate of 0.50 m × 0.50 m dimensions and weighing 500 N slides down an inclined plane making 30° angle with the horizontal. The velocity of the plate is 1.75 m/s. If the 2 mm gap between the plate and the inclined surface is filled with lubricating oil, find the viscosity of oil and express it in units of poise as well as N-s/m^2. Assume the plate as frictionless.

[12 marks : 2024]

Solution:

Given:

Angle of inclination, $\theta = 30°$

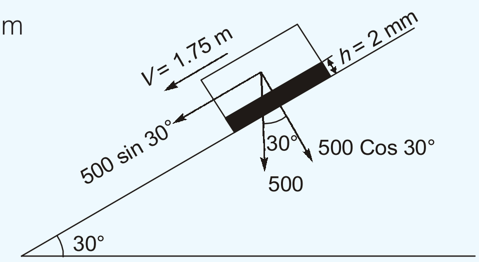
Area of plate, $A = 0.5 \text{ m} \times 0.5 \text{ m} = 0.25 \text{ m}^2$

Weight of plate, $W = 500$ N

Velocity of plate, $V = 1.75$ m/s

Gap between plate and surface,

$$h = 2 \text{ mm} = 2 \times 10^{-3} \text{ m}$$



On the plate, drag force will act due to shear resistance between plate and oil.

Now, Drag force, $F_D = W \sin 30°$

$\Rightarrow$ $\tau A = 500 \sin 30°$

where τ is shear stress acting on plate

$$\Rightarrow \quad \mu\left(\frac{V-0}{h}\right) \times A = 250$$

where μ is coefficient of viscosity

$$\Rightarrow \quad \mu\left(\frac{1.75}{2 \times 10^{-3}}\right) \times 0.5 \times 0.5 = 250$$

$$\Rightarrow \quad \mu = 1.143 \text{ N–s/m}^2 = 11.43 \text{ poise}$$

End of Solution

Q.1 (b) The following is the set of observed data for successive 15 minutes period of 105 minutes storm in a catchment:

Duration (min)	15	30	45	60	75	90	105
Rainfall (cm/hr)	2.0	2.0	8.0	7.0	1.25	1.25	4.5

If the value of ϕ-index is 3.0 cm/hr, estimate the net runoff, the total rainfall and the value of W-index.

[12 marks : 2024]

Solution:

Runoff in each step is equal to incremental rainfall in that time step minus the infiltration loss calculated as $\phi\Delta t$ where Δt is 0.25 hour. This number i.e. runoff is always equal to or greater than zero, as runoff is always a positive quantity. Calculations are tabulated below.

Time from start (hr)	Increment of time (Δt) (in hrs)	Rainfall (in cm/hr)	Incremental Rainfall (Rainfall × Δt) (in cm)	Infiltration loss = $\phi \times \Delta t$ (in cm)	Runoff (cm)
(1)	(2)	(3)	(4)	(5)	(6)
0	0	0	0	0	0
0.25	0.25	2.0	0.5	0.75	0
0.5	0.25	2.0	0.5	0.75	0
0.75	0.25	8.0	2	0.75	1.25
1	0.25	7.0	1.75	0.75	1
1.25	0.25	1.25	0.3125	0.75	0
1.5	0.25	1.25	0.3125	0.75	0
1.75	0.25	4.5	1.125	0.75	0.375
		Total	= 6.5 cm		= 2.625 cm

So, Net runoff, $R = 2.625$ cm

Precipitation, $P = 6.5$ cm

Now, $$W \text{ index} = \frac{P-R}{\text{Duration}} = \frac{6.5-2.625}{1.75}$$
$$= 2.214 \text{ cm/hr}$$

End of Solution

Q.1 (c) A hydraulic turbine has an output of 6600 kW when it works under a head of 25 m and runs at 100 r.p.m. What is the type of the turbine? What would be its speed and what power will it develop when working under a head of 16 m?

[12 marks : 2024]

Solution:

Given:

Shaft Power, $S.P. = 6600$ kW

Head, $H = 25$ m

Speed, $N = 100$ rpm

Now, specific speed, $$N_s = \frac{N\sqrt{P}}{H^{5/4}} = \frac{100\sqrt{6600}}{25^{5/4}}$$
$$= 145.327 \quad \text{(S.I. unit)}$$

So, it is a francis turbine.

Now, when the turbine is working under the head of 16 m.

From similarities laws,

$$\frac{N_1}{\sqrt{H_1}} = \frac{N_2}{\sqrt{H_2}}$$

$$\Rightarrow \quad \frac{100}{\sqrt{25}} = \frac{N_2}{\sqrt{16}}$$

$$\Rightarrow \quad N_2 = \frac{100\sqrt{16}}{\sqrt{25}} = 80 \; rpm$$

Also, $$\frac{P_1}{H_1^{3/2}} = \frac{P_2}{H_2^{3/2}}$$

$$\Rightarrow \quad \frac{6600}{25^{3/2}} = \frac{P_2}{16^{3/2}}$$

$$\Rightarrow \quad P_2 = 3379.2 \text{ kW}$$

End of Solution

Q.1 (d) A large stream flowing through an industrialised area is the only source of raw water for the community water supply. The stream water is consistently turbid, has hardness in excess of 300 mg/L as $CaCO_3$ and has refractory organics that are known precursor of trihalomethanes. Draw a schematic diagram of a treatment plant that could render this water potable. Identify all the units. State their purpose, show points of chemical addition and identify all the chemicals.

[12 marks : 2024]

Solution:

The following treatments are required to be done to a water consisting of high turbidity, high hardness and refracting organics:

1. Screening :
   Unit used: Coarse screen
   Purpose: Removes larger particles which are commonly present in stream water.
2. Aeration :
   Unit used: Cascade Aerator
   Purpose: To increase the surface area of water such that if any VOCs are there, they can be removed. It also reduces harmful gases and increases the DO content.
3. Coagulation and Flocculation
   Unit used: Coagulation Tank and Flocculation chamber
   Purpose: Lime and soda for water softening. Alum to ensure formation of flocs which can also help remove the refractory organics from the water. Addition of coagulant and Fast mixing will be a part of coagulation process. Slow or gentle mixing will be a part of flocculation process.
4. Sedimentation :
   Unit used: Sedimentation Tank
   Purpose: Allow the flocs to settle under the action of gravity.
5. Recarbonation
   Unit used: Recarbonation Tank
   Purpose: To ensure availability of carbonate hardness in water by passing CO_2 gas through the settled water.
6. Filtration :
   Unit used: Rapid Sand Filter
   Purpose: To remove the remaining suspended solids.
7. Activated Carbon Bed Adsorption :
   Unit used: Activated Carbon filter
   Purpose: to remove refractory organics (if any) by passing the filtered water through a granular bed of activated carbon.

8. Disinfection :

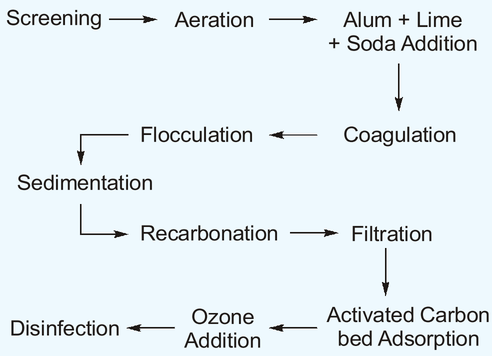
Unit used: Disinfection Tank

Chemical used: Ozone

Purpose: to kill the micro-organisms. We will not use chlorine in this case since chlorine is itself a halogen and it can promote formation of THM (Trihalomethanes).

Finally, the schematic diagram of the treatment process can be shown as follows:

Moreover, in before coagulation process, pH adjustment can also be done (if required).



End of Solution

Q.1 (e) For BOD analysis, 30 mL of treated wastewater sample with DO of zero was mixed with 270 mL of dilution water with DO of 10 mg/L. The 5^{th} and 6^{th} days being holidays, the lab was closed. The final DO was measured as 4 mg/L on the 7^{th} day. It was also found that the incubator was set at 30°C. Assuming the BOD reaction rate constant as 0.23 day^{-1} at 20°C and the temperature coefficient as 1.047, determine the 5-day, 20°C BOD of the sample.

[12 marks : 2024]

Solution:

DO of sample, $DO_{ww} = 0$

DO of dilution water, $DO_{DW} = 10$ mg/l

Volume of sample, $V_{WW} = 30$ mL

Volume of dilution water, $V_{DW} = 270$ mL

Now, Initial DO of mix, $(DO_i)_{mix} = \dfrac{DO_{WW} \times V_{WW} + DO_{DW} \times V_{DW}}{V_{WW} + V_{DW}}$

$$= \frac{0 \times 30 + 10 \times 270}{30 + 270} = 9 \text{ mg/l}$$

Final DO of mix after 7 days, $(DO_f)_{mix} = 4$ mg/l

Now,BOD after 7 days at 30°C, $BOD_{7@30°C} = ((DO_i)_{mix} - (DO_f)_{mix}) \times$ Dilution factor

$$= (9 - 4) \times \frac{300}{30} = 50 \text{ mg/l}$$

Now,deoxygenation constant, $k_{@20°C} = 0.23$ per day

So, $k_{@30°C} = k_{@20°C} \times (1.047)^{30° - 20°}$

$$= 0.23 \times 1.583 = 0.364 \text{ per day}$$

Now, $BOD_{7@30°C} = L_0(1 - e^{-k@30° \times t})$

where L_0 is ultimate BOD

$\Rightarrow$ $50 = L_0(1 - e^{-0.364 \times 7})$

$\Rightarrow$ $L_0 = 54.24 \text{ mg/l}$

Now, $BOD_{5@20°C} = L_0(1 - e^{-k@20° \times t})$

$$= 54.24(1 - e^{-0.364 \times 5})$$

$$= 37.065 \text{ mg/l}$$

End of Solution

Q.2 (a) Treated wastewater having a peak flow rate of 12000 m^3/day, BOD_5 of 30 mg/L, DO concentration of 1 mg/L and temperature of 27°C is discharged in a stream. Before getting mixed with the wastewater, the stream has a minimum flow rate of 0.4 m^3/s, BOD_5 of 4 mg/L, DO concentration of 7 mg/L and temperature of 25°C. After instantaneous and complete mixing, the velocity of the mixed flow is 0.2 m/s. For the mixed flow, the BOD reaction rate constant is 0.2 day^{-1} and the reaeration constant is 0.4 day^{-1} at 20°C. Estimate the initial oxygen deficit and DO after two days of flow. Take temperature coefficient for BOD reaction rate constant as 1.047 and for stream reaeration rate constant as 1.016. Take equilibrium concentration of DO for water after mixing as 8.3 mg/L.

[20 marks : 2024]

Solution:

For wastewater

Discharge, $Q = 12000 \text{ m}^3/\text{day} = 0.139 \text{ m}^3/\text{s}$

$BOD_5 = 30 \text{ mg/L}$

$DO = 1 \text{ mg/L}$

Temperature, $T = 27°C$

For stream

Discharge, $Q = 0.4 \text{ m}^3/\text{s}$

$BOD_5 = 4 \text{ mg/L}$

$DO = 7 \text{ mg/L}$

Temperature $= 25°C$

Now, $$BOD_{mix} = \frac{0.139 \times 30 + 0.4 \times 4}{0.139 + 0.4} = 10.70 \text{ mg/L}$$

Ultimate BOD of mix, $$L_0 = \frac{BOD_{mix}}{1 - e^{-k_1 \times t}}$$

where k_1 is deoxygenation rate constant for mix

$$= \frac{10.7}{1 - e^{-0.2 \times 5}} = 16.93 \text{ mg/L}$$

Now, $$DO_{mix} = \frac{0.139 \times 1 + 0.4 \times 7}{0.139 + 0.4}$$
$$= 5.45 \text{ mg/L}$$
$$T_{mix} = \frac{0.139 \times 27° + 0.4 \times 25°}{0.139 + 0.4}$$
$$= 25.52°C$$

Now, $$k_{1@25.52°C} = k_{1@20°C} \times (1.047)^{T-20°}$$
$$= 0.2 \times (1.047)^{25.52° - 20°}$$
$$= 0.26 \text{ /day}$$
$$k_{2@25.52°C} = k_{2@20°C} \times (1.016)^{T-20°}$$
$$= 0.4 \times (1.016)^{25.52 - 20°}$$
$$= 0.44 \text{ /day}$$

Now, equilibrium concentration of DO after mixing = 8.3 mg/L

So, initial oxygen deficit, D_O = 8.3 – 5.45 = 2.85 mg/L

Deficit after 2 days at 25.52°C, $D_t = \frac{k_1 L_0}{k_2 - k_1}\left(e^{-k_1 t} - ^{-k_2 t}\right) + D_0 e^{-k_2 t}$

$$= \frac{0.26 \times 16.93}{0.44 - 0.26}\left(e^{-0.26 \times 2} - e^{-0.44 \times 2}\right) + 2.85 \times e^{-0.44 \times 2}$$
$$= 4.395 + 1.182 = 5.58 \text{ mg/L}$$

So, DO after 2 days of mixing = 8.3 – 5.58 = 2.72 mg/L

End of Solution

Q.2 (b) (i) For a hydraulic jump in a rectangular channel, the velocity and depth after the jump are known to be 0.80 m/s and 1.75 m respectively. Calculate the depth before jump, the energy loss and the power dissipated per metre width.

[15 marks : 2024]

(ii) What do you mean by diversion headworks? Distinguish clearly between a weir and a barrage.

[5 marks : 2024]

Solution:

(i)

Velocity after jump, V_2 = 0.8 m/s

Depth after jump, y_2 = 1.75 m

Now, Froude's number after jump, $F_2 = \frac{V_2}{\sqrt{gy_2}} = \frac{0.8}{\sqrt{9.81 \times 1.75}} = 0.193$

Now, Sequent depth ratio, $\frac{y_1}{y_2} = \frac{1}{2}\left[-1 + \sqrt{1 + 8F_2^2}\right]$

where y_1 is depth before jump

$$\Rightarrow \quad \frac{y_1}{1.75} = \frac{1}{2}\left[-1+\sqrt{1+8\times0.193^2}\right]$$

$$\Rightarrow \quad y_1 = 0.12 \text{ m}$$

Also, Energy loss, $E_L = \dfrac{(y_2 - y_1)^3}{4y_1y_2}$

$$= \frac{(1.75-0.12)^3}{4\times0.12\times1.75} = 5.15 \text{ m}$$

Also, $\dfrac{2q^2}{g} = y_1y_2(y_1 + y_2)$

where q is discharge per unit width

$$\Rightarrow \quad \frac{2\times q^2}{9.81} = 0.12 \times 1.75\,(0.12 + 1.75)$$

$$\Rightarrow \quad q = 1.39 \text{ m}^3\text{/s/m}$$

Now, power dissipated per metre = $\gamma q E_L$

$= 9810 \times 1.39 \times 5.15$

$= 70224.89$ Watts = 70.22 kW

(ii)

The works, which are constructed at the head of the canal, in order to divert the river water towards the canal, so as to ensure a regulated continuous supply of silt-free water with a certain minimum head into the canal, are known as Diversion Head Works.

Weir and Barrage:

In general, the above purpose can be accomplished by constructing a barrier across the river, so as to raise the water level on the upstream side of the obstruction, and thus, to feed the main canals taking off from its upstream side at one or both of its flanks. The ponding of water can be achieved either only by a permanent pucca raised crest across the river or by a raised crest supplemented by falling counter-balanced gates or shutters, working over the crest. If the major part or the entire ponding of water is achieved by a raised crest and a smaller part or nil part of it is achieved by the shutters, then this barrier is known as a weir. On the other hand, if most of the ponding is done by gates and a smaller or nil part of it is done by the raised crest, then the barrier is known as a Barrage or a River Regulator.

End of Solution

Q.2 (c) (i) A water treatment plant in a city of 100000 population supplies water at the rate of 150 lpcd. Two equal capacity circular settling tanks are to be provided to settle flocculent suspension through Type-II settling. Design the tanks. Take SOR as 20 m^3/m^2-d and water depth of 3.5 m. Leave sludge zone of 0.5 m and keep inlet and outlet zones equal to the side water depth. Calculate the weir loading. Draw the sketch of the tank showing all the zones and dimensions.

[12 marks : 2024]

(ii) In an ideal granular media filter, the entire depth of the filter media should contribute to the retention and removal of solids, ensuring longer filter runs, less head loss and greater filtration rates. Why will the single media filters fail to achieve this? How can the mixed media filter approach an ideal filter in performance?

[8 marks : 2024]

Solution:

(i)

Total water flow, $Q = 150 \times 100000$

$= 15 \times 10^6\ L/d$

$= 15\ MLD$

As the two tanks will be used, so flow in each circular tank will be 7.5 MLD

Now, surface overflow rate, SOR = 20 $m^3/m^2 - d$

$$\text{Area required} = \frac{7.5 \times 10^6 \times 10^{-3}}{20} = 375\ m^2$$

Let, the diameter of each tank is d

$$\therefore \quad \frac{\pi}{4} d^2 = 3.75$$

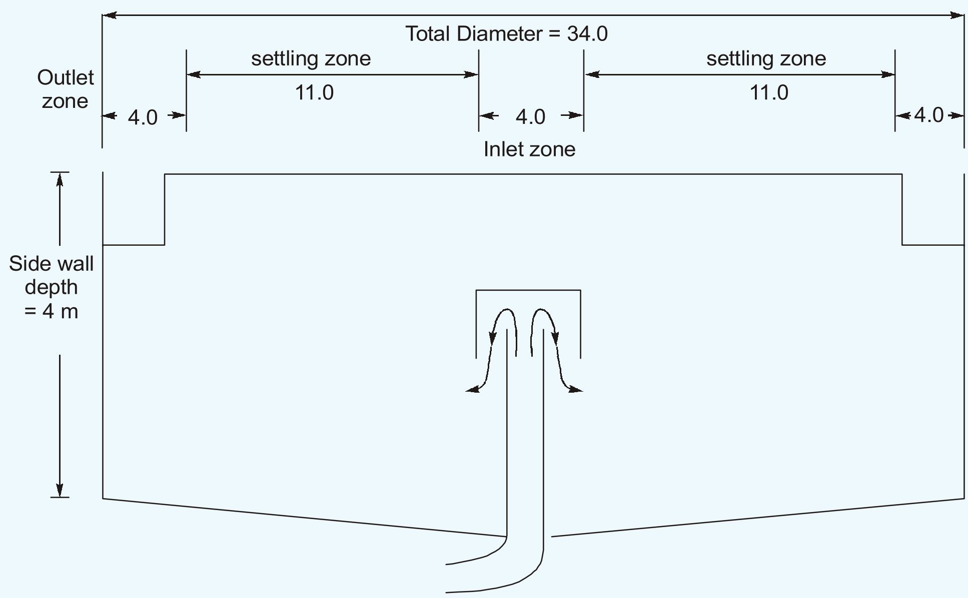
$$\Rightarrow \quad d = 21.85 \text{ m say } 22 \text{ m}$$

Total depth of tank = 3.5 + 0.5 = 4 m [∵ 0.5 m of freeboard is also added]

$$\text{Weir loading rate} = \frac{\text{Discharge for each basin}}{\pi \times \text{diameter of each basin}}$$

$$= \frac{7.5 \times 10^6 \times 10^{-3}}{\pi \times 22} = 108.51\ m^3/\text{m-day}$$

Inlet, outlet and sludge zones are shown below:



All dimensions in metre

(ii)

Single media filters, such as those using only one type of granular media (e.g., sand filters), may fail to fully achieve the ideal performance for several reasons:

1. **Uniformity of Particle Size:** Granular media filters typically operate based on the size of particles they can retain. Using a single type of media can limit the range of particle sizes that can be effectively captured. Smaller particles may pass through or cause premature clogging, reducing filter efficiency.
2. **Head Loss and Filter Runs:** Single media filters may experience higher head loss as the filter bed compacts and particles accumulate, leading to reduced flow rates and necessitating more frequent backwashing. This can shorten the filter runs compared to ideal conditions.
3. **Depth Utilization:** In single media filters, the entire depth of the filter bed may not be effectively utilized for particle retention. Channeling or preferential flow paths can develop, allowing water to bypass sections of the media, thereby reducing overall filtration efficiency.

To approach the ideal filter performance, mixed media filters are often used. Here's how mixed media filters can improve performance:

1. **Enhanced Filtration Efficiency:** By combining different media types (e.g., anthracite, sand, garnet), mixed media filters can achieve a broader range of particle size removal. Coarser media at the top can remove larger particles, while finer media deeper in the bed can capture smaller particles effectively.
2. **Reduced Head Loss:** Mixed media filters are designed to minimize channeling and ensure uniform distribution of flow throughout the depth of the filter bed. This helps maintain lower head loss over longer periods, allowing for extended filter runs before backwashing is required.
3. **Longer Filter Runs:** The optimized depth utilization and diverse particle capture capabilities of mixed media filters contribute to longer filter runs. This increases operational efficiency and reduces the frequency of maintenance interventions.
4. **Higher Filtration Rates:** Mixed media filters can handle higher filtration rates due to their improved depth utilization and reduced head loss characteristics. This makes them suitable for applications requiring high flow rates and stringent particle removal requirements.

   In summary, while single media filters may fall short of achieving ideal performance due to limitations in particle size range, depth utilization, and head loss control, mixed media filters address these shortcomings by leveraging the complementary characteristics of different media types. This approach enhances filtration efficiency, extends filter runs, reduces head loss, and improves overall filtration rates, approaching the performance benchmarks of an ideal granular media filter.

End of Solution

Q.3 (a) (i) Design a tube well for the following data:
Yield required = 0.10 m^3/s
Radius of circle of influence = 200 m
Coefficient of permeability = 60 m/day
Drawdown = 6 m
Thickness of confined aquifer = 30 m

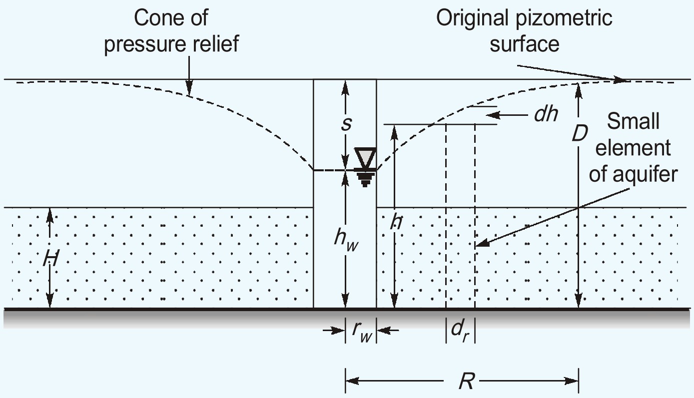
[15 marks : 2024]

(ii) Describe briefly the various methods adopted as anti-waterlogging measures.

[5 marks : 2024]

Solution:

(i)



By Darcy's law

$$\text{Discharge, } Q = kiA$$

where k is coefficient of permeability.

$$\Rightarrow \quad Q = \frac{kdh}{dr} 2\pi rh$$

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

Integrating the above equation between limits r_w and R, we get

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

where r_w is radius of well and R is radius of influence

$$\Rightarrow \quad [\ln r]_{r_w}^{R} = \frac{2\pi kH}{Q}(D - h_w)$$

$$\Rightarrow \quad Q = \frac{2\pi kH(D - h_w)}{\ln(R/r_w)} = \frac{2\pi kHS}{\ln(R/r_w)}$$

where, S = Drawdown in well $= D - h_w$

Now, $Q = 0.1\ m^3/s$, $R = 200$ m, $k = 60$ m/day, S = 6 m

$H = 30$ m

$$\Rightarrow \quad 0.1 \times 86400 = \frac{2\pi \times 60 \times 30 \times 6}{\ln(200/r_w)}$$

$$\Rightarrow \quad r_w = 0.0776 \text{ m} = 7.76 \text{ cm}$$

So, diameter of tubewell is 15.52 cm.

(ii)

The various measures adopted for controlling water- logging are enumerated below :

1. **Lining of Canals and Water Courses:** Attempts should be made to reduce the seepage of water from the canals and water courses. This can be achieved by lining them. It is a very effective method to control water-logging.
2. **Reducing the Intensity of Irrigation:** In areas where there is a possibility of water-logging, intensity of irrigation should be reduced. Only a small portion of irrigation land should receive canal water in one particular season. The remaining areas can receive water in the next season, by rotation.
3. **By Providing Intercepting Drains:** Intercepting drains along the canals should be constructed, wherever necessary. These drains can intercept and prevent the seeping canal water from reaching the area likely to be water-logged.
4. **By Provision of an Efficient Drainage System:** An efficient drainage system should be provided in order to drain away the storm water and the excess irrigation water. A good drainage system consists of surface drains as well as sub-surface drains.
5. **By Improving the Natural Drainage of the Area:** To reduce the percolation, the water should not be allowed to stand for a longer period. Some relief in this direction can be obtained by removing the obstructions from the path of natural flow. This can be achieved by removing bushes, jungles, forests, etc. and improving the slopes of the natural drainage lines.
6. **By Adopting Consumptive Use of Surface and Subsurface Water:** The introduction of lift irrigation to utilize ground water helps in lowering the water- table in a canal irrigated area, where water-table tends to go up. Hence, the ground water should also be used in conjunction with canal water for irrigation, as the continuous use of ground water will not allow any appreciable rise in the level of water-table, due to continuous seepage of canal water.

   This combined use of subsurface water (ground water) and the surface water (canal water) in a judicious manner, as to derive maximum benefits, called conjunctive use, should hence be adopted to control water-logging.

End of Solution

Q.3 (b) (i) Design an irrigation channel in alluvial soil according to Lacey's silt theory for the following data:

Full supply discharge = 10 m^3/s

Lacey's silt factor = 0.9

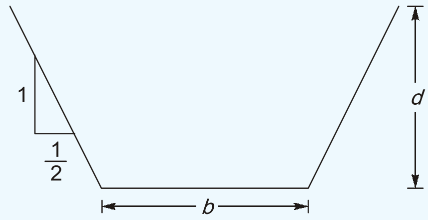
Side slopes of channel = $\frac{1}{2}$(H) : 1 (V)

[15 marks : 2024]

(ii) What is gravity dam? Enumerate the various forces acting on gravity dam.
[5 marks : 2024]

Solution:

(i)



$$\text{Discharge, } Q = 10 \text{ m}^3/s$$
$$\text{Lacey silt factor, } f = 0.9$$
$$\text{Side slope of channel} = \frac{1}{2} H : IV$$

Let, the width and depth of channel are b and d respectively.

As per Lacey's theory

$$\text{Velocity, } V = \left(\frac{Qf^2}{140}\right)^{\frac{1}{6}}$$

$$\Rightarrow \quad V = \left(\frac{10 \times 0.9^2}{140}\right)^{\frac{1}{6}} = 0.62 \text{ m/s}$$

Now, $$\text{Area required, } A = \frac{Q}{V} = \frac{10}{0.62} = 16.13 \text{ m}^2$$

$$\text{Perimeter, } P = 4.75\sqrt{Q} = 4.75\sqrt{10} = 15.02 \text{ m}$$

Now, $$P = b + \sqrt{5}y$$
$$A = (b + 0.5y)\,y$$

$$\Rightarrow \quad 15.02 = b + \sqrt{5}y \quad \text{...(i)}$$
$$\Rightarrow \quad 16.13 = by + 0.5\,y^2 \quad \text{...(ii)}$$

Solving (i) and (ii), we get

$$y = 1.26 \text{ m and } b = 12.2 \text{ m}$$

$$\text{Bed slope, } S_0 = \frac{f^{5/3}}{3340\, Q^{1/6}} = \frac{0.9^{5/3}}{3340 \times 10^{1/6}} = 1 \text{ in } 5843.53$$

(ii)

A gravity dam is a type of dam constructed from concrete or stone masonry and designed to hold back water by utilizing the weight (mass) of the material alone to resist the horizontal pressure of the water pushing against it. Its stability is primarily provided by gravity acting on the dam's mass, which helps it to stay in place and resist overturning and sliding.

Forces Acting on a Gravity Dam are:

1. Weight of the dam
2. Water pressure
3. Uplift pressure
4. Wave pressure
5. Earth and Silt pressure
6. Earthquake forces
7. Ice pressure
8. Wind pressure
9. Thermal loads.

End of Solution

Q.3 (c) (i) A settling column analysis is run to determine the settling characteristics of sludge from an activated sludge reactor with the following results:

Concentration of MLSS (mg/L)	1000	2000	3000	4000	5000	6000
Settling velocity (m/hr)	2.8	1.4	0.4	0.2	0.1	0.06

The flow to the secondary clarifier is 4200 m^3/day with MLSS concentration of 2000 mg/L. Determine the required diameter of the clarifier for a preselected solid flux rate of 2.5 kg/m^2-hr. Check the area requirement for the clarification function also.

[12 marks : 2024]

(ii) Why do the conventional channel type horizontal flow grit chambers require the velocity control devices? What are the common velocity control devices that are used? What advantages the aerated grit chamber has over the conventional grit chamber?

[8 marks : 2024]

Solution:

(i)

$$\text{Flow to clarifier, } Q = 4200 \text{ m}^3/\text{day}$$

$$\text{MLSS concentration} = 2000 \text{ mg}/L = 2 \text{ kg/m}^3$$

$$\text{Solid flux rate} = 2.5 \text{ kg/m}^2 - \text{hr}$$

Now, total solid loading to clarifier $= \dfrac{4200}{24} \times 2 = 350$ kg/h

Now, surface area of clarifier, $A = \dfrac{\text{Total solid loading}}{\text{Solid flux rate}} = \dfrac{350 \text{ kg/h}}{2.5 \text{ kg/m}^2\text{-hr}} = 140 \text{ m}^2$

Let, the clarifier is circular in shape having diameter D.

$$\Rightarrow \quad \frac{\pi}{4} \times D^2 = 140$$

$$\Rightarrow \quad D = 13.35 \text{ m}$$

Check for clarification function

At MLSS concentration of 2000 mg/L, settling velocity is 1.4 m/hr.

Now, surface are required $= \dfrac{4200}{24 \times 1.4} = 125 \text{ m}^2 < 140 \text{ m}^2$

As, Area provided is greater than required area, therefore provide $D = 13.35$ m

(ii)

Generally, grit chambers are designed to remove, by type-1 settling, discrete particles with diameters of 0.2 mm and specific gravity of 2.65. In channel type horizontal flow grit chamber, it is important to maintain the horizontal velocity at approximately 0.3 m/s. A 25-percent increase in velocity may result in washout of grit, while a 25-percent reduction in velocity may result in retention of non-targeted organics. Since a wide variation in flow rates may be encountered, the horizontal velocity must be artificially controlled.

Velocity control section, such as a properly designed modifier weir, called a proportional flow weir or a sutro weir is provided at lower end of rectangular grit channel, which helps in varying the flow area of section in direct proportion to flow, and thus helps to maintain a constant velocity in the channel, even at varying discharges.

Aerated grit channels are like spiral flow aeration tanks. The performance of an aerated grit chamber is function of roll velocity and detention time. Turbulence created by injection of compressed air keeps lighter organic material in suspension while the heavier grit falls to the bottom. Since roll velocity, rather than horizontal velocity, serves to separate the non-targeted organics from the grit, artificial control of horizontal velocity is not necessary in this unit. Adjustment of air quantities provides settling control.

End of Solution

Q.4 (a) (i) A kite weighing 12.26 N has an effective area of 0.9 m². The tension in the kite string is 32.37 N when the string makes an angle of 45° with the horizontal. For a wind of 32 km/hr, what are the coefficients of lift and drag if the kite assumes an angle of 8° with the horizontal? Take specific weight of air as 11.801 N/m³.

[10 marks : 2024]

(ii) A 1.25 m diameter pipe has to be provided to convey oil of specific gravity 0.85 and kinematic viscosity of 2.75 centistokes at a velocity of 1.25 m/s. In order to model the flow, if a 120 mm diameter pipe is used to convey water of kinematic viscosity 1.0 centistokes, what should be the velocity and the discharge in the model?

[10 marks : 2024]

Solution:

(i)

Weight of kite, $W = 12.26$ kN

Effective Area, $A = 0.9 \text{ m}^2$

Tension in kite string, $T = 32.37$ N

Angle of inclination of string with horizontal, $\theta = 45°$

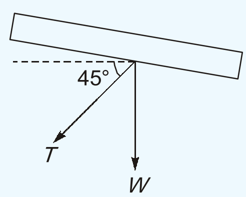
Speed of wind, $V = 32$ kmph

Angle of inclination of kite with horizontal, $\theta_1 = 8°$

Specific weight of air, $\gamma = 11.801 \text{ N/m}^3$

Now, Drag force, $F_D = \frac{1}{2} C_D \rho A V^2$ where C_D is coefficient of drag

Also, $F_D = T \cos 45°$



$$\Rightarrow \frac{1}{2} C_D \times \frac{11.801}{9.81} \times 0.9 \times \left(32 \times \frac{5}{18}\right)^2 = 32.37 \cos 45°$$

$$\Rightarrow \quad C_D = 0.535$$

Also, lift force, $F_L = \frac{1}{2} C_L \rho A V^2$ where C_L is coefficient of lift

Also, $F_L = W + T \sin 45°$

$$\Rightarrow \frac{1}{2}\times C_L \times \frac{11.801}{9.81}\times 0.9\times\left(32\times\frac{5}{18}\right)^2 = 12.26 + 32.37 \sin 45°$$

$$\Rightarrow \quad C_L = 0.822$$

(ii)

For prototype,

Diameter of pipe, d = 1.25 m

Specific gravity of oil = 0.85

So, density of oil, $\rho = 0.85 \times 1000 = 850$ kg/m^3

Kinematic viscosity of oil, ν = 2.75 centistoke

Velocity of oil, V = 1.25 m/s

For model

Diameter of pipe, d = 0.12 m

Kinematic viscosity of water, ν = 1 centistoke

Now, as per Reynold's model law,

$$(Re)_p = (Re)_m$$

$$\Rightarrow \left(\frac{Vd}{\nu}\right)_p = \left(\frac{Vd}{\nu}\right)_m$$

$$\Rightarrow \frac{1.25\times 1.25}{2.75} = \frac{v\times 0.12}{1}$$

$$\Rightarrow V_m = 4.735 \text{ m/s}$$

Also, discharge through model,

$$Q_m = A_m \times V_m$$

$$= \frac{\pi}{4}\times 0.12^2 \times 4.735$$

$$= 0.05355 \text{ m}^3/s$$

$$= 53.55\ l/s$$

Hence, velocity and discharge in pipe in model is 4.735 m/s and 53.55 l/s

End of Solution

Q.4 (b) A city of 1 million population generates 0.45 kg per capita per day of MSW. Collection trucks of capacity 4.5 metric tonnes averaging two trips per day at 75% capacity operate all the days in a week to transfer the waste to centralised processing and landfill site. How many trucks per day will be required to transfer the waste? If about 45% waste is recycled, what is the mass of MSW entering the landfill? If the density of the waste is 280 kg/m^3, what is the volume of MSW? Determine the area required for the landfill with the projected life of 30 years, if the density of the compacted waste is 450 kg/m^3 and the maximum height of the landfill is limited to 15 m. Neglect the volume of cover.

[20 marks : 2024]

Solution:

MSW generated per day = $0.45 \times 10^6 = 4.5 \times 10^5$ kg/day

Capacity of truck = 4.5×10^3 kg

Number of trips per day = 2

Efficiency of each truck = 75%

So, MSW transferred per day by 1 day = $4.5 \times 10^3 \times 2 \times 0.75 = 6750$ kg

Hence, number of trucks required = $\dfrac{4.5\times10^5}{6750} = 66.67 \approx 67$ (say)

As 45% of waste is recycled.

So, waste going in landfill per day = $(1 - 0.45) \times 4.5 \times 10^5$ kg = 247500 kg/day

Density of waste, ρ = 280 kg/m^3

So, volume of daily waste, $V = \dfrac{4.5\times10^5}{280} = 1607.14$ m^3/day

Now, Waste going daily in landfill = 247500 kg/day

Waste going in landfill in 30 years = $247500 \times 30 \times 365 = 2.7 \times 10^9$ kg

Density of compacted waste = 450 kg/m^3

So, volume of compacted waste in 30 years = $\dfrac{2.7\times10^9}{450} = 6\times10^6$ m^3

Now, Height of landfill = 15 m

So, Area of landfill required = $\dfrac{6\times10^6}{15} = 4\times10^5$ m^2

End of Solution

Q.4 (c) (i) Explain the following characteristic terms for biological organisms based on their carbon and energy sources:

(I) Phototrophs
(II) Chemotrophs
(III) Autotrophs
(IV) Heterotrophs

Arrange the following organisms according to their trophic levels giving' your reasoning:

(A) Chemoheterotrophs
(B) Photoheterotrophs
(C) Photoautotrophs
(D) Chemoautotrophs

[10 marks : 2024]

(ii) The ambient air concentration of carbon monoxide was reported as 4 mg/ m^3 at the temperature of 25°C and pressure of 103.193 kPa. What will be the concentration in ppm at STP?

[10 marks : 2024]

Solution:

(i)

On the basis of carbon and energy sources:

(I) **Phototrophs:** Phototrophs are organisms that capture light energy to carry out cellular functions, primarily through the process of photosynthesis. They can be either autotrophs or heterotrophs:

- **Photoautotrophs:** Use light energy to synthesize organic compounds from inorganic sources. Examples include plants, algae, and cyanobacteria.
- **Photoheterotrophs:** Use light for energy but require organic compounds as a carbon source. Examples include certain bacteria like purple non-sulfur bacteria.

(II) **Chemotrophs:** Chemotrophs are organisms that obtain energy by the oxidation of electron donors in their environments. They can be further categorized based on their source of carbon:

- **Chemoautotrophs:** Use inorganic chemicals as an energy source and carbon dioxide as a carbon source. Examples include nitrifying bacteria and sulfur-oxidizing bacteria.
- **Chemoheterotrophs:** Obtain energy by oxidizing organic molecules and also use organic compounds as a carbon source. Examples include most bacteria, fungi, and animals.

(III) **Autotrophs:** Autotrophs are organisms that produce their own food from inorganic substances using light or chemical energy. They are primary producers in the food chain. There are two main types of autotrophs:

- **Photoautotrophs:** Use light energy to synthesize organic compounds from carbon dioxide and water through photosynthesis. Examples include plants, algae, and some bacteria.
- **Chemoautotrophs:** Obtain energy by oxidizing inorganic substances, such as hydrogen sulfide or ammonia, to synthesize organic compounds. Examples include certain bacteria and archaea found in extreme environments like hydrothermal vents.

(IV) **Heterotrophs:** Heterotrophs are organisms that cannot synthesize their own food and depend on other organisms for nutrition. They consume organic substances to obtain energy and carbon. Heterotrophs include:

- **Herbivores:** Eat plants (e.g., cows, rabbits).
- **Carnivores:** Eat other animals (e.g., lions, wolves).
- **Omnivores:** Eat both plants and animals (e.g., humans, bears).
- **Decomposers:** Break down dead organic material (e.g., fungi, bacteria).

Organisms according to their trophic levels are as following:

1. **Photoautotrophs:**
   - **Trophic Level:** Primary Producers

   Photoautotrophs, such as plants, algae, and cyanobacteria, use light energy to synthesize organic compounds from carbon dioxide and water through photosynthesis. They form the base of the food chain and provide energy for higher trophic levels.

2. **Chemoautotrophs:**
   - **Trophic Level:** Primary Producers

   Chemoautotrophs, like certain bacteria and archaea, obtain energy by oxidizing inorganic substances and use this energy to fix carbon dioxide into organic compounds. They are primary producers in ecosystems where light is not available, such as deep-sea hydrothermal vents.

3. **Photoheterotrophs:**
   - **Trophic Level:** Primary Consumers
     Photoheterotrophs use light for energy but cannot fix carbon dioxide and thus require organic compounds as a carbon source. They depend on primary producers for organic compounds and occupy the level of primary consumers.
4. **Chemoheterotrophs :**
   - **Trophic Level:** Primary or Secondary Consumers
     Chemoheterotrophs obtain both energy and carbon from organic compounds. They include organisms such as animals, fungi, and many bacteria, which can act as primary consumers by feeding on plants or secondary consumers by feeding on other animals or decomposed organic matter.

(ii)

Concentration of carbon monoxide = 4 mg/m^3

Temperature, T_1 = 25°C = 298 K

Pressure, P_1 = 10393 kPa

At STP, Temperature, T_2 = 273 K

Pressure, P_2 = 101.325 kPa

Volume, V_2 = 22.4*l*

where V_2 is volume occupied by 1 mole of gas at STP

As per ideal gas law

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

where V_1 is volume occupied by 1 mole of gas at given conditions.

$$\Rightarrow \quad \frac{103.193\times V_1}{298} = \frac{101.325\times 22.4}{273}$$

$$\Rightarrow \quad V_1 = 24 \text{ liters/moles}$$

Now, in 1 m^3 of air, 4 mg of CO is present.

So, in 10^6 m^3 of air, 4 kg of CO is present.

Molecular mass of CO = 28 gm

So, number of moles in 4 kg CO = $\frac{4\times 10^3}{28}$ = 142.86

Now, volume occupied by 142.86 moles of CO = 24 × 142.86

= 3428.64 *l* = 3.43 m^3

So, concentration of CO in ppm = 5.43 m^3

End of Solution

SECTION : B

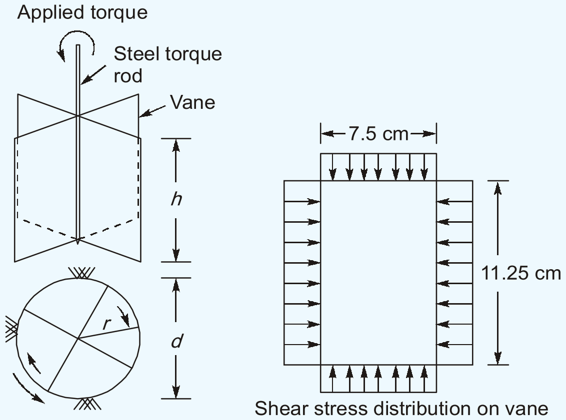
Q.5 (a) A field vane shear test was carried out on a deep-seated soft clay layer. The vane was 11.25 cm high and 7.5 cm across the blades. The equivalent torque recorded at the torque head at failure was 800 kg-cm. The vane was then rotated very rapidly in order to completely remould the soil. It was found that the remoulded soil can be sheared by applying a torque of 400 kg-cm. Compute the shear strength of the soil in the undisturbed and remoulded states and its sensitivity.

[12 marks : 2024]

Solution:

- In this test, there is no mechanism to measure pore pressure, hence it is essentially an undrained test. So it is used to determine the undrained shear strength of soils. This test is suitable for plastic cohesive soil which is very sensitive and obtaining its undisturbed specimen is difficult. The vane is pushed gently into the soil upto the required depth at the bottom of a borehole and torque is applied gradually to the upper end of the rod until the soil fails in shear, due to the rotation of the vane.
- The torque is imparted to the vane by means of a disc at the top of the rod. The disc is calibrated to measure the applied torque.
- Assuming that the shear stress acting along the surface, top and bottom of the shear cylinder is uniform and equal to τ,

  Total shearing resistance of the soil at failure,



Vane shear test

$$= \pi d h S + 2\int_0^{d/2} (2\pi r dr) \cdot S$$

where, S = unit undrained shearing resistance

r = radius of sheared surface

The moment of the total shear resistance about the centre is the torque 'T' at failure,

$$\therefore \quad T = \pi \cdot d \cdot h \cdot S \times \frac{d}{2} + \int_0^{d/2} (2\pi r dr) \cdot S \times r$$

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

$$\text{or} \quad S = \frac{T}{\pi d^2 \left(\frac{h}{2} + \frac{d}{6} \right)}$$

Now, Height of vane, H = 11.25 cm

Diameter of vane, D = 7.5 cm

Torque for undisturbed sample, T_1 = 800 kg-cm

Torque for remoulded sample, T_2 = 400 kg-cm

Now, shear strength of soil in undisturbed state,

$$S_1 = \frac{T_1}{\pi D^2\left(\frac{H}{2}+\frac{D}{6}\right)} = \frac{800}{\pi\times 7.5^2\left(\frac{11.25}{2}+\frac{7.5}{6}\right)} = 0.658 \text{ kg/cm}^2$$

Shear strength of soil in remoulded state,

$$S_2 = \frac{T_2}{\pi D^2\left(\frac{H}{2}+\frac{D}{6}\right)} = \frac{400}{\pi\times 7.5^2\left(\frac{11.25}{2}+\frac{7.5}{6}\right)} = 0.329 \text{ kg/cm}^2$$

Now, Sensitivity $= \frac{S_1}{S_2} = \frac{0.658}{0.329} = 2$

End of Solution

Q.5 (b) A 2.5 m wide strip footing is founded at a depth of 2.0 m below the ground level in a homogeneous pure clay bed. The unit cohesion of clay is 35 kPa. Due to seasonal fluctuations of water table from peak summer (fully dry soil) to peak monsoon (fully saturated soil), compute the change in the net ultimate bearing capacity as per Terzaghi's theory.

[12 marks : 2024]

Solution:

Width of strip footing, B = 2.5 m

Depth of strip footing, D_f = 2 m

Cohesion, C = 35 kPa

As per Terzaghi's theory

Net ultimate bearing capacity, $q_{nu} = CN_c + \gamma D_f(N_q - 1) + 0.5\,\gamma B N_\gamma$

For pure clay, $N_c = 5.7$, $N_q = 1$ and $N_\gamma = 0$

Case-1: When soil is dry

$$q_{nu} = 35 \times 5.7 + \gamma_{dry} \times 2 \times (1-1) + 0 = 199.5 \text{ kN/m}^2$$

where γ_{dry} is dry unit weight of soil

Case-2: When soil is saturated

$$q_{nu} = 35 \times 5.7 + \gamma_{sat} \times 2 \times (1-1) + 0 = 199.5 \text{ kN/m}^2$$

where γ_{sat} is saturated unit weight of soil

So, there is no change in net ultimate bearing capacity of soil.

End of Solution

Q.5 (c) Design the thickness of a flexible pavement for the design life of 15 years having two-lane single carriageway 7.0 m wide and present traffic of 800 commercial vehicles per day (CVPD). Out of total 800 CVPD, 300 have vehicle damage factor (VDF) of 2.5 and 500 have VDF of 3.0. The planning and construction period is 2 years and annual vehicle growth rate is 7.5%. Design the flexible pavement from the data given below if the effective CBR of the subgrade is 9%. Assume any missing data suitably:

Design traffic	Wearing course (mm)	Binder course (mm)	Base (mm)	Sab-base (mm)
5 msa	25 SDBC	50 DBM	250	150
10 msa	40 BC	50 DBM	250	200
20 msa	40 BC	80 DBM	250	200
30 msa	40 BC	95 DBM	250	200

[12 marks : 2024]

Solution:

Given data:

Design life, n = 15 years

Width of road, W = 7.0 m

P_1 = 300 CVPD, P_2 = 500 CVPD

$(VDF)_1 = 2.5$, $(VDF)_2 = 3.0$

Construction period, x = 2 years

Traffic growth rate, i = 7.5%

CBR = 9%

Lane distribution factor (LDF) for two lane single carriage way is 0.5.

Traffic in the year of completion of construction A is given by

$$A_1 = P_1(1+i)^x$$

$$= 300\,(1+0.075)^2 = 346.68 \text{ CVPD}$$

$$A_2 = P_2(1+i)^x$$

$$= 500\,(1+0.075)^2 = 577.81 \text{ CVPD}$$

Now, the cumulative standard axles (in msa) is given by

$$N = \frac{365\left(A_1\cdot(\text{VDF})_1 + A_2\cdot(\text{VDF})_2\right)\left[(1+r)^n - 1\right]\cdot \text{LDF}}{i\times 10^6}$$

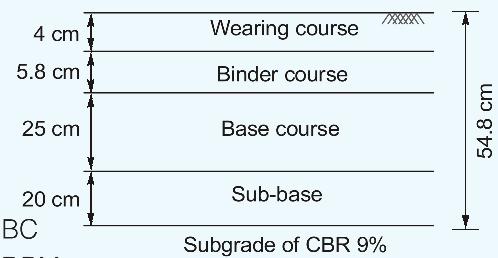
$$= \frac{365\left[(346.68)(2.5)+577.81(3)\right]\left[(1+0.075)^{15}-1\right]\times 0.5}{(0.075)\times 10^6}$$

$$= 12.39 \text{ msa}$$

Now from the table given, binder course thickness t_{BC} is calculated as

$$\frac{80-50}{20-10} = \frac{t_{B.C.}-50}{12.39-10}$$

$$t_{B.C.} = 57.17 \text{ mm}$$



Say 58 mm

Now the thickness of courses are given as,

Wearing course thickness = 40 mm BC

Binder course thickness = 58 mm DBM

Base course = 250 mm

Sub base = 200 mm

End of Solution

Q.5 (d) Calculate the speed restriction for a 2° curve on a broad-gauge section with maximum permissible speed of 100 km/hr. Due to space restrictions, the length of transition curve is limited to 50 m and superelevation provided is 60 mm.

[12 marks : 2024]

Solution:

Degree of curve, $D = 2°$

Permissible speed, $V_{max} = 100$ kmph

Length of transition curve, $L = 50$ m

Provided equilibrium superelevation, $C_a = 60$ mm

1. Speed on basis of superelevation

$$V_{max} = 0.27\sqrt{(C_a + C_d) \times R}$$

where, C_d is cant deficiency i.e. 100 mm for BG

R is radius of curve i.e. $\frac{1750}{2°}$ or 875 m

So, $V_{max} = 0.27\sqrt{(60+100)\times 875} = 101.02$ kmph

2. Speed on basis of transition curve

$$V_{max} = \frac{198L}{C_a} = \frac{198\times 50}{60} = 165 \text{ kmph}$$

Also, $V_{max} = \frac{198L}{C_d} = \frac{198\times 50}{100} = 99$ kmph

So, Permissible speed = min (101.02, 165, 99) = 99 kmph

Check: Cant gradient $= \frac{L}{C_d} = \frac{50}{60\times 10^{-3}} = 1$ in 833.33

which is not steeper than 1 in 720.

End of Solution

Q.5 (e) The following staff readings were taken with a level:

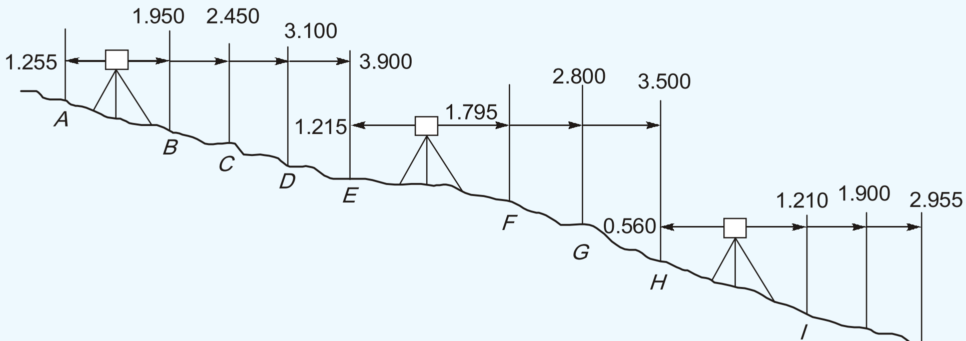
1.255, 1.950, 2.450, 3.100, 3.900, 1.215, 1.795,
2.800, 3.500, 0.560, 1.210, 1.900, 2.955

The level was shifted after the 5th and 9th reading, and the 7th reading was taken to a benchmark of RL 120.00 m. Arrange the data in tabular form and find the reduced level of all the points by rise and fall method. Also apply the usual checks for calculations.

[12 marks : 2024]

Solution:

A schematic representation of levelling work is hsonw below.



Staff station	Back sight (m)	Intermediate sight (m)	Fore sight (m)	Rise (m)	Fall (m)	R.L. (m)	Remarks
A	1.255	–	–	–	–	123.225	–
B	–	1.95	–	–	0.695	122.53	–
C	–	2.45	–	–	0.5	122.03	–
D	–	3.10	–	–	0.65	121.38	–
E	1.215	–	3.9	–	0.8	120.58	C.P.
F	–	1.795	–	–	0.58	120	R.L.
G	–	2.80	–	–	1.005	118.995	–
H	0.560	–	3.5	–	0.7	118.295	C.P.
I	–	1.210	–	–	0.65	117.645	–
J	–	1.900	–	–	0.69	116.955	–
K	–	–	2.955	–	1.055	115.9	–

Checks:

$$\text{Last R.L.} - \text{First R.L.} = 115.9 - 123.225 = -7.325 \text{ m}$$

$$\sum \text{Rise} = 0$$

$$\sum \text{Fall} = 7.325$$

$$\sum \text{Back sights} = 3.03 \text{ m}$$

$$\sum \text{Fore sights} = 10.355 \text{ m}$$

$$\sum \text{B.S.} - \sum \text{F.S.} = \sum \text{Rise} - \sum \text{Fall}$$

$$= \text{Last R.L.} - \text{First R.L} = -7.325 \text{ m}$$

End of Solution

Q.6 (a) (i) Two straights *AB* and *BC* are to be connected by a 2° simple circular curve. Two points *P* and *Q* are selected on *AB* and *BC* respectively and the following observations are done in the field:

$\angle APQ = 130°$ Length $PQ = 120$ m

$\angle CPQ = 120°$ Chainage of point $P = 1700$ m

Calculate the chainages of intersection and all other important points in the curve. Assume the standard chord length of 20 m.

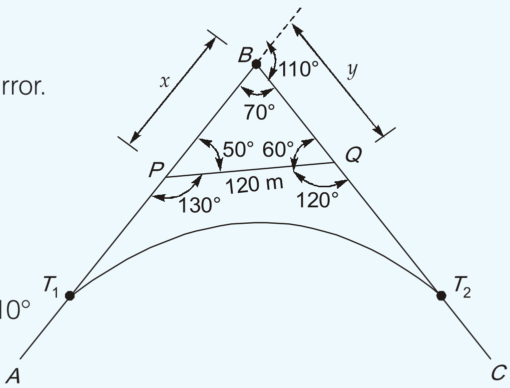
[10 marks : 2024]

(ii) Explain the various sources of errors and their corrections in positioning with Global Positioning System (GPS).

[10 marks : 2024]

Solution:

(i)



Note: In question, ∠CPQ is given which is an error. Actually, it is ∠CQP

Given: ∠APQ = 130°, ∠CQP = 120°

$$\text{Chainage of point, P} = 1700\text{ m}$$
$$\text{Length } PQ = 120\text{ m}$$
$$\text{Standard chord length} = 20\text{ m}$$
$$\text{Deflection angle, } \delta = 180° - 70° = 110°$$

In ΔBPQ

$$\frac{x}{\sin 60°} = \frac{y}{\sin 50°} = \frac{120}{\sin 70°}$$

$\Rightarrow$ $x = 110.592$ m

$\Rightarrow$ $y = 97.824$ m

∴Degree of curve is 2°, radius of curve, R can be calculatd as follows.

$$R = \frac{180 \times 20}{\pi \times 2°} = 572.95\text{ m} \quad \text{(Assuming chain length to be 20 m)}$$

$\Rightarrow$ $R \simeq 573$ m

Chainage of point of intersection, Point B = Chainage of point P $+ x$

= 1700 + 110.592 = 1810.592 m

We know that

$$\text{Length of tangent} = R\tan\frac{\delta}{2}$$

$$\Rightarrow \quad T_1B = 573\tan\frac{110°}{2} = 818.328\text{m}$$

$$\text{Length of curve, } L_C = \frac{2\pi R}{360}\delta = \frac{2\pi \times 573 \times 110}{360} = 1100.08\text{m}$$

$\simeq 1100$ m

Chainage at T_1 = Chainage at B – T_1B

= 1810.592 – 818.328

= 992.264 m

Chaninage at T_2 = Chainage at T_1 + Length of the curve

= 992.264 + 1100 m = 2092.265 m

(ii)

Inaccuracies in GPS signals come from the variety of sources, like satellite clocks, imperfect orbits and especially from the signal's trip through the earth's atmosphere. The error sources can be classified into three groups, namely satellite-related errors, propagation-medium related errors, and receiver related errors.

1. Signal propagation errors:

   As a GPS signal comes down through the charged particles in the ionosphere and then through the water vapour in the troposphere, it gets delayed a little. This delay results into a miscalculation of the satellite's distance, which in turn translates into an error in position.

2. Receiver errors:

   - **Multipath:** As the GPS signal arrives at the surface of the earth it may get reflected by local obstructions and gets to the receiver's antenna via more than one path. This form of error is called multipath error. The elimination of multipath signal is possible by selecting an antenna that takes advantage of the signal polarisation. A reduction of multipath effect may also be achieved by digital filtering, wideband antennas and radio frequency absorbent antenna ground planes.
   - **Antenna phase centre offset and variation:** The phase centre of the antenna is the point to which the radio signal measurement is referred.
     The true antenna phase centre may be different from the manufacturer- indicated centre. Further, the antenna phase centre can vary with respect to the incoming satellite signals. The variation is systematic and may be investigated by test series.

     Systematic effects can be eliminated by appropriate combinations of the observables.Both effects, multipath and imaging, can be considerably reduced by selecting sites protected from reflections (buildings, vehicles, trees, etc.) and by appropriate antenna design. Differential GPS, counteracts above errors, It tightens up the working accuracy of GPS to just a few metres.

End of Solution

Q.6 (b) (i) A greenfield airport is proposed at an elevation of 250 m above mean sea level (m.s.l.). The monthly average of the maximum daily temperature at the proposed site is 45°C during the hottest month of the year. During the same month, the average daily temperature is 35°C. The maximum difference in elevation is 6.0 m along the proposed runway of basic length 2000 m. Calculate the actual length of runway to be provided.

[15 marks : 2024]

(ii) What are the various considerations in the selection of the site for a harbour?

[5 marks : 2024]

Solution:

(i)

Elevation of runway, $H =$ 250 m above MSL

Monthly average of maximum daily temperatures, $T_m = 45°C$

Monthly average of average daily temperatures, $T_a = 35°C$
Maximum difference in elevation = 6 m
Basic runway length, L = 2000 m

1. **Correction for elevation:**

$$\text{Increase in length} = \frac{0.07}{300} \times 250 \times 2000 = 116.67 \text{ m}$$

So, corrected length, $L_{corrected}$ = 2000 + 116.67 = 2116.67 m

2. **Correction for temperature:**

Standard atmospheric temperature, SAT = 15 – 0.0065 (H)
= 15 – 0.0065 × 250 = 13.37°C

$$\text{Airport reference temperature, ART} = T_a + \frac{T_m - T_a}{3} = 35 + \frac{45-35}{3} = 38.333°C$$

Difference in temperature, ΔT = 38.333 – 13.375 = 24.96°C
So, length will be increased by 24.96%
So, corrected length, $L_{corrected}$ = 2116.67 × 1.2496 = 2645 m
Check: Total correction due to elevation and temperature must not be more than 35% of basic runway length.

$$\text{So,} \quad \text{Correction} = \frac{2645-2000}{2000} \times 100 = 32.25 < 35\% \text{ o.k.}$$

3. **Gradient correction:**

Length after applying correction for elevation and temperature is increased at the rate of 20% for every 1% effective gradient.

$$\text{Effective gradient} = \frac{6}{2645} \times 100 = 0.2268\%$$

So, correction for gradient = 0.2268 × 0.2 × 2645 = 120 m
Hence, corrected length = 2645 + 120 = 2765 m

$$\text{Now, revised gradient} = \frac{6}{2765} \times 100 = 0.2169\%$$

Gradient correction = 0.2169 × 0.2 × 2645 = 114.74 m
So, corrected length = 2645 + 114.75 ≃ 2760 m

(ii)

- **Site Selection:** In selection of a site for harbour, apart from engineering considerations, commercial, defence and strategic aspects should also be examined.

The guiding factors in the choice of a site for harbour are:

1. Sea approach and marine conditions
2. Sea-bed, subsoil and foundation conditions
3. Transport and communication links
4. Sea-borne traffic potential
5. Industrial infrastructure and industrial development or potential in the hinterland.
6. Agricultural base of the hinterland and also its mining resources
7. Electrical energy and fresh water supplies.
8. Availability of cheap land and proximity of constructional materials.

End of Solution

Q.6 (c) A concrete driven pile of 20 m length and 1 m × 1 m in cross-section is fully embedded in sand having unit weight, γ = 18 kN/m^3 and ϕ' = 30°. Estimate the ultimate load Q_u which the pile can take and mention the contributions from point load (tip load Q_p using Meyerhof's method) and frictional resistance Q_s. Consider N_q^* = 55 (for ϕ' = 30°), δ' = 0.8 ϕ', K = 1.8 (1 – sin ϕ'), L_{cr} = 15D.

[20 marks : 2024]

Solution:

Given:

Length of pile, L = 20 m

Side of pile, B = 1 m

Cross-section area of pile, A_b = 1 × 1 = 1 m^2

Unit weight of sand, γ = 18 kN/m^3

ϕ' = 30°, N_q = 55, δ' = 0.8 ϕ'

K = 1.8 (1 – sin ϕ') = 1.8 (1 – sin 30°) = 0.9

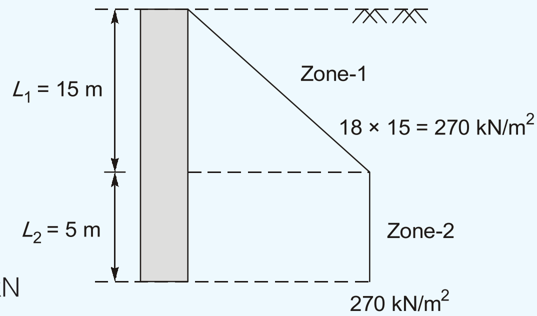
L_{cr} = 15D = 15 × 1 = 15 m

For piles in sand ultimate load, $Q_u = Q_{eb} + Q_{sf1} + Q_{sf2}$

where, Q_{eb} = End bearing resistance

Q_{sf1} = Skin friction in zone-1

Q_{sf2} = Skin friction in zone-2



Now, $Q_{eb} = q_{eb} \times A_b$

where, $q_{eb} = (\bar{\sigma}_v)_{base} \times N_q$

$= 270 \times 55 = 14850$ kN/m^2

But, q_{eb} is limited to 11000 kN/m^2

So, $Q_{eb} = 11000 \times 1 = 11000$ kN

Now, $Q_{sf1} = q_{sf1} \times A_{s1}$

where, $q_{sf1} = K(\bar{\sigma}_v)_{avg} \times \tan\delta$

$$= 0.9\left(\frac{0+270}{2}\right) \times \tan(0.8 \times 30°)$$

$= 54.09$ kN/m^2 < 100 kN/m^2 Hence (OK)

So, $Q_{sf1} = q_{sf1} \times A_{s1}$

$= 54.09 \times 4 \times 1 \times 15 = 3245.4$ kN

Similarly, $$q_{sf2} = 0.9 \times \left(\frac{270+270}{2}\right) \times \tan(0.8 \times 30°) = 108.19 \text{ kN/m}^2$$

But it is limited to 100 kN/m^2

So, $Q_{sf2} = q_{sf2} \times A_{s2}$

$= 100 \times 4 \times 1 \times 5 = 2000$ kN

So, $Q_u = q_u + Q_{sf1} + Q_{sf2}$

$= 11000 + 3245.4 + 2000 = 16245.4$ kN

End of Solution

Q.7 (a) An infinite soil slope is having a slope angle as 25°. The soil properties are $c' = 26$ kN/m^2, $\phi' = 20°$, $e = 0.71$ and $G = 2.65$. Given $\gamma_w = 10$ kN/m^3. Find out the critical height of the slope considering stability number which represents cohesion and $F_\phi = 1.0$, for cases (i) soil slope is dry and (ii) soil slope is submerged.

[20 marks : 2024]

Solution:

Given: Slope angle, $\beta = 25°$, Cohesion, $c' = 26$ kN/m^2, $\phi' = 20°$,
$e = 0.71$, $G = 2.65$, $\gamma_w = 10$ kN/m^3

Dry unit weight of soil, $\gamma_d = \dfrac{G\gamma_w}{1+e} = \dfrac{2.65\times10}{1+0.71} = 15.497$ kN/m^3

Saturated unit weight of soil, $\gamma_{sat} = \dfrac{(G+e)\gamma_w}{1+e} = \dfrac{(2.65+0.71)\times10}{1+071} = 19.649$ kN/m^3

Now, Taylor's stability number $S_n = (\tan\beta - \tan\phi')\cos^2\beta$
$= (\tan 25° - \tan 20°)\cos^2(25°) = 0.084$

1. When soil is dry

$$S_n = \frac{c'}{\gamma_{dry}H_c}$$ where H_c is critical height of slope

So, $$H_c = \frac{26}{15.497\times0.084} = 19.973 \text{ m}$$

2. When soil is submerged

$$S_n = \frac{c'}{\gamma_{sub}H_c}$$

where, $\gamma_{sub} = 19.649 - 10 = 9.649$ kN/m^3

$\Rightarrow$ $$H_c = \frac{26}{9.649\times0.084} = 32.08 \text{ m}$$

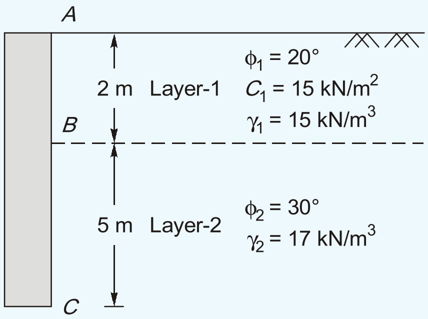
End of Solution

Q.7 (b) A smooth rigid vertical retaining wall of height 7.0 m supports two layers of horizontal backfill. Top layer 1 is of 2.0 m depth having $\phi = 20°$, $c = 15$ kN/m^2 and $\gamma = 15$ kN/m^3. Bottom layer 2 is pure sand with $\phi = 30°$ and $\gamma = 17$ kN/m^3. Mention the practical depth of tensile crack. Also draw active earth pressure diagram and compute the total active thrust on the wall. Assume that the entire soil layers are dry.

[20 marks : 2024]

Solution:

For upper layer:



Active earth pressure coefficient,

$$k_{a1} = \frac{1-\sin\phi_1}{1+\sin\phi_1} = \frac{1-\sin 20°}{1+\sin 20°} = 0.49$$

Now, active earth pressure,

$$p_a = k_{a1}\gamma_1 z - 2C_1\sqrt{k_{a1}}$$

$$= 0.49\times 15z - 2\times 15\times\sqrt{0.49} = 7.35z - 21$$

At $z = 0$, p_a (at A) = 7.35 × 0 – 21 = –21 kN/m^2

At $z = 2$ m, p_a (just above B) = 7.35 × 2 – 21 = –6.3 kN/m^2

For bottom layer:

Active earth pressure coefficient,

$$k_{a2} = \frac{1-\sin\phi_2}{1+\sin\phi_2} = \frac{1-\sin 30°}{1+\sin 30°} = \frac{1}{3}$$

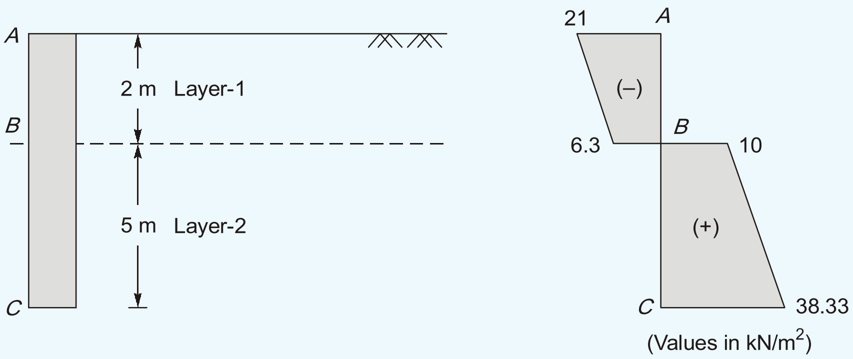
Now, active earth pressure, $p_a = k_a(2\gamma_1 + \gamma_2 z)$

$$= \frac{1}{3}(2\times 15 + 17z) = \frac{1}{3}(30+17z)$$

At $z = 0$, p_a(just below B) $= \frac{1}{3}(30+17\times 0) = 10$ kN/m^2

At z= 5 m, p_a(at C) $= \frac{1}{3}(30+17\times 5) = 38.33$ kN/m^2

Its active earth pressure diagram is shown below:



Now, depth of tension cracks = 2 m

After formation of cracks

$$\text{Total active thrust on wall} = \frac{1}{2}(10+38.33)\times 5$$

$$= 120.82 \text{ kN/m length of wall}$$

End of Solution

Q.7 (c) (i) What is meant by wear of rails? How is it measured? Explain the methods adopted to reduce wear of rails.

[10 marks : 2024]

(ii) What is 'm ucking' in the construction of tunnels? Explain the various techniques for haulage of muck from the tunnel.

[10 marks : 2024]

Solution:

(i)

Due to the passage of moving loads and friction between the rail and the wheel, the rail head gets worn out. The impact of moving loads, the effect of the forces of acceleration, deceleration, and braking of wheels, the abrasion due to rail-wheel interaction, the effects of weather conditions such as changes in temperature, snow, and rains, the presence of materials such as sand cause considerable wear and tear of the vertical and lateral planes of the rail head. Lateral wear occurs more on curves because of the lateral thrust exerted on the outer rail by centrifugal force. A lot of the metal of the rail head gets worn out, causing the weight of the rail to decrease. This loss of weight of the rail section should not be such that the stresses exceed their permissible values

Wear on rails can be measured using any of the following methods:

(a) By weighing the rail
(b) By profiling the rail section with the help of lead strips
(c) By profiling the rail section with the help of needles
(d) By using special instruments designed to measure the profile of the rail and record it simultaneously on graph paper.

Based on field experience, some of the methods adopted to reduce vertical wear and lateral wear on straight pallis and curves are as follows

(a) Better maintenance of the track to ensure good packing as well as proper alignment and use of the correct gauge
(b) Reduction in the number of joints by welding
(c) Use of heavier and higher UTS rails, which are more wear resistant
(d) Use of bearing plates and proper adzing in case of wooden sleepers
(e) Lubricating the gauge face of the outer rail in case of curves
(f) Providing check rails in the case of sharp curves
(g) Interchanging the inner and outer rails
(h) Changing the rail by carrying out track renewal

(ii)

Mucking in the construction of tunnels refers to the process of removing the excavated material, or "muck," from the tunnel. This is a critical part of tunnel construction as it ensures the excavation site remains clear and safe for workers and machinery to continue their tasks efficiently. Several techniques are used for muck haulage, each suited to different conditions and project requirements. Here are some common methods:

1. **Conveyor Belts:** Conveyor belts are a popular choice for muck haulage, especially in longer tunnels where continuous removal is required. They offer a consistent and automated method for transporting muck from the excavation face to the surface or an intermediate location.

- **Advantages :** High efficiency, continuous operation, and low labor requirements.
- **Disadvantages :** High initial cost and maintenance requirements.

2. **Rail Systems:** Rail systems involve using muck cars on tracks to transport the muck. This method is well-suited for medium to long tunnels.
   - **Advantages :**High load capacity and efficient for long-distance haulage.
   - **Disadvantages :** Requires a substantial setup of tracks and maintenance of the rail system.
3. **Haul Trucks:** Dump trucks or other haul trucks can be used to transport muck, particularly in shorter tunnels or where flexibility in movement is required.
   - **Advantages:** Flexibility, ease of implementation, and suitability for varying tunnel lengths.
   - **Disadvantages:** Higher labor and fuel costs, and potential for traffic congestion within the tunnel.
4. **Shaft Hoisting:** In this method, muck is transported vertically via a shaft using skips, cages, or hoists. This technique is common when the tunnel is deep and direct vertical access is available.
   - **Advantages :**Efficient for deep tunnels with vertical shafts, minimizing horizontal transport distance.
   - **Disadvantages:** High initial cost for shaft construction and hoisting equipment.
5. **Screw Conveyors:** Screw conveyors can be used for smaller scale tunneling projects or in conjunction with other methods to transport muck over short distances.
   - **Advantages :**Simple and effective for short distances and small volumes of muck.
   - **Disadvantages :** Limited capacity and distance, requiring frequent emptying.
6. **Pneumatic Transport:** This technique uses air pressure to transport muck through pipes, suitable for small and fine-grained muck material.
   - **Advantages:** Suitable for fine materials, low dust generation.
   - **Disadvantages:** Limited capacity and range, requiring specialized equipment.
7. **Hydraulic Transport:** Hydraulic transport involves using water to carry the muck through pipelines, often referred to as slurry transport.
   - **Advantages :** Effective for fine-grained material, minimizes dust.
   - **Disadvantages :** Requires water treatment facilities and can be less efficient for coarse or heavy materials.

End of Solution

Q.8 (a) Estimate the traffic density and theoretical capacity of six-lane expressway at a stream speed of 80 km/hr. The average reaction time is 0.75 s and the average length of vehicle is 5 m.

[10 marks : 2024]

Solution:

Speed, V = 80 km/hr

Reaction time, t_r = 0.75 s

Average length of vehicle, L = 5 m

Average reaction time, t_r = 0.75 Sec

Traffic density, k is given as

$$K = \frac{1000}{S}$$

where S is space gap between the vehicles and is given by

$$S = 0.278 \times V \times t_r + L$$
$$= 0.278 \times 80 \times 0.75 + 5 = 21.68 \text{ m}$$

Now, $$K = \frac{1000}{21.68} = 46.125 \text{ veh/km}$$

Now, theoretical capacity, q is given as

$$q = K \cdot V$$
$$= 16.125 \times 80 = 3690 \text{ veh/hr}$$

Note: 'q' calculated is capacity per lane.

So, theoretical capacity for road = 3690 × 6 = 22140 veh/hr

End of Solution

Q.8 (b) List all the major methods of ground modifications (ground improvement) in (i) cohesive soil and (ii) cohesionless soil.

[10 marks : 2024]

Solution:

Ground improvement techniques are essential for enhancing the properties of both cohesive and cohesionless soils to ensure stability and support for various construction projects.

Methods used for ground improvement in both types of soils are:

Cohesive Soils: Cohesive soils, such as clay, have fine particles and exhibit significant plasticity and cohesion. The following methods are commonly used for improving cohesive soils:

1. **Preloading and Surcharge:** Involves placing a temporary load on the soil to accelerate consolidation and settlement before construction.
2. **Vertical Drains:** Prefabricated vertical drains (PVDs) or sand drains are used in conjunction with preloading to expedite the consolidation process by providing shorter drainage paths.
3. **Lime Stabilization:** Lime is mixed with soil to reduce plasticity, increase strength, and improve workability.
4. **Cement Stabilization:** Cement is mixed with soil to increase strength and durability.
5. **Chemical Grouting:** Injection of chemical grouts to bind soil particles and reduce permeability.
6. **Electro-Osmosis:** An electric current is passed through the soil to remove water, reducing volume and increasing strength.

Cohesionless Soils: Cohesionless soils, such as sand and gravel, have larger particles and lack significant cohesion. The following methods are commonly used for improving cohesionless soils:

1. **Compaction:**
   - **Dynamic Compaction:** Dropping heavy weights repeatedly on the ground surface to densify the soil.

     Vibro-Compaction: Using vibratory probes to densify soil by rearranging particles.

Surface Compaction: Using rollers and compactors to densify the soil at or near the surface.

2. **Grouting:**
   Compaction Grouting: Injection of a stiff grout to displace and compact the surrounding soil.
   Permeation Grouting: Injection of a grout that permeates the soil and solidifies to increase strength and reduce permeability.
3. **Soil Mixing:**
   Deep Soil Mixing: Blending cement or other binders with soil in-situ using augers to improve strength and stiffness.
4. **Geosynthetics:** Using geotextiles, geogrids, or geomembranes to reinforce and stabilize soil.
5. **Sand Compaction Piles:** Installing compacted sand piles to densify surrounding loose soil.
6. **Blast Densification:** Using controlled explosions to densify loose granular soils.

End of Solution

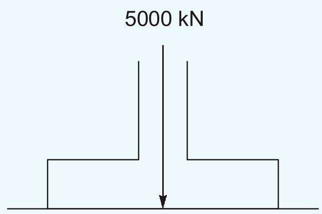
Q.8 (c) A building is proposed to be constructed on a thick silty clay deposit. The maximum vertical load on a column is 5000 kN. Using Boussinesq's stress distribution, calculate the minimum depth of soil exploration required for the foundation design. Note that as per De Beer's recommendation, the vertical additional stress should be less than or equal to 10% of the effective vertical stress. Take unit weight, γ, of soil as 18 kN/m^3 and γ_w = 10 kN/m^3.

[20 marks : 2024]

Solution:

Let, the minimum depth of exploration is z

Now, as per Boussinesq's equation



Vertical stress at depth z, $\sigma_z = \dfrac{3}{2\pi}\left(\dfrac{1}{1+\dfrac{r^2}{z^2}}\right)^{5/2} \times \dfrac{Q}{z^2}$

where, Q = 5000 kN, $r = 0$

So, $\sigma_v = \dfrac{3}{2\pi} \times \dfrac{5000}{z^2}$

Now, effective stress at depth z,

$\bar{\sigma} = (\gamma - \gamma_w)z$

$= (18 - 10)z = 8z$

As per De Beer's recommendation

$\sigma_v \leq 0.1\bar{\sigma}$

$\Rightarrow$ $\dfrac{3}{2\pi} \times \dfrac{5000}{z^2} \leq 0.1 \times 8z$

$\Rightarrow$ $z \geq 14.38$ m

Hence, minimum depth of soil exploration is 14.38 m.

End of Solution

Q.8 (d) (i) A survey line *OPQR* running in the east direction has a lake between points *P* and *Q*; *P* and *Q* are intervisible but it is not possible to measure its length in the field. A traverse *PABCQ* was run around the lake and the following measurements were done in the field:

Line	Length (m)	Bearing
PA	160	N 15° E
AB	300	N 45° E
BC	200	N 60° E
CQ	–	S 30° E

Calculate the lengths of the lines *CQ* and *QP*.

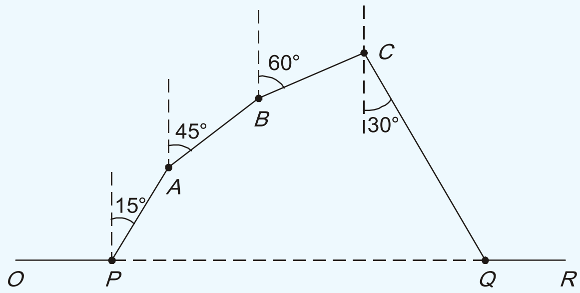
[10 marks : 2024]

(ii) Enlist the various geological challenges need to be considered for construction of tunnels in the Himalayan region.

[10 marks : 2024]

Solution:

(i)



Line	Bearing (in WCB)	Length (in m)
PA	15°	160
AB	45°	300
BC	60°	200
CQ	150°	x
QP	270°	y

In closed traverse *PABCQP*

$$\sum \text{Latitude} = \sum \text{Departure} = 0$$

$\Rightarrow$ $160 \cos 15° + 300 \cos 45° + 200 \cos 60° + x \cos 150° + y \cos 270° = 0$

$\Rightarrow$ $154.55 + 212.13 + 100 + x \cos 150° + 0 = 0$

$\Rightarrow$ $x = 538.88 \text{ m}$

Also,

$\Rightarrow$ $160 \sin 15° + 300 \sin 45° + 200 \sin 60° + x \sin 150° + y \sin 270° = 0$

$\Rightarrow$ $41.41 + 212.13 + 173.20 + 538.88 \times \sin 150° + y(-1) = 0$

$\Rightarrow$ $y = 696.18 \text{ m}$

So, length of CQ = 696.18 m
length of QP = 696.79 m

(ii)

The Himalayan region presents numerous geological challenges that need to be carefully considered for the construction of tunnels. These challenges arise due to the complex and dynamic geological conditions prevalent in this mountainous area.

Here are the key geological challenges:

1. **Seismic Activity:** The Himalayas are seismically active due to the ongoing collision between the Indian and Eurasian tectonic plates, leading to frequent earthquakes that can impact tunnel stability and safety.
2. **High Stress Regime:** The high overburden and tectonic forces result in significant rock stresses, which can cause rock bursts, spalling, and deformation of tunnel linings.
3. **Complex Geology:** The region is characterized by a heterogeneous mix of rock types, including schists, gneisses, quartzites, and limestones, often interspersed with weak zones such as shear zones, faults, and folds.
4. **Fault Zones and Shear Zones:** Faults and shear zones can lead to sudden changes in rock conditions, creating zones of weakness that may cause collapse or excessive deformation.
5. **Water Ingress:** The presence of high groundwater levels and water-bearing strata can lead to significant water ingress into tunnels, necessitating effective drainage and waterproofing measures.
6. **Weak and Fragmented Rock Masses:** Weak and fragmented rock masses, often due to weathering, can result in unstable tunnel faces and require extensive support systems to maintain stability.
7. **High Overburden Pressure:** Tunnels in the Himalayas often have high overburden pressures due to the mountainous terrain, leading to challenges in maintaining tunnel integrity and preventing collapse.
8. **Landslides and Rockfalls:** The region is prone to landslides and rockfalls, especially during the monsoon season, which can obstruct tunnel portals and access routes.
9. **Swelling and Squeezing Ground:** Certain rock types, such as clay-rich rocks, can swell when exposed to moisture, while others may exhibit squeezing behavior under high stress, leading to deformation and potential collapse.
10. **Temperature Variations:** The extreme temperature variations, from freezing conditions in winter to high temperatures in summer, can cause thermal stresses and affect construction materials and processes.
11. **Cultural and Environmental Sensitivity:** The Himalayan region is environmentally and culturally sensitive, requiring careful planning to minimize ecological impact and respect local communities and heritage sites.
12. **Access and Logistics:** The remote and rugged terrain poses significant challenges for transporting materials, equipment, and personnel to the construction site, impacting project logistics and timelines.

End of Solution

■■■■