ESE 2022

Main Exam Detailed Solutions

Civil Engineering

PAPER-II

EXAM DATE : 26-06-2022 | 2:00 PM to 5:00 PM

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ANALYSIS

Civil Engineering Paper-II
ESE 2022 Main Examination

Sl.	Subjects	Marks
1.	Fluid Mechanics & Hydraulic Machines	89
2.	Engineering Hydrology	0
3.	Water Resource Engineering	20
4.	Environmental Engineering	131
5.	Soil Mechanics & Foundation Engg.	106
6.	Surveying and Geology	60
7.	Transportation Engineering	74
	Total	**480**

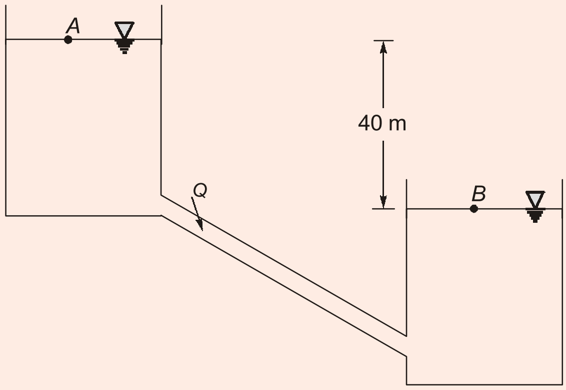
Scroll down for detailed solutions

Section-A

Q.1 (a) A straight 20 cm diameter pipeline 4 km long is laid between two reservoirs having a difference of levels of 40 m. To increase the capacity of the system, an additional 2 km long, 20 cm diameter pipe is laid parallel from the upper reservoir to the mid-point of the original pipe. Find the increase in discharge due to installation of the new pipe. Assume f as 0.00625.

[12 marks]

Solution:



$$\text{Diameter, } d = 0.2 \text{ m}$$
$$\text{Length, } L = 4000 \text{ m}$$
$$f = 0.00625$$

Apply energy equation between (A) and (B)

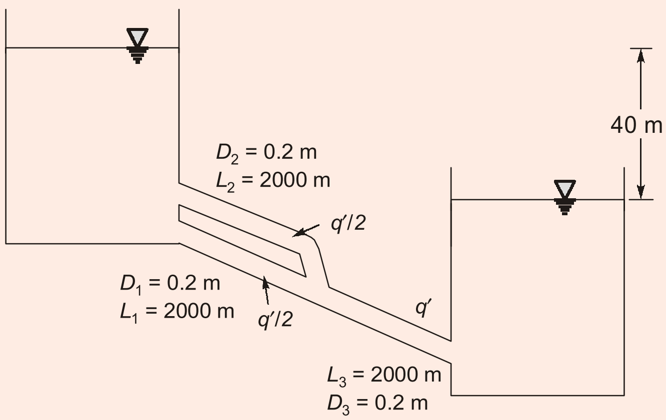
$$\frac{P_A}{\rho g} + \frac{V_A^2}{\rho g} + Z_A = \frac{P_B}{\rho g} + \frac{V_B^2}{\rho g} + Z_B + h_f$$

$$Z_A - Z_B = \frac{8Q^2}{\pi^2 g} \cdot \frac{fL}{D^5}$$

$$40 = \frac{8 \times Q^2}{\pi^2 g}\left[\frac{0.00625 \times 4000}{(0.2)^5}\right]$$

$$Q = 0.078718 \text{ m}^3/\text{sec.}$$

or $$Q = 78.718 \text{ lps}$$



Apply energy equation between (A) and (B)

$$\frac{P_A}{\rho g} + \frac{V_A^2}{2g} + Z_A = \frac{P_B}{\rho g} + \frac{V_B^2}{2g} + Z_B + h_f$$

$$40 = \frac{8(q'/2)}{\pi^2 g} \times \frac{f \cdot L_1}{D_1^5} + \frac{8 \times [q']^2}{\pi^2 g} \cdot \frac{f(L/2)}{D^5}$$

$$40 = \frac{8(q')^2}{\pi^2 g} \times \frac{f \cdot L_1}{D^5}\left[\frac{1}{2} \times \frac{1}{4} + \frac{1}{2}\right]$$

$$40 = \frac{8(q')^2}{\pi^2 \times 9.81} \times \frac{0.00625 \times 4000}{(0.2)^5} \times 0.625$$

$$q' = 0.099571 \text{ m}^3\text{/sec.} = 99.57 \text{ lps}$$

Increase in discharge: $= 99.57 - 78.71$

$= 20.8533$ lps

End of Solution

Q.1 (b) What is cavitation? How does it affect the performance of hydraulic machines? Also mention the significance of Thoma cavitation number. [12 marks]

Solution:

When pumping liquids, it is possible for the local pressure inside the pump to fall below the vapor pressure of the liquid. P_v,(P_v, is also called the saturation pressure P_{sat} and is listed in thermodynamics tables as a function of saturation temperature.) When $P < P_v$, vapor-filled bubbles called cavitation bubbles appear. The liquid boils locally typically on the suction side of the rotating impeller blades where the pressure is lowest. After the cavitation bubbles are formed, they are transported through the pump to regions where the pressure is higher, causing rapid collapse of the bubbles. It is this collapse of the bubbles that is undesirable, since it causes noise, vibration, reduced efficiency, and most importantly, damage to the impeller blades. Repeated bubble collapse near a blade surface leads to pitting or erosion of the blade and eventually catastrophic blade failure.

For Turbine:

Thoma Cavitation Factor (σ):

$$\sigma = \frac{(H_a - h_s) - H_v}{H} = \frac{\text{NPSH}}{H}$$

H_a = Atmospheric pressure head, H_v = Vapour pressure head, h_s = Suction head (at the outlet of reaction turbine), H = Working head, NPSH = Net Positive Suction Head

Critical value of Thoma's number (σ_c) depends upon N_s and is given by:

(i) For Francis turbine, $\sigma_c = 0.044\left(\frac{N_s}{100}\right)^2$

(ii) For Propeller turbine, $\sigma_c = 0.3 + 0.0032\left(\frac{N_s}{100}\right)^{2.73}$

(iii) For Kaplan turbine, σ_c is 10% higher than σ_c for propeller turbine.

Condition for no cavitation

$$\sigma \geq \sigma_c$$

$$\therefore \quad NPSH \geq \sigma_c \times H$$

For pump:

For no cavitation $NPSH \geq \sigma_c H$

σ_c = Critical Thoma's number = $1.042 \times 10^{-3} (N_s)^{4/3}$

where N_s is specific speed of pump.

$$NPSH = (H_a - h_s) - H_v$$

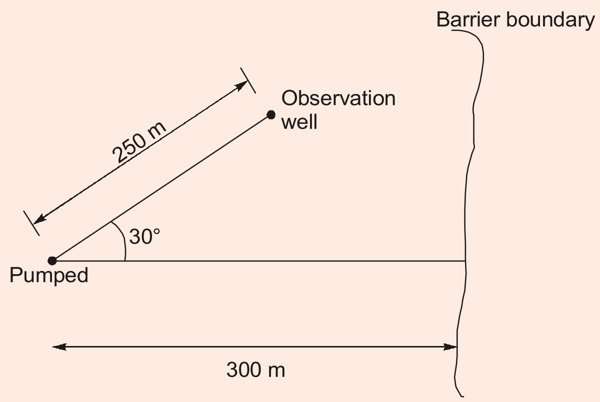
where, H_a = atmospheric pressure head

H_v = vapour pressure head

h_s = suction head

End of Solution

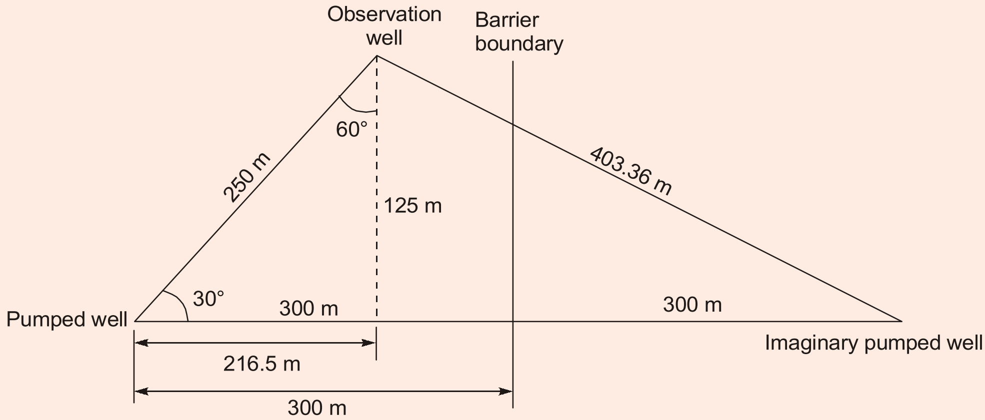
Q.1 (c) A well is pumping near a barrier boundary at a rate of 0.04 m^3/s from a confined aquifer 20 m thick. The hydraulic conductivity of the aquifer is 3.5×10^{-4} m/s and its storactivity is 3×10^{-5}. Determine the drawdown in the observation well after 15 hours of continuous pumping. What is the fraction of the drawdown attributable to the impermeable barrier boundary?



u	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
×1	0.219	0.049	0.013	0.0038	0.0011	0.00036	0.00012	0.000038	0.000012
$\times 10^{-1}$	1.82	1.22	0.91	0.70	0.56	0.45	0.37	0.31	0.26
$\times 10^{-2}$	4.04	3.35	2.96	2.68	2.47	2.30	2.15	2.03	1.92
$\times 10^{-3}$	6.33	5.64	5.23	4.95	4.73	4.54	4.39	4.26	4.14
$\times 10^{-4}$	8.63	7.94	7.53	7.25	7.02	6.84	6.69	6.55	6.44
$\times 10^{-5}$	10.94	10.24	9.84	9.55	9.33	9.14	8.99	8.86	8.74
$\times 10^{-6}$	13.24	12.55	12.14	11.85	11.63	11.45	11.29	11.16	11.04
$\times 10^{-7}$	15.54	14.85	14.44	14.15	13.93	13.75	13.60	13.46	13.34
$\times 10^{-8}$	17.84	17.15	16.74	16.46	16.23	16.05	15.90	15.76	15.65
$\times 10^{-9}$	20.15	19.45	19.05	18.76	18.54	18.35	18.20	18.07	17.95
$\times 10^{-10}$	22.45	21.76	21.35	21.06	20.84	20.66	20.50	20.37	20.25
$\times 10^{-11}$	24.75	24.06	23.65	23.36	23.14	22.96	22.81	22.67	22.55
$\times 10^{-12}$	27.05	26.36	25.96	25.67	25.44	25.26	25.11	24.97	24.86
$\times 10^{-13}$	29.36	28.66	28.26	27.97	27.75	27.56	27.41	27.28	27.16
$\times 10^{-14}$	31.66	30.97	30.56	30.28	30.05	29.87	29.71	29.58	29.46
$\times 10^{-15}$	33.96	33.27	32.86	32.58	32.35	32.17	32.02	31.88	31.76

[12 marks]

Solution:



Discharge through a pumped well, $Q = 0.04\ m^3/s$

Thickness of confined aquifer, $B = 20$ m

Hydraulic conductivity of aquifer, $k = 3.5 \times 10–4$ m/s

Storativity, $s = 3 \times 10^{-5}$

Drawdown in the observation well is

$$s = s_1 + s_2$$

$$= \frac{Q}{4\pi T} W(u_1) + \frac{Q}{4\pi T} W(u_2)$$

where, $u_1 = \frac{r_1^2 S}{4Tt}$ (for pumped well)

and $u_2 = \frac{r_2^2 S}{4Tt}$ (for imaginary pumped well)

$$u_1 = \frac{250^2 \times 3 \times 10^{-5}}{4 \times 3.5 \times 10^{-4} \times 20 \times (15 \times 3600)} = 1.24 \times 10^{-3}$$

$$u_2 = \frac{403.36^2 \times 3 \times 10^{-5}}{4 \times 3.5 \times 10^{-4} \times 20 \times 15 \times 3600} = 3.228 \times 10^{-3}$$

$$\simeq 3.23 \times 10^{-3}$$

The value of $W(u_1)$ from the table is:

For $u = 1 \times 10^{-3}$, $W(u) = 6.33$

For $u = 2 \times 10^{-3}$, $W(u) = 5.64$

By interpolation, for $u_1 = 1.24 \times 10^{-3}$:

$$W(u_1) - 6.33 = \frac{5.64 - 6.33}{2 \times 10^{-3} - 1 \times 10^{-3}}\left(1.24 \times 10^{-3} - 1 \times 10^{-3}\right)$$

$$W(u_1) = 6.1644$$

The value of $W(u_2)$ from the table is

For $u = 3 \times 10^{-3}$, $W(u) = 5.23$

For $u = 4 \times 10^{-3}$, $W(u) = 4.95$

By interpolation, for $u_2 = 3.23 \times 10^{-3}$:

$$W(u_2) - 5.23 = \frac{4.95 - 5.23}{\left(4 \times 10^{-3}\right) - \left(3 \times 10^{-3}\right)}\left(3.23 \times 10^{-3} - 3 \times 10^{-3}\right)$$

$$W(u_2) = 5.1656$$

$$\therefore \quad S = \frac{0.04\,\text{m}^3/\text{s}}{4\pi \times \left(3.5 \times 10^{-4} \times 20\right)\text{m}^2/\text{s}}[6.1644 + 5.1656]$$

$$= 5.15 \text{ m}$$

If the impermeable barrier boundary would not exist, then drawdown in the well,

$$S' = \frac{0.04\,\text{m}^3/\text{s}}{4\pi \times \left(3.5 \times 10^{-4} \times 20\right)\text{m}^2/\text{s}} \times 6.1644 = 2.80 \text{ m}$$

Drawdown additionally caused due to impermeable barrier

$$S - S' = 5.152 - 2.80 = 2.35 \text{ m}$$

Fraction of total drawdown due to barrier $= \frac{2.35}{5.15} = 0.46$

End of Solution

Q.1 (d) What do you mean by Environmental Lapse Rate (ELR) and Adiabatic Lapse Rate (ALR)? How and in what manner do the environmental lapse rate and adiabatic lapse rate affect the dispersion of an air pollutant into the atmosphere? Explain clearly.

[12 marks]

Solution:

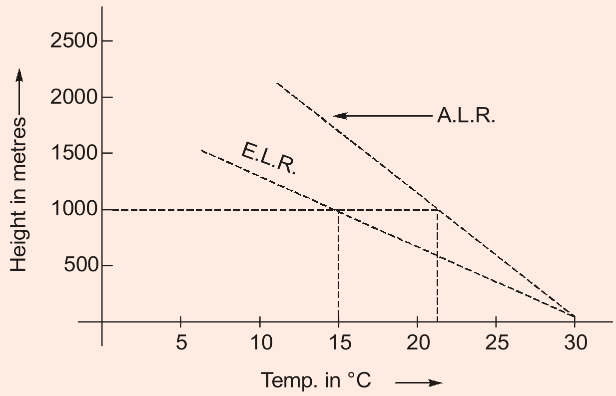
Lapse rate: In the troposphere, the temperature of the ambient air usually decrease with an increase in attitude. This rate of temperature change is called the lapse rate. This rate will differ from place to place and from time to time even at the same place.

Environmental lapse rate (ELR)/Ambient lapse: The ELR can be determined by sending up a balloon equipped with a thermometer. The balloon moves through the air, not with it, and the temperature gradient of ambient air, which the rising balloon measures is called the ambient lapse rate, the environmental lapse rate or the prevailing lapse rate.

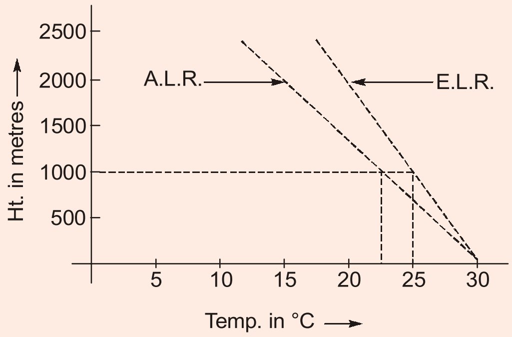
Adiabatic Lapse Rate: When a parcel of air, which is hotter and lighter than the surrounding air is released, then naturally it tends to rise up, until it reaches to a level at which its own temperature and density becomes equal to that of the surrounding using the law of conservation of energy and gas law. This-rate of decrease of temperature with height is called adiabatic lapse rate. Dry air expanding adiabatically, cools at rate of 9.8°C per kilometer and it is called dry adiabatic lapse rate. In wet adiabatic process a saturated parcel of air rises and cools. Temperature changes of the parcel are due to liberation of latent heat as well as of expansion of the air. Wet adiabatic lapse rate (6°C/km) is thus lesser than dry adiabatic lapse rate. Since a rising parcel of emitted smokes will normally, neither be fully dry nor fully saturated, the actual adiabatic lapse rate (ALR), representing cooling of the emitted smokes will be between the dry adiabatic rate and wet adiabatic rate. The three major relative position of ELR line with reference to ALR line are as follows:

(a) **Super Adiabatic Lapse Rate:** When the ELR is more than the ALR then ambient lapse rate is super adiabatic and the environment is said to unstable.

Dispersion of pollutants will be rapid due to rapid vertical mixing of the air making the environment unstable.



(b) Sub-adiabatic Lapse Rate: When ELR is less than the ALR the environment set to be stable and environmental lapse rate is called the sub-adiabatic lapse rate.



Under such condition, the atmosphere is said to be stable.

(c) Neutral: When ELR equals the ALR and both the lines coincide, the environment in such a case is called neutral.

End of Solution

Q.1 (e) A community of 50,000 people uses a 12 ha landfill site that can be filled to an average depth of 20 m. If the municipal solid waste is generated at the rate of 25 N per person per day, and its compacted unit weight in the fill is 8 kN/m^3 and the municipal solid waste to cover ratio is 4 : 1, what is the anticipated useful life of the landfill site?

[12 marks]

Solution:

Volume of landfill site available = 12 ha × 20 m = 240 ha-m

Total MSW generated = 50000 × 25 N/d = 1250000 N/d

$$\frac{MSW}{\text{Cover}} = \frac{4}{1}$$

$$\therefore \quad \text{Weight of cover} = \frac{1}{4} \times 1250000 \text{ N/d}$$

$$= 312500 \text{ N/d}$$

Total landfill weight filled per day = 1562500 N/d

Volume of compacted landfill filled per day

$$= \frac{1562500\, N/d}{8000 \text{ N/m}^3} = 195.31 \text{ m}^3/\text{d}$$

Time required fo fill the volume of landfill i.e. 240 ha-m is

$$= \frac{240 \times 10^4 \text{ m}^3}{195.31 \text{ m}^3/\text{d}} = 12288.16 \text{ days}$$

$$= 33.67 \text{ yrs.}$$

End of Solution

Q.2 (a) A centrifugal pump having outer diameter equal to two times the inner diameter and running at 1200 rpm, works against a total head of 75 m. The velocity of flow through the impeller is constant and equal to 3.0 m/s. The vanes are set back at an angle of 30° at the outlet. If the outlet diameter of the impeller is 600 mm and width at the outlet is 50 mm, determine the following:

(i) Vane angle at the inlet.

(ii) Work done per second by the impeller.

(iii) Manometric efficiency.

(iv) Loss of head at inlet to impeller when the discharge is reduced by 40% with changing the speed.

[20 marks]

Solution:

Given: Manometric head, $H_m = 75$ m

Flow velocity, $V_{f1} = V_{f2} = 3$ m/s

$N = 1200$ rpm

$\phi = 30°$

Outer diameter of impeller, $D_2 = 0.6$ m

Width of outlet, $B_2 = 0.05$ m

$$\text{Inner diameter of impeller, } D_1 = \frac{D_2}{2} = \frac{0.6}{2} = 0.3\,\text{m}$$

$$\text{Discharge, } Q = \pi D_2 B_2 \times V_{f2}$$

$$= \pi \times 0.6 \times 0.05 \times 3 = 0.2827\ \text{m}^3/\text{s}$$

$$u_1 = \frac{\pi \times 0.3 \times 1200}{60} = 18.85\,\text{m/s}$$

$$u_2 = \frac{\pi \times 0.6 \times 1200}{60} = 37.7\,\text{m/s}$$

(i) Vane angle at inlet, $\tan\theta = \dfrac{V_{f1}}{u_1} = \dfrac{3}{18.85}$, $\theta = 9.043°$

$$V_{w2} = u_2 - \frac{V_{f2}}{\tan\phi} = 37.7 - \frac{3}{\tan 30°} = 32.504\,\text{m/s}$$

(ii) Work done per second,

$$W = \rho Q V_{w2} u_2$$

$$= 1000 \times 0.2827 \times 32.504 \times 37.7$$

$$= 346420.81\ \text{Nm/s}$$

(iii) Manometric efficiency,

$$\eta_m = \frac{gH_m}{V_{w2} \times u_2} = \frac{9.81 \times 75}{32.504 \times 37.7}$$

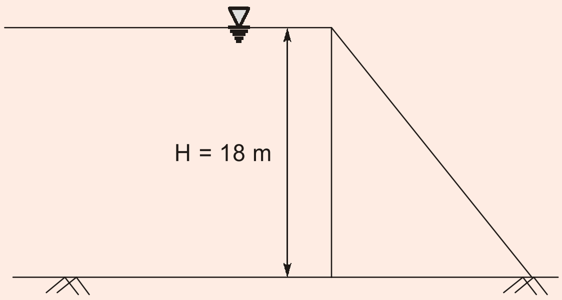
$$\eta_m = 0.6004 \simeq 60\%$$

End of Solution

Q.2 (b) A gravity is 18 m high, in triangular shape. The specific gravity of the dam material is 2.25. Find the minimum safe width of the dam. Use uplift factor K as 0.45. Also calculate the principal and shear stress at the toe of the dam. Consider safety against sliding when the reservoir is full.

[20 marks]

Solution:



G_c - Specific gravity of dam material = 2.25

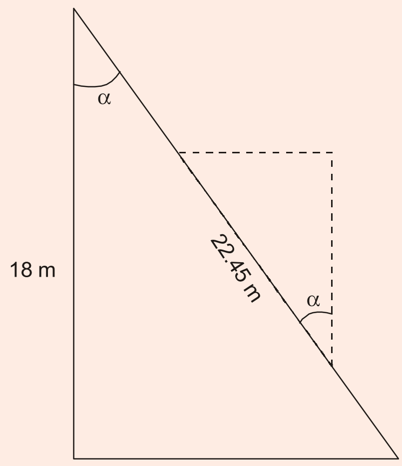
Uplift factor, K = 0.45

For safety against tension,

B_{min} – Minimum width of the dam

$$B_{min} = \frac{H}{\sqrt{G_c - K}} = \frac{18\text{m}}{\sqrt{2.25 - 0.45}} = 13.4164 \text{ m}$$

$$= 13.42 \text{ m}$$



Principal stress at the toe of the dam

$$\sigma = \gamma_w H(G_c - K + 1)$$
$$= 9.81 \text{ kN/m}^3 \times 18 \text{ m} \times (2.25 - 0.45 + 1)$$
$$= 494.424 \text{ kN/m}^2$$

Maximum normal stress at the toe of the dam,

$$p_{\text{max toe}} = \gamma_w H(G_c - K)$$

$$= 9.81 \times \text{kN/m}^3 \times 18\text{ m}(2.25 - 0.45)$$
$$= 317.844\text{ kN/m}^2$$

Shear stress at the toe,

$$\tau_{toe} = p_{max\ toe} \tan\alpha$$
$$= 317.844 \times \frac{13.42}{18} = 236.97\text{ kN/m}^2$$

End of Solution

Q.2 (c) A wastewater treatment plant produces 900 kg of dry solids per day at a moisture content of 96 percent. The solids are 70 percent volatile with a specific gravity of 1.0 and 30 percent non-volatile with a specific gravity of 2.5. What would be the sludge volume under the following conditions:

(i) After digestion process, which reduces volatile solids content by 50 percent and decreases the moisture content to 91 percent.

(ii) After dewatering process to 72 percent moisture.

[20 marks]

Solution:

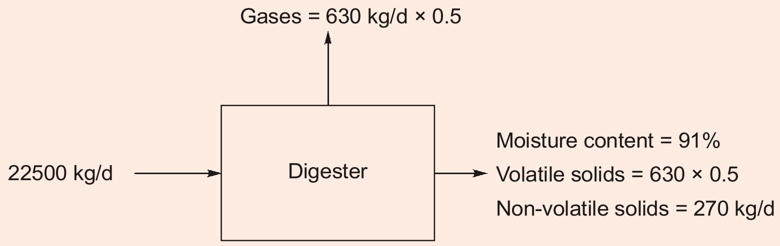
Quantity of dry sludge produced = 900 kg/d

$$\text{Total mass of sludge} = 900\text{ kg/d} \times \frac{100}{4} = 22500\text{ kg/d}$$

Quantity of volatile solids in the sludge = 900 × 0.7 = 630 kg/d

Quantity of non-volatile solids in the sludge = 900 × 0.3 = 270 kg/d

(i)



Total solids present in the digested sludge

$$= (630 \times 0.5) + 270 = 585\text{ kg/d}$$

These solids are 9% of total mass

$$\therefore \quad \text{Total mass of sludge} = 585\text{ kg/d} \times \frac{100}{9} = 6500\text{ kg/d}$$

$$\text{Mass of water in the sludge} = 6500 - 585 = 5915\text{ kg/d}$$

$$\text{Volume of water in the digested sludge} = \frac{5915\text{ kg/d}}{1000\text{ kg/m}^3} = 5.915\text{ m}^3\text{/d}$$

Specific gravity of volatile solids = 1

$$\therefore \text{Volume of volatile solids in the digested sludge} = \frac{(630 \times 0.5)\text{ kg/d}}{1 \times 1000\text{ kg/m}^3} = 0.315\text{ m}^3\text{/d}$$

Specific gravity of non-volatile solids = 2.5

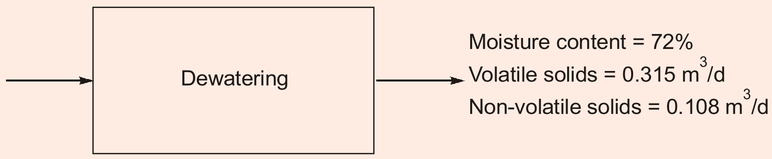
$\therefore$ Volume of non-volatile solids in the digest sludge $= \dfrac{270\,\text{kg/d}}{2.5 \times 1000\,\text{kg/m}^3} = 0.108\,\text{m}^3/\text{d}$

$\therefore$ Total volume of digested sludge $= V_{water} + V_{volatile} + V_{non\text{-}volatile}$

$= (5.915 + 0.315 + 0.108)\text{m}^3/\text{d}$

$= 6.338\ \text{m}^3/\text{d}$

(ii)



Dewatering is assumed to reduce volume by explusion of water only.

Mass of solids in the dewatered sludge

$= 315 + 270 = 585$ kg/d

Now, mass of moisture in the dewatered sludge

$$= 585\,\text{kg/d} \times \frac{72}{28} = 1504.285\,\text{kg/d}$$

Volume of moisture in the dewatered sludge $= \dfrac{1504.28\,\text{kg/d}}{1000\,\text{kg/m}^3} = 1.504\,\text{m}^3/\text{d}$

Thus, volume of dewatered sludge,

Volume $= (1.504 + 0.315 + 0.108)\ \text{m}^3/\text{d}$

$= 1.927\ \text{m}^3/\text{d}$

End of Solution

Q3 (a) Design a sewer to serve a population of 50,000 with per capita water supply of 150 litres per day. Assume that the sewer should run 0.7 times full at the maximum discharge. The slope available for the sewer to be laid is 1 in 500 and the sewer should be designed with a peaking factor of 3.0. Assume Manning's rugosity coefficient value (N) = 0.012. Also perform check for self-cleaning velocity. The following table may be used if required:

Proportionate depth	Proportionate velocity	Proportionate discharge
0.20	0.615	0.088
0.30	0.776	0.196

[20 marks]

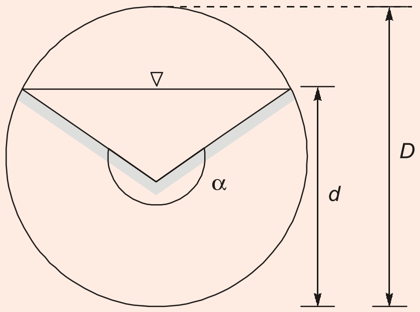
Solution:

Design discharge of the sewer,

$$q = 3 \times (150 \text{ l/c/d} \times 0.8) \times 50000 \text{ c}$$
$$= 18 \times 10^6 \text{ l/d}$$

(A factor of 0.8 is taken for assuming 8070 of water supplied is converted to sewage).

$$\therefore \quad q = 0.2083 \text{ m}^3\text{/s}$$



Given:
$$\frac{d}{D} = 0.7$$
$$0.7 = \frac{1}{2}\left(1 - \cos\frac{\alpha}{2}\right)$$
$$1.4 = 1 - \cos\frac{\alpha}{2}$$
$$\alpha = 227.156°$$

Now,
$$\frac{q}{Q} = \left(\frac{\alpha}{360°} - \frac{\sin\alpha}{2\pi}\right)\left(\frac{\frac{\alpha}{360°} - \frac{\sin\alpha}{2\pi}}{\frac{\alpha}{360°}}\right)^{2/3}$$
$$= 0.748 \times \frac{(0.748)^{2/3}}{(0.631)^{2/3}} = 0.838$$

For assumed full flow

$$Q = \frac{q}{0.838} = \frac{0.2083 \text{ m}^3\text{/s}}{0.838}$$
$$= \left(\frac{1}{0.012}\left(\frac{D}{4}\right)^{2/3}\sqrt{\frac{1}{500}}\right)\frac{\pi D^2}{4}$$
$$D = 0.561 \text{ m}$$

Check for self cleansing velocity:

Self cleansing velocity must be generated at minimum flow.

Assuming the minimum flow in the sewer to be $\frac{1}{3}^{rd}$ the average flow.

$$q_{min} = (150 l/c/d \times 0.8 \times 50000c) \times \frac{1}{3}$$

$$= 2 \times 10^6\ l/d = 0.0231\ m^3/s$$

$$\therefore \quad \frac{q_{min}}{Q} = \frac{0.0231}{0.2486} = 0.0929$$

$$\therefore \quad Q = \frac{q}{0.838} = 0.2486\ m^3/s$$

For $\frac{q_{min}}{Q}$ =0.0929, from the given table, by interpolation, $\frac{V_{min}}{V}$ and $\frac{d_{min}}{D}$ can be found out.

$\frac{q_{min}}{Q}$	$\frac{V_{min}}{V}$
0.088	0.615
0.196	0.776
0.0927	X

$$X - 0.615 = \frac{0.776 - 0.615}{0.196 - 0.088}(0.0927 - 0.088)$$

$$X = \frac{V_{min}}{V} = 0.622$$

$$\therefore \quad V_{min.} = 0.622 \times \frac{1}{n} R^{2/3} S^{1/2}$$

$$= 0.622 \times \frac{1}{0.012} \times \left(\frac{0.561}{4}\right)^{2/3} \sqrt{\frac{1}{500}}$$

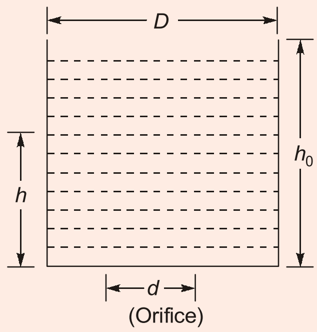
$$= 0.621\ m/s$$

Usually, minimum velocity greater than 0.6 m/s is satisfactory as per Criteria 3.15.1 of GOI manual on sewage and sewage treatment. Hence, O.K.

End of Solution

Q.3 (b) An open tank of diameter D containing water to depth h_0 is emptied by a smooth orifice at the bottom. Derive an expression for the time taken to reduce the height to h.

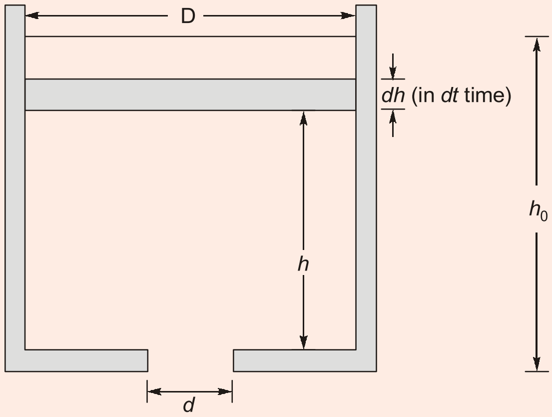
Also deduce the expression for time if $d << D$. Then estimate the time if D is 0.5 m, diameter of orifice is 0.025 m with water level as 0.5 m.



[20 marks]

Solution:

Given, $D = 0.5$ m, $d = 0.025$ m, $h_0 = 0.5$ m



$$\text{Diameter of tank} = D$$

$$\text{Area of tank} = A, \quad \text{i.e. } A = \frac{\pi}{4}D^2$$

$$\text{Diameter of orifice} = d$$

$$\text{Area of orifice} = a \quad \text{i.e. } a = \frac{\pi}{4}d^2$$

Let time for liquid to fall from h_0 to $h = T$

and Coefficient of discharge $= C_d$

$$-A.dh = C_d a\sqrt{2gh}\cdot dt$$

$$\frac{-A}{C_d a\sqrt{2g}}\frac{dh}{\sqrt{h}} = dt$$

Integrate it:

$$\frac{-A}{C_d a\sqrt{2g}}\int_{h_0}^{h}\frac{dh}{\sqrt{h}} = \int_0^T dt$$

$$\frac{A}{C_d a\sqrt{2g}}\int_{h}^{h_0}\frac{dh}{\sqrt{h}} = T$$

$$\frac{2A}{C_d\cdot a\cdot\sqrt{2g}}\left(\sqrt{h_0}-\sqrt{h}\right) = T$$

$$\frac{2\frac{\pi}{4}D^2}{C_d\frac{\pi}{4}d^2\sqrt{2g}}\left(\sqrt{h_0}-\sqrt{h}\right) = T$$

$$T = \frac{2D^2}{C_d d^2\sqrt{2g}}\left(\sqrt{h_0}-\sqrt{h}\right)$$

$$T = \frac{2(0.5)^2}{C_d (0.025)^2 \sqrt{2g}} \left(\sqrt{0.5} - \sqrt{h}\right)$$

$$T = \frac{180.609}{C_d} \left(\sqrt{0.5} - \sqrt{h}\right) \text{ seconds}$$

where h is in meter.

End of Solution

Q.3 (c) State Buckingham's π-theorem. Write the procedure for selecting the repeating variables.

[15 marks]

Solution:

Buckingham π–Method

- The theorem states that if there are n dimensional variables involved in a phenomenon, which can be completely described by m fundamental quantities or dimensions (such as mass, length, time etc.), and are related by dimensionally homogeneous equation, then the relationship among the n-quantities can always be expressed in terms of exactly $(n - m)$ dimensionless and independent π terms.
- In a general dimensional analysis problem, there is one π that we call the dependent π, giving it the notation π. The parameter π, is in general a function of several other π's, which we call independent π's. Thus,

  $$\pi_1 = f(\pi_2, \pi_3, \ldots \pi_k)$$

  where k is the total number of π's.
- If a quantity is dimensionless, it is a π-term.
- If any two quantities have same dimension, then their ratios will be a π-term.
- Any π-term can be replaced by any power of that term, it can also be replaced by multiplying or dividing it by another π-term.

Procedure for Selecting Repeating Variables

(i) Select the first repeating variable from those describing the geometry of flow e.g. size and shape of fluid passage or of the moving body such as diameter, length, height, etc.

(ii) Select the second repeating variable from those representing the fluid properties such as density, viscosity, surface tension, elasticity, vapour pressure, etc.

(iii) Select the third repeating variable from those characterising the fluid motion such as velocity, acceleration, discharge, pressure, force, power.

End of Solution

Q.4 (a) A rectangular channel of 5 m width discharge water at 2 m³/s into a 5 m wide apron with 1/3500 slope at a velocity of 6 m/s. Determine the height of hydraulic jump and energy loss.

[10 marks]

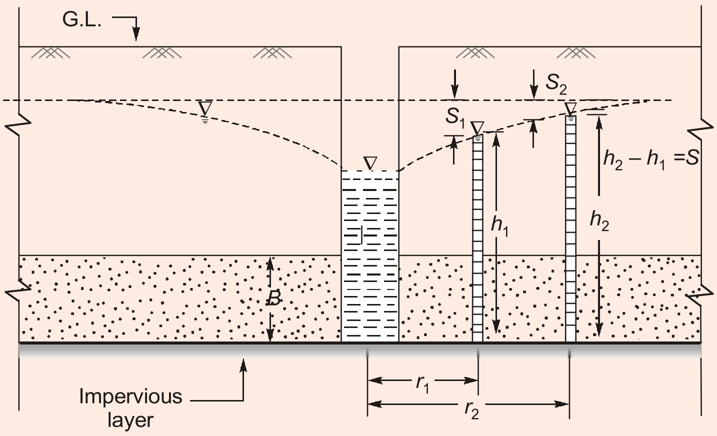
Solution:

End of Solution

Q.4 (b) A 20 cm diameter well fully penetrates a confined aquifer of thickness 25 m when the will is pumped at a rate of 200 litres/minute. The steady state drawdown in two observation wells located at 10 m and 100 m distance from the pumping well are found to be 3.5 m and 0.05 m, respectively. Calculate the permeability and transmissivity of the aquifer.

[10 marks]

Solution:



S_1 – drawdown in first observation well

S_1 = 3.5 m

S_2 = drawdown in second observation well

S_2 = 0.05 m

Applying Thiem's equation:

$$Q = \frac{2\pi kB(h_2 - h_1)}{ln\left(\frac{r_2}{r_1}\right)} = \frac{2\pi kB(S_1 - S_2)}{ln\left(\frac{r_2}{r_1}\right)}$$

$$\frac{200\times10^{-3}}{60}\,\text{m}^3/\text{s} = \frac{2\pi\times k\times 25\,\text{m}(3.5-0.05)\,\text{m}}{\ln\left(\frac{100}{10}\right)}$$

$$k = 1.4163 \times 10^{-5} \text{ m/s}$$

$$\text{Transmissibility, } T = kB$$

$$= 1.4163 \times 10^{-5} \text{ m/s} \times 25 \text{ m}$$

$$= 3.541 \times 10^{-4} \text{ m}^2\text{/s}$$

End of Solution

Q.4 (c) A drinking water treatment plant has a circular sedimentation basin to treat 13 million litres of river water per day. After storms occur upstream, the river often carries 0.010 mm silt particles with an average density of 2300 kg/m^3, and the silt must be removed before the water can be used. The sedimentation basin is 3.5 m deep and 21.0 m in diameter. The water is at 15°C. Answer the following:

(i) What is the hydraulic detention time of the basin?

(ii) Will the sedimentation basin (clarifier) remove all of the silt particles from the river water? Justify your answer with appropriate calculations. (Take density of water (ρ) = 999.1 kg/m^3 and viscosity of water (μ) = 0.00114 kg/m.s at 15°C)

[20 marks]

Solution:

(i) Assuming a standard circular tank with side water depth,

$$H = 3.5 \text{ m}$$

and Diameter, $D = 21$ m

Hydraulic detention time,

$$D_t = \frac{\text{Volume of the tank}}{\text{Discharge passing through the tank}}$$

$$D_t = \frac{D^2(0.785H + 0.011D)}{Q}$$

$$= \frac{21^2(0.785 \times 3.5 + 0.011 \times 21)\text{m}^3}{13 \times 10^3 \text{ m}^3\text{/d}}$$

$$= 0.101039 \text{ m}^3\text{/d} \times 24\text{h/d} = 2.424 \text{ h}$$

(ii) Surface overflow rate,

$$V_0 = \frac{Q}{\pi \frac{D^2}{4}} = \frac{13 \times 10^3 \text{ m}^3\text{/d}}{(\pi \times 21^2/4)\text{m}^2}$$

$$= 37.533 \text{ m}^3\text{/m}^2\text{/d}$$

The settling velocity can be found at by stokes law.

$$V_s = \frac{418(G_s - 1)(3T + 70)d^2}{100} = 0.0624 \text{ mm/s}$$

$$= \frac{418(2.3-1)(3\times15+70)}{100}\times(0.01)^2$$

$= 0.0624$ mm/s

$V_0 = 37.53$ m/d $= 0.4344$ mm/s

$$V_s = \frac{(G-1)\gamma_w d^2}{18\mu}$$

$$= \frac{(2.3-1)\times9.81\times999.1\times\left(0.010\times10^{-3}\right)^2}{18\times0.00114}$$

$= 0.0621$ mm/s

∴ $V_s = \text{minimum}\{0.0624, 0.0621\}$

$= 0.0621$ mm/s

∴ Settling velocity is less than surface overflow rate therefore all silt particles will not be removed.

End of Solution

Q4 (d) Explain the Hardy Cross method used for pipe network analysis in the water distribution system. Also derive the expression to apply correction to assumed flow successively for each pipe loop in the network.

[20 marks]

Solution:

In any pipe network, the following two conditions must be satisfied:

(i) The algebraic sum of the pressure drops around a closed loop must be zero, i.e. there can be no discontinuity in pressure.

(ii) The flow entering a junction must be equal to the flow leaving the same junction; i.e. the law of continuity must be satisfied.

Gardt-Cross Method: The flow in each pipe is assumed by the designer (in magnitude as well as in direction) in such a way that the principle of continuity is satisfied at each junction (i.e. the inflow at any junction becomes equal to the outflow at that junction).

A correction to these assumed flows is then computed successively for each pipe loop in the network, until the correction is reduced to an acceptable magnitude.

If Q_a is the assumed flow and Q is the actual flow in the pipe, then that correction Δ is given by

$$\Delta = Q - Q_a$$

or $$Q = Q_s + \Delta$$

Now, expressing the head loss (H_L) as

$$H_L = KQ^s$$

We have, the head loss in a pipe,

$= K(Q_e + \Delta)^x$

$= [Q_0^x + Q_a^{x=1}\Delta + ...$ Neglecting terms containing higher powers of $\Delta]$

$$= \left[Q_a^x + xQ_a^{x-1}\Delta\right]$$

Now, around a closed loop, the summation of head losses must be zero.

$$\therefore \qquad \Sigma K\left[Q_a^x + xQ_a^{x-1}\cdot\Delta\right] = 0$$

or
$$\Sigma K\cdot Q_a^x = -\Sigma K_x\cdot Q_a^{x-1}$$

or
$$\Delta = -\frac{\Sigma K\cdot Q_a^x}{\Sigma x\cdot Q_a^{x-1}}$$

Since Δ is given the same sign (or direction) in all pipes of the loop, the denominator of the above equation is taken as the absolute sum of the individual items in the summation. Hence

or
$$\Delta = \frac{\Sigma K\cdot Q_a^x}{\Sigma\left|x\cdot KQ_a^{x-1}\right|}$$

or
$$\Delta = \frac{-\Sigma H_L}{x\cdot\Sigma\left|\frac{H_L}{Q_a}\right|} \quad (\because KQ^x = H_L \text{ and } x = \text{constant})$$

where H_L = head loss for the assumed flow Q_a.

End of Solution

Section-B

Q.5 (a) The following two size of sampling tubes are available in the market:

Parameters	Sampling Tube 1	Sampling Tube 2
Outer Dia (mm)	75	50
Inner Dia (mm)	72	35
Length (mm)	600	600

To obtain undisturbed soil sample from borehole, which sampling tube needs to be selected and why?

[12 marks]

Solution:

The data provided in the question is not sufficient to determine inside clearance, outside clearance and area ratio, because diameter of cutting teeth is not given.

So, as per given data:

$$A_r = \frac{D_0^2 - D_i^2}{D_i^2}$$

For sampling tube-1,
$$A_r = \frac{75^2 - 72^2}{72^2} \times 100 = 8.5\%$$

For sampling tube-2, $A_r = \dfrac{50^2 - 35^2}{35^2} \times 100 = 104.08\,\%$

As per IS1892: Area ratio should be kept as low as possible. It's value should not be greater than about 20% for stiff soil and for soft sensitive clays, area ratio of 10% or less should be preferred.
Hence Sample-1 should be selected.

End of Solution

Q.5 (b) An infinte dry sandy slope is just stable at a slope angle of 35°. Unit weight of sand = 20 kN/m^3. In monsoon, water starts flowing through the sand down the slope. At what inclination of slope will it be stable in such condition?

[12 marks]

Solution:

Given: Slope angle, $\beta = 35°$

$\gamma_{sand} = 20\ \text{kN/m}^3$

In dry infinite slope, for the slope to be just stable,

$$\text{FOS} = 1$$

$$\frac{\tan\phi}{\tan\beta} = 1$$

$$\frac{\tan\phi}{\tan 35} = 1$$

$$\phi = \beta = 35°$$

When flow takes place at ground slope surface,

$$\text{FOS} = \frac{\gamma'}{\gamma_{sat}} \times \frac{\tan\phi}{\tan\beta} \simeq \frac{1}{2}\frac{\tan\phi}{\tan\beta}$$

$$1 = \frac{1}{2}\frac{\tan\phi}{\tan\beta}$$

$$\beta = \tan^{-1}\left[\frac{1}{2}\tan\phi\right] = \tan^{-1}\left[\frac{1}{2}\tan(35)\right]$$

$$\beta = 19.29°$$

End of Solution

Q.5 (c) What do you mean by spot speed, running speed, space-mean speed and time-mean speed? Explain them with appropriate examples. Also discuss the main purposes of spot speed studies.

[12 marks]

Solution:

1. Spot speed is the instantaneous speed of a vehicle at a specified section or location.
2. Running speed is the average speed maintained by a vehicle over a particular stretch of road, while the vehicle is in motion. This is obtained by dividing the distance covered by the time during which the vehicle is actually in motion.
3. Space-mean speed represents the average speed of vehicles in a certain road length at any time. This is obtained from the observed travel time of the vehicles over a relatively long stretch of the road. Space-mean speed is calculated from:

$$V_s = \frac{3.6dn}{\sum_{i=1}^{n} t_1}$$

where V_s = space-mean speed, kmph

d = length of road considered, (in m)

n = number of individual vehicle observations

t_1 = observed travel time (sec) for the vehicle to travel distance d, m

The average travel time of all the vehicles is obtained from the reciprocal of space mean speed.

4. Time-mean speed represents the speed distribution of vehicles at a point on the roadway and it is the average of instantaneous speeds of observed vehicles at the spot. Time-mean speed is calculated from:

$$V_t = \frac{\sum_{i=1}^{n} V_i}{n}$$

where, V_t = time-mean speed, kmph

V_i = observed instantaneous speed of ith vehicles, kmph

n = number of vehicles observed

Ths space-mean speed is slightly lower than time mean speed under typical speed conditions on rural highway.

Purpose of spot speed study is:

(a) Planning traffic control and in traffic regulations.
(b) Geometric design-for redesigning existing highways.
(c) In accident studies.
(d) Study the traffic capacity.
(e) Decide the speed trends.
(f) Compare diverse types of drivers and vehicles under specified conditions.

End of Solution

Q.5 (d) What is meant by crossing? What are the essential requirements of a good crossing? Discuss various types of crossing in use in Indian Railways.
[12 marks]

Solution:

A 'crossing' or a 'frog' is a device which provides two flangeways through which the wheels of the flanges may move, when two rails intersect each other at an angle.

The flanged wheel of the train jump over the gap from 'throat' ot 'nose' of crossing and to check the wheel flanges from striking the nose, the opposite wheel flanges are guided by use of 'check rails' inside the running rail.

Components of Crossing:

(i) A crossing or Vee piece.
(ii) Point and splice rails.
(iii) Wing rails.
(iv) Check rails.
(v) Chairs at crossing, at toe and at heel.
(vi) Throat of crossing

Requirements and characteristics of a good crossing:

(i) The assembly of a crossing has to be rigid to stand against severe vibrations.and splice rails.
(ii) The wear on parts of the wing rails, opposite the nose and also of nose itself must be protected. The medium manganese steel (i.e., an alloy steel) is used where traffic is light whereas high manganese steel is used where traffic is heavy.
(iii) The crossing body should be as rigid as possible and as long as practicable.
(iv) Ramp the wing rails by 3 mm to 6 mm at the top from throat to nose and flushing it to the normal level of the chair.
(v) By use of the distance blocks closely touching the web.
(vi) The nose of crossing should have some thickness, aries from 6 mm to 18 mm.

Type of Crossings: Crossing can be classified as below:

1. Acute angle crossing or "V" crossing or Frog.
2. Obtuse angle crossing or Diamond crossing.
3. Square crossing.

1. Acute angle crossing: It is obtained when a left-hand rail of one track crosses a right-hand rail of another track or vice versa. The crossing used widely.
2. Obtuse angle crossing: This crossing is obtained when left-hand rail of one track crosses right hand rail of another track or vice versa at an obtuse angle.
   In diamond crossing, a pair of special crossing is used which is called "Obtuse crossing".

3. **Square crossing**: When two straight tracks cross each other at right angles, they give rise to square crossing. This type of crossing must be avoided on main lines because there is heavy wear due to dynamic loads.

End of Solution

Q.5 (e) The top point *P* of a tower having reduced level of 200 m was sighted using the theodolite from two stations *A* and *B* which were 100 m apart and were on the same side of the tower. All the three points *A*, *B* and *P* were in the same plane. The angles of elevation of point P from instrument stations A and B were 10°30′ and 16° 20′ respectively. The horizontal axis of instrument at point A was 2.5 m below the horizontal axis of instrument at point B and 1.5 m above the base of the tower. Calculate the:

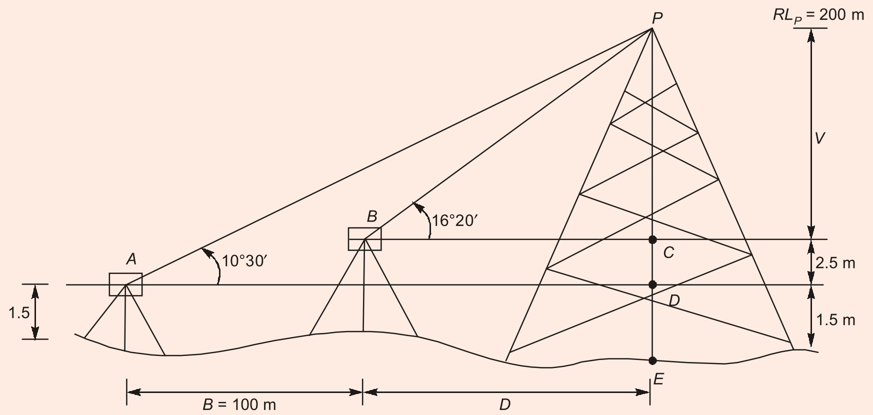
(i) horizontal distance between point *A* and the top of the tower.

(ii) height of the tower.

(iii) reduced level of station *A*, if the height of instrument at *A* was 1.5 m.

[12 marks]

Solution:



From ΔAPD:

$$\tan 10°30' = \frac{V+2.5}{D+100}$$

$$\Rightarrow \quad V + 2.5 = D\tan 10°30' + 100\tan 10°30' \quad ....(1)$$

From ΔBPC,

$$\tan 16°20' = \frac{V}{D}$$

$$\Rightarrow \quad V = D\tan 16°20' \quad ....(2)$$

$$\Rightarrow V = 0.293\text{ D}$$

From (1) and (2), $D = 149.53$ m

$V = 43.81$ m

$V = 148.857 \times \tan 16°20' = 43.81$ m

(i) Horizontal distance between (A) and tower:

$= (D + 100) = 149.53 + 100 = 249.53$ m

(ii) Height of tower $PE = (V + 2.5 + 1.5)$

$= (43.81 + 2.5 + 1.5) = 47.81$ m

(iii) RL of ground statrm A: $= RL_P - V - 2.5 - 1.5$

$= (200 - 43.81 - 2.5 - 1.5) = 152.19$ m

End of Solution

Q.6 (a) Dust, gravel and intact pieces of rock are produced during rock coring with core advance of 2 m. The lengths of the rock pieces are 150 mm, 200 m, 90 mm, 300 mm, 60 mm, 250 mm, 120 mm, 170 mm, 80 mm, 210 mm and 75 mm.

Calculate *RQD* and comment on the rock quality based on *RQD*.

[20 marks]

Solution:

Total length of rock pieces greater than 100 mm/l

$$l = 150 + 200 + 300 + 250 + 120 + 170 + 210$$

$$l = 1400 \text{ mm}$$

Total care run length = 2000 mm

$$RQD = \frac{1400}{2000} \times 100$$

$$RQD = 70\%$$

For RQD value between 51 – 75%, rock quality is considered to be fair i.e. moderate weathered.

SO, rock quality is fair.

End of Solution

Q.6 (b) A 5 m high rigid vertical retaining wall has to retain a dry backfill cohesionless soil with the following properties:

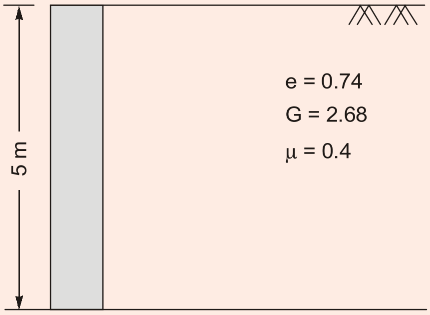
Void ratio (e) = 0.74, specific gravity of soil (G) = 2.68, Poisson's ratio of soil (μ) = 0.4.

The wall needs to be designed for no lateral movement condition of earth pressure. In monsoon, the dry backfill becomes fully submerged with water table at the top of the backfill surface. Estimate the percentage change in the total lateral thrust acting on the wall during monsoon.

[12 marks]

Solution:

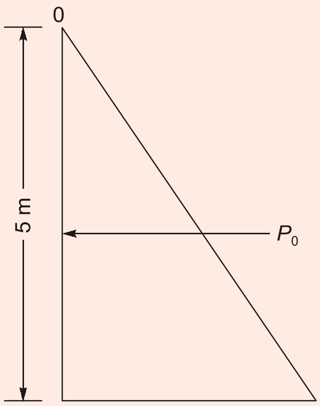
(i) For design of rigid vertical retaining wall (no lateral movement),



$$k_0 = \frac{\mu}{1-\mu} = \frac{0.4}{1-0.4} = 0.67$$

$$\gamma_d = \frac{G\gamma_w}{1+e} = \frac{2.68 \times 9.81}{1+0.7u} = 15.10 \text{ kN/m}^2$$

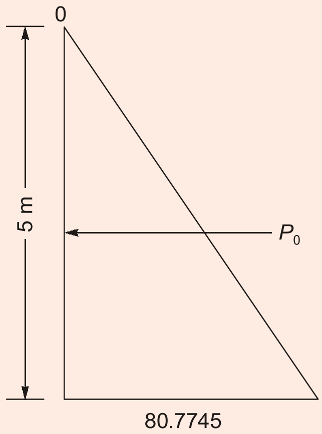
1. $\sigma_v = \gamma z = 15.1 \times z$ (at any depth z)
2. $p_0 = k_0\sigma_v = 0.67 \times 15.1 \times z$
3. for $z = 0$, $p_0 = 0$
   for $z = 5$ m, $p_0 = 50.585$ kN/m^2



4. Total earth pressure, $P_0 = \frac{1}{2}k_0 \cdot \gamma \cdot H^2 = \frac{1}{2} \times 0.67 \times 15.1 \times 5^2$

$$= 126.46 \text{ kN/m}$$

(ii) When the backfill is submerged:



$$\gamma' = \left[\frac{G-1}{1+e}\right]\gamma_w = \frac{2.68-1}{1+0.74}\times 9.81 = 9.47 \text{ kN/m}^3$$

1. $\bar{\sigma}_v = \gamma' x z = 9.47\times z$, $u = \gamma_w \times z = 9.81z$ [at any depth z]

2. $p_0 = k_0\bar{\sigma}_v + u = 0.67\times 9.47z + 9.81z$

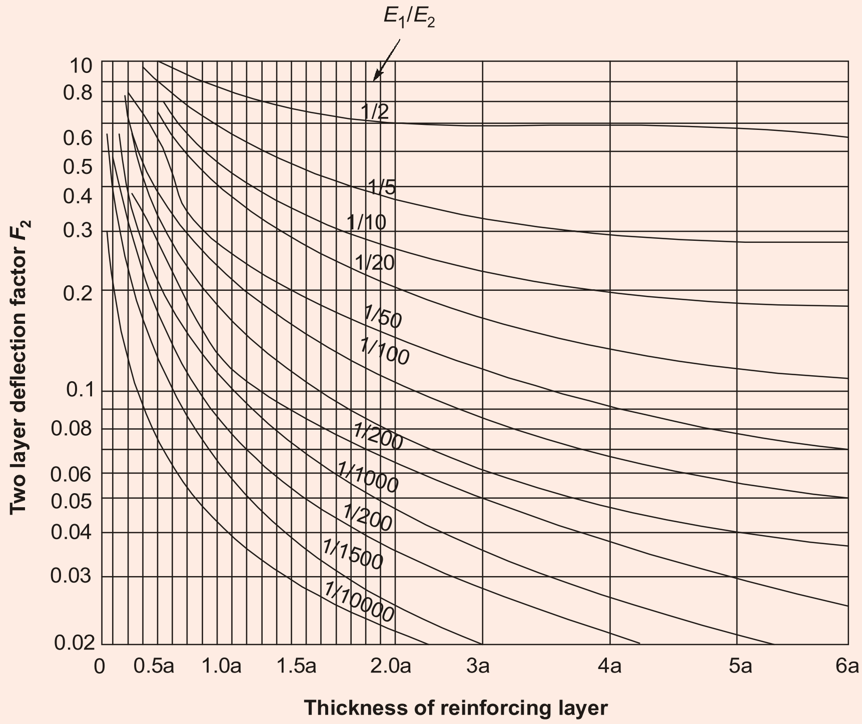
3. at $z = 0$, $p_0 = 0$
   at $z = 5$ m, $p_0 = 80.7745$ kN/m^2

4. Total earth pressure, $P_0 = \frac{1}{2}\times 80.7745\times 5 = 201.9$ kN/m

$$\%\text{age change} = \frac{201.9-126.46}{126.46}\times 100 = 59.65\%$$

End of Solution

Q.6 (c) Plate bearing tests were conducted with 30 cm diameter plate on soil subgrade and over 15 cm base course. The pressure yielded at 0.25 cm deflection is 1.25 kg/cm^2 and 5 kg/cm^2 for subgrade and base course respectively. Design the thickness of flexible pavement for a wheel load of 4080 kg with tyre pressure of 4.5 kg/cm^2. Take rigidity factor 1.11.



[20 marks]

Solution:

Plate bearing test conducted on subgrade,

$$a = \frac{30}{2}$$

$$p = 1.25 \text{ kg/cm}^2$$

$$\Delta = 0.25 \text{ cm} \qquad F_2 = 1$$

$$\Delta = 1.18\frac{p.a}{E_s} \times F_2$$

$$0.25 = 1.18 \times \frac{1.25 \times 15}{E_s} \times 1$$

$$E_s = 88.5 \text{ kg/cm}^2$$

Plate bearing test conducted on 15 cm base,

$$h = 15 \text{ cm}, \; a = 15 \text{ cm}, \; \frac{h}{a} = 1$$

$$\Delta = 1.18\frac{p.a}{E_s} \times F_2$$

$$0.25 = 1.18\frac{5\times 15}{88.5}\times F_2$$

$$F_2 = 0.25$$

Using given curve, $\frac{h}{a} = 1$

$\Rightarrow$ $h = 1.0a$

$$F_2 = 0.25$$

$$\frac{E_1}{E_2} = \frac{1}{100}$$

$$E_2 = 100E_1$$

For pavement thickness:

$$p = 4080 \text{ kg}$$

$$p = 4.5 \text{ kg/cm}^2$$

$$p = \frac{P}{\pi a^2}$$

$$a = \sqrt{\frac{P}{\pi p}} = \sqrt{\frac{4080}{4.5\times\pi}} = 16.99 \text{ cm}$$

$$\Delta = 1.5\frac{p.a}{E_s}\times F_2$$

$$0.25 = 1.5\times\frac{4.5\times 16.99}{88.5}\times F_2$$

For $F_2 = 0.193$ and $\frac{E_1}{E_2} = \frac{1}{100} \Rightarrow \frac{h}{a} = 1.25$ From cumec

For $F_2 = 0.193$

$$\frac{E_1}{E_2} = \frac{1}{100}, \quad \frac{h}{a} = 1.25$$

$$h = 1.25\times 16.99 = 21.24 \text{ cm}$$

Thickness of pavement = 21.24 cm

End of Solution

Q.6 (d) (i) Briefly explain the working principle of Global Poistioning System (GPS). Write any three advantages and any three limitations of GPS in surveying.

(ii) A city of site 25 km × 50 km is to be surveyed for aerial photogrammetry using camera having focal length of 150 mm mounted on an airplane flying at the height of 1500 m above the ground level. The longitudinal and side lap will be 80% and 30% respectively. The size of the photograph will be 250 mm × 250 mm. It is planned to set the exposure interval of camera at 10 seconds.

Calculate the following:

(I) The number of photographs required to cover the area.

(II) The flying speed of the airplane.

(III) The total time required to capture the photographs.

[10 marks]

Solution:

(i) Working Principle: The global positioning system is a space based navigation system. It consists of 24 satellites nominally orbiting the earth in medium earth orbit.

- Each GPS satellite transmits data that indicates its location and the current time.
- All GPS satellites synchronize operations so that these repeating signals are transmitted at the same instant.
- The signals, moving at the speed of light, arrive at a GPS receiver at slightly different times because some satellites are further away than others.
- The distance to the GPS satellites can be determined by estimating the amount of time it takes for their signals to reach the receiver.
- When the receive estimates the distance to at least four GPS satellites. It can calculate its position in three dimensions.

Advantages:

1. Positional accuracy irrespective of network geometry acts as a function for two or more different station distance.
2. Comparatively more flexible, consuming less time and also more effective.
3. High accuracy with 3-dimensional geographic information irrespective of place and time.

Current Limitations of GPS:

1. Clear and fine visibility of sky and no obstructions through any obstacles e.g. branches etc.
2. Not easily universally acceptable.
3. Highly skilled workers are required.

(ii)

$$\text{Area} = [25 \text{ km} \times 50 \text{ km}]$$

$$f = 150 \text{ mm}$$

$$(H - h_{avg}) = 1500 \text{ m}$$

$$\text{Scale} = \left(\frac{f}{H - h_{avg}}\right) = \frac{150 \times 10^{-3}}{1500} = \frac{1}{10000}$$

$$p_l = 80\%$$

$$p_b = 30\%$$

Size of photo given is 250 mm × 250 mm.

$$T = 10 \text{ sec.}$$

1. Number of photos per strip,

$$n_L = \frac{L}{ls(1 - p_e)} + 1 = \frac{50}{250 \times 10000 \times 10^{-6}(1 - 0.8)} + 1 = 101$$

Number of strip,
$$n_s = \frac{B}{lb(1 - p_b)} + 1 = \frac{25}{250 \times 10000 \times 10^{-6}(1 - 0.3)} + 1$$

$= 15.280 \simeq 16$

Number of photos, $n = (n_L \times n_s) = 101 \times 16 = 1616$ photos

2. $T = \dfrac{3600L}{v}$

$L = ls(1 - p_e)$

$= 250 \times 10000 \times (1 - 0.8) \times 10^{-6} = 0.5$ km

$10 \text{ sec} = \dfrac{3600 \times 0.5}{v}$

$v = 180$ kmph

3. Time taken to cover one complete strip $= 10 \times (100) = 1000$ s

Total time $= 1000 \times 16 = 1600$ s

End of Solution

Q.7 (a) A 400 m radius curve is introduced between straight portions of a Broad Gauge (BG) railway line intersecting to form a deflection angle of 50 degrees. The speed for determining the equilibrium cant is fixed at 100 kmph and the maximum sectional speed is 120 kmph. Determine the equilibrium cant, the maximum permissible speed (considering the cant deficiency, cant excess) and desirable length of transition curve. The maximum permissible cant and cant deficiency are 165 mm and 100 mm respectively. Cant excess is restricted to 75 mm. The lowest speed of any train can be taken as 50 kmph.

[20 marks]

Solution:

Given:

Radius of curve = 400 m

Equilibrium speed = 100 kmph

Maximum sectional speed = 120 kmph

Speed of lowest train = 50 kmph

Cant required for lowest train $= \dfrac{GV^2}{127R} = \dfrac{1750 \times 50^2}{127 \times 400} = 86.12$ mm

$e_{act} = e_{slow\ moving} +$ cant excess

Actual cant to be provided $= 86.12 + 75 = 161.12$ mm

Theoretical maximum permissible speed possible on given track

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

$$= 0.27\sqrt{(161.12 + 100) \times 400} = 87.25 \text{ kmph}$$

Length of transion curve,

$$L = 0.72\, C_a = 0.72 \times 161.12 = 116 \text{ m}$$
$$L = 0.008\, C_a V_{max} = 0.008 \times 161.2 \times 87.25 = 112.5 \text{ m}$$
$$L = 0.008\, C_d V_{max} = 0.008 \times 100 \times 87.25 = 69.8 \text{ m}$$

Length of transition curve = 116 m

End of Solution

Q.7 (b) A pile group with 12 piles, each having a diameter of 0.5 m and 30 m long, supports a raft foundation. The piles are arranged in 3 rows and spaced at 1.25 m c/c. The properties of the foundation soil are as follows:

$\gamma' = 11$ kN/m^3, $C_u = 40$ kN/m^2, $\phi = 0°$.

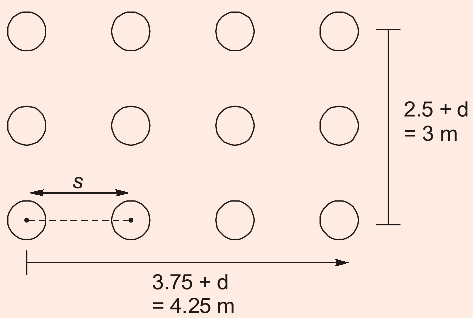
Take $\alpha = 0.85$ and F.O.S = 2.5.

Determine the capacity of the pile group.

[20 marks]

Solution:

Given:
Number of piles = 12
Diameter of each pile = 0.5 m
Length of each pile = 30 m
Spacing = 1.25 m c/c
$\gamma' = 11$ kN/m^3
$C_u = 40$ kN/m^2
$\phi = 0$
$\alpha = 0.85$
FOS = 2.5



Group action:

$$Q_{ug} = 9 \cdot c \cdot A_b + \alpha \cdot C \cdot A_s$$
$$= 9 \times 40 \times [4.25 \times 3] + 1 \times 40 \times [2\,(3 + 4.25) \times 30]$$
$$= 21990 \text{ kN}$$

Individual action:

$$\eta Q_{up} = n[9 \cdot C \cdot A_b + \alpha \cdot C \cdot A_s]$$

$$= 12\left[9 \times 40 \times \frac{\pi}{4} \times 0.5^2 + 0.85 \times 40 \times \pi \times 0.5 \times 30\right]$$

$$= 20074.77 \text{ kN}$$

Now,

$$Q_{safe} = \begin{Bmatrix} \dfrac{Q_{ug}}{FOS} \\ \dfrac{nQ_{up}}{FOS} \end{Bmatrix}_{\text{minimum}}$$

$$= \begin{Bmatrix} \dfrac{21990}{2.5} = 8796\,\text{kN} \\ \text{OR} \\ \dfrac{20074.77}{2.5} = 8029.9\,\text{kN} \end{Bmatrix}_{\text{minimum}}$$

$$Q_{safe} = 8029.9\,\text{kN}$$

End of Solution

Q.7 (c) An oedometer test on a 2 cm thick clay sample took 15 minutes time to attain 50% consolidation under a loading with double drainage condition. How many days will it take in the field to achieve the same degree of consolidation for the same clay soil 4 m thick? Consider similar loading and draiange conditions for laboratory and field.

[10 marks]

Solution:

Lab test sample: Thickness, $H = 2$ cm

Double drainage condition,

$$\therefore \quad T_v = C_v \frac{t}{[H/2]^2}$$

For 50% consolidation, $T_v = 0.196$

$t = 15$ min

$$\therefore \quad 0.196 = C_v \times \frac{15\,\text{min}}{\left[\dfrac{2\times10^{-2}}{2}\right]^2}$$

$$C_v = 1.31 \times 10^{-6}\ \text{m}^2/\text{min}$$

Field conditions: Thickness, $H = 4$ m

$$[T_v]_{50\%} = C_v \times \frac{t}{[H/2]^2}$$

$$0.196 = 1.31\times10^{-6} \times \frac{t}{[4/2]^2}$$

$$t = 416.67 \text{ days}$$

End of Solution

Q.7 (d) List and briefly discuss the geological factors affecting the construction of high speed rail project.

[10 marks]

Solution:

Following geological factors can affect the construction of high speed rail:

1. Rock Types
2. Attitude of Rocks
3. Batter and Slope Angle
4. Surface and Groundwater
5. Joints, Shear Zones, Fault and Fault Zone

1. **Rock Types:** The overall behavior of rock mass will depend on its intrinsic properties such as density, porosity, strength, cohesion a factor of mineral composition and texture of rocks as well as on the presence of joints and shear zones in a rock mass.
2. **Attitude of Rocks:** The strike and dip of layers in rocks such as volcanic flows, bedding, lamination and foliation planes with respect to slope cut and bench plays a very important role. Horizontal rocks will provide moderate to good conditions while vertical rocks will pose problems on cut slope and bench.
3. **Batter and Slope Angle:** The inclination and height of side slope are also important as they are going to control the space that would be available after cut and fill for laying the rail.
4. **Surface and Groundwater:** Water is the most important factor in aiding and triggering the landslides. Surface runoff caused by rainfall result into sudden mass transportation of debris on the slopes. Infiltration of water through pores and fractures result in to reduction of frictional resistance along fractures, increased pore pressure and swelling of clays all causing landslides.
5. **Joints, Shear Zones, Fault and Fault Zone:** Joints the most ubiquitous feature in rock mass will control the overall rock mass characteristics. Lesser the joint sets, farther the joints, closed joint apertures and high degree of asperities will make the rock slope stronger and stable.

End of Solution

Q.8 (a) Two different contractors carried out plate load test at the same site location as per IS code. Details are as follows:

Parameters	Contractor 1	Contractor 2
Size of plate	45 cm × 45 cm	75 cm × 75 cm
Load	100 kN	175 kN
Settlement at above load	10 mm	10 mm

Estimate the maximum load which a footing of size 3 m × 3 m can carry at the settlement of 10 mm at the same site location. Consider the depths of both tests and that of proposed footing are same.

[10 marks]

Solution:

Plate load test:

Parameter	Contractor 1	Contractor 2
Area of plate	0.2025 m^2	0.5625 m^2
Perimeter of plate	1.8 m	3 m
Ultimate load	100 kN	175 kN

As per Housel approach,

$$Q_1 = A_1 m + P_1 n$$
$$Q_2 = A_2 m + P_2 n$$
$$\Rightarrow \quad 100 = 0.2025\,m + 1.8\,m \quad ...(1)$$
$$175 = 0.5625\,m + 3\,n \quad ...(2)$$

On solving (1) and (2), we get

$$m = 37.02$$
$$n = 51.388$$

Now, for footing of size 3 × 3m:

$$Q_f = A_f m + P_f n$$
$$Q_f = (3 \times 3) \times 37.02 + [4 \times 3] \times 51.388$$
$$= 949.836 \text{ kN}$$

Ultimate bearing capacity of footing:

$$q_u = \frac{Q_f}{A_f} = \frac{949.836}{3 \times 3} = 105.537 \text{ kN/m}^2$$

Maximum load of 949.86 kN can be carried by the footing.

End of Solution

Q.8 (b) A twenty-storeyed building carries a load of 10 kN/m^2 at each floor level. A fully compensated (buoyant) raft foundation is proposed for such building at a soft clay soil site with unit weight of clay as 15 kN/m^3. Find the depth at which the raft foundation needs to be placed.

[10 marks]

Solution:

$$\text{Load acting on each floor} = 10 \text{ kN/m}^2$$
$$\text{Number of floors} = 20$$
$$\therefore \quad \text{Total load} = 20 \times 10 = 200 \text{ kN/m}^2$$

For floating/buoyant raft:

$$\text{Total load} = \gamma \times D_f$$
$$200 = 15 \times D_f$$
$$D_f = 13.33 \text{ m}$$

∴ Depth at which raft is place is 13.33 m.

End of Solution

Q.8 (c) (i) What are the different types of resolutions in Remote Sensing? Briefly explain the significance of each resolution in the field of Civil Engineering.

(ii) Two points *A* and *B* were selected 80 m apart from each other for testing permanent adjustment of a dumpy level using two peg test. Following staff readings were observed at both the points while keeping dumpy level at two different locations:

Instrument Location	Staff Reading (in m)	
	A	*B*
Midway betwen A and B	1.430	1.780
At P (10 m from A and 70 m from B)	1.500	1.950

Calculate the following:

(I) Level difference between point *A* and point *B*.

(II) Inclination of line of sight, if any.

(III) Corrected staff readings at point *A* and point *B* when dumpy level was set at *P* and having no error in its permanent adjustment.

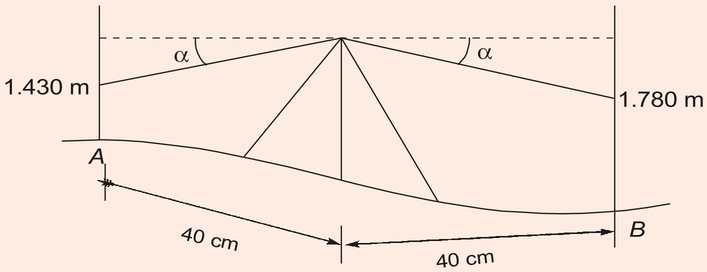
[10 marks]

Solution:

(i) Resolution in Remote Sensing: Resolution is the ability to obtain the finer details of an image. It determines the details of the surface features that can be distinguished. Four types of resolutions are generally considered-spatial resolution, spectral resolution, temporal resolutions, and radiometric resolution.

1. Spatial resolution: This refers to the ability of the remote sensing system to record spatial details. The concept of spatial resolution is different for photographs and digital images. In the case of aerial photographs, spatial resolution is defined as the sharpness of the image. In the case of optical scanning systems, resolution depends upon the focal length of the optical system, the height of the imaging platform, and the size of the sensor element. Resolution is usually expressed in terms of the instant field of view.
2. Spectral resolution: This refers to the wavelengths to which the remote sensing system is sensitive. Aerial photography uses only a narrow band of the spectrum (visible light). The spectral resolution of aerial photographs thus happens to be low. The resolution depends upon the number of wavelength bands as well as on the width of each band. For higher resolutions, a large number of bands of narrower bandwidth are used.
3. Temporal resolution: This refers to the frequency with which images are obtained in terms of time.
   Temporal resolution is important for predicting environmental changes, vegetation cover, and crop patterns.
4. Radiometric resolution: This refers to the sensitivity of the system to small changes in the radiation (wavelength). In photography, this referred to as contrast or the number of grey tones in the image.

(ii) Assume, indication error = α (downward)



When instrument kept midway,

Collimation error = $40 \tan\alpha$

Corrected staff reading at A = $1.430 + 40\tan\alpha$

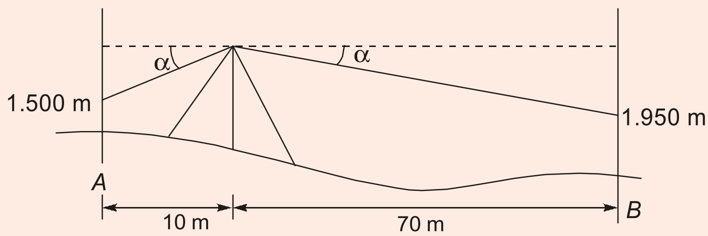
Corrected staff ready at B = $1.780 + 40\tan\alpha$

1. Level difference between A and B

$$H = |\text{Corrected staff ready at A-Corrected staff ready at } B|$$

$$= |1.430 + 40\tan\alpha - (1.780 + 40\tan\alpha)| = 0.35 \text{ m}$$

2. Inclination of LOS



Corrected staff leadingat A = $1.5 + 10\tan\alpha$

$B = 1.95 + 70\tan\alpha$

$$\text{Level diff.} = |\text{Corrected ready at A} - \text{Correctedready at } B|$$

$$0.35 = |1.95 + 70\tan\alpha - 10\tan\alpha|$$

$$0.35 = 0.45 + 60\tan\alpha$$

$$\alpha = -0°5' 43.77'$$

It means our assumption was incorrect, inclination error is upward.

3. Corrected staff ready at A = $1.5 - 10\tan\alpha$

$= 1.5 - 10\tan 0°5'43.77'' = 1.483$ m

Corrected staff reading at B = $1.95 - 70\tan\alpha$

$= 1.98 - 70\tan(0°5' 43.77'') = 1.833$ m

End of Solution

Q.8 (d) The design speed of a highway is 80 km/h. There is a horizontal curve of radius 200 m in a certain locality. What should be the superelevation required to maintain this design speed? If the maximum superelevation of 0.07 is not to be exceeded, what should be the maximum allowable speed on this curve? Also determine the extra widening required and length of transition curve using the following data:

Length of wheel base of the largest vehicle = 6.1 m.

Pavement width = 7.2 m.

Number of lanes = 2.

Rate of introduction of superelevation = 1 in 200.

Type of terrain = Plain.

Safe limit of coefficient of friction = 0.15.

[20 marks]

Solution:

Design speed, $V = 80$ kmph

Radius of curve, $R = 200$ m

$e_{max} = 7\%$

Superelevation required maintain design speed,

$$e = \frac{V^2}{225R} = \frac{80^2}{225 \times 200} = 0.1422$$

Provide, $e = 7\%$ and check for friction

$$f = \left(\frac{V^2}{127R} - e_{max}\right) = \left(\frac{80^2}{127 \times 200} - 0.07\right) = 0.1819 \not> \quad 0.15$$

Max. allowable speed,

$$V_{max} = \sqrt{127R(e_{max} + f)}$$

$$= \sqrt{127 \times 200 \times (0.07 + 0.15)} = 74.75 \text{ kmph}$$

Extra widing,

$$W_e = \left(\frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}\right)$$

$$= \frac{2 \times 6.1^2}{2 \times 200} + \frac{80}{9.5\sqrt{200}} = 0.781 \text{ m}$$

Length of Transition curve.

Critera: 1 As per rate of change of centrifugal acceleration,

$$C = \frac{80}{75 + V} = \frac{80}{75 + 80} = 0.516 \text{ m/s}^3$$

$$L_T = \frac{0.0215V^3}{CR}$$

$$= \frac{0.0215 \times 80^3}{0.516 \times 200} = 106.33\,\text{m}$$

Critera: 2 As per rate of attainment of superelevation,

Assume rotation about @ inner edge,

$$L_T = eN(w + W_e)$$

$$= 0.07 \times 200 \times (7.2 + 0.781) = 111.734 \text{ m}$$

Critera: 3 As per minimum length, IRC method for plain terrain.

$$L_T = 2.7\frac{V^2}{R} = 2.7 \times \frac{80^2}{200} = 86.4\,\text{m}$$

Minimum length of transition curve is maximum of all above criteria i.e. 111.734 m.

End of Solution

■■■■