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Institute for Engineers (IES/GATE/PSUs)

UPSC
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Mains Exam Solution

CIVIL ENGINEERING

Paper-II

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SECTION-A

Q-1(a): ***The annual rainfall of six different rainguage stations of a river basin is 136.70 cm, 102.90 cm, 98.80 cm, 180.30 cm, 82.60 cm and 110.30 cm. Determine:***

(i) ***The standard error in the estimation of average rainfall of the six raingauge stations.***

(ii) ***The optimum number of raingauge stations in the river basin for a 10% error in the estimation of average rainfall*** ***[12 MARKS]***

Sol: Given,

Annual rainfall of six existing rain gauge stations are:

$$P_1 = 136.70 \text{ cm},\ P_2 = 102.90 \text{ cm},\ P_3 = 98.80 \text{ cm}$$

$$P_4 = 180.30 \text{ cm},\ P_5 = 82.60 \text{ cm},\ P_6 = 110.30 \text{ cm}$$

(i) Calculation of standard error (e)

$$\boxed{\text{Standard error (e)} = \frac{C_v}{\sqrt{n}} = \frac{\text{Coefficient of variance}}{\sqrt{\text{No. of existing rain gauges}}}} \quad \ldots\text{(i)}$$

where,

$$\boxed{C_v = \frac{\sigma_{n-1}}{P_m} = \frac{\text{Standard deviation of rainfall data}}{\text{Mean of rainfall data}}}$$

So,

$$P_m = \frac{P_1 + P_2 + P_3 + P_4 + P_5 + P_6}{6}$$

$$P_m = \frac{(136.70) + (102.90) + (98.80) + (180.30) + (82.60) + (110.30)}{6}$$

$$\boxed{P_m = 118.6 \text{ cm}}$$

Also,

$$\sigma_{n-1} = \sqrt{\frac{(136.70-118.6)^2 + (102.90-118.6)^2 + (98.80-118.6)^2 + (180.30-118.6)^2 + (82.6-118.6)^2 + (110.30-118.6)^2}{6-1}}$$

$$\boxed{\sigma_{n-1} = 35.037 \text{ cm}}$$

So,

$$\boxed{C_v = \frac{35.037}{118.6} = 0.2954 \text{ or } 29.54\%}$$

On substituting the above value in equation (i)

$$\text{Standard error (e)} = \frac{29.54\%}{\sqrt{6}} = 12.059\%$$

So, standard error in the estimation of average rainfall based on existing stations is 12.059%.

(ii) Calculation of optimum number of rain gauge (N)

Given, Standard error (e) = 10%

So,

$$\boxed{\text{Optimum number of rain gauge (N)} = \left(\frac{C_v}{e}\right)^2}$$

$$N = \left(\frac{29.54}{10}\right)^2 = 8.72 \simeq 9$$

Hence, optimum number of rain gauges required are 9.

Q-1(b): ***A 1.3 m wide rectangular channel had 0.35 m depth of water at a certain section of the channel. The flow discharge through the channel is 2.0 cumecs. Determine whether the hydraulic jump will take place or not. Find the height of jump and loss of energy.*** ***[12 MARKS]***

Sol: Data insufficient

Q-1(c): ***Find out the power required to drive the centrifugal pump if it lifts water to a height of 22 m. The overall efficiency to the pump is 70%. The pipe diameter is 10 cm and length is 100 m. It delivers 1500 l/min as discharge with the coefficient of friction of pipe as 0.004 and γ as ρg (1000 × 9.81).*** ***[12 MARKS]***

Sol: $H_s = 22$ m, $\eta_0 = 0.70$; $d_s = d_d = d = 10$ cm, $\ell_s + \ell_d = \ell = 100$ m

$$Q = 150\,\frac{\ell}{\text{min}} = \frac{1500}{1000 \times 60} = 0.025\ \text{m}^3/\text{s}$$

$$\text{Velocity of water in the pipes } (V_s = V_d) = V = \frac{Q}{\frac{\pi}{4}d^2} = \frac{0.025}{\frac{\pi}{4}(0.10)^2} = 3.184\ \text{m/s}$$

$$\text{Velocity head in the pipe} = \frac{V^2}{2g} = 0.517\ \text{m}$$

$$\text{Frictional losses in the pipe } (h_{fs} + h_{fd}) = h_f = \frac{f\ell V^2}{2gd} = \frac{0.004 \times 100 \times (3.184)^2}{2 \times 9.81 \times 0.10} = 2.066\ \text{m}$$

$$\text{Manometric head, } H_m = H_s + h_f + \frac{V_d^2}{2g}$$

$$= 22 + 2.066 + 0.517 = 24.583\ \text{m}$$

$$\text{Power required to drive the pump} = \frac{\rho g Q H_m}{\eta_0}$$

$$= \frac{1000 \times 9.81 \times 0.025 \times 24.583}{0.70}$$

$$= 8.613\ \text{kW}$$

Q-1(d): ***A PST 15 m long, 6 m wide and 3 m deep treats water for town with a population of 20,000 supplied with 100 lpcd. The raw water sample indicated suspended solids conc. as 60 ppm. The PST worked with efficiency of 70% SS removal and the average specific gravity of the deposit in PST was 2.6. Compute***

(i) Detention Time

(ii) Horizontal Velocity

(iii) Rate of dry solids deposited

(iv) Overflow rate ***[12 MARKS]***

Sol: Given, the dimensions $(L*B*H)$ of primary sedimentaiton tank are 15 m * 6 m * 3 m.

$$p = 20,000$$

$$x = \text{per capita demand} = 100\ l\text{pcd}$$

$$\text{Suspended solid concentration } (S_0) = 60 \text{ ppm}$$

$$\eta = 70\%, \text{ AADD(Q)} = px = 20,000 * 100 = 2*10^3 \text{ m}^3\text{/day}$$

$$G_s = 2.60$$

(i) Detention time $(t_d) = \frac{V}{Q} = \frac{15*6*3*24}{2*10^3}$ hours

$$\boxed{t_d = 3.24 \text{ hours}}$$

(ii) Horizontal velocity $(v_H) = \frac{L}{t_d} = \frac{15}{3.24}$

$$v_h = 4.63 \text{ m/hr}$$

or, $$v_h = 1.286 \text{ mm/sec}$$

(iii) Rate of dry solid deposited, $= \eta$ * total weight of solids per day

$$\text{Rate of dry solid deposited} = 0.70*(Q_0S_0)$$

$$\text{Rate of dry solid deposited} = 0.7*2*10^6 \text{ (L/d)} * 60 \text{ mg/L} = 84 \text{ kg/day}$$

(iv) Overflow rate $(V_0) = \frac{\text{Discharge}}{\text{Plan area}}$

$$V_0 = \frac{2*10^3 \text{ m}^3\text{ / day}}{15*6}$$

$$V_0 = 22.22 \text{ m/day}$$

or, $$V_0 = 22.22 \text{ m}^3\text{/day/m}^2$$

Q-1(e): ***Discuss the imapct of heavy metals in industrial wastewater when disposed into surface water.***

With the help of sketches, explain the working principle of the two methods used for removal of heavy metal from industrial wastewater. ***[12 MARKS]***

Sol: The disposal of industrial waste water containing heavy metals into surface water bodies can have significant environmental and human health impacts. Heavy metals are naturally occuring elements with high atomic weights, such as lead, mercury, cadium, arsenic, and chrominum. They are can enter wastewater as by products or contaminants.

When heavy metal laden wastewater is discharges into surface water, several adverse effects can occur:

1. **Environmental contamination:** Heavy metals can persist in the environment for long periods and accumulate in sediments, plants and aquatic organisms. This contamination disrupts the ecosystem balance, affecting the biodiversity and overall health of the aquatic environment.

2. **Toxicity to aquatic life:** Heavy metals are highly toxic to aquatic organism. They can impair fish and other aquatic species growth, reproduction, and behaviour. Metal ions interfere with enzyme systems, disrupt metabolic processes, and cause oxidation stress, leading to reduced survival rates and compromised ecosystems.

3. **Bio-accumulation and biomagnification:** Heavy metals have the potential to accumulate in the tissues of aquatic organisms through a process known as bioaccumulation. When smaller organism consume contaminated water or food, the heavy metals gradually accumulate in their bodies. This process can continue up the food chain through biomagnification, resulting in higher concentration of heavy metals in predators or higher trophic level species, including humans.

4. **Human health risks:** Consuming or coming into contact with surface water contaminated by heavy metals can pose serious health risks to humans Ingestion or inhalation of heavy metals can lead to various health probmels, such as neurological disorders, kidney damage, liver damage, developmental issues, and certain type of cancer.

5. **Water supply contamination:** Discharge industrial wastewater bodies can contaminate the local water supply. If these water sources are used for drinking water, the heavy metals can enter the waste water treatment plants and depending on the efficiency of treatment processes, may not be completely removed. This can result in the distribution of drinking water with elevated levels of heavy metals, jeopardizing public health.

Two commonly used methods for the removal of heavy metals from industrial wastewater are precipitation/ chemical precipitation and ion exchange. Lets discuss the working principles of each method:

1. Precipitation/Chemical precipitation:

Flow diagram for the working principle of chemical precipitation

pH adjustment → Addition of precipitating agents → Mixing and reaction → Separation → Disposal and recovery

(a) **pH adjustment:** The pH of the wastewater is adjusted to an optimum range using acidic or alkaline chemicals, depending on the specifc heavy metal to be removed.

(b) **Addition of precipitating agents:** Precipitating agents, such as lime (CaO), sodium hydroxide or sodium sulfide, are added to the wastewater. These chemicals react with heavy metals ion, forming insoluble metal hydroxides, surfides, or carbonates.

(c) **Mixing and reaction:** The wastewater is throughly mixed to ensure proper contact between the precipitating agents and the heavy metal ions, this allows for the complete reaction and formation of insooluble metal compounds.

(d) **Separation:** The mixture is then allowed to settle or undergo filtration to seprate the solid precipitates from the liquid, sedimentation tanks or filtration systems are commonly used for this purpose.

(e) **Disposal or recovery:** The separated solid precipitates contaning the heavy metals are typically disposed of in a controlled manner such as through landfilling or appropriate hazardous waste management methods. In some cases the precipitates may undergo further processing to recover valuable metals.

2. Ion exchange method

Flow diagram for the working principle of ion exchange

Selection of ion exchange resin → Contacting the wastewater with resin → Saturation of the resin → Regeneration → Disposal or recovery

The working principle of ion exchange is as follows:

(a) **Selection of ion exchange resin:** An appropriate ion exchange resin is chosen based on the specific heavy metal ions to be removed the resin consist of small beads or particle with functional groups on their surface that can attract and bind heavy metal ions.

(b) **Contacting the wastewater with resin:** The wastewater is passed through a column or vessel contaning the ion exchange resion. As the wastewater flows through the resin bed, the heavy metal ions bind to the functional group on the resin surface. While other ions in the wastewater are not significantly affected.

(c) **Saturation of the resin:** Over time, the ion exchange resin becomes saturated with heavy metal ions, and its capacity to bind additional ions decreases, at this point, the resin needs to be regenerated or replaced.

(d) **Regeneration:** The resin regeneration process involves washing the resin bed with a regenerated solution, typically on acidic or alkaline solution. The regerant displaces the bound heavy metal ions from the resin, restoring its capacity for further metal removal.

(e) **Disposal or recovery:** The regerant solution contaning the stripped heavy metal ions is treated separately to recover or safely dispose of the heavy metals, the regenerated resin can then be reused for subsequent cycles of metal, removed.

Q-2(a): (i) ***Define the "dilution method" of flow measurement by sudden injection and constant injection of chemicals in flowing water with diagram and governing equations.*** ***[10 MARKS]***

(ii) ***A Rhodamine dye solution was discharged in a river section at a constatn rate. Estimate the discharge if the dye is found to reach an equilibrium of 5 parts epr billion (ppb).***

Given: Amount of Rhodamine Dye = 25 g/ℓ

Constant rate of flow: 10 cm^3/s

Assume C_0 = 0. ***[10 MARKS]***

Sol: (i) In this method a solution of a stable chemical such as common salt or sodium dichromate or a radioactive chemical, known as the *tracer*, is injected into the stream at either a constant rate or all at once. When the tracer is introduced into the stream at a constant rate, it is called the *plateau* method and when it is introduced all at once it is called the '*gulp method*'.

When the tracer is injected suddenly (Gulp Method)

Let C_0 be the small initial concentration of the tracer in the streamflow. At section 1 a small quantity (volume V_1) of high concentration C_1 of this tracer is added all at once. The concentration profile at section 2, which is far away from 1 is schematically shown in the figure.

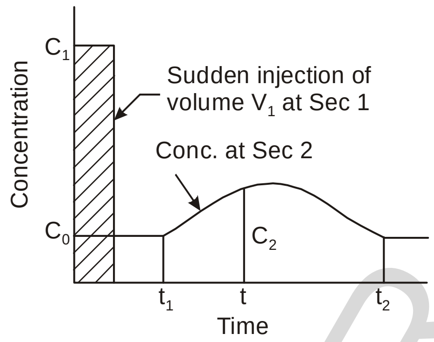


Fig.: Sudden-injection method.

The concentration will have a base value of C_0, increases from time t_1 to a peak value and gradually reaches the base value of C_0 at time t_2. The stream flow is assumed to be steady.

By Continuity Equation

Mass of tracer at section 1 = Mass of tracer in the original discharge of stream (Q) at section 2 + mass of tracer in the added additional volume (V_1) at section 2

$\Rightarrow$ $$V_1C_1 = \int_{t_1}^{t_2} Q\,(C_2 - C_0)\,dt + \int_{t_1}^{t_2} \frac{V_1(C_2 - C_0)}{(t_2 - t_1)}\,dt$$

The 2nd term is negligible and hence

$\Rightarrow$ $$\boxed{Q = \frac{V_1C_1}{\int_{t_1}^{t_2}(C_2 - C_0)\,dt}} = \text{Discharge of stream}$$

When the Tracer is Injected Continuously (Plateau Method)

Let concentration C_1 is added continuously at constant rate Q_t at section 1. Let the initial concentration in tracer in stream be C_0 and at section 2 after some time the concentration becomes constant at C_2 then $Q_tC_1 + Q \times C_0 = (Q + Q_t)\,C_2$

$\Rightarrow$ $$\boxed{Q = \frac{Q_t(C_1 - C_2)}{(C_2 - C_0)}} = \text{discharge of stream}$$

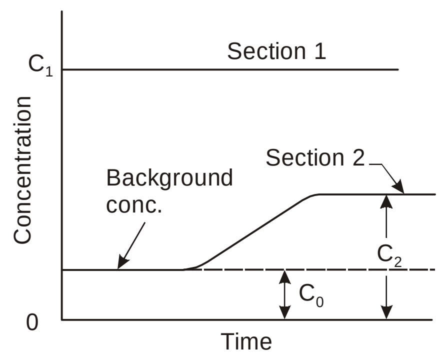


Fig.: Constant rate injection method.

Tracer method is most suitable for small turbulent streams in mountainous areas.

Sol: (ii) Given,

$$C_1 = 25 \text{ g/L},\ C_2 = 5 \times 10^{-6} \text{ g/L}$$

$$C_0 = 0,\ Q_t = 10 \text{ cm}^3/\text{sec}$$

Using constant rate injection (i.e. Plateau method)

$$Q = \frac{Q_t(C_1 - C_2)}{(C_2 - C_0)} = \frac{Q_t(C_1 - C_2)}{C_2} \qquad (\text{As } C_0 = 0)$$

$$Q = (10\text{ cm}^3/\text{sec})\,(10\text{ cm}^3/\text{sec})\,\frac{[25 - 5\times10^{-6}]}{5\times10^{-6}}$$

$$\boxed{Q = 49.999\text{ m}^3/\text{sec} \simeq 50\text{ m}^3/\text{sec}}$$

$\boxed{\text{Hence, discharge of river is } 50\text{ m}^3/\text{sec}}$

Q-2(b): ***A city with population of 5 lakhs is to be supplied water @ 150 lpcd. Using the data given below, determine the storage capacity of the reservoir assuming***

(i) Continuous pumping

(ii) Pumping for 9 hours from 6 PM – 3AM

Also assume fire demand @ 2 lpcd and power breakdown for 2 hours.

0 – 3 AM – 5% of total

3 – 6 AM – 5% of total

6 – 9 AM – 40% of total

9 – 12 PM – 10% of total

12 – 3 PM – 5% of total

3 – 6 PM – 10% of total

6 – 9 PM – 20% of total

9 – 12 AM – 5% of total **[20 MARKS]**

Sol: **(i)** Total daily supply = Rate of supply × Population

$= 150 \times 5 \times 10^5\ \ell/\text{day} = 75\ \text{M}\ell/\text{day}$

Period (hours)	Rate of demand Mℓ/d	Cumulative demand (Mℓ/d)	Supply (Mℓ/d)	Cumulative supply	Excess of demand Mℓ/d	Excess of supply Mℓ/d
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0 – 3 AM	3.75	3.75	9.375	9.375	Nil	5.625
3 – 6 AM	3.75	7.5	9.375	18.75	Nil	$\boxed{11.25}$
6 – 9 AM	30	37.5	9.375	28.125	$\boxed{9.375}$	Nil
9 – 12 PM	7.5	45	9.375	37.5	7.5	Nil
12 – 3 PM	3.75	48.75	9.375	46.875	1.875	Nil
3 – 6 PM	7.5	56.25	9.375	56.25	0	0
6 – 9 PM	15	71.25	9.375	65.625	5.625	Nil
9 – 12 PM	3.75	75	9.375	75	0	0

$$\text{Total supply during the day} = \frac{75\times10^6\,\ell}{24\text{ (h)}} = 3.125\,\frac{\text{M}\ell}{\text{d}}$$

$\therefore$ 3 hour supply $= 3.125 \times 3 = 9.375\ \text{M}\ell/\text{d}$ = constant

From table; maximum excess of demand = 9.375 Mℓ/d

Maximum of excess of supply = 11.25 Mℓ/d

Hence, Total storage required = 9.375 + 11.25 = 20.625 Mℓ/d

Fire demand = 2 $l$pcd × P = 2 × 5 × 10^5 = 1 Mℓ/d

Breakdown demand for 2 hours = $\frac{75}{24} \times 2 = 6.25$ Mℓ/d

So, storage required = 20.625 + 1 + 6.25 = 27.875 Mℓ/d

(ii) Pumping for 9 hours from 6 PM – 3 AM

Period (hours)	Rate of demand Mℓ/d	Cumulative demand (Mℓ/d)	Supply (Mℓ/d)	Cumulative supply (Mℓ / d)	Excess of demand Mℓ/d	Excess of supply Mℓ/d
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0 – 3 AM	3.75	3.75	25	25	0	$\boxed{21.25}$
3 – 6 AM	3.75	7.5	0	25	0	17.5
6 – 9 AM	30	37.5	0	25	12.5	Nil
9 – 12 PM	7.5	45	0	25	20	Nil
12 – 3 PM	3.75	48.75	0	25	23.75	Nil
3 – 6 PM	7.5	56.25	0	25	$\boxed{31.25}$	Nil
6 – 9 PM	15	71.25	25	50	21.25	Nil
9 – 12 PM	3.75	75	25	75	0	0

Total supply is obtained in 9 hours at a rate = $\frac{75}{9}\left(\frac{M\ell}{day}\right) \times 3 = 25$ Mℓ/d

From, table maximum excess of demand = 31.25 Mℓ/d

Maximum of excess of supply = 21.25 Mℓ/d

Hence, Total storage required = 31.25 + 21.25 = 52.5 Mℓ/d

Fire demand = 2 $l$pcd × P = 2 × 5 × 10^5 = 1 Mℓ/d

Losses due to power breakdown for 2 hours = $\frac{75}{24} \times 2 = 6.25$ Mℓ/d

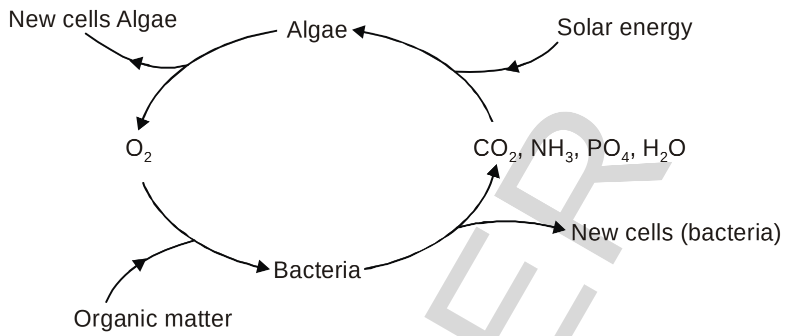
So, Storage required = 52.5 + 1 + 6.25 = 59.75 Mℓ/d

Q-2(c): ***Differentiate between Symbiosis and Parasitism relationship. Explaining the working principles of oxidation ponds, discuss the importance of Algal-Bacteria symbiosis relationship in oxidation ponds.*** ***[20 MARKS]***

Sol: **Symbiosis:**

- In a totally aerobic pond, stabilisation is brought about by aerobic bacteria. The oxygen demand is met by combined action of algae and other mciro organism. This process is called algal photo-synthesis or algal symbiosis.

- In this symbiosis, the algae while growing in the presence of sunlight produces oxygen by photo-synthesis this oxygen is utilized by the bacteria for oxidising the waste organic matter.
- The end product of this processes are CO_2, NH_3, PO_4, H_2O which are required by algae to grow and continue producing oxygen. This mutually beneficial arrangement is called symbiotic relation.



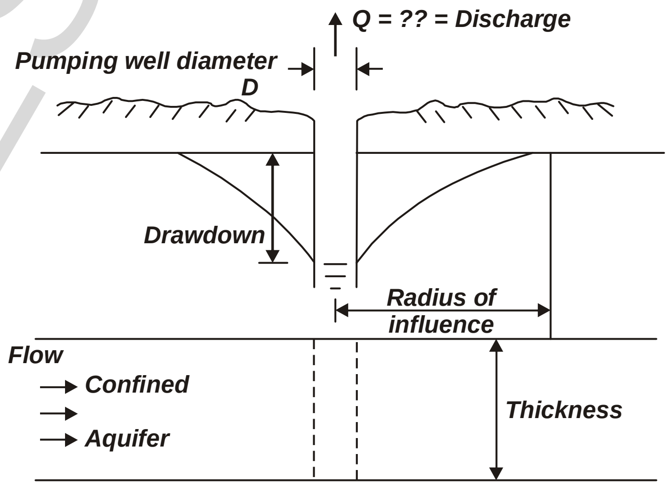
- **Parasitism:** Parasitism is generally defined as a relationship between the two living species in which are organism is benefitted at the expense of the other the organism that is benefitted is called the parasites, whiile the one that is harmed is called the host.

  As examples of parasites are tapeworms, fleas, and barnacles.
- **Working principle of oxidation ponds:** They are open flow through the earthen basin, such ponds provide comparatively long detention period during which the waste get stabilized by the action of natural forces. In a totally aerobic pond depth should be 0.5 m at the maximum so that sunlight can penetrate the whole depth.

Importance of algal bacteria symbiosis relationship in oxidation ponds–

- The applied sewage organics are stabilized by both aerobic and anaerobic reaction in different zones of the ponds. In the top aerobic layer, where oxygen is supplied through algal photosynthesis, dissolved organic matter in the incoming sewage oxidized to CO_2 and H_2O. The settled sludge mass originating from raw waste and microbial synthesis in the aerobic layer and dissolved and suspended organics in the bottom layers undergo stabilisation through conversion to CH_4 which escaped the pond in the form of bubble. Each kg of BOD ultimate stabilised to 0.25 kg or 0.35 m^3 of CH_4.

Q-3(a): ***Referring to figure 1, calculate the discharge from the well in steady state condition. The well completely penetrates the confined aquifer.***



Given: Diameter of pumping well = 30 cm

Permeability = 45 m/day

Length of the strainer = 20 m

Drawdown = 3.0 m

Radius of influence = 300 m

Discharge = ? **[20 MARKS]**

Sol: Given,

Nature of Aquifer = Confined

Diameter of main well (d_w) = 30 cm

Length of strainer (D) = 20 cm

Drawdown of main well (S_w) = 3 m

Radius of influence (R) = 300 m

Discharge (Q) = ?

Permeability (K) = 45 m/day

For confined aquifer,

$$Q = \frac{2\pi KD\,(S_w)}{\log_e(R/r_w)} = \frac{2\pi \times 45\text{ m/day} \times 20\text{ m} \times 3\text{ m}}{\log_e\left(\dfrac{300}{0.15}\right)}$$

$$\boxed{\begin{array}{c} Q = 2231.91\,m^3/\text{day} \\ \text{OR} \\ Q = 25.832\text{ litres/sec} \end{array}} \text{ Ans.}$$

Q-3(b): Find the discharge of water through the pipe, the velocity of venturimeter throat and the pressure 600 cm above the venturimeter using Bernoulli's theorem.

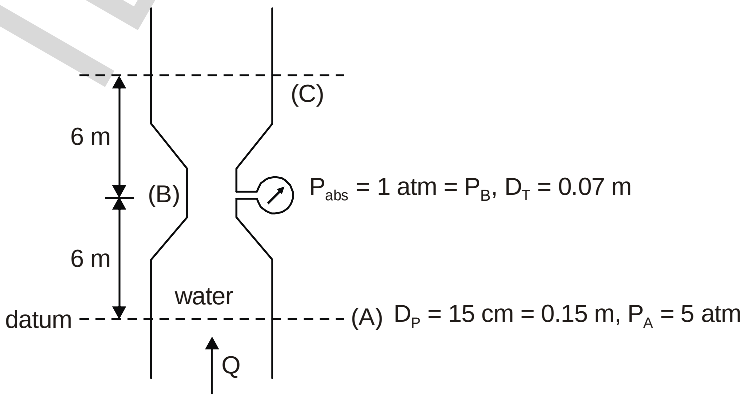
Given: Diameter of vertical pipe = 15 cm

Ventirumeter throat = 7 cm

Absolute pressure at throat = 1 atm

Pressure at 600 cm below the ventirumeter = 5 atm **[20 MARKS]**

Sol:



Applying Bernoulis equation between A and B

$$\frac{P_A}{\gamma}+\underset{0}{\cancel{Z_A}}+\frac{V_A^2}{2g} = \frac{P_B}{\gamma}+\underset{6m}{\cancel{Z_B}}+\frac{V_B^2}{2g}$$

$$\frac{P_A-P_B}{\gamma}-6 = \frac{V_B^2-V_B^2}{2g}=\frac{Q^2}{2g}\left[\frac{1}{A_B^2}-\frac{1}{A_A^2}\right]$$

$$\frac{(5-1)\times 101.325}{9.81}-6 = \frac{Q^2}{2\times 9.81}\left[\frac{1}{\frac{\pi^2}{16}(D_T^4)}-\frac{1}{\frac{\pi^2}{16}(D_P^4)}\right]$$

$$35.315 = \frac{Q^2\times 16}{\pi^2\times 2\times 9.81}\left[\frac{1}{(0.07)^4}-\frac{1}{(0.15)^4}\right]=Q^2\times 3278.138$$

$$\Rightarrow \qquad \boxed{Q = 0.1038\ m^3/s}$$

$$\text{Velocity at throat} = \frac{Q}{\frac{\pi}{4}D_T^2}=\frac{0.1038\times 4}{\pi\times(0.07)^2}=26.97\ m/s$$

Pressure at (c) is given by P_C

$$\frac{P_A}{\gamma}+\underset{0}{\cancel{Z_A}}+\frac{V_A^2}{2g} = \frac{P_C}{\gamma}+\underset{12\ m}{\cancel{Z_C}}+\frac{V_C^2}{2g} \quad (\text{since } V_A = V_C)$$

$$P_C = P_A-12\gamma = 5\ \text{atm}-\frac{12\times 9.81}{101.325}=3.838\ \text{atm}$$

Q-3(c): ***With the help of sketches, explain the effect of lapse rate on plume behaviour indicating the possible plume shapes and dispersion conditions.*** ***[20 MARKS]***

Sol: **Lapse rate:** In the troposphere, the temperature of the ambient (surrounding) air normally decreases with increase in the altitude (height). This rate of change of temperature is called lapse rate.

Types of Lapse rate

(i) Environmental Lapse Rate/Ambient Lapse Rate (ELR)

The ELR can be determined by sending up a ballon equipped with a thermometer and a self recording mechanism. The lapse rate so obtained is known as the prevailing lapse rate, or the ambient lapse rate or the environmental lapse rate (ELR).

(ii) 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 a level at which its own temperature and density becomes equal to that of the surrounding air. This rate of decrease of temperature with height is called adiabatic lapse rate.

(a) Super Adiabatic Lapse Rate

When the ambient lapse rate (ELR) exceeds the adiabatic lapse rate (ALR), the ambient lapse rate is said to be super adiabatic and the atmosphere is said to be highly unstable.

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(b) Sub-adiabatic Lapse Rate

When the ambient lapse rate (LR) is less than adiabatic lapse rate, the ambient lapse rate is termed sub-adiabatic lapse rate and the atmosphere is stable.

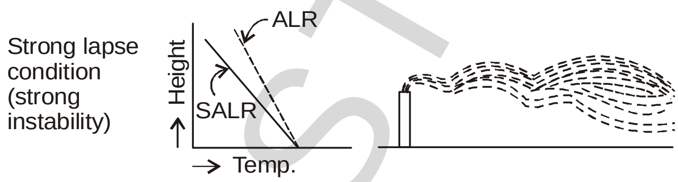
(c) Neutral

When the two lapse i.e. ELR and ALR are exactly equal, the atmosphere is said to be neutral.

Effect of Lapse Rate on Plume Behaviour

(i) Looping plume

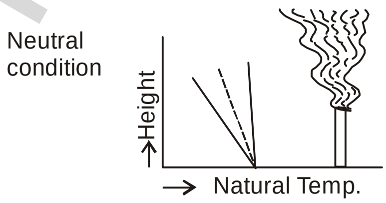
- This is common type of plume behaviour which occurs under superadiabatic lapse rate (SALR) conditions with light to moderate wind speeds on a hot summer afternoon when large scale thermal eddies are present.
- The plume has wavy behaviour since it occurs in a highly *unstable* atmosphere.



Looping Plume

(ii) Neutral plume

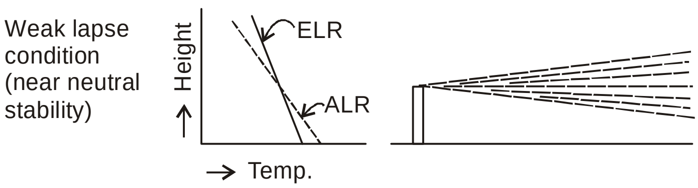
- Neutral plume is the upward vertical rise of the plume from the stack, which occurs when the ELR is equal to ALR.
- The upward lifting of the plume will continue till the air density becomes similar to that of the plume itself.



Neutral Plume

(iii) Coning plume

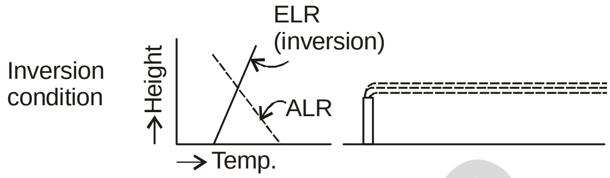
- Coning plume occurs on cloudy day or nights with strong winds velocity (> 32 km/hr) when the lapse rate is near neutral.
- The plume shape is vertically symmetrical about the plume line.



Coning plume

(iv) Fanning plume

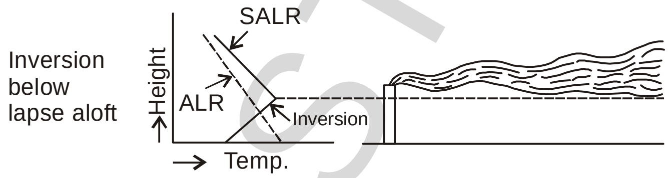
- This occurs under extreme inversion conditions, in the presence of light wind.



Fanning Plume

(v) Lofting plume

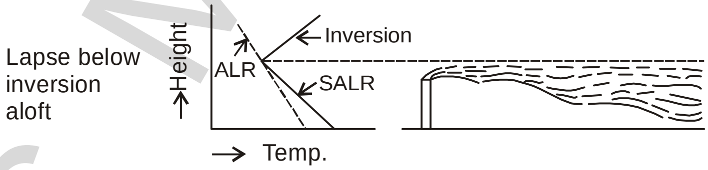
- Plume is said to be lofting when there exists a strong super adiabatic lapse rate (SALR) above inversion.
- Lofting is the most favourable plume type as far as ground level concentrations are concerned and is one of the major goals of tall-stack operation.



Lofting Plume

(vi) Fumigating plume

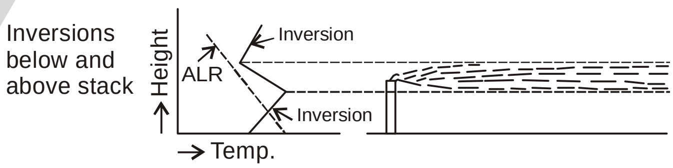
- The conditions for fumigation are just the inversion of lofting plume.
- Fumigation represents quite a bad case of atmosphere dispersion.



Fumigating Plume

(vii) Trapping plume

- This condition is achieved when the plume caught between two inversion layers. Hence the emitted plume can neither go up nor down and will be trapped between the two levels.



Trapping Plume

Q-4(a): ***Calculate (i) total installed capacity of turbo generators, (ii) load factor, (iii) plant factor, and (iv) utilization factor of three generators of a hydel power station, each having a capacity of 10000 kW. The load of the plant varies from 12000 kW to 26000 kW.*** **[20 MARKS]**

Sol:

$$\text{Total installed capacity} = 3 \times 10000 = 30000 \text{ kW}$$

$$\text{Maximum demand} = 26000 \text{ kW}$$

$$\therefore \quad \text{Load factor} = \frac{\text{Average load during certain period}}{\text{Peak load during that period}}$$

$$= \frac{\left(\frac{12000+26000}{2}\right)}{26000} \times 100 = 73.08\%$$

$$\text{Plant factor/capacity factor} = \frac{\text{Average load}}{\text{Installed capacity}}$$

$$= \frac{\left(\frac{12000+26000}{2}\right)}{30000} \times 100$$

$$= 63.33\%$$

$$\text{Utilization factor} = \frac{\text{Maximum power utilized}}{\text{Installed capacity}}$$

$$= \frac{26000}{30000} \times 100 = 86.67\%$$

Q-4(b): ***The MLSS concentration in an aeration tank of ASP system was 3000 mg/L. Sludge volume was 180 mL after 30 minutes os settling in 1000 mL graduated measuring jar. For the above sample, find***

(i) SVI

(ii) SDI

(iii) Return sludge ratio required

(iv) SS conc. in recirculated sludge **[20 MARKS]**

Sol: Given,

$$\text{MLSS}(x) = 3000 \text{ m/g}$$

$$\text{Sludge volume } (V_s) = 180 \text{ ml}$$

(i) $$\text{Sludge Volume Index (SVI)} = \frac{1000 \times V_s}{x} = \frac{1000 \times 180}{3000} = 60 \text{ ml/g}$$

(ii) $$\text{Sludge Density Index} = \frac{100}{SVI} = \frac{100}{60} = 1.67 \left(\frac{g}{ml}\right)$$

(iii) $$\text{Return Sludge Ratio} \left(\frac{Q_R}{Q_0}\right) = \frac{x}{x_u - x} = \frac{3000}{\frac{10^6}{60} - 3000} = 0.2195 \qquad \left(\because x_u = \frac{10^6}{SVI}\right)$$

(iv) $$\text{SS concentration in recirculated sludge} = x_u = \frac{10^6}{SVI} = \frac{10^6}{60} = 16666.67 \text{ mg/l}$$

Q-4(c): ***Using the data given below, find the moisture content (Wet and dry basis) of the municipal solid wate. Also estimate the as-discarded density. If the comapction is 3, find the size of collection vehicle required for 1000 kg of MSW.***

S.No.	***Waste Component***	***Mass (%)***	***MC (%)***	***Density (kg/m^3)***
1.	***Newspaper***	***15***	***6***	***85***
2.	***Other paper***	***24***	***6***	***85***
3.	***Cardboard***	***33***	***5***	***50***
4.	***Glass***	***4.2***	***0.5***	***195***
5.	***Plastic***	***0.49***	***2***	***65***
6.	***Alauminium***	***0.13***	***0.5***	***160***
7.	***Iron***	***1.18***	***0.5***	***320***
8.	***Non-ferrous***	***0.35***	***0.5***	***160***
9.	***Yard wastes***	***17.97***	***60***	***105***
10.	***Food wastes***	***1.67***	***60***	***290***
11.	***Soil and dust***	***2.01***	***8***	***480***

[20 MARKS]

Sol: **Calculation of moisture content (wet & dry basis)**

Waste component	Mass (%)	MC (%)	Density (Kg/m^3)	Dry mass (%)	Volume = $\frac{\text{Mass}}{\text{Density}}$
Newspaper	15	6	85	14.01	0.1765
Other paper	24	6	85	22.56	0.2823
Cardboard	33	5	50	31.35	0.660
Glass	4.2	0.50	195	4.179	0.0215
Plastic	0.49	2	65	0.4802	0.0075
Aluminium	0.13	0.50	160	0.1293	0.00081
Iron	1.18	0.50	320	1.1741	0.00368
Non-ferrous	0.35	0.50	160	0.3482	0.00218
Yard waste	17.97	60	105	7.188	0.1711
Food waste	1.67	60	290	0.668	0.00575
Soil & dust	2.01	8	480	1.8492	0.00418
Total	W = 100			W_s = 83.936	V = 1.3355

Dry mass (%)

$$\text{Newspaper waste} = 15 - (0.06) \times 15 = 14.01\%$$

Similarly, for other waste, dry mass is calculated in the above table.

$$\text{So, wet moisture content or \% moisture} = \frac{W - W_s}{W} \times 100$$

$$= \frac{100 - 83.936}{100} \times 100 = \boxed{16.064\%}$$

Also,

$$\text{Dry basis moisture content of MSW} = \frac{\text{Moist mass}}{\text{Total dry mass}} \times 100$$

$$= \frac{16.064}{83.936} \times 100$$

$$= \boxed{19.138\%}$$

(ii) **Calculation of As-discarded density**

$$\text{As-discarded density} = \frac{W}{V} = \frac{100}{1.3355}$$

So, $\boxed{\text{As-discarded density} = 74.878 \text{ Kg/m}^3}$

(iii) **Calculation of size of collection vehicle (V)**

As, Compaction ratio = 3

$$\text{So, Compaction ratio} = \frac{\text{Density of MSW in vehicle}}{\text{As-discarded density}}$$

$$\boxed{\text{Density of MSW in vehicle} = 3 \times 74.878 \text{ Kg/m}^3}$$

As, Mass of MSW = 1000 Kg

$$\text{So, Density of MSW in vehicle} = \frac{\text{Mass of MSW in vehicle}}{\text{Volume of vehicle}}$$

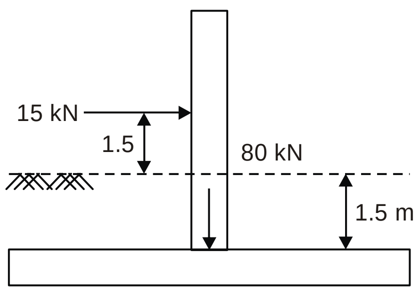
$$\text{Volume of collection vehicle} = \frac{1000 \text{ Kg}}{3 \times 74.878 \text{ Kg/m}^3}$$

$$\boxed{\text{Volume of collection vehicle} = 4.452 \text{ m}^3}$$

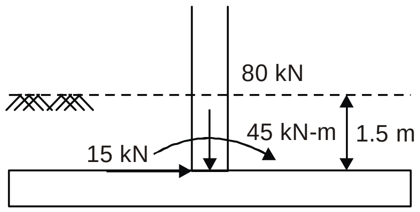
SECTION-B

Q-5(a): ***A 6 m high pier rests on a 2 m × 2 m square footing at 1.5 m depth from the surface at a site having uniform clayey soils. The unconfined compressive strength of the clay is 100 kPa and its bulk unit weight is 20 kN/m³. The pier carries a vertical load of 80 kN at the centre including its self-weight. A resultant horizontal load of 15 kN also acts on one side of the pier at 1.5 m above the surface. Determine the factor of safety with respect to the pier's net ultimate bearing capacity as per IS 6403 recommendations. [12 MARKS]***

Sol: Given unconfined compressive strength = 100 kPa



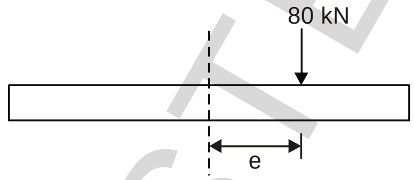
Bringing all load at the base of footing



$$\text{Resultant} = \sqrt{80^2+15^2} = 81.39 \text{ kN}$$

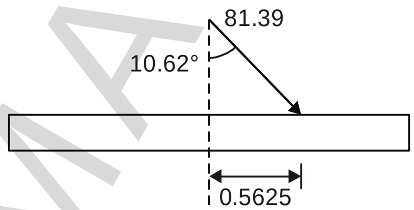
$$\theta = \tan^{-1}\frac{15}{80} = 10.62°$$

Considering the load acting at eccentric for moment consideration



$$80 \times e = 45$$

$\therefore$ $$e = 0.5625 \text{ m}$$



As the load is eccentric, new dimension of footing = (2 – 2 × 0.5625) = 0.87 m and 2 m

Ultimate net bearing capcity of cohessive soil as per IS 6403

$$q_{nu} = CN_C S_C i_C$$

Where, $$N_C = 5.14,\ C = 50 \text{ kPa}$$

$$S_C = \left(1+0.2\frac{B}{L}\right)$$

$$= \left(1+0.2\times\frac{0.87}{2}\right) = 1.087$$

Also, $$i_C = \left(1-\frac{\theta}{90}\right)^2 = \left(1-\frac{10.62}{90}\right)^2 = 0.986$$

$\therefore$ $$q_{xx} = 50 \times 5.14 \times 1.087 \times 0.986 = 275.45 \text{ kN/m2}$$

Also, pressure coming due to vertical load of 80 kN = $\frac{80}{2\times 0.87} = 45.98 \text{ kN/m}^2$

$\therefore$ $$\text{Factored of safety} = \frac{275.95}{45.98} = 5.99 \approx 6$$

Q-5(b): ***An electric power transmission pole is embedded 8 m into the ground. The pole weighs 30 kN and has base diaemter of 450 mm. If the poles is assumed to transmit the load as point load in the soil, determine the stress increase at a depth 1 m below the base, and:***

(i) Along the centre, and

(ii) 1 m from the centre. ***[12 MARKS]***

Sol: As per given in the question the laod is assumed as point load.

Since the electric pole is embeded inside the soil the stress calculated will be stress increament beneath the base of pole

(i) Stress increament at 1 m depth below the base of pole along the centerline

Using Boussinesq's equation,

$$(\sigma_V)_{center} = \frac{3Q}{2\pi z^2} = \frac{3 \times 30}{2 \times \pi \times 1^2} = 14.32 \text{ kN/m}^2$$

(ii) Stress increament at depth 1 m below the base and 1 m away from the centre.

$$\sigma_V = \frac{3Q}{2\pi z^2}\left[\frac{1}{\left(1+\frac{\pi^2}{z^2}\right)^{5/2}}\right] = \frac{3 \times 30}{2\pi / 2}\left[\frac{1}{\left(1+\frac{1}{1}\right)^{5/2}}\right]$$

$$= 2.53 \text{ kN/m}^2$$

Q-5(c): ***What are the key factor considered in the modernization of railway track with the aim to increase the average speed and capacity of the modernized section?*** ***[12 MARKS]***

Sol: There are sveral actions that have been taken to increase the average speed of trains.

Some of the most common include:

1. Inesting in new and improved rail infrastructure, such as upgrading tracks and signalling systems to allow for higher speeds.
2. Develping new train technology, such as high speed trains that are specifically designed to travel at faster speeds.
3. Implementing train traffic management systems, which are real time data to optimize train schedules and reduce delays.
4. Impriving train maintanance and inspection protocols to reduce downtime and ensures that trains are able to operate at maximum efficiency. Its worth nothing that increasing the average speed of trains is a complex and ongoing process, and it can be challenging to double the speed.

It varies from country to country and depends on the exttent of the infrastrurcture upgrade, the budget and the political will.

Some countries have already implemented high speed trains and others are in the process of doing so. In most cases it's a long term project that requires significant investmenta dn planning.

Transportation increases capacity in some railway infrastructure places becomes insufficient. Usually increment of member of tracks in all or part of an overloaded lines seens the most simple and clear solution. The main parameter influencing railway line capacity is difference in train speeds increasing the difference betwen the highest and the lowest train speed, feasible line capacity decreases.

- Keeping large radius and low gradient also ensure the high speed of trains.
- Providing thick web section at turn out.

Q-5(d): ***A car moving with a speed of 80 kmph has to overtake another car moving at a speed of 64 kmph in th two-lane one-way highway. if the reaction time of the driver is 2.5 s and acceleration of voertking car is 0.95 m/s², calculate the safe overtaking sight distance.*** ***[12 MARKS]***

Sol:

$$v = (80 \times 0.278) \text{ m/s}$$

$$v_b = (64 \times 0.278) \text{ m/sec}$$

$$a = 0.95 \text{ m/sec}^2$$

$$t_r = 2.5 \text{ sec.}$$

$$D_1 = v_b t_r = (64 \times 0.278) \times 2.5 = 44.48 \text{ m}$$

$$S = 0.2v_b \times L = 0.2 \times 64 + 6 = 18.8 \text{ m}$$

$$T = \sqrt{\frac{4S}{a}} = 8.9 \text{ sec}$$

$$D_2 = v_b T + 2S = 195.948 \text{ m}$$

Hence, $$OSD = D_1 + D_2 = 240.428$$

Q-5(e): ***In running fly levels from a banchmark of reduced level 212.40 m, a surveyor took an intermediate sight of 0.420 m with the staff held on a benchmark of reduced level 264.005 m. The sum of Back Sights and Fore Sights from the start to second BM is 75.205 m and 23.405 m, respectively. What is the closing erro on the second benchmark? If the distance between the first BM and second BM is 30 km, comment whether the work is satisfactory for ordinarylevelling for location and construction survey or not.*** ***[12 MARKS]***

Sol: Considering the last reading on last bench mark as the fore sight i.e., 0.42 m.

$\therefore$ $$\text{Sum of F.S.} = 23.45 + 0.42 = 23.87$$

$\therefore$ $$\sum BS - \sum FS = 75.205 - 23.87 = 51.335 \text{ m}$$

Actual difference between last and first

$$\text{B.M.} = 264.005 - 212.40 = 51.605$$

$\therefore$ $$\text{Error of closing} = 51.605 - 51.335 = 0.27 \text{ m}$$

For ordinary levelling,

$$\text{Permissible misclosure (e)} = \pm 24\sqrt{K} \text{ mm}$$

For K = 30 km

$$e = \pm 24\sqrt{30}$$

$$\boxed{e = \pm 131.453 \text{ mm}}$$

As the closing error is beyond the above permissible unit hence levelling work has to be reconducted.

Q-6(a): **(i)** ***An embankment is to be constructed using sandy clay compacted to dry unit weight of 18 kN/m³. The sandy clay has to be transported to the site from a borrow pit. The bulk unit weight of the sandyclay int he borow pit is 16 kN/m³ and its natural water content is 11%. Calculate the volume of sandy clay from the borrow pit required for 1 cubic metre of finished embankment. Assume tha the soil swells by 10% due to excavation and during transportation. You can take G_s = 2.7.*** **[12 MARKS]**

(ii) ***A 1.2 m thick embankment of loose sand is to be compacted using a Vibratory Roller. If the void ratio decreases from 1.2 to 0.8 due to comapction, calculate the final thickness of the embankment.*** **[8 MARKS]**

Sol: (i) Given,(γ_d) dry unit weight of embankment = 18 kN/m³

(γ_b) bulk unit weight of sandy clay = 16 kN/m³

(w_N) natural water content = 11%

(V_E) volume of embankment = 1 m³

(G_s) specific gravity = 2.7

$$(\gamma_d) \text{ of sandy clay} = \frac{r_{b\ \text{sandy clay}}}{1 + \text{water content}}$$

$$\gamma_d = \frac{16}{1+0.11} = \frac{16}{1.11} = 14.41 \text{ kN/m}^3$$

$\therefore$ Weight of solids for embankment = weight of solids for sandy clay

$(\gamma_d \times \text{volume of embankment}) = (\gamma_d \times \text{volume of borrow pit})$

$(18 \times 1) = 14.41 \times \text{volume of borrow pit}$

Volume of borrow pit without considering expansion & swelling = 1.249 m³

Since there is swelling expansion of 10% during excavation & transportaiton

So, required volume of sandy clay from borrow pit

$$= 1.1 \times 1.249 = 1.3739 \text{ m}^3$$

Sol: (ii) (H_i) initial thickness of embankment =1.2 m

(e_i) = initial void ratio = 1.2

(e_f) = final void ratio = 0.8

(H_f) = Final thickness of the embankment = ?

Assuming 1-dimension settling,

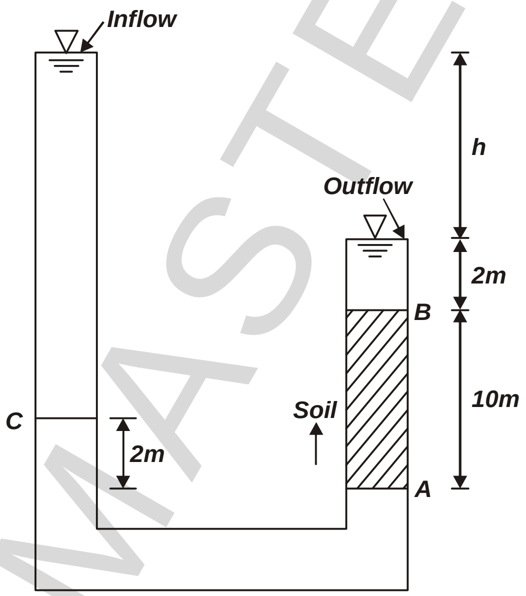
$$\therefore \quad \frac{\Delta H}{H_i} = \frac{\Delta e}{1+e_i} = \frac{\Delta H}{1.2} = \frac{1.2-0.8}{1+1.2}$$

$$\frac{\Delta H}{1.2} = \frac{0.4}{2.2}, \quad \boxed{\Delta H = 0.218\ \text{m}}$$

$$H_f = H_i - \Delta H = 1.2 - 0.218$$

$$\boxed{H_f = 0.982\ \text{m}}$$

Q-6(b): ***Soil sample and flow condition are shown in the following figure:***



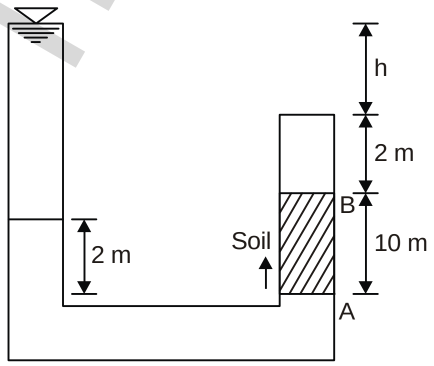
γ_{sat} of sand = 20 kN/m^3, γ_w = 20 kN/m^3

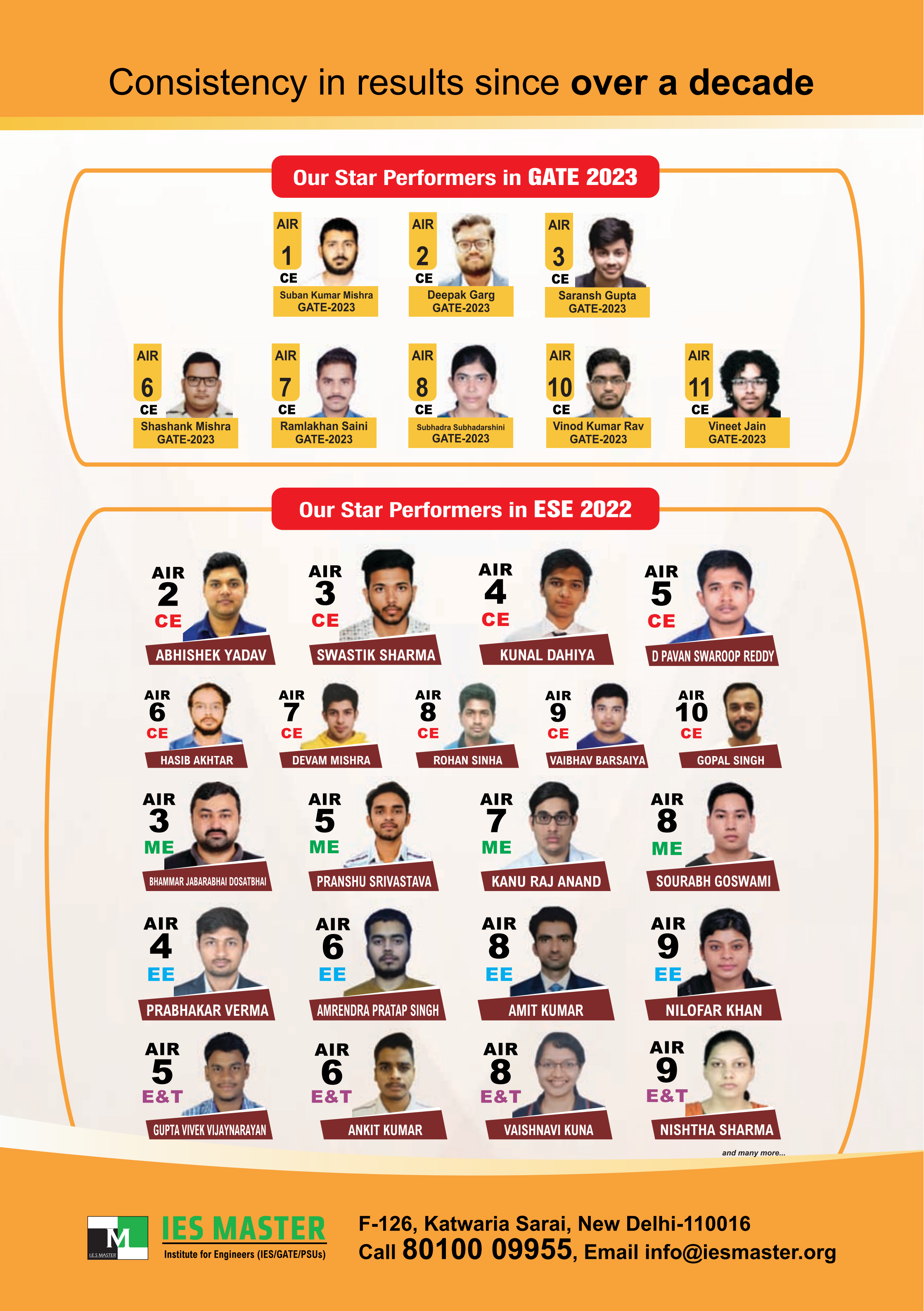
(i) ***Find the head, h required to cause quick condition.***

(ii) ***Compute the seepage force per unit volume at quick condition. Use cross-section area of tube as 1 m^2.***

(iii) ***A student accidentally broke the left hand riser tube to the point C at an elevation 2 m above point A. Assuming that the water level is now maintained at C, compute the new hydraulic gradient, effective stress at elevation A and seepage force at elevation A.*** ***[20 MARKS]***

Sol:

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AIR 8 ME SOURABH GOSWAMI
AIR 4 EE PRABHAKAR VERMA
AIR 6 EE AMRENDRA PRATAP SINGH
AIR 8 EE AMIT KUMAR
AIR 9 EE NILOFAR KHAN
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(i) Given, γ_{sat} of sand $= 20\ kN/m^3$

$\gamma_w = 10\ kN/m^3$

Critical hydraulic gradient $(i_{cr}) = \dfrac{\gamma_{sat}-\gamma_w}{\gamma_w} = \dfrac{20-10}{10} = 1$

$i_{actual} = \dfrac{h}{L} = \dfrac{h}{10}$

For quick sand condtion $i_{critical} = i_{actual}$

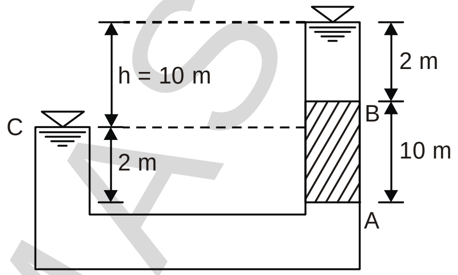
$\dfrac{h}{10} = 1 \Rightarrow \boxed{h = 10\ m}$

(ii) $A = 1\ m^2$

Seepage force per unit volume $= i_{cr}\gamma_w$

$= (1)(10) = 10\ kN/m^2$

(iii)



New hydraulic gradient $= \dfrac{h_L}{L} = \dfrac{10}{10} = 1$

Total stress at evaporation A $= 2\gamma_w + \gamma_{sat} \times 10$

$(\sigma_T) = 2 \times 10 + 20 \times 10 = 220\ kN/m^2$

Pore water pressure (v) $= 2\gamma_w = 20\ kN/m^2$

Seepage pressure due to downward flow $= h_L\gamma_w = 10 \times 10 = 100$

Effective stress at point A $= 220 - 20 = 200\ kN/m^2$

Seepage force $=$ Seepage pressure × Area

$= 100 \times 1 = 100\ kN$

Q-6(c): (i) Elaborate the various criteria which need to be considered for slection of site of a civilian greenfield airport in the hilly region. ***[15 MARKS]***

(ii) Discuss the essential features of an ideal comemercial harbour. ***[5 MARKS]***

Sol: (i) **Selection of site of a civilian green field airport in the hilly region:**

1. Atmospheric and meteorological conditions.
2. Availability of land for expansion.

3. Availability of utilities.
4. Development of the surrounding area.
5. Economy of construction
6. Ground accessibility
7. Presence of other airports
8. Regional plan
9. Soil characteristics
10. Topography
11. Use of airport
12. Aviation facilities that are constructed entirely from scratch on land that has never been used for aviation.
13. Greenfield project ex. are new factories, power plants, airport which are built from scratch on greenfield land.
14. Greenfield airport improved connectivity, lower operating costs, and move efficient operations.
15. Biju patnaik international airport, Bhubaneshwar this is one of the largest greenfield airport in India spread over 2000 acres.

Sol: (ii) Essential features of an ideal commercial harbour:

Following features are discussed below:

(i) Harbour should be protected naturally as through break water against storm and large walls. There should be sufficient area for furning the ship called as turning basin. Size of bearth and number of bearth should be adequate.

(ii) Depth of channel should be sufficient far draft of largest vessel.

(iii) Harbour is the important transportation hubs that facilitate goods movement.

(iv) I should be easily connect with rail and highway so that commodities can transport easily and quickly. Should have proper anchorage facilities for mooring of ships.

(v) Port must posses adequate facilities for holding and storing the commodities passing through the port.

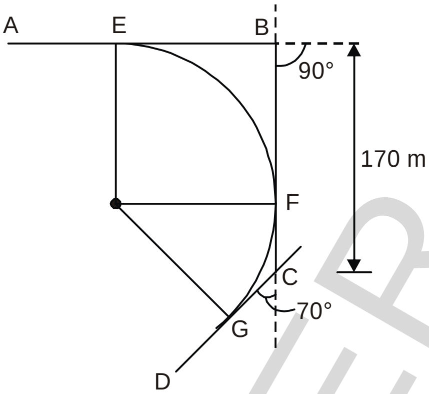
(vi) port must have facilities for servicing the ship

Q-7(a): ***A simple circular curve is to set out in a National Highway touching the three lines having following details:***

Line	***Reduced Bearing***	***Length (m)***
AB	***N 90º E***	***–***
BC	***S 0° E***	***170***
CD	***S 70° W***	***–***

If the chainage of point B is 700 m, calculate the radius of curve and chainage of all the tangent points in the curve. ***[20 MARKS]***

Sol: Assuming CF = x



$$BF = 170 - x$$

For curve E to F, EB is the tangent length

$\therefore$ $$EB = BF = R\tan\left(\frac{90}{2}\right)$$

or $$R \tan 45° = (170 - x) \quad \text{...(1)}$$

For curve F to G, FC is the tangent length

$\therefore$ $$FC = R\tan\left(\frac{70}{2}\right) = x \quad \text{...(2)}$$

Equating x from both equation

$$170 - R \tan 45° = R \tan 35°$$

$\therefore$ $$\boxed{R \approx 100 \text{ m}}$$

Now, $$\text{Length of curve EF} = \frac{\pi R\Delta}{180} = \frac{\pi \times 100 \times 90}{180} = 157.08 \text{ m}$$

Also, $$\text{Length of curve E to G} = \frac{\pi \times R \times 70°}{180} = 122.17 \text{ m}$$

$\therefore$ Chainage of tangent point E = 700 – 100 = 600 m

Chainage tangent point F = 600 + 157.08 = 757.08 m

Chainage of tangent point G = 757.08 + 122.17 = 879.25 m

Q-7(b): ***(i)*** ***A long trench with vertical sides is to be excavated in soft saturated clay deposits (ϕ_u + 0) to lay a sewage pipeline. If the maximum depth of the trench is 2 m, what shold be the approximate undrained cohesion of teh clay (C_u) to maintain a minimum safety factor of 3? Assume that the clay has a unit weight of 20 kN/m^3 and that the groundwater table is sufficiently below the excavation depth.*** ***[10 MARKS]***

(ii) ***A clay has plastic limit and liquid limit of 18 and 39 percent, respectively. What water content would correspond to its liquidity index of –0.1? Comment on the consistency of this clay.*** ***[10 MARKS]***

Sol: (i) Given,

$$(H)\text{ maximum depth of trench} = 2\text{ m}$$

$$\text{Factor of safety} = 3$$

$$(\gamma_b)\text{ unit weight of clay} = 20\text{ kN/m}^3$$

$$\text{Factors of safety} = 3$$

$$H_{max} = H \times 3 = 2 \times 3 = 6\text{ m}$$

$$H_{max} = \frac{4C}{\gamma\sqrt{K_a}}$$

$$H_{max} = \frac{4 \times C}{20 \times \sqrt{K_a}}$$

For $\phi = 0$, i.e.,

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin 0}{1+\sin 0} = 1$$

$$6\text{ m} = \frac{4C}{20 \times 1}$$

$$C = \frac{20 \times 6}{4} = 30\text{ kN/m}^2$$

Sol: (ii) Given,

$$(w_P)\text{ plastic limit} = 18\%$$

$$(w_L)\text{ liquid limit} = 39\%$$

$$(i_L)\text{ liquidity index} = -0.1$$

$$(w_n)\text{ natural water content} = ?$$

$\therefore$

$$(i_L)\text{ liquidity index} = \frac{w_N - w_P}{w_L - w_P} = \frac{w_N - 0.18}{0.39 - 0.18}$$

$$-0.1 = \frac{w_N - 0.18}{0.21}$$

On solving $w_N = 15.9\%$

So, a natural water content of (15.9%) would corresponds to a liquidity index of –0.1

Now, $\therefore$ liquidity index is less than zero

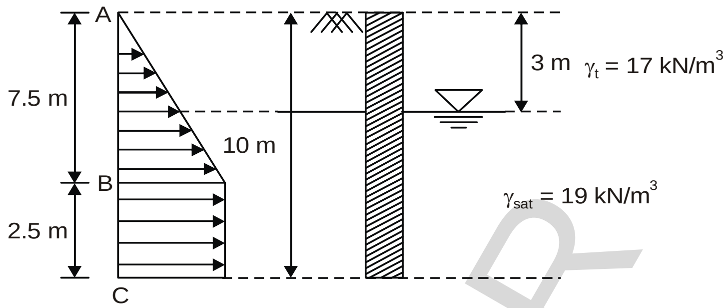
It indicates ($w_P > w_N$) & hence the soil is in solid/semisolid state of consistency.

Q-7(c): ***A prestressed concrete pipe of 0.5 m diameter is driven in medium dense sand up to 10 m depth. The groundwater table level is at 3 m depth below the surface. The properties of the sand are:***

Angle of internal friction of sand, ϕ'	*30 degrees*
Angle of wall friction between pile and sand, δ	*20 degrees*
Post–driving horizontal earth pressure co–efficient	*1*
Saturated unit weight of sand	*19 kN/m^3*
Unit weight of sand above groundwater table	*17 kN/m^3*

If the unit shaft resistance reaches a limiting value at 15 D, where D is the diameter of the pile, estimate the skin friction resistance of the pile. **[20 MARKS]**

Sol: Neglecting friction inside the pipe due to small valve.



$$D = 0.5\ m,\ L = 10\ m$$

$$\phi' = 30°,\ \delta = 20°$$

$$k = 1$$

$$\gamma_{sat} = 19\ kN/m^3$$

$$\gamma_t = 17\ kN/m^3$$

Effective stress at point A = 0, at point B = $3 \times 17 + 4.5(19 - 9.81) = 92.355\ kN/m^2$

at point C effective stress = $92.355\ kN/m^2$

$$\frac{L}{D} = 15 \Rightarrow L = 15D = 15 \times 0.5 = 7.5\ m$$

Skin friction resistance $= Q_f = f_s \cdot A_s$

$$f_s = k\bar{\sigma}_{avg} \tan\delta$$

$$Q_f = f_{s_1}A_{s_1} + f_{s_2}A_{s_2} \qquad f_s = k\sigma_{avg}\tan\delta$$

$$k = 1 \qquad A_s = \pi DL$$

$$\delta = 20°$$

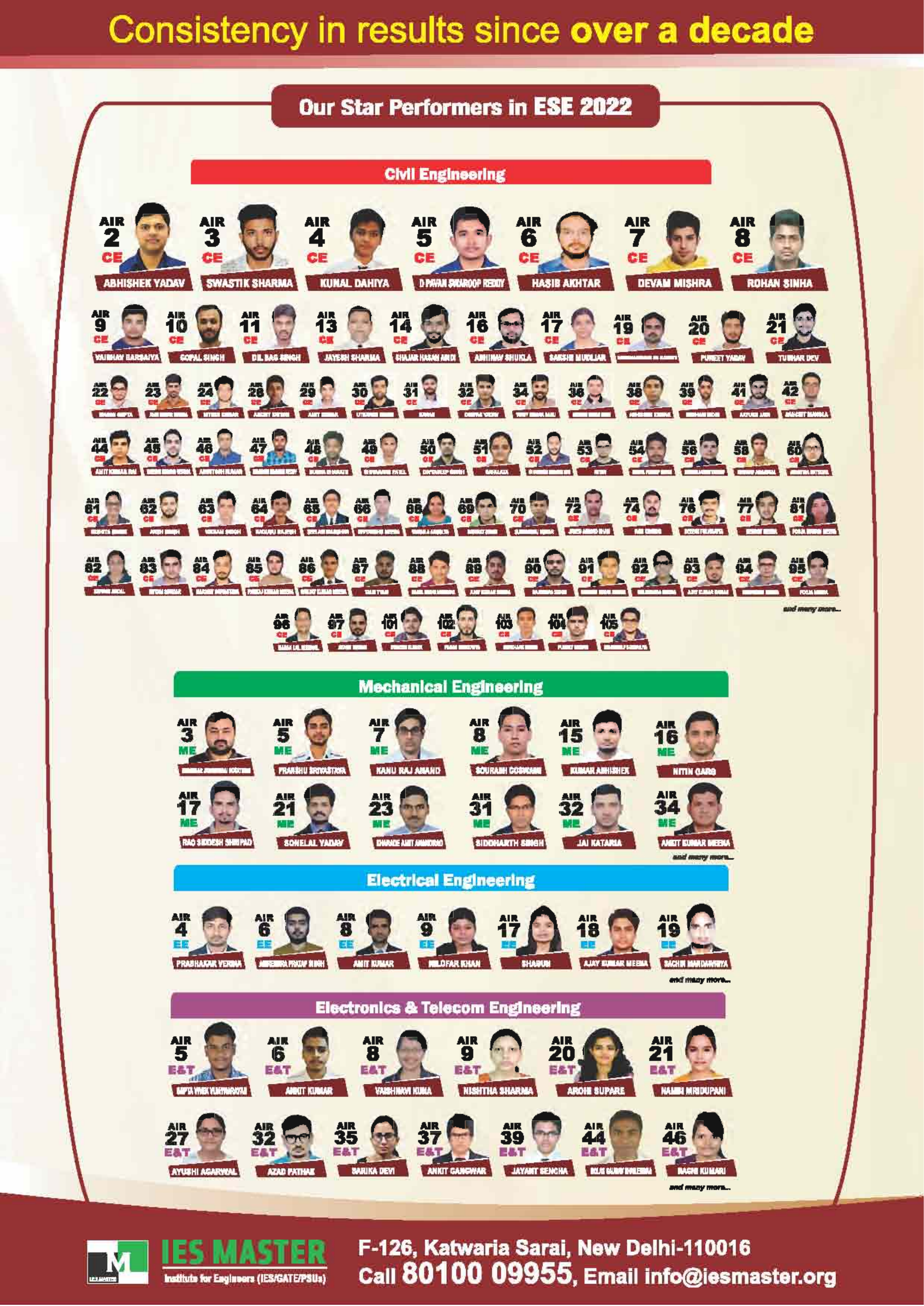
$$Q_f = 1 \times \tan(20)\left[\left[\frac{0 + 92.355}{2}\right] \times \pi \times 0.5 \times 7.5 + 92.355 \times \pi \times 0.5 \times 2.5\right]$$

$$= 330\ kN$$

Q-8(a): ***(i)*** ***A 600 mm diameter pile is installed upto the bottom of a 16 m thick stiff clayey soil. The pile rests on dense gravelly strata. The average undrained shear strength of the clay is 60 kPa (ϕ_u = 0) and its saturated unit weightis 18 kN/m³. If the pile has an enlarged base of diameter 1.2 m, determine its ultimate uplift capacity. Assume that the groundwater level is at the ground surface. Ignore the benefit due to the weight of the pile. Take adhesion factor α = 0.8 and friction coefficient in uplift K = 0.5.*** ***[12 MARKS]***

(ii) ***A single-storeyed structure is to be constructed at a site in which construction debris has been dumped down to a depth of 3 m over a period of time. The debris is in loose state and consists of concrete lumps, broken tiles and brickbats mixed with soil. Describe how to proceed to find a solution for design and construction of foundation without basement.***

[8 MARKS]



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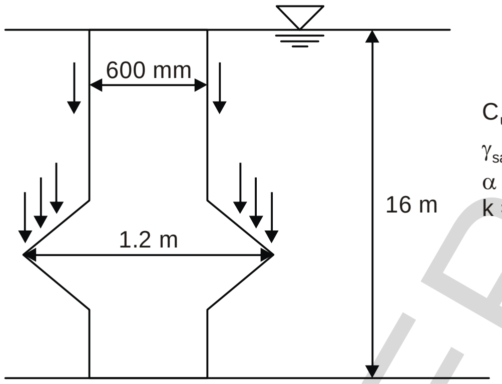
Sol: (i)



$$\text{Total uplift capacity} = C_u N_C \times \frac{\pi}{4}\left(d_b^2 - d_s^2\right) + \alpha \times C_u \times \pi d_s \times L$$

$$= 60 \times 9 \times \frac{\pi}{4}\left(1.2^2 - 0.6^2\right) + 0.8 \times 60 \times \pi \times 0.6 \times 16$$

$$= 1905.68 \text{ kN}$$

Sol: (ii) Since, single storeyed structure is to be constructed at a site. The load that will act on to foundation will be lower. Hence, shallow foundation will be used as foundation for the structure.

- To compact the debris before construction of foundation (which is in loose state and consist of concrete lumps, broken tiles and brickbats mixed with soil) ramming and vibratory roller will be used.

Ramming the soil using Vibratory Roller ⟶ Compaction of debris ⟶ Construction of shallow foundation

Q-8(b): ***Spot speed study was carried out redesign the stretch of major district road. The data collected during th estudy is given below.***

Speed Range kmph	*Frequency of vehicles*		
	Two Wheelers	*Cars*	*Others*
0-10	*5*	*0*	*0*
10-20	*20*	*6*	*4*
20-30	*24*	*12*	*4*
30-40	*20*	*30*	*5*
40-50	*30*	*60*	*30*
50-60	*35*	*35*	*30*
60-70	*25*	*35*	*15*
70-80	*10*	*15*	*10*
80-90	*10*	*18*	*2*
90-100	*1*	*9*	*0*

(i) ***What is the design speed for redesigning existing MDR?***

(ii) ***What are upper and lowe speed limits for mixed traffic?***

(iii) ***What are the different measures to increase the spot speed of vehicles moving on the road?***

(iv) ***Check whether the speed distribution is reasonably normal or not.*** ***[20 MARKS]***

Sol:

Speed range (kmph)	Mid point of speed range	Freuency			Total frequency	% frequency	Cumulative %
		2-wheel	Car	Others			
0 – 10	5	5	0	0	5	1	1
10 – 20	15	20	6	4	30	6	7
20 – 30	25	24	12	4	40	8	15
30 – 40	35	20	30	5	55	11	26
40 – 50	45	30	60	30	120	24	50
50 – 60	55	35	35	30	100	20	70
60 – 70	65	25	35	15	75	15	85
70 – 80	75	10	15	10	35	7	92
80 – 90	85	10	18	2	30	6	98
90 – 100	95	1	9	0	10	2	100
					$\Sigma 500$		

(i) Design speed i.e., 98th percentile speed

$$V_{98} = 85 \text{ km/hr}$$

(ii) Lower limit at speed i.e., 15th percentile speed

$$V_{15} = 25 \text{ km/hr}$$

Upper limit of speed i.e., 85th percentile speed

$$V_{85} = 65 \text{ km/hr}$$

(iii) Factors affecting spot speed are

(a) geometric design

(b) traffic conditions

(c) time and place

(d) traffic system in general

(e) environment and driver

Hence, methods to increase spot speed can be

1. Adopting proper geometric design parameter like sufficient width, lateral clearance, visibility etc.
2. Improving traffic condition by segregating vehicles moving below 15th percentile speed to reduce congestion.
3. Optimising traffic control agencies like rotary, traffic segnal & cordination etc.

(iv)

$$\text{Mean speed } \bar{u} = \frac{\sum \text{frequency} \times \text{speed}}{\sum \text{Frequency}}$$

$$= \frac{25300}{500} = 50.6 \text{ kmph}$$

$$\text{Standard deviation (s)} = \sqrt{\frac{\sum f(u-\bar{u})^2}{n-1}}$$

$$= \sqrt{\frac{185320}{500-1}} = 19.27 \text{ kmph}$$

For a speed distribution to be reasonably normal, standard deviation should be approximately about half the difference between 85th and 15th percentile speed.

This condition is satisfied as $\left(\frac{V_{85}-V_{15}}{2} = 20 \text{ kmph}\right)$ and standard deviation is 19.27 kmph. hence the distribution is reasonably normal.

Q-8(c): ***A straight bridge is set out between two points A and B, whose independent coordinates are given below:***

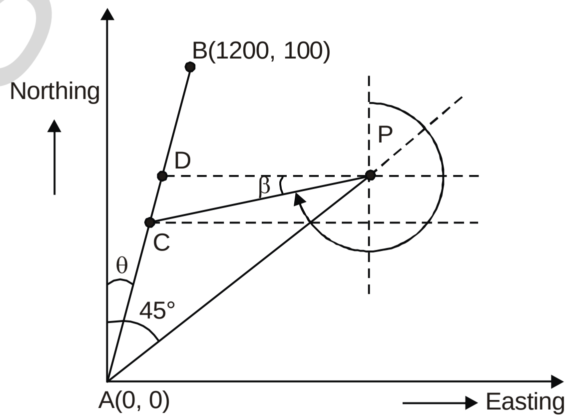
Point	***Northing (N)***	***Easting (E)***
A	***0***	***0***
B	***1200***	***100***

It is required to set out the pillar at point C which is 400 m from point A. It is not possible to set the instrument either at point A or B. To set point C, another point P is selected at a horizontal distance of 600 m. Calculate:

(i) The independent coordinates of points C and P.

(ii) The length and bearing of line PC. **[20 MARKS]**

Sol:



The independent co-ordinates of points A & B are shown above

$$\text{Length of line AC} = L_{AC} = 400 \text{ m}$$

$$\text{Length of AP} = L_{AP} = 600 \text{ m}$$

Bearing of line AP = $\theta_{AP} = 45°$

(i) Calculation of independent co-ordinates of C & P

For point 'P'

Independent northing of 'P' = $L_{AP} \cos 45°$

= 600 cos 45° = 424.264 m

Independent easting of 'P' = $L_{AP} \sin 45°$

= 600 sin 45° = 424.264 m

So, independent co-ordinates of P are (424.264 m, 424.264 m)

Similarly, for point 'C'

As the point 'C' lies on the line AB so the bearing of line AB & line AC would be same.

i.e., Bearing of line AB = Bearing of line AC = θ

So, $$\tan\theta = \frac{100}{1200}$$

$$\boxed{\theta = 4.763°}$$

So, Independent northing of 'C' = L_{AC} cos 4.763° = 400 cos 4.763° = 398.618 m

Independent easting of 'C' = L_{AC} sin 4.763° = 400 sin 4.763° = 33.213 m

So, independent co-ordinates of 'C' are (398.618 m, 33.213 m)

(ii) Calculation of length & bearing of line 'PC'

Length of line 'PC' i.e., L_{PC}

$$L_{PC} = \sqrt{(424.264 - 398.618)^2 + (424.264 - 33.213)^2}$$

$$\boxed{L_{PC} = 391.891\,\text{m}}$$

Bearing of line 'PC'

Let the angle, $\angle DPC = \beta$

So, $$\tan\beta = \frac{424.264 - 398.681}{424.264 - 33.213}$$

$$\boxed{\beta = 3.743°}$$

So, Bearing of line 'PC' = 270° – 3.743° = 266.256°

or, = 266°15′25″

So, length & bearing of line PC is 391.891 m & 266°15′25″ respectively.