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# ESE 2019 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

## Civil Engineering

### Test-3: Strength of Materials
### Transportation Engineering-1 + Surveying & Geology-1
### Geo-technical & Foundation Engg-2 + Environmental Engg-2

Name : .....

Roll No : C E 1 9 M T D L A 7 4 3

**Test Centres**

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**Student's Signature**

**Instructions for Candidates**

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. Answer must be written in English only.
3. Use only black/blue pen.
4. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
5. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
6. Last two pages of this booklet are provided for rough work. Strike off these two pages after completion of the examination.

* Nice accuracy

**FOR OFFICE USE**

| Question No. | Marks Obtained |
|---|---|
| Section-A | |
| Q.1 | 48+2= 50 |
| Q.2 | — |
| Q.3 | — |
| Q.4 | 48 |
| Section-B | |
| Q.5 | 41-2= 39 |
| Q.6 | |
| Q.7 | 50 |
| Q.8 | 48 |
| **Total Marks Obtained** | 235 |

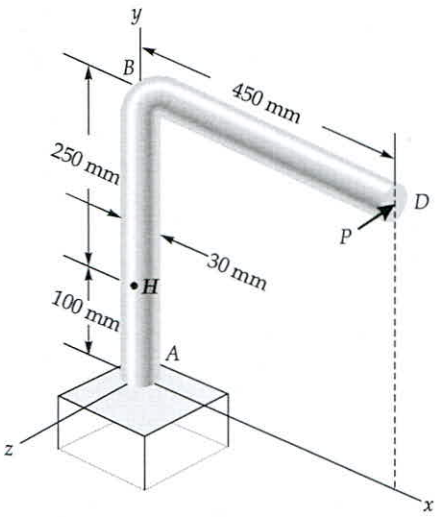
Signature of Evaluator ..... Cross Checked by .....

## Section A : Strength of Materials

**(a)** A single horizontal force P of magnitude 600 N is applied to end D of lever ABD. The diameter of lever ABD is 30 mm. Determine :

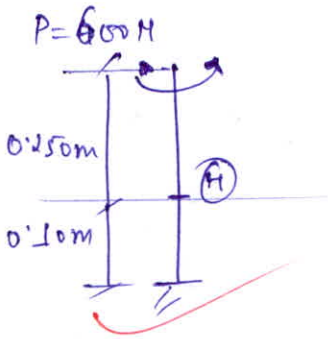
**(i)** The normal and shearing stress on an element located at point H having sides parallel to $x$ and $y$ axis.

**(ii)** The directions of principal planes and principal stresses at point H.




Dia = 30mm

**[12 marks]**



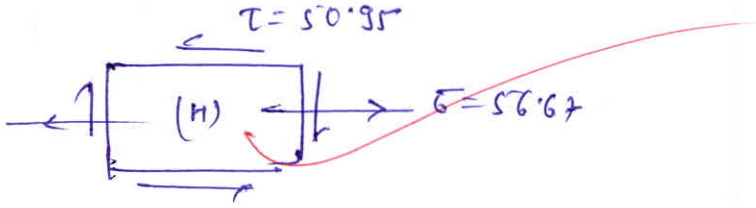

$T = (P \times 0.450) = 600 \times 0.450$

$= 270 Nm$

$\frac{M}{I} = \frac{\sigma}{y} \Rightarrow \sigma = \left(\frac{My}{I}\right) = \frac{(600 \times 0.250) \times 32 \times 1000}{\pi \times (60)^3}$

$= 56.617 N/mm^2$

$\frac{T}{I_p} = \left(\frac{\tau}{r}\right) \Rightarrow \tau = \left(\frac{Tr}{I_p}\right) = \frac{270 \times 16}{\pi \times (30)^3} = 50.95 N/mm^2$



$$\tan 2\theta_p = \left(\frac{2\tau_{xy}}{\sigma_x - \sigma_y}\right)$$

$$= \frac{2 \times -50.95}{56.67}$$

$$= -1.798$$

$$2\theta_p = (119.08)$$

$$\theta_{p_1} = 59.5408$$

$$\theta_{p_2} = 149.5408$$

$$\sigma_{p_1}/\sigma_{p_2} = \left(\frac{\sigma_x + \sigma_y}{2}\right) \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$= \left(\frac{56.67 + 0}{2}\right)^2 \pm \sqrt{\left(\frac{56.67 - 0}{2}\right)^2 + (50.95)^2}$$

$$28.335 \pm 58.29$$

$$\sigma_{p_1} = 86.625 \text{ N/mm}^2$$

$$\sigma_{p_2} = -29.955 \text{ N/mm}^2$$

10

**(b)** A steel specimen is subjected to the following principal stresses: (i) 120 N/mm$^2$ tensile (ii) 60 N/mm$^2$ tensile and (iii) 30 N/mm$^2$ compressive. The proportionality limit for the steel specimen is 250 N/mm$^2$. Find the factor of safety according to

*(i)* Maximum shear stress theory. *(ii)* Maximum principal strain theory.

*(iii)*Maximum strain energy theory.

Take Poisson's ratio = 0.3

**[12 marks]**

$\sigma_1 = 120, \sigma_2 = 60, \sigma_3 = -30 \quad \sigma_y = 250 N/mm^2$

Max. Shear Stress

$\tau_{max} = \left(\frac{\sigma_1 - \sigma_2}{2}, \frac{\sigma_2 - \sigma_3}{2}, \frac{\sigma_1 - \sigma_3}{2}\right) = \left(\frac{120-60}{2}, \frac{60+30}{2}, \frac{120+30}{2}\right)$

$= (30, 45, 75)_{max}$

$\tau_{max} = 75 N/mm^2$

According to Max. Shear Stress Theory

$\tau_{max} \leq \frac{(\sigma_y / FOS)}{2}$

$75 \leq \frac{(250)}{FOS \times 2}$

$FOS \leq \frac{125}{75} \leq 1.67$

(ii) Max. principal strain theory

$$\left(\frac{\sigma_1}{E} - \frac{\mu\sigma_2}{E} - \frac{\mu\sigma_3}{E}\right) \le \frac{(\sigma_y/FOS)}{E}$$

$$(120 - 0.3\times 60 + 0.3\times 30) \le \left(\frac{250}{FOS}\right)$$

$$\boxed{FOS \le 2.052}$$

(iii) According to Max. strain Energy Theory

$$\frac{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2\mu(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_1\sigma_3)}{2E} \le \frac{(\sigma_y/FOS)^2}{2E}$$

$$(120)^2 + (60)^2 + (30)^2 - 2\times 0.3\left[120\times 60 + 60\times -30 + 120\times -30\right] \le \left(\frac{250}{FOS}\right)^2$$

$$17850 \le \left(\frac{250}{FOS}\right)^2$$

$$\boxed{FOS \le 1.4727}$$

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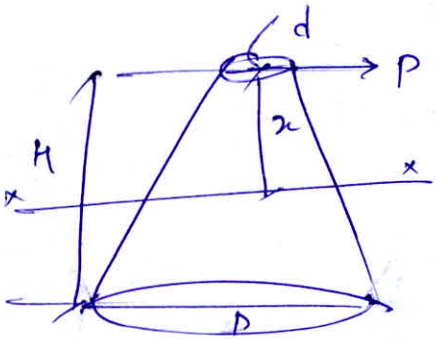
**(c)** A uniformly tapering vertical post of height $H$ having a diameter D at the base and a diameter $d$ at the top is fixed at its base. A horizontal force P is applied at the top of the post. Determine the maximum bending stress for the post and state where it occurs.

**[12 marks]**




$$d_x = d + \left(\frac{D-d}{H}\right)x$$

$$\boxed{d_x = a + bx}$$

$$I = \frac{\pi}{64}(d_x)^4 = \frac{\pi}{64}(a+bx)^4$$

$$\frac{M}{I} = \frac{\sigma}{y}$$

$$\sigma = \left(\frac{Mg}{I}\right) = \frac{(Px) \times 32}{(d_x)^3} = \frac{32Px}{\pi(a+bx)^3}$$

$$\sigma_{xx} = \frac{32Px}{\pi(a+bx)^3}$$

$$\frac{d\sigma_x}{dx} = \frac{32P}{\pi}\left[\frac{(a+bx)^3 \times 1 - x \times 3(a+bx)^2 \times b}{(a+bx)^6}\right] = 0$$

$$(a+bx)^2\left[(a+bx) - 3xb\right] = 0$$

$$\therefore a = 2bx$$

$$x = \left(\frac{a}{2b}\right) = \frac{d}{2} \times \frac{H}{(D-d)} = \frac{dH}{2(D-d)}$$

and

$$\sigma_{max} = \frac{32Px}{\pi\left[d + \frac{(D-d)}{H} \times \frac{dH}{2(D-d)}\right]^3} = \frac{32 \times P \times \left(\frac{dH}{2(D-d)}\right)}{\pi(1.5d)^3}$$

$$\sigma_{max} = \frac{32P\left[\frac{dH}{2(D-d)}\right]}{\pi \times (1.5d)^3}$$

Ans

$$n = \frac{dH}{2(D-d)}$$

12

**(d)** A 10 mm diameter mild steel bar of length 1.50 metre is stressed by a weight of 120 N dropping freely through 20 mm before commencing to stretch the bar. Find the maximum instantaneous stress and the elongation produced in the bar.

[Take $E = 2 \times 10^5$ N/mm$^2$]

**[12 marks]**

$d = 10mm$

$L = 1.50m$

$W = 120N$

$h = 20mm$

$$\sigma_i = \frac{P}{A}\left[1 + \sqrt{1 + \frac{2hAE}{PL}}\right]$$

$$= \frac{120}{\frac{\pi}{4}\times(10)^2}\left[1 + \sqrt{1 + \frac{2\times 20\times\left(\frac{\pi}{4}\times 10^2\right)\times 2\times 10^5}{120\times 1500}}\right]$$

$$= 91.83\ N/mm^2$$

$\sigma_i = E\epsilon$

$$\epsilon = \left(\frac{\sigma_i}{E}\right) = \frac{91.83}{2\times 10^5}$$

$$\epsilon = 4.5915\times 10^{-4}$$

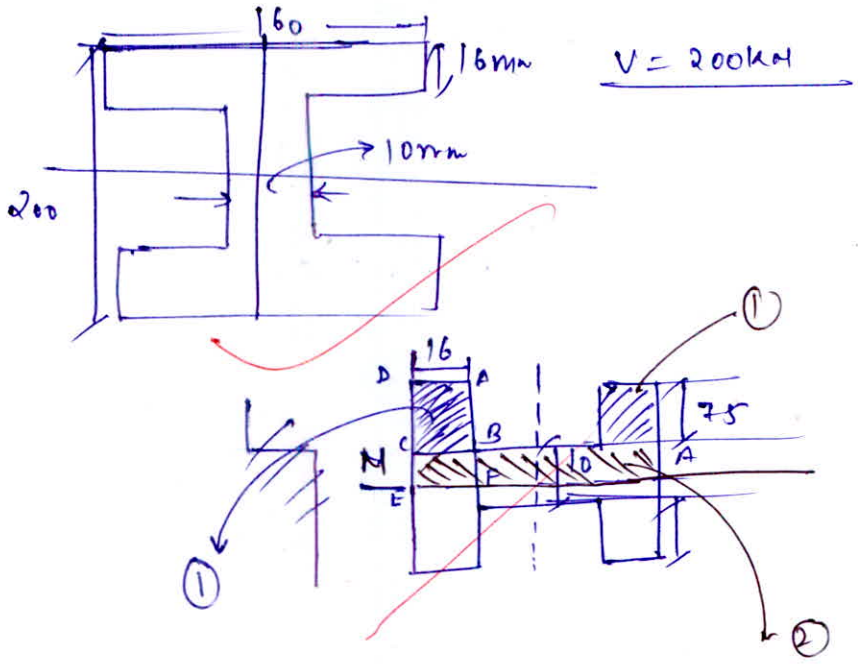
$$\epsilon = \left(\frac{\Delta L}{L}\right) \Rightarrow \boxed{\Delta L = 0.688mm}$$

10 + 2

Objective Approach adopted.

**Q.1 (e)** A steel beam of I-section, 200 mm deep and 160 mm wide has 16 mm thick flanges and 10 mm thick web. The beam is subjected to a shear force of 200 kN. Draw the shear stress distribution, if the web of the beam is kept horizontal.

**[12 marks]**



$$I_{xx} = \frac{16\times(160)^3}{12}\times 2 + \frac{[200-(16+16)]\times(10)^3}{12}$$

$$I_{xx} = 1.0936\times10^7\ mm^4$$

For shaded portion upto CE

$$\tau = \frac{SA\bar{y}}{Ib}$$

$$= \frac{200\times10^3\times[16\times75\times42.5]}{1.0936\times10^7\times16\times2}$$

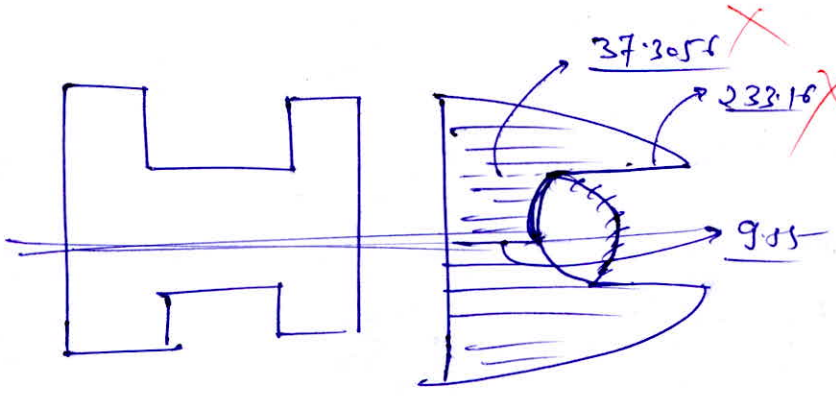
$$= 233.16\ N/mm^2$$

for portion shaded ② upto EF

$$\tau = \frac{SA\bar{y}}{Ib}$$

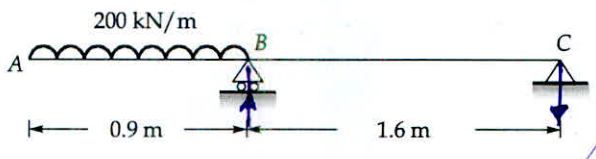
$$= \frac{200\times10^3\times[(16\times80\times40)\times2 + (168\times5\times2.5)]}{1.0936\times10^7\times200}$$

$$= 9.55\ N/mm^2$$

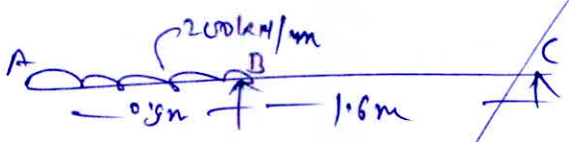



64

**Q.2 (a)** For the beam shown below, find the deflection at end A, using moment area method. [Take EI = constant]



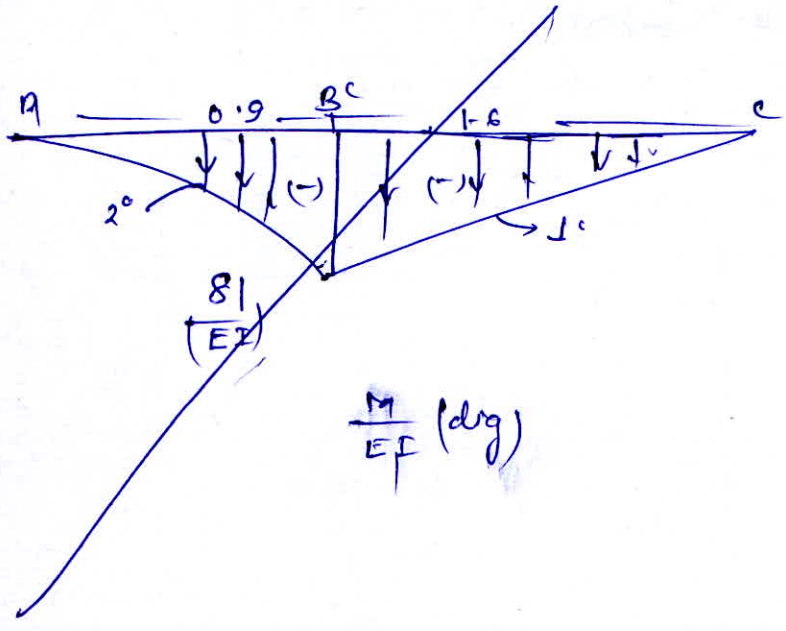

**[20 marks]**



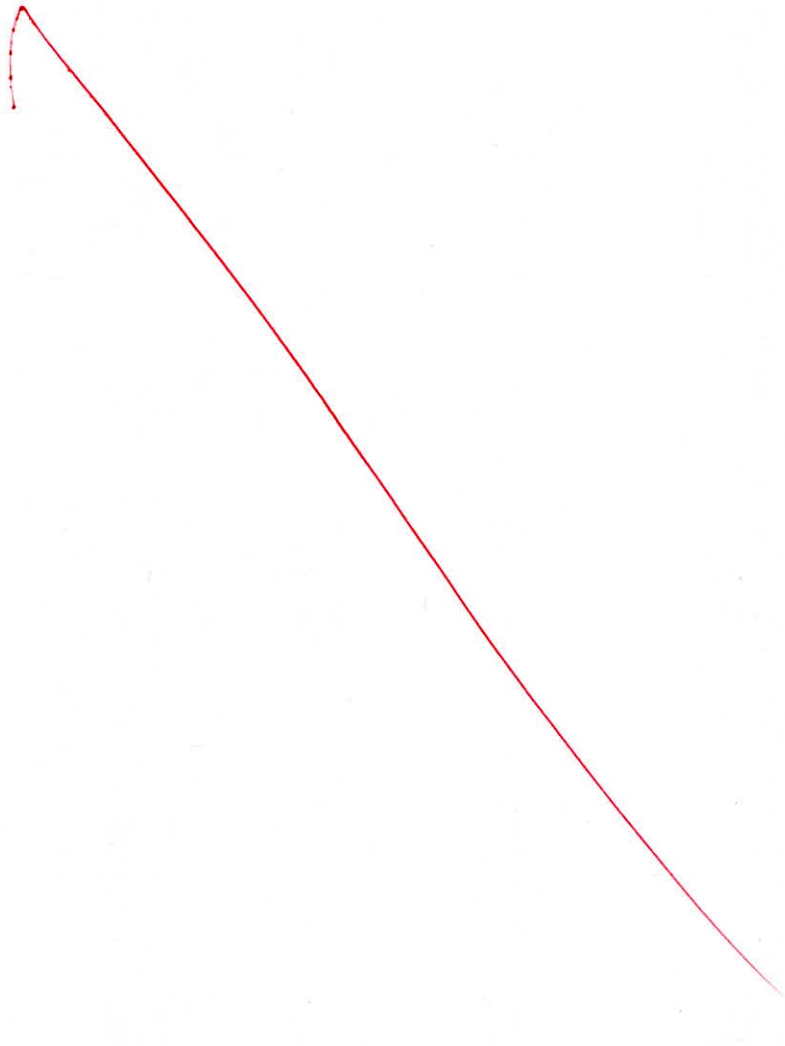

$R_B \times 1.6 - 200 \times 0.9 \times \left(1.6 + \frac{0.9}{2}\right)$

$R_B = 230.625\,kN$ (↑)

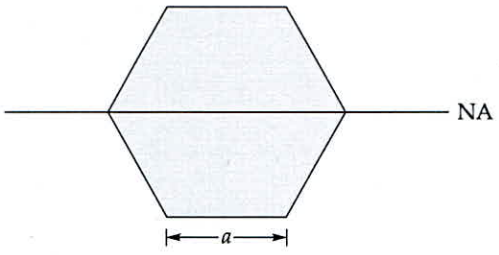
$R_C = -50.625\,kN$ (↓)




$\frac{M}{EI}$ (drg)

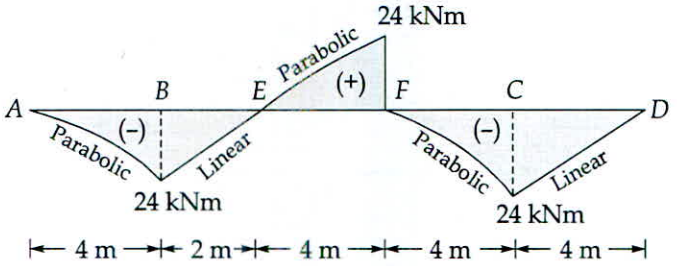


**? (b)** A beam section is a regular hexagon of side 'a' and is placed so that one diagonal is horizontal as shown below. If the beam section is subjected to a shear force $S$, obtain an expression for the shearing stress at any distance $x$ from the horizontal diagonal.



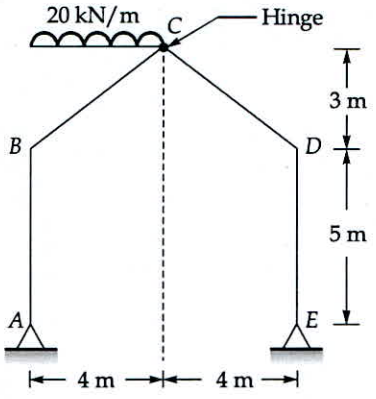

**[20 marks]**

**Q.2 (c)** A beam ABCD is supported at B and C and has over-hangs AB and CD. Its bending moment diagram is shown below. Determine the loading diagram and the shear force diagram of the beam.



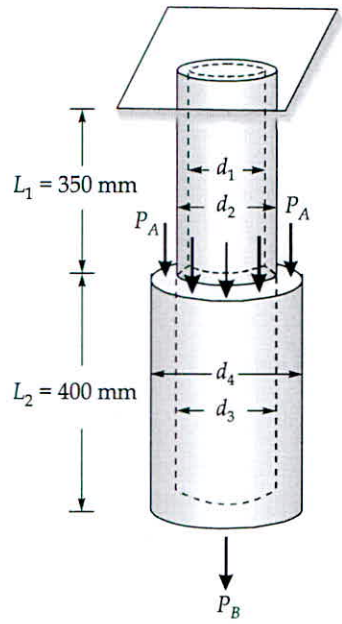

**[20 marks]**

3 (a) Draw the bending moment diagram for the frame shown below.




**[20 marks]**

**Q.3 (b)** A hollow circular nylon pipe as shown in figure supports a load $P_A$ = 7800 N, which is uniformly distributed around a cap plate at the top of lower pipe. A second load $P_B$ is applied at the bottom. The inner and outer diameters of the upper and lower parts of the pipe are $d_1$ = 51 mm, $d_2$ = 60 mm, $d_3$ = 57 mm and $d_4$ = 63 mm respectively. The upper pipe has a length $L_1$ = 350 mm and lower pipe has a length $L_2$ = 400 mm. Neglect the self weight of the pipes.



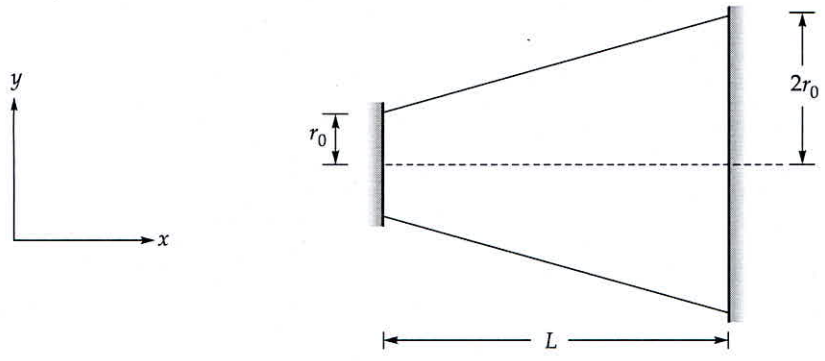

**(i)** Find $P_B$ so that the tensile stress in the upper pipe is 14.5 MPa. Also determine the resulting stress in lower pipe?

**(ii)** If $P_A$ remains unchanged, find the new value of $P_B$ so that upper and lower pipes have same tensile stress.

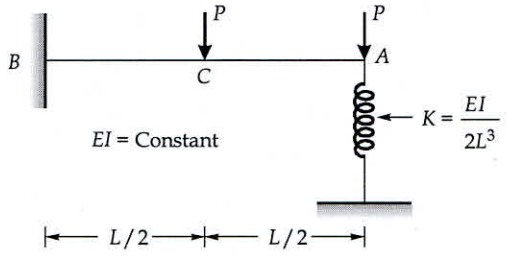
**(iii)** Find the tensile strains in the upper and lower pipe segments for the loads in part (ii) if the elongation of the upper pipe is 3.56 mm and downward displacement of bottom pipe is 7.63 mm?

**[20 marks]**

3 (c) **(i)** A bar as shown in figure below is in a shape of a solid, truncated cone of circular cross-section and is situated between two rigid supports. The temperature of the entire bar is then raised by $\Delta T$. Assume that the cross-sections perpendicular to longitudinal axis of symmetry remain plane and neglect localised end effect due to the end supports. Determine the normal stress at any point in the bar.

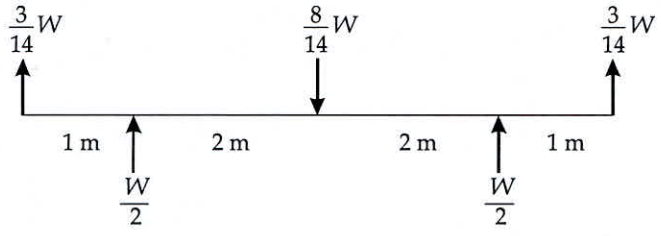



**(ii)** Determine the bending moment and shear force at support $B$ in the uniform beam $AB$ with flexural rigidity $EI$ shown in the figure. Take spring constant $K = \dfrac{EI}{2L^3}$.



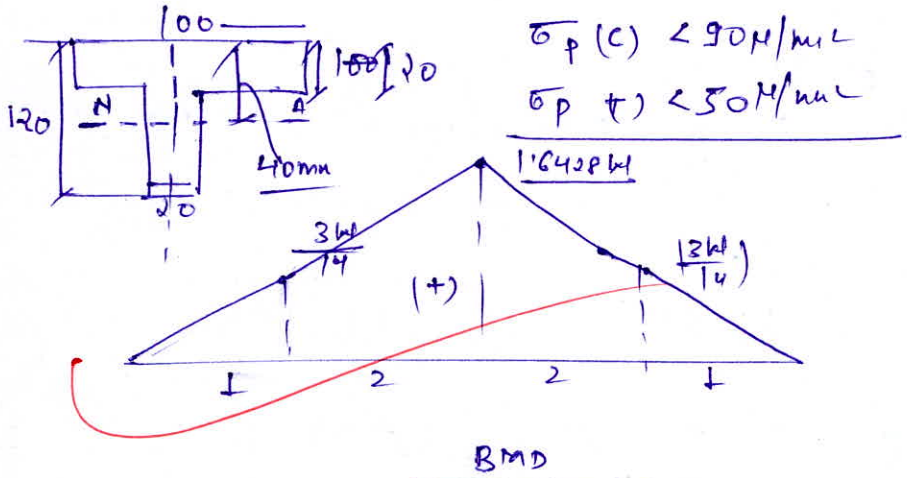

**[10 + 10 marks]**

(a) **(i)** A beam of T-section 6 m long supports the load system as shown below. The beam has a flange width of 100 mm and an overall depth of 120 mm. The flange and the web are 20 mm thick. The section is placed with flange at the bottom. Find the safe value of W if the stresses in compression and tension shall not exceed 90 N/mm$^2$ and 50 N/mm$^2$ respectively.




**(ii)** If a tension test bar is found to taper uniformly from (D – a) diameter to (D + a) diameter, prove that the error involved in using the mean diameter to calculate the Young's modulus is $\left(\frac{10a}{D}\right)^2$ percent.

**[10 + 10 marks]**




$M_{max} = 1.6428\ kN\ (kNm)$ Sagging

MA Depth

$$\frac{100\times20\times10 + 100\times20\times(50+20)}{100\times20 + 100\times20} = 40mm \text{ from Top}$$

$$I_{NA} = \left(\frac{100\times(20)^3}{12} + 100\times20\times(40-10)^2 + \frac{20\times(100)^3}{12} + 20\times100\times(70-40)^2\right)$$

$$I_{NA} = 3.593\times10^6\ mm^4$$

$y_t = 40$

$y_c = 80$

$\frac{M}{I} = \frac{\sigma}{y}$

$\sigma_{Top} = \left(\frac{My_t}{I}\right) = \frac{(1.6028\ kNm) \times 10^6 \times 40}{3.593 \times 10^6} = 18.28\ N$

$\sigma_{Bottom} = \left(\frac{My_b}{I}\right) = \frac{(1.6028\ kNm) \times 10^6 \times 80}{3.593 \times 10^6} = 36.57\ N$

$\sigma_{Top}$ => Compression

$\frac{\sigma_{Top}}{\sigma_{Bottom}} = \frac{\sigma_c}{\sigma_T} = \left(\frac{40}{80}\right) = \left(\frac{1}{2}\right)$

if $\sigma_c = 90$

then $\sigma_{Tension} = (90 \times 2) = 180 > 50$ (Not ok)

if $\sigma_{Tension} = 50$

$\sigma_c = 25 < 90$ (O.K.)

therefore $\sigma_T = 50,\ \sigma_c = 25$

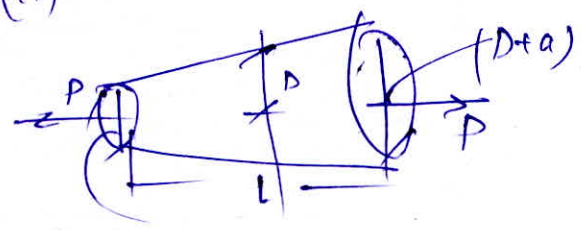
$\therefore \sigma_{Top} = \sigma_c = 25\ N/mm^2$

$25 = 18.28\ W$

$W = \frac{25}{18.28} = 1.3676\ KN$

8

(ii)




(D-a)

$d_1 = (D-a)$

$d_2 = (D+a)$

$$\delta = \frac{4PL}{\pi E d_1 d_2}$$

$$\delta = \frac{4PL}{\pi E_1 (D-a)(D+a)}$$

Similarly


$$\delta = \frac{4PL}{\pi E_2 D^2}$$

$$\frac{4PL}{\pi E_2 D^2} = \frac{4PL}{\pi E_1 (D^2-a^2)}$$

$$E_1(D^2-a^2) = E_2 D^2$$

$$\frac{E_1}{E_2} = \frac{D^2}{(D^2-a^2)}$$

$$\frac{E_1 - E_2}{E_2} = \frac{(D^2 - D^2 + a^2)}{(D^2-a^2)}$$

$$\frac{\Delta E}{E_2} = \frac{a^2}{(D^2-a^2)}$$

$a \ll D$ ∴ neglected

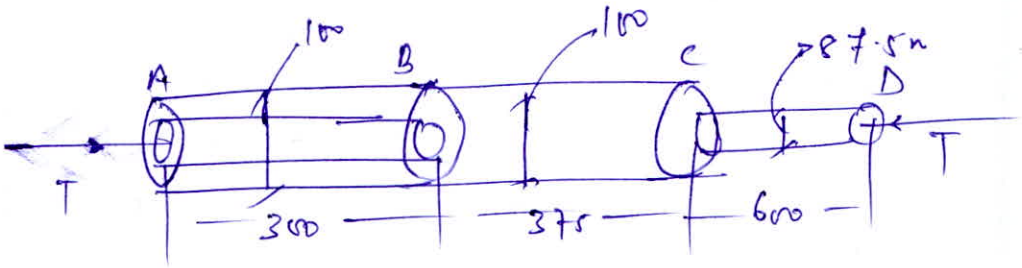
$$= \left(\frac{a^2}{D^2}\right)$$

$$\% \text{ Error} = \frac{100\,a^2}{D^2}$$

10

**(b)** A steel shaft ABCD has a total length of 1275 mm and is made up as follows: AB = 300 mm, BC = 375 mm and CD = 600 mm. AB is hollow, its outside diameter being 100 mm and inside diameter $d_1$ mm. BC and CD are solid having diameters of 100 mm and 87.5 mm respectively. If equal and opposite torques are applied at the ends of the shaft, then find the maximum permissible value of $d_1$ for the maximum shearing stress in AB not to exceed that in CD. If the torque applied to the shaft is 9000 Nm, what is the total angle of twist? Take $G = 8 \times 10^4$ N/mm$^2$.

**[20 marks]**




$T = 9000$ N/m

$G = 8 \times 10^4$ N/mm$^2$

$$\tau_{max(AB)} = \left(\frac{T \times r}{J_p}\right) = \frac{9000 \times 10^3 \times (100/2)}{\frac{\pi}{32}(100^4 - d_1^4)}$$

$$\tau_{max(CD)} = \frac{9000 \times 10^3 \times (87.5/2)}{\frac{\pi}{32} \times (87.5)^4} = 68.455 \text{ N/mm}^2$$

$$\frac{4.5859 \times 10^9}{(100)^4 - (d_1)^4} \leq 68.455$$

$$\boxed{d_1 \leq 75.79 \text{ mm}}$$

20

$$\theta_{AD} = \theta_{AB} + \theta_{BC} + \theta_{CD}$$

$$= \frac{Tl_1}{GJ_{p_1}} + \frac{Tl_2}{GJ_{p_2}} + \frac{Tl_3}{GJ_{p_3}}$$

$$= \frac{9000 \times 10^3}{8 \times 10^4}\left[\frac{300}{\frac{\pi}{32} \times (100^4 - 75.79^4)} + \frac{375}{\frac{\pi}{32} \times (100)^4} + \frac{600}{\frac{\pi}{32} \times (87.5)^4}\right]$$

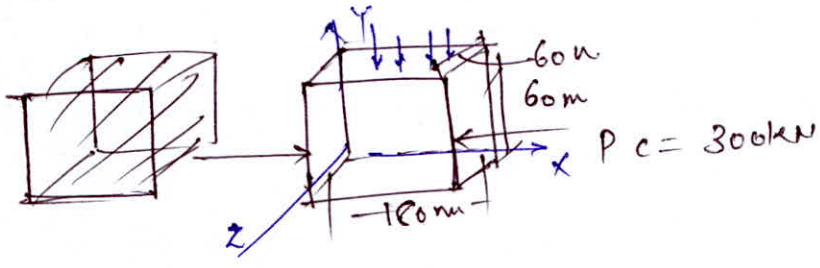
$$\boxed{\theta_{Total} = 0.02116 \text{ rad}}$$

(c) A steel bar of square section 60 mm × 60 mm and 180 mm long is subjected to an axial compressive load of 300 kN. The lateral strain is prevented by the application of uniform external pressure. If $\mu = 0.3$ and $E = 2 \times 10^5$ N/mm$^2$, find the alteration in the length of the bar.

If however, only one-half the lateral strain is prevented then what would be the alteration in the length of bar?

**[20 marks]**

Sol$^n$




$$\epsilon_y = \left(\frac{\sigma_y}{E} - \frac{\mu\sigma_x}{E} - \frac{\mu\sigma_z}{E}\right)$$

$$\epsilon_y = \left(\frac{+q_1}{E} + \frac{\mu \times \sigma_x}{E} - \frac{\mu q_2}{E}\right)$$

$\epsilon_y = 0 \Rightarrow q_1 + (0.3 \times 83.33) - 0.3q_2 = 0$

$q_1 + 25 - 0.3q_2 = 0$ — (1)

Similarly $\epsilon_z = 0$

$$\left(\frac{\sigma_z}{E} - \frac{\mu\sigma_x}{E} - \frac{\mu\sigma_y}{E}\right) = 0$$

$$\frac{q_2}{E} + \frac{0.3 \times 83.33}{E} - \frac{0.3q_1}{E} = 0$$

$q_2 + 25 - 0.3q_1 = 0$ — (2)

$25 = 0.3q_2 - q_1$

$25 = 0.3q_1 - q_2$

$q_1 = -35.71$ N/mm$^2$

$q_2 = -35.71$ "

10

$$\epsilon_x = \left(\frac{\sigma_x}{E} - \frac{\mu\sigma_y}{E} - \frac{\mu\sigma_z}{E}\right)$$

$$= \frac{1}{E}\left[-83.33 + 0.3 \times 35.71 \times 2\right] = \left(\frac{-61.904}{2 \times 10^5}\right)$$

$$= -3.09 \times 10^{-4}$$

$\Delta L = \epsilon L = -0.0557$ mm

$L' = 179.94$

?

D

?

**Section B : Transportation Engg-1 + Surveying and Geology-1**
**Geo-technical & Foundation Engg-2 + Environmental Engg-2**

**(a)** A footing 3 m × 2 m in size transmits a pressure of 140 kN/m$^2$ on a soil having $E = 5 \times 10^4$ kN/m$^2$ and $\mu = 0.50$. Find the immediate settlement for the footing at the centre. Assuming it to be (i) Flexible footing (ii) Rigid footing

For $L/B = 1.5$, Influence factor = 1.36 for flexible and 1.06 for rigid footing.

**[12 marks]**

Immediate settlement.

$$\delta = \frac{q\sqrt{A}(1-\mu^2) I_f}{E_s}$$

$$\delta_{flexible} = \frac{140 \times 2 (1-(0.5)^2) \times 1.36}{5 \times 10^4}$$

$$= 5.712 \text{ mm}$$

Similarly

$$\delta_{Rigid} = \frac{140 \times 2 (1-(0.5)^2) \times 1.06}{5 \times 10^4}$$

$$= 4.452 \text{ mm}$$

12

**Q.5 (b)** A column footing of 1.8 m × 1.8 m is to be placed 1.5 m below ground level in a dry cohesionless soil. The unit weight of soil is 21 kN/m$^3$ and angle of internal friction, $\phi = 36°$. The footing is required to carry a total load of 1350 kN including column load, weight of footing and weight of soil surcharge. Determine the factor of safety against bearing capacity failure assuming:

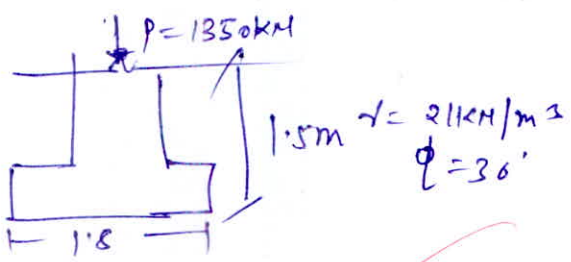
(i) Ground water table well below the base of footing, and

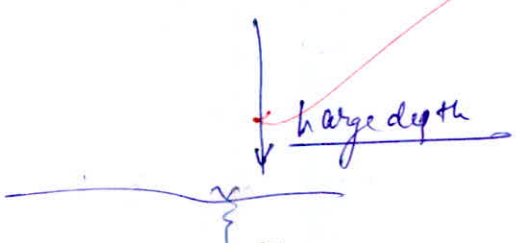
(ii) Ground water table at ground level

Given for $\phi = 36°$, $N_c = 63.53$, $N_q = 47.16$, $N_\gamma = 51.7$

[Assume , $\gamma_{bulk} = \gamma_{saturated} = 21$ kN/m$^3$]

**[12 marks]**




$$q_{nu} = cN_c(1.3) + (N_q - 1)\gamma D_f + 0.5 \times 0.8 \times 1.8 \times 21 \times N_\gamma$$

$$= (47.16 - 1) \times 21 \times 1.5 + 0.5 \times 0.8 \times 1.8 \times 21 \times 51.7$$

$$= 2235.7141 \text{ kN/m}^2$$

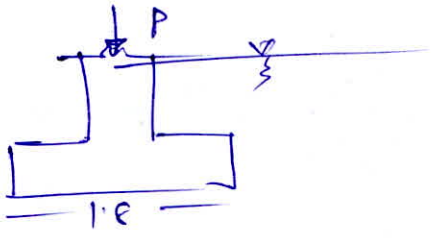
$$q_{net\,safe} = \frac{2235.744}{FOS}$$

$$q_{safe} = \left(\frac{2235.744}{FOS} + 21 \times 1.5\right)$$

$$\frac{1350}{1.8 \times 1.8} = \left(\frac{2235.744}{FOS}\right) + 21 \times 1.5$$

$$\boxed{FOS = 5.8046}$$

Case II When water Table is at ground surface




$$\therefore q_{nu} = 1.3 c N_c + (N_q - 1) \gamma D_f + 0.5 \times 0.8 \times B \times \gamma' \times N_\gamma$$

$$= (40.6 - 1) \times (21 - 9.81) \times 1.5 + 0.5 \times 0.8 \times 1.8 \times (21 - 9.81) \times 51.4$$

$$= 1191.332 \text{ kN/m}^2$$

$$q_{net\,safe} = \frac{1191.332}{FOS}$$

$$q_{safe} = \frac{1191.332}{FOS} + \gamma D_f$$

$$\frac{1350}{1.8 \times 1.8} = \frac{1191.232}{FOS} + (21 - 9.81) \times 1.5$$

$$\boxed{FOS = 2.979}$$

12

**Q.5 (c)** **(i)** Define the processes involved in MBBR (Moving Bed Biofilm Reactor) used for secondary wastewater treatment?

**(ii)** One hundred cubic meters per day (100 $m^3/d$) of mixed sludge at 4 percent solids is to be thickened to 8.0 percent solids. What is the approximate volume of the sludge after thickening and also comment on the result?

**[6 + 6 marks]**

(ii)

$Q = 100\ m^3/d$

% of solid before thickening = 4%. $M_c = 96\%$

% " after " = 8%. $M_c' = 92\%$

$\therefore (100 - P_1)V_1 = (100 - P_2)V_2$

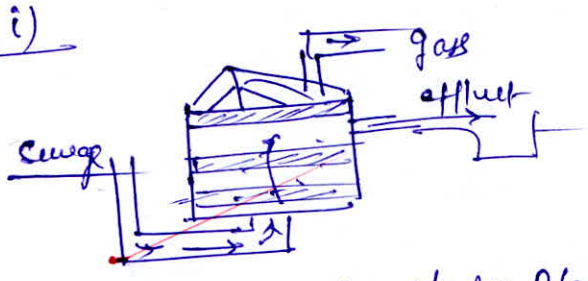
$(100 - 96) \times 100 = (100 - 92)V_2$

$\therefore V_2 = 50\ m^3/day$

5

$\therefore$ After the thickening volume reduces to half of the initial value

(i)




Upflow Anaerobic Sludge Blanket Reactor

→ Waste water is allow to flow is upward direction from the closed tank (containing large amount of Bacteria)

→ Sludge while moving upward collect the bacteria & these start decomposing the O/M.

→ The conc. of Biomass increase from Top to Bottom

→ The Bed of Bacteria / Dirty layer moves as the sludge enter from Bottom.

→ It maintain high conc. of Biomass & thereby speed up the decomposition process

→ The gases are collected inside dome and the treated effluent is allowed to pass through.

4 - 2 = 2

**Q.5 (d)** A 4-lane National Highway is passing through a built up area. Design the following geometric features for a horizontal circular curve of radius 350 m for this highway considering design speed as 80 kmph and the length of wheel base of largest truck as 6.0 m:

**(i)** Superelevation

**(ii)** Length of transition curve

Also suggest the most suitable shape of curve.

**[12 marks]**

$n = 4.0$

$R = 350\,m$

$V_D = 80\,kmph$

$L = 6.0\,m$

Design the Road for mixed Traffic

$$e = \frac{(0.75V)^2}{127 \times R}$$

$= 0.0809 = 8.09\% > 7\%$

$\therefore$ limit $e = 7\%$ or $0.07$

No co

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

$f = \frac{V^2}{127R} - e$

$f = 0.0739 < 0.15$ (O.K.)

Transition curve

(i) $L = \left(\frac{V^3}{CR}\right)$ $\quad e = \frac{60}{75V} = 0.516$

$V = \left(\frac{80 \times 5}{18}\right) = 22.22$ m/s

$\therefore L = \frac{(22.22)^3}{0.516 \times 350} = 60.763$ m

(ii) $L = Ne(W + WE)$

$WE = W_M + W_{lp}$

$= \frac{nl^2}{\alpha R} + \frac{V}{9.5\sqrt{R}}$

$= \frac{4 \times (6)^2}{8 \times 350} + \frac{80}{9.5\sqrt{350}} = 0.655$ m

$\therefore W_T = 3.5 \times 4 + 0.655 = 14.655$ m

[Considering $N = \frac{1}{120}$ for plain area and rotation of Pavement about centre line ~~inner edge~~]

$L = \frac{120 \times}{2} 0.07 (14.655) = 61.593$ (100 for built up area)

(iii) $L = \frac{2.7V^2}{R} = \frac{2.7 \times (80)^2}{350} = 49.37$

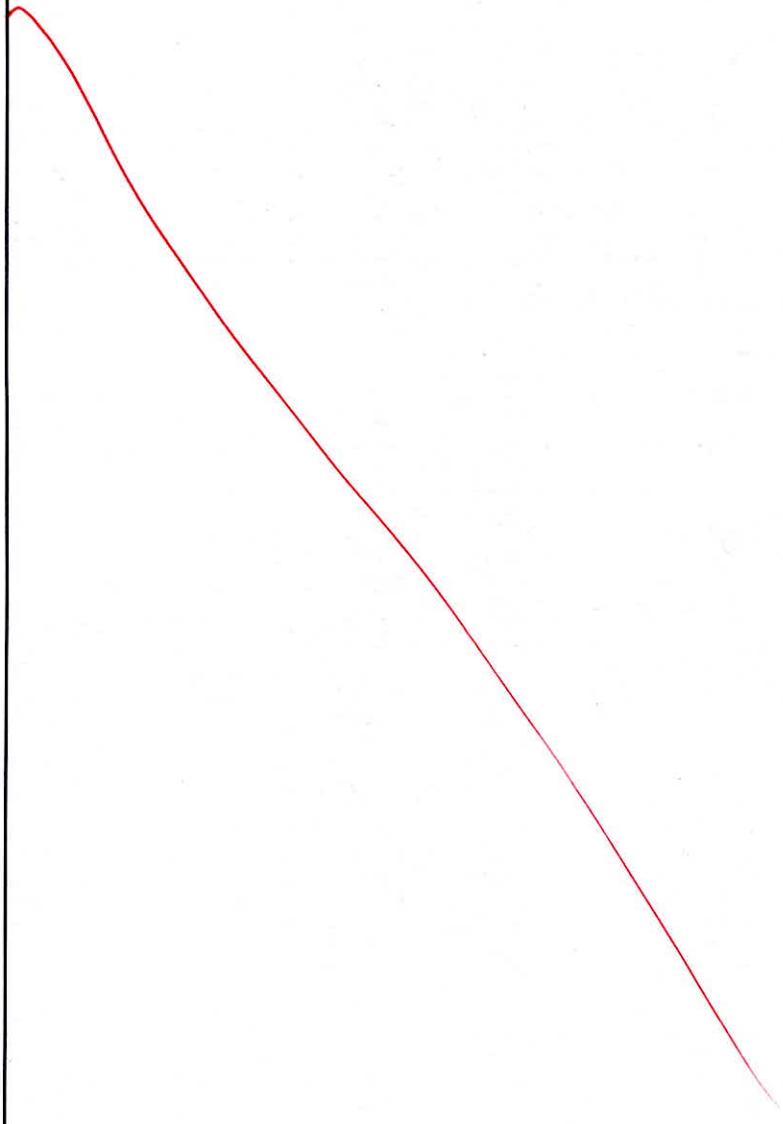
Length = 61.593 m

Spiral is the most suitable for the Horizontal Transition Curve.

**Q.5 (e)** A railway embankment, 500 m long, has a width at formation level of 9 m with side slopes of 2 to 1. The ground levels at every 100 m distance along the centreline are as follows:

| **Distance, (m)** | 0 | 100 | 200 | 300 | 400 | 500 |
|---|---|---|---|---|---|---|
| **Ground level, (m)** | 107.8 | 106.3 | 110.5 | 111.0 | 110.7 | 112.2 |

The embankment has a rising gradient of 1.2 m per 100 m and the formation level is 110.5 m at zero chainage. Assume the ground to be level across the centerline, compute the volume of earthwork using trapezoidal method.



**[12 marks]**

**Q.6 (a)** **(i)** For a railway track 7 m high embankment is required. The clay to be used for the embankment was found to have $c = 20\ kN/m^2$ and unit weight = $19\ kN/m^3$. Compute the critical maximum side slope angle for the embankment if a hard rocky stratum was found 3.5 m below the ground level. Assume $\phi$ for the clay equal to zero. The following values are given from Taylor's chart for depth factor D = 1.5 :

| $S_n$ | 0.181 | 0.174 | 0.164 | 0.150 |
|---|---|---|---|---|
| $\beta$ | 53° | 45° | 30° | 20° |

**(ii)** Using Terzaghi's method, determine the ultimate bearing capacity of a square footing of size 1.5 m with its base at a depth of 1 m below the ground level, resting on a dry sand stratum.

Take $\gamma_d = 17\ kN/m^3$, $\phi' = 38°$, $c' = 0$, $N_q = 60$, $N_\gamma = 75$.

**[10 + 10 marks]**

**(b)** Consider the following data for a completely mixed activated sludge system to treat wastewater from a community of 60000 persons:

Sewage flow, Q = 9000 $m^3$/day

$BOD_5$ = 360 mg/$l$ (raw)

Assume 30% BOD removal in primary settling and 90% in biological treatment.

Winter temperature of mixed liquor = 10°C

Yield, $y = 0.6$

$k_d = 0.07$/day ($BOD_5$ basis at 15°C)

MLSS = 4000 mg/$l$, $\frac{VSS}{SS} = 0.8$

Adopt sludge age ($\theta_c$) = 10 days

Determine F/M ratio and oxygen requirement uptake per day for this completely mixed activated sludge system.

**[20 marks]**

Q.6 (c) (i) What are the advantages of photogrammetric techniques in highway location and design? What are the various objectives of highway planning?

(ii) Following five alternate road plan development proposals with particulars as mentioned below are available:

| Proposal | Number of towns and villages served along with population range | | | | | Total industrial products in thousand tonnes |
|---|---|---|---|---|---|---|
| | <2000 | 2001-5000 | 5001-10000 | 10001-20000 | > 20000 | |
| A | 80 | 10 | 25 | 5 | 1 | 60 |
| B | 115 | 120 | 30 | 10 | 2 | 370 |
| C | 340 | 230 | 25 | 20 | 4 | 350 |
| D | 150 | 200 | 100 | 35 | 6 | 750 |
| E | 200 | 90 | 70 | 60 | 3 | 500 |

If the total road length of proposals A, B, C, D and E are respectively 200 km, 380 km, 605 km, 700 km and 400 km, calculate the utility rate per unit length of each road proposal and indicate the priority based on saturation system. Assume the utility units as follows:

**For population :**

| Range | | Unit |
|---|---|---|
| < 2000 | : | 0.25 |
| 2001 to 5000 | : | 0.50 |
| 5001 to 10000 | : | 1.00 |
| 10001 to 20000 | : | 2.00 |
| > 20000 | : | 3.00 |

**For products :**

One unit for 1000 tonnes.

**[8 + 12 marks]**

Q.7 (a) **(i)** What are conditions which necessitate taking up of a realignment project of a highway? Discuss the general principles in the realignment of a highway and explain how the work is carried out.

**(ii)** Determine the extra width required for a road of carriageway 7.5 m on a horizontal curve of radius 300 m. The longest wheel base of vehicle using the road may be taken as 6.1 m. Design speed is 80 km/hr.

**[16 + 4 marks]**

(ii)

$w = 7.5\,m$

$R = 300\,m$

$l = 6.1\,m$

$V_D = 80\,kmph$

$w_E = w_m + w_p$

$= \frac{n l^2}{2R} + \frac{V}{9.5\sqrt{R}}$

$= \frac{2 \times (6.1)^2}{2 \times 300} + \frac{80}{9.5\sqrt{300}}$

$w_E = 0.610\,m$

5

- Realignment is carried out by performing certain surveys

1.) Reconnaissance - It is the 1st step of observing the general features of a place by itself visiting there.

- Existing Alignment does not cater the overshooting Traffic volume.
- Considerable no. of cross-drainage works comes in the alignment that increases cost.
- Slope is highly undulating & Terrain is not flat for considerable portion.
- Existing users have different desire lines for the Road map.
- Large no. of village Habitation comes under the alignment which increase compensation cost.
- Large no. of Fertile and cultivable land comes under the Alignment project.
- Cost-Benefit Ratio < 1.0
- Basic amenities is lacking and future expansion cannot be done.
- No provision for the Building Line, Control Line, and offset margin.

Highway Alignment Principle

- Origin & Destination Study -

It gives the desire of the Road user for the given route.

- Reconnaissance

- It is the 1st step of planning the route alignment
- It consist of visiting the places and collect the general information about the place.
- It consist of marking the points on the geographical contour maps.

- Primary survey

- It is process of doing the survey & taking samples for soil stability & soil strength
- Drawing more than 1 route for a particular Alignment and finalising the most feasible one.
- Collecting Traffic Data & other imp. parameter.
- Centreline is marked.

- Final location & Detailed survey

- Detailing about survey & Test is now done on the finalise route
- Detailed cost estimation is done
- D.P.R is prepared

Refer solution

8

**(b)** Design a septic tank with the following data :

(i) Number of users = 200

(ii) Rate of water supply = 150 *l*/head/day

(iii) Detention period = 18 hours

(iv) Percolating capacity of filter media of soak well = 1250 litres/$m^3$

(v) Rate of sludge accumulation = 40 litres/person/year

Also find the diameter of soak well. Assume reasonable data, if required.

**[20 marks]**

$P = 200$

$Q_H = 150\ l/c/d$

$\therefore Q_{wat} = 200 \times 150 \times 10^{-3}\ m^3/d$

$= 30 m^3/d$

$td = 18 hr$

$Q_{waste} = 0.8\ Q_{wat} = 24\ m^2/day$

~~Assuming~~ sludge accumulation Rate = 40 l/p/ year

assuming cleaning period = 1 year

$\therefore N = (Q_H \times td) + SAR \times$ Cleaning Period

$= \left(\frac{24}{24} \times 18\right) + \frac{40 \times 200 \times 10^{-3} \times 1}{}$

$18 \quad + 8$

$\boxed{\text{Vol.} = 26 m^3}$

Assuming Depth of septic tank $= (1.5 m)$

$\therefore$ Area $= 17.33 m^2$

$\frac{L}{B} = 1.5$

$\therefore 1.5(B)^2 = 17.33$

$B = 3.39$

$L = 5.09$

Adopt $L = 5.2$, $B = 3.5$, $H = (1.5 + 0.3) = 1.8$

$5.2 \times 3.5 \times 1.8$

percolation capacity = 1250 l/m³

∴ volume of soak Pit = $\frac{1250 \times 10^3}{1\ m^3} \times 24\ m^3$

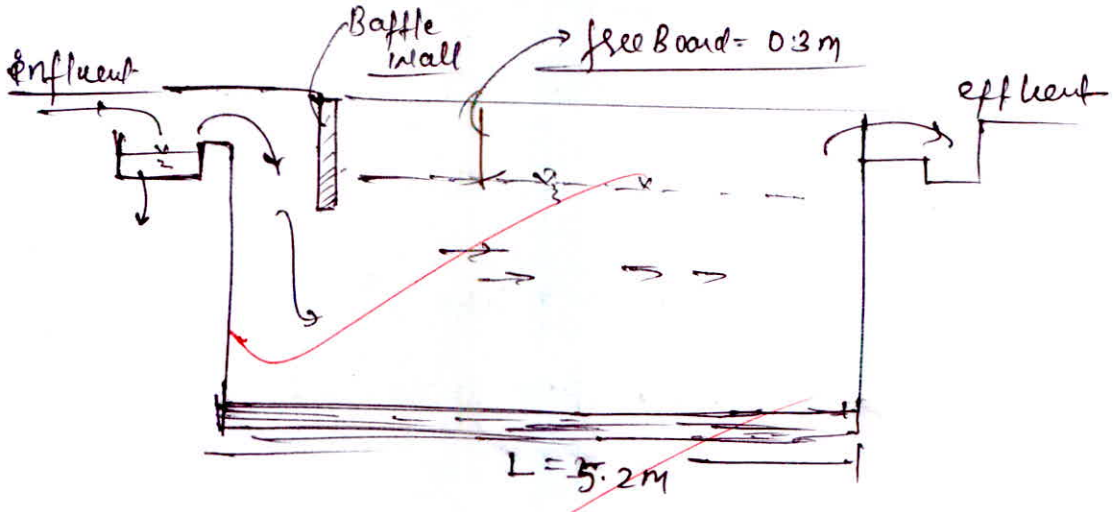
= 30 m³

Adopt depth as 1.2 m

∴ plan Area = $\left(\frac{V}{H}\right) = \frac{30}{1.2} = 25 m^2$

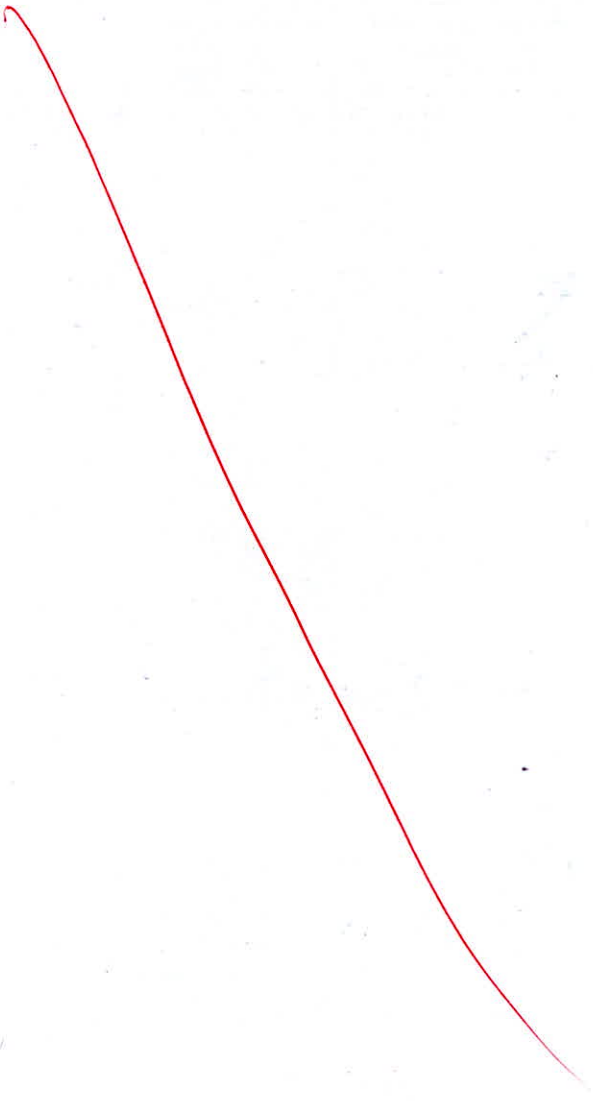
$\frac{\pi}{4} D^2 = 25$

$D = 5.643 m$




Septic Tank

18



**Q.7 (c)** Two sets of tacheometric readings were taken from an instrument station A (RL of A = 100 m) to a staff station B as shown below.

| Instruments | P | Q |
|---|---|---|
| Multiplying constant | 100 | 95 |
| Additive constant | 0.30 | 0.45 |
| Height of instrument | 1.40 m | 1.45 m |
| Staff held | Vertical | Normal |

| Instruments | Instruments station | Staff station | Vertical angle | Stadia readings |
|---|---|---|---|---|
| P | A | B | 5°44′ | 1.090, 1.440, 1.795 |
| Q | A | B | 5°44′ | ? |

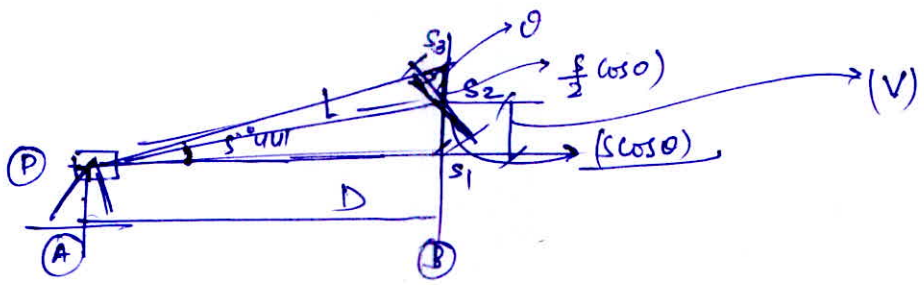
**Determine:**

**(i)** The distance between instrument station and staff station.

**(ii)** The R.L. of staff station B.

**(iii)** Stadia readings with instrument Q.

**[20 marks]**




(i) $D = Ks + C$

$s_1 = 1.090$
$s_2 = 1.440$
$s_3 = 1.795$

$s = (1.795 - 1.090) = 0.705\ m$

$L = K(s\cos\theta) + C$

$= 100 \times 0.705 \times (\cos 5°44') + 0.30$

$= 70.447\ m$

$\cos\theta = \frac{D}{L} \Rightarrow D = L\cos\theta$

$\Rightarrow D = 70.447 \cos 5°44'$

$D = 70.09\ m$

(ii) $\sin\theta = \frac{V}{L} \Rightarrow V = L\sin\theta = 70.447 \sin 5°44'$

$= 7.037\ m$

$\therefore$ RL of $(S_2)$ = RL of (A) + HI + V

= 100 + 1.40 + 7.037

= 108.437m

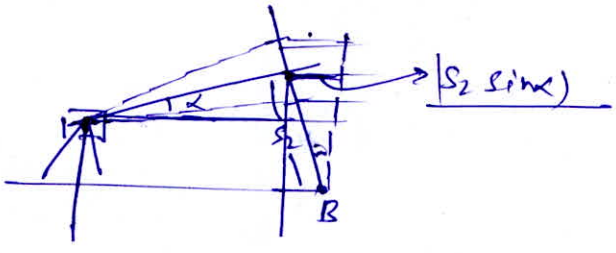
$\therefore$ RL of B = $(108.437 - S_2)$

= 108.437 − 1.440

RL of B = 106.997m

(iii)

Now




$D = (KS + C)\cos\alpha + S_2 \sin\alpha$

$70.09 = [95 \times (S_1 - S_2) + 0.45]\cos 5°44' + S_2 \sin 5°44'$

$70.09 = 94.524\,(S_1 - S_2) + 0.45 + 0.1\,S_2$

$S_1 - S_2 = S$

also

RL of B

106.997 = RL of A + 1.45 + $\sin\alpha(KS + C) - S_2\cos\alpha$

$106.997 = 100 + 1.45 + \sin\alpha[95(S) + 0.45] - S_2\cos\alpha]$

$5.547 = 9.490\,S + 0.045 - S_2$ — (2)

$$70.09 = 94.524(S) + 0.45 + 0.1 S_2$$

$$5.547 = 9.490S + 0.045 + -S_2$$

$$69.64 = 94.524(S) + 0.1 S_2$$

$$5.502 = 9.490(S) + -S_2$$

$$S = 0.735\ m$$

$$S_2 = 1.475\ m$$

$$S_2 = \frac{S_1 + S_3}{2} \qquad S_1 + S_2 = 2.95$$

$$S = (S_1 - S_2) \qquad S_1 - S_2 = 0.735$$

$$S_1 = 1.842\ m$$

$$S_2 = 1.475\ m$$

$$S_3 = 1.107\ m$$

20

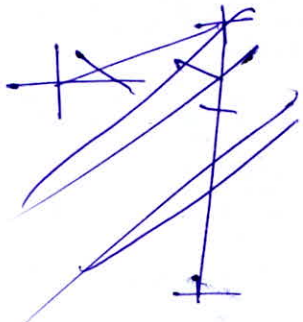
a) The following whole circle bearings were observed in running a closed traverse:

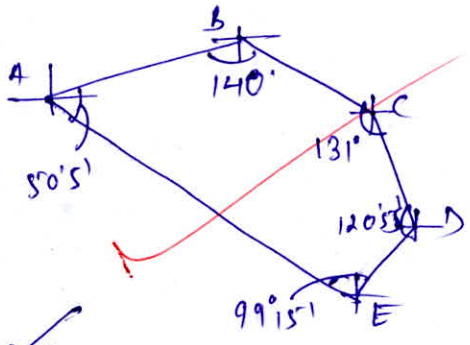
| Line | F.B. | B.B. | BB − FB |
|---|---|---|---|
| AB | 71°05′ | 250°20′ | 179°15′ |
| BC | 110°20′ | 292°35′ | 182°15′ |
| CD | 161°35′ | 341°45′ | 180°10′ |
| DE | 220°50′ | 40°05′ | −180°41′ |
| EA | 300°50′ | 121°10′ | 179°40′ |

Internal Angle

Determine the correct magnetic bearings of the lines.

**[20 marks]**





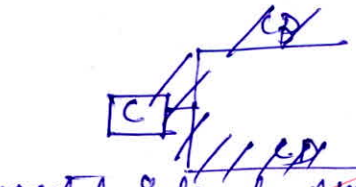

| Line | FB | BB | Difference |
|---|---|---|---|
| AB | | | |
| BC | | | |
| CD | | | |
| DE | | | |
| EA | | | |

Since the difference is least in the CD

∴ Corrected Bearing of Line

| | FB | BB |
|---|---|---|
| CD − | 161°40′ | 341°40′ |

Difference = 180° 0'0.




Σ Internal Angles = 541°15′ ≠ 540°

∴ Error = 1°15′

Correction/Angle = −0°15′

Corrected Internal Angles

∠A = 49°50′

∠B = 139°45′

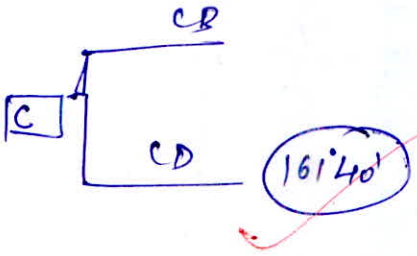
∠C = 130°45′

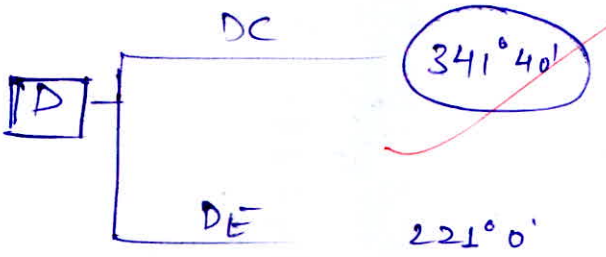
∠D = 120°40′

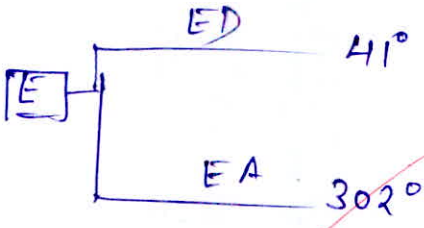
∠E = 99°

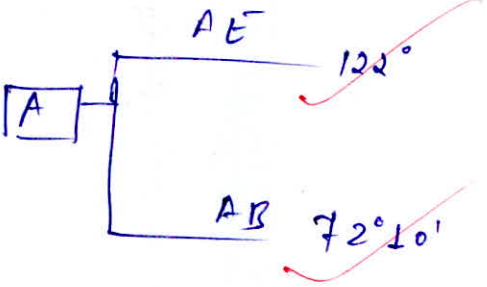
Σ = 540° (0'0.)

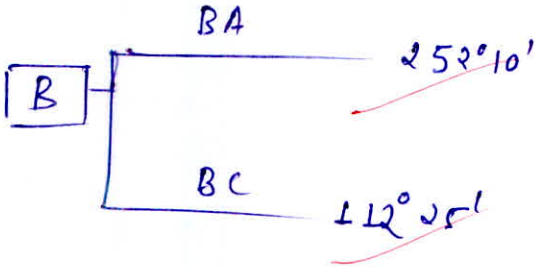
Starting from 'C' and calculating forward

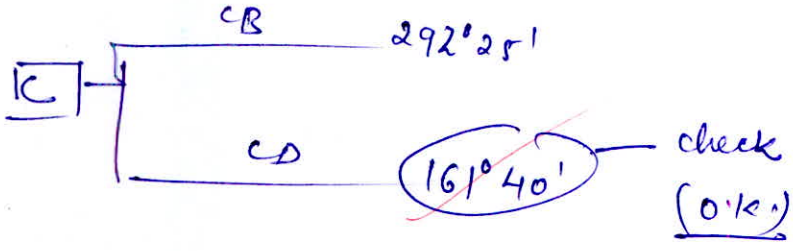


Corrected Bearing

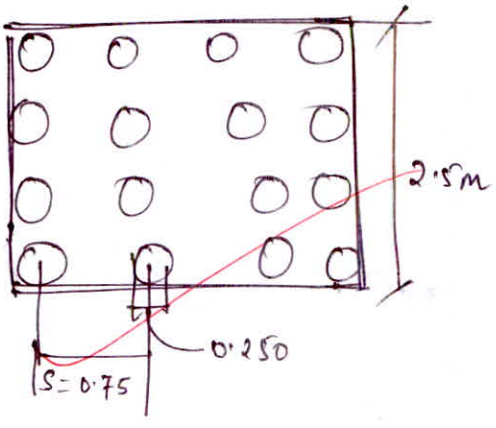
| Line | FB | BB |
|---|---|---|
| AB | 72°15' | 252°10' |
| BC | 112°25' | 292°20' |
| CD | 161°40' | 341°40' |
| DE | 221° | 41° |
| EA | 302° | 122° |

20

**Q.8 (b)** **(i)** What are the desirable characteristics of grouting material in soils? List some of grouting methods adopted in practice.

**(ii)** A square pile group of 16 piles penetrates through a filled up soil of 3 m depth. The pile diameter is 250 mm and pile spacing is 0.75 m. The unit cohesion of the material is 18 kN/m$^2$ and the unit weight of soil is 15 kN/m$^3$. Draw plan and sectional elevation of the pile group and compute the negative skin friction on the group. [Take $\alpha = 0.7$]

**[6 + 14 marks]**

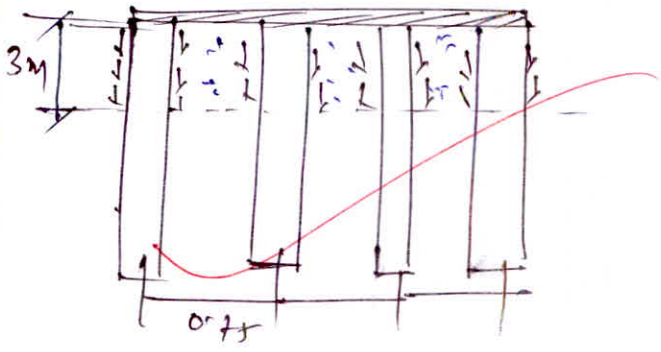



$C = 18\ kN/m^2$

$\gamma = 15\ kN/m^3$

$\alpha = 0.7m$

$B = 2.5m$




Negative skin friction for pile group

$$q_{nsf} = (\alpha \bar{c} \text{ Abase } 4BxL) + (\gamma_{soil} \times A \times L)$$

$$= (1.0 \times 18 \times 4 \times 2.5 \times 3.0) + 15 \times 2.5 \times 2.5 \times 3.0$$

$$= 821.25\ kN$$

Consider individual action

$$q = n \times (\alpha \bar{c} \times p \times L)$$

$$= (16 \times 0.7 \times 18 \times \pi \times 0.250 \times 3.0)$$

$$= 474.768\ kN$$

∴ Negative skin friction of group
= 82.25 kN

14

(i) grouting material should form good interlocking with soil and thereby compact the structure for the less permeability.

- grouting material should not be corrosive in nature
- it should have good cementing property.
- it must R/F the soil with minimum effort.
- It should fill up the poses in the soil & thereby changes it grain size distribution.

- cement grouting
- Lime grouting
- (Lime + sulphi) grouting
- ~~Polymer~~ silica Polymer grouting
- Grouting under injection pressure.

3

More explaination req.

Do not write this

**Q.8 (c)** **(i)** The driver of a vehicle requires 15 m less to stop after he applies the brakes while travelling up a grade than a driver travelling at the same initial speed down the same grade. Consider the coefficient of friction between tyres and pavement as 0.35 and initial speed to be 90 kmph. What is the percent grade?

**(ii)** Compute the moisture deficit in a landfill for each each cubic meter of waste if the parameters are :

Density of waste at time of deposit = 800 kg/m$^3$.

Field capacity = 60% by weight.

Water content of waste being deposited = 30% by weight.

Also discuss the result.

**[10 + 10 marks]**

$SSD$ = Lag + Braking

$SSD = 0.278 V_B \times t_r + \frac{V^2}{254(mf \pm S\%)}$

$SSD_1 = (0.278 V_B \times t_r) + \frac{V^2}{254(0.35 + S)}$

$SSD_1 = 0.278 V_B \times t_r + \frac{V^2}{254(0.35 - S)}$

$SSD_2 = SSD_1 + 15$

$\frac{V^2}{254(0.35-S)} = \frac{V^2}{254(0.35+S)} + 15$

$\frac{V^2}{254}\left[\frac{2S}{(0.35)^2 - (S)^2}\right] = 15$

$\frac{(90)^2}{254}\frac{2S}{(0.35)^2 - (S)^2} = 15$

$\frac{2S}{(0.35)^2 - (S)^2} = 0.470$

$2S = 0.05576 - (0.470)S^2$

$S = 0.0286$

$\boxed{S = \frac{1}{35}} = 2.857\%$

10

(ii) ~~60~~ 70kg of solid → 30kg water

1 " → $\frac{30}{70}$

800 " → $\frac{30}{70} \times 800$

= 342.857 kg of water

FC = 60% by weight

40kg → 60kg $H_2O$

1 → $\frac{60}{40}$

∴ 800kg = $\frac{60}{40} \times 800$

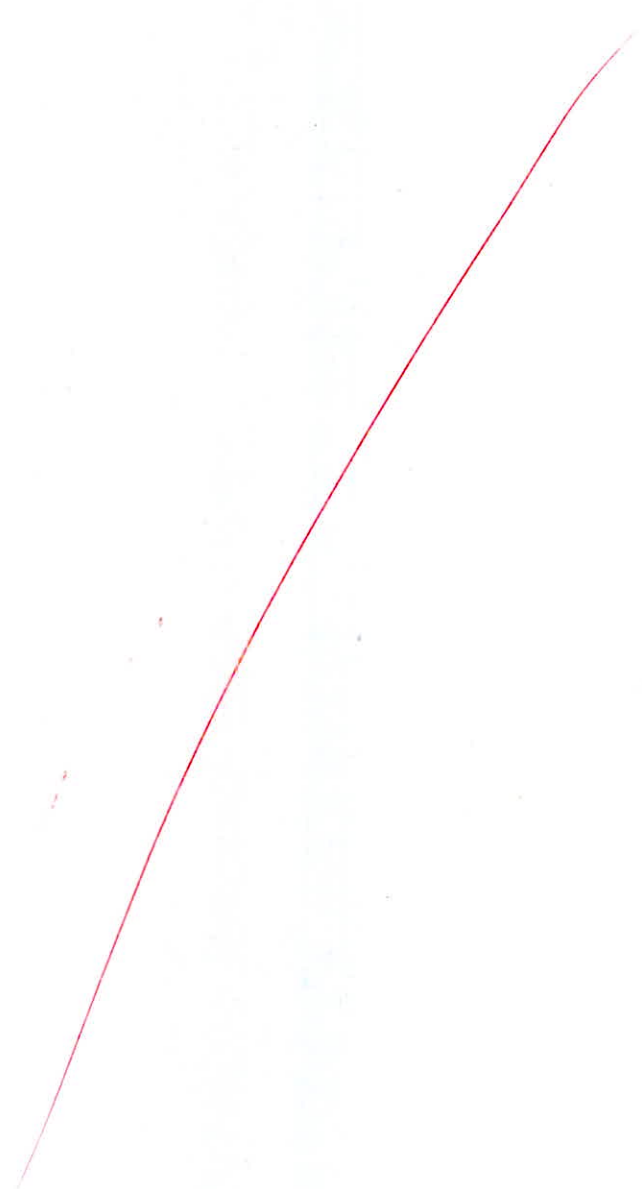
= 1200

∴ MDeficit = 857.143 kg

wrong Approach

Refer soln

4M



OOOO

## Space for Rough Work

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