194

MADE EASY

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ESE 2023 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Civil Engineering

Test-1 : Strength of Materials + Environmental Engineering [All Topics]

Name : .....

Roll No :

Test Centres	Student's Signature
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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.

FOR OFFICE USE	
Question No.	Marks Obtained
Section-A	
Q.1	
Q.2	
Q.3	
Q.4	
Section-B	
Q.5	
Q.6	
Q.7	
Q.8	
Total Marks Obtained	

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IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

- Accuracy is good.
- Improve presentation in writing answer.
- Draw FBD wherever required
- Try to define notations used in formula.
- overall good work.
- Keep it up.

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Section-A : Strength of Materials

Q.1 (a) A copper rod of cross-sectional area 305 sq. mm connects two parallel walls distant 5 m apart. When the rod is heated to 80° C, the nuts at the end gets heated up. Calculate the pull exerted by the bar on cooling at atmospheric temperature at 20° C if

(i) the ends do not yield.

(ii) if the ends yield by 2.5 mm.

Take: α_{copper} = 0.0000175 °C; μ_{copper} = 0.35 and modulus of rigidity of copper = 40000 N/mm^2.

[12 marks]

$E = 2G(1+\mu) = 108$ GPa

(i) $\Delta_{Net} = 0$

$\Rightarrow L\alpha\Delta\theta = \frac{PL}{AE}$

$\Rightarrow 17.5\times10^{-6}\times(80-20) = \frac{P}{305\times108}$

$\Rightarrow \boxed{P = 34.587 \text{ kN}}$

Hence for No yielding Pull exerted = 34.587 kN

(ii) $\Delta_{net} = 2.5$ mm

$\Rightarrow L\alpha\Delta\theta - \frac{PL}{AE} = 2.5$ mm

$\Rightarrow 5000\times17.5\times10^{-6}\times60 - \frac{P\times5000}{305\times108} = 2.5$

$\Rightarrow \boxed{P = 18.117 \text{ kN}}$

Hence when ends yield by 2.5 mm then pull required = 18.117 kN

12

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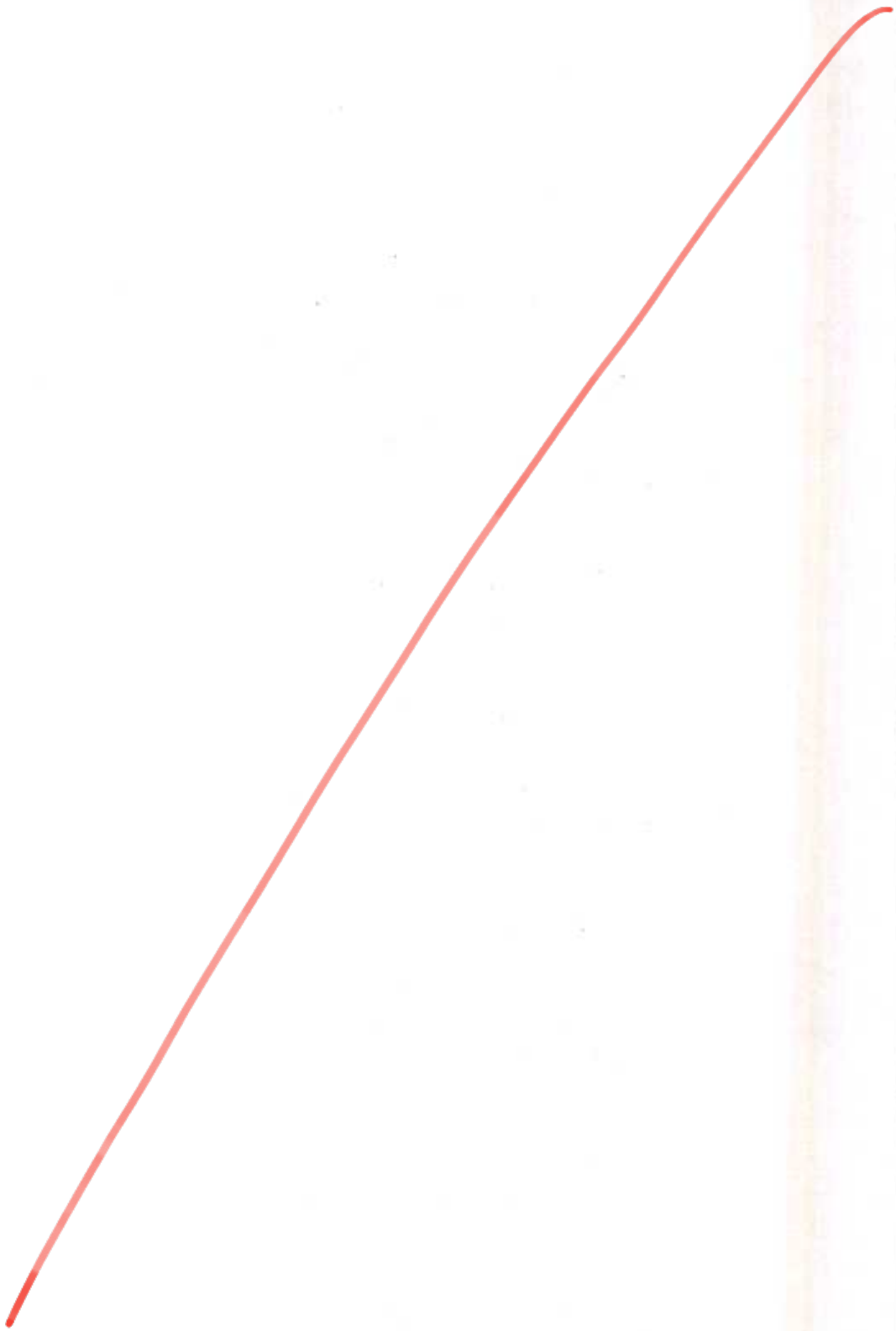

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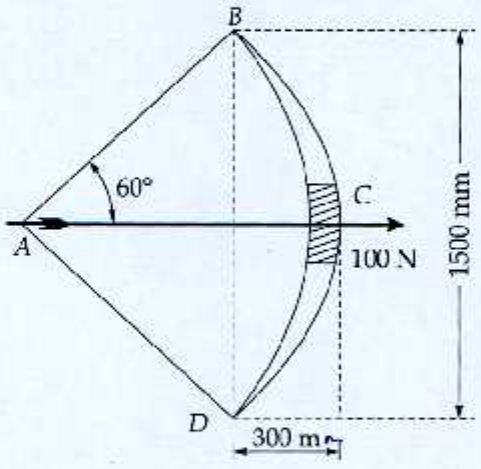
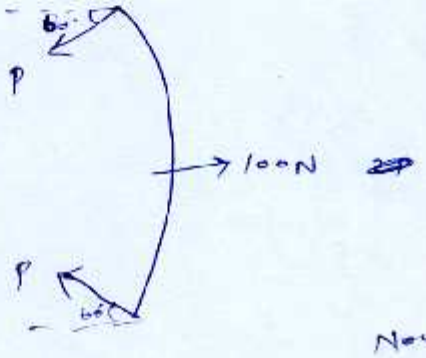
Q.1 (b) At full draw, an archer applies a pull of 100 N to the bow string of the bow as shown in the figure. Determine the bending moment at the midpoint of the bow.



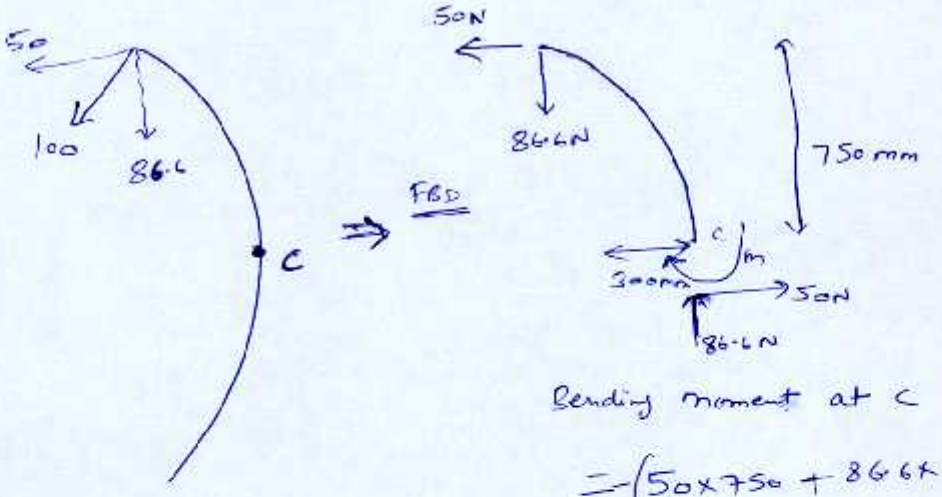
[12 marks]



$2P\cos 60^\circ = 100$

$\Rightarrow P = 100$ N

Now



Bending moment at C

$= -(50 \times 750 + 86.6 \times 300)$

$(BM)_C = -(63480)$ N-mm

Hence $(BM)_C = 63480$ Nmm (hogging)

12

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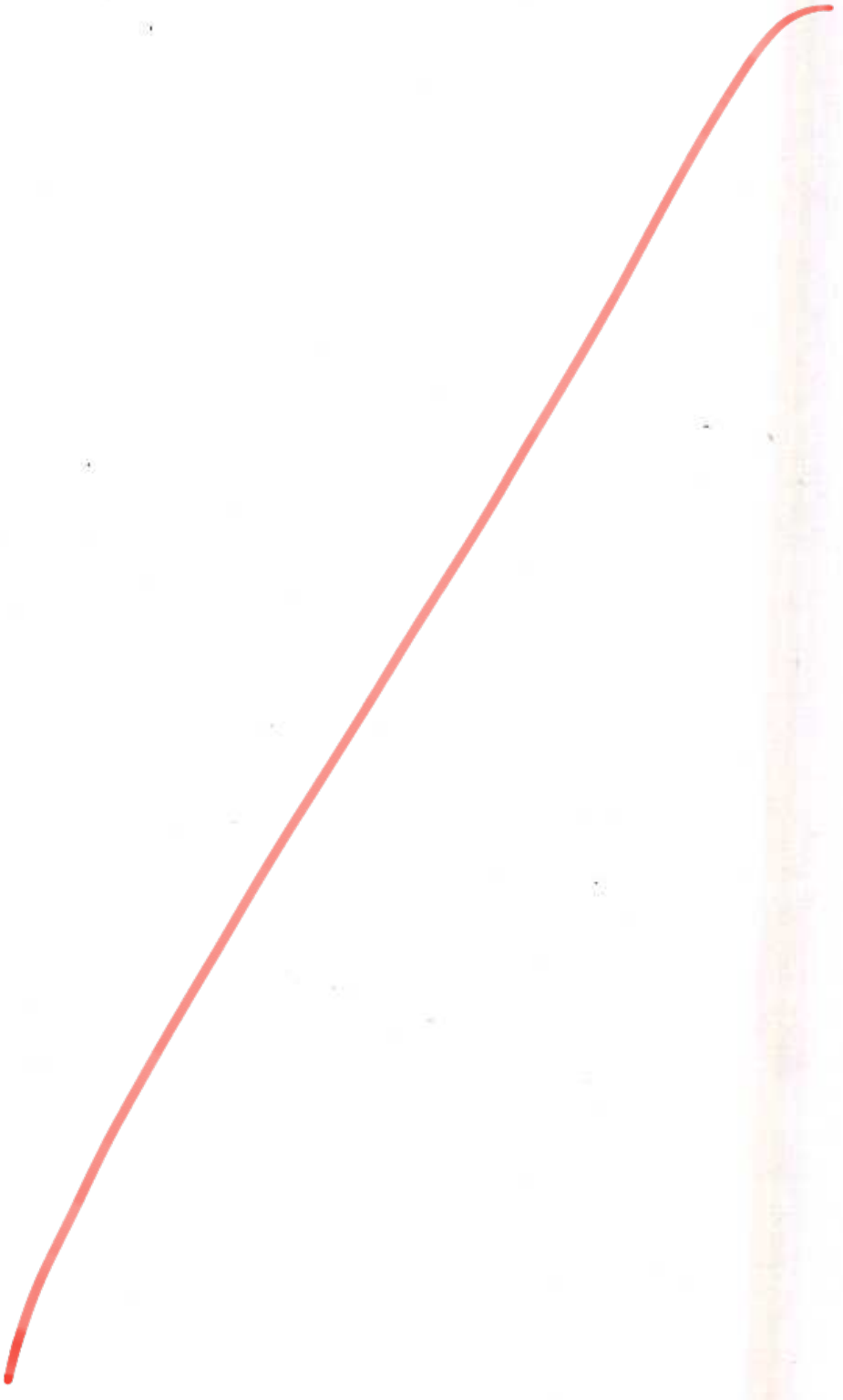

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Q.1 (c) A brass plate is stretched by tensile forces in x and y directions at right angle to each other. The strains given by strain gauges in the two directions are as follows:

(*a*) x-direction = 0.00088 (*b*) y-direction = 0.00022

Take modulus of elasticity as 0.8×10^5 MPa and Poisson's ratio as 0.3.

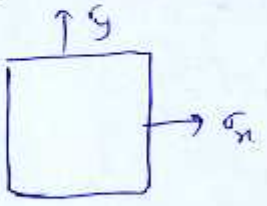
Find:

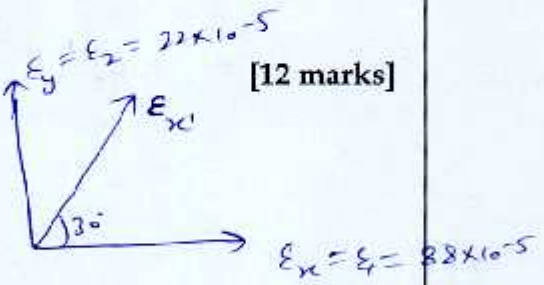
(i) Stresses in the x and y-direction.

(ii) Direct strain on a plane at 30° to the x-direction.

(iii) Stresses on the plane inclined at 30° to the x-axis.

[12 marks]





(i) $\sigma_x = \frac{E}{1-\mu^2}(\varepsilon_1 + \mu\varepsilon_2)$

$= \frac{0.8\times10^5}{1-0.3^2}(88\times10^{-5} + 0.3\times22\times10^{-5})$

$\sigma_x = 83.165$ mPa A

$\sigma_y = \frac{E}{1-\mu^2}(\varepsilon_2 + \mu\varepsilon_1)$

$= \frac{0.8\times10^5}{1-0.3^2}(22\times10^{-5} + 0.3\times88\times10^{-5})$

$\sigma_y = 42.55$ mPa A

(ii) $\theta = 30°$

$\varepsilon_x' = \frac{\varepsilon_x+\varepsilon_y}{2} + \left(\frac{\varepsilon_x-\varepsilon_y}{2}\right)\cos 2\theta + \frac{\gamma_{xy}}{2}\sin(2\theta)$

$= \frac{(88+22)\times10^{-5}}{2} + \left(\frac{88-22}{2}\right)\times10^{-5}\times\cos 60°$

$\varepsilon_x' = 71.5\times10^{-5}$ A

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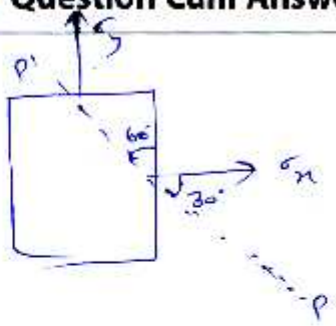


Plane PP'

$\Rightarrow \theta = 60°$

$$\sigma_{x'} = \frac{\sigma_x + \sigma_y}{2} + \left(\frac{\sigma_x - \sigma_y}{2}\right)\cos 2\theta + \tau_{xy}\sin 2\theta \quad (\tau_{xy} \to 0)$$

θ will be 30°

$$= \frac{83.165 + 42.55}{2} + \left(\frac{83.165 - 42.55}{2}\right) \times \cos 120°$$

$$= 52.70 \text{ MPa}$$

$$\tau_{xy'} = -\left(\frac{\sigma_x - \sigma_y}{2}\right)\sin 2\theta + \tau_{xy}\cos 2\theta \quad (\tau_{xy} \to 0)$$

$$= -\left[\frac{83.165 - 42.55}{2}\right] \times \sin 120°$$

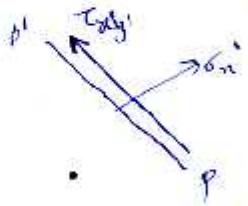
$$= -17.58 \text{ MPa}$$

8

Hence

$\sigma_{x'} = 52.70$ MPa

$\tau_{xy'} = -17.58$ MPa



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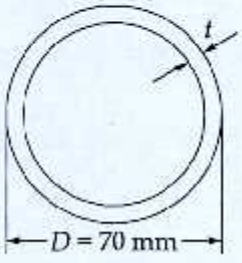
Q.1 (d) A pinned end strut of steel (E = 210 GPa) with length L = 3 m is constructed of circular tubing with outside diameter D = 70 mm as shown in figure. The strut must resist an axial load P = 35 kN with a factor of safety 2.0 with respect to critical load. Determine the minimum required thickness of the tube.



Let inner dia = x

[12 marks]

$$I_{min} = \frac{\pi(70)^4}{64} - \frac{\pi x^4}{64}$$

$$= \frac{\pi}{64}(70^4 - x^4)$$

FOS = 2

$$P_{cr} = \frac{\pi^2 E I_{min}}{L_{eff}^2} = \frac{\pi^2 \times 210 \times \frac{\pi}{64}(70^4 - x^4)}{(3000 \times 1)^2} = 2 \times 35$$

$$\Rightarrow x = 64.97 \text{ mm}$$

$$\Rightarrow D - 2t = 64.97 \text{ m}$$

$$\Rightarrow \boxed{t = 2.515 \text{ mm}}$$

12

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Q.1 (e) **(i)** A motor drives a shaft at 15 Hz and delivers 25 kW of power.

(*a*) If the shaft has a diameter of 30 mm, what is the maximum shear stress developed in the shaft?

(*b*) If the maximum allowable shear stress is 40 MPa, then what is the minimum permissible diameter of the shaft?

(ii) Describe the following theories of failure (elastic) giving necessary formulae along with associated limitations:

(*a*) St. Venant's theory. (*b*) Guest's theory.

[6 + 6 marks]

(i), (a) $T\omega = 25 \times 10^3$ $\quad \frac{\omega}{2\pi} = 15$ Hz

$\omega = 15 \times 2\pi$

$\Rightarrow T \times (2\pi \times 15) = 25 \times 10^3$

$\Rightarrow T = 0.265$ kNm

$\tau_{max} = \frac{16T}{\pi d^3} = \frac{16 \times 0.265}{\pi \times 30^3} \times 10^6$

$= 49.986$

$\tau_{max} \simeq 50$ MPa

(b) $\frac{16 \times 0.265 \times 10^6}{\pi d^3} = 40$

$\Rightarrow d = 32.31$ mm

$\Rightarrow \boxed{d_{min} = 32.31 \text{ mm}}$

6

(ii), (a) St. Venant theory → Also known as 'max. Principal Strain theory'.

→ Acc. to this theory max. Principal Strain in a body subjected to any loading should not exceed the max Principal Strain corresponding

to uniaxial loading. (that is yield strain)

$$\Rightarrow (\varepsilon_1)_{\text{any loading}} \leq (\varepsilon_1)_{\text{uniaxial}}$$

$$\Rightarrow \frac{\sigma_1}{E} - \mu\frac{\sigma_2}{E} - \mu\frac{\sigma_3}{E} \leq \left(\frac{\sigma_y}{E}\right) \times \frac{1}{FOS}$$

⇒ This theory gives satisfactory result for brittle material (Not good results) but can not be applied to ductile material.

(b) Guest theory :- Also known as 'max. shear stress theory'.

→ Acc. to this theory, max. shear stress that would occur in a material from any complex loading should not exceed the max. shear stress value arising from uniaxial loading

$$\Rightarrow (\tau_{max})_{\text{Any loading}} \leq (\tau_{max})_{\text{uniaxial}}$$

$$\Rightarrow \max\left[\left|\frac{\sigma_1-\sigma_2}{E}\right|, \left|\frac{\sigma_2-\sigma_3}{E}\right|, \left|\frac{\sigma_1-\sigma_3}{E}\right|\right] \leq \left(\frac{\sigma_y}{2}\right) \times \frac{1}{FOS}$$

→ Limitation → Result can not be applied to brittle & ductile material.

→ Not suitable for hydrostatic loading.

4

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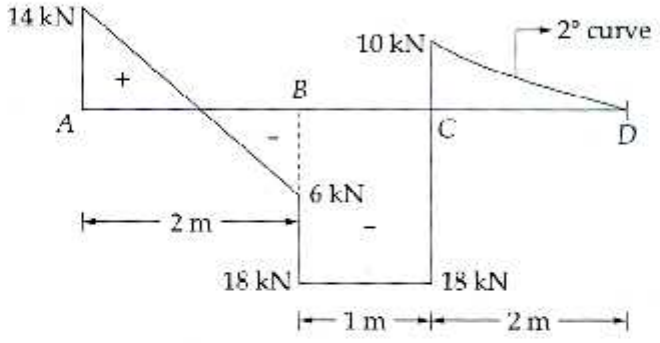
Q.2 (a) The shear force diagram for a simply supported beam AC with overhang CD is as shown in the figure.

Determine the loading on the beam and draw the bending moment diagram, assuming that a clockwise moment is acting at the point B. Also, the equation of shear force for the overhang portion CD (x from C) is given by $V = \frac{3x^2}{2} - 8x + 10$.

Write all the equations involved along with maximum bending moment and location of point of contraflexture.



[20 marks]

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Q.2 (b) A uniformly tapered bar AB of solid cross section is twisted by a torque T. The diameter of the bar varies linearly from d_A at the left end to d_B at the right end.

(i) Show that the angle of twist of the tapered bar is $\theta = \dfrac{T_L}{G(I_P)_A}\left(\dfrac{\beta^2+\beta+1}{3\beta^3}\right)$,

where, $(I_P)_A$ = Polar moment of inertia of end A and, $\beta = \dfrac{d_B}{d_A}$.

(ii) For what ratio of d_B/d_A will the angle of twist of tapered bar be one-fourth the angle of twist of a prismatic bar of diameter d_A?
(Assume, the prismatic bar is made of the same material, has the same length and is subjected to same torque as the tapered bar).

[15 + 5 marks]

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Q.2 (c) Two rectangular plates, one of steel and other of brass each 50 mm wide and 15 mm deep are placed together to form a beam of 50 mm width and 30 mm depth, on two supports 3.0 m apart, the brass plate being on the top of the steel plate. Determine the maximum load which can be applied at the centre of the beam, if the plates are:

(i) Separate and can bend independently.

(ii) Firmly secured throughout their length. Maximum allowable stress in steel = 115 N/mm^2 and that in brass = 80 N/mm^2.

Take $E_s = 2 \times 10^5$ N/mm^2 and $E_b = 8 \times 10^4$ N/mm^2.

[20 marks]

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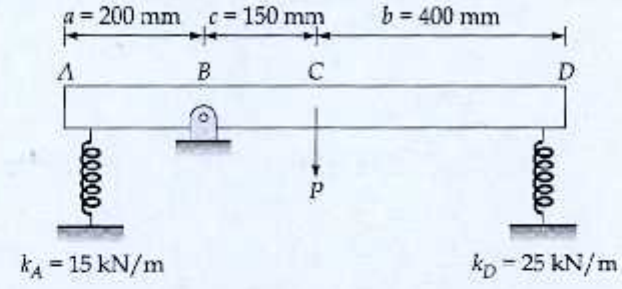
Q.3 (a) A rigid bar ABCD is pinned at point B and is supported by springs at A and D having stiffness $K_A = 15$ kN/m and $K_D = 25$ kN/m respectively. The dimensions are shown in figure below. A load P acts at point C. The angle of rotation of the bar due to the action of load P is limited to 2°. What is the maximum permissible load P_{max}?



Also, determine the maximum forces resisted by the springs at A and D and the reaction force at B.

[20 marks]

max. $x_A = \frac{2 \times \pi}{180} \times 200\ mm$

$= 6.98\ mm$

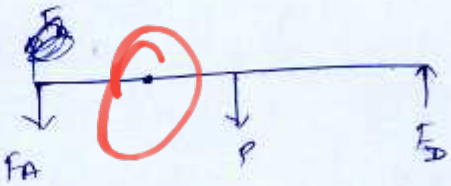
max. $x_D = \frac{2 \times \pi}{180} \times 550\ mm$

$= 19.2\ mm$

Draw FBD

$(F_A)_{max} = K_A x_A = 104.7\ N$

$(F_D)_{max} = K_B x_B = 480\ N$



There is reaction at point B.

$P = F_D - F_A$ -(i)

$P \times 150 = F_A \times 200 + F_D \times 550$ -(ii)

$\Rightarrow P = \frac{4}{3} F_A + \frac{11}{3} F_D$

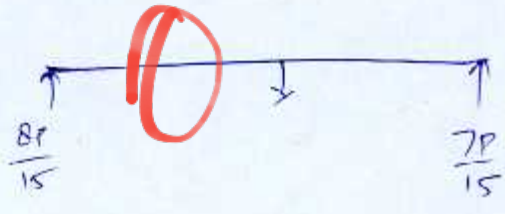
$\Rightarrow 3P = 4F_A + 11F_D$ -(iii)

4(i) + (iii)

$7P = 15 F_D$

$\Rightarrow F_D = \frac{7P}{15}$

$F_A = -\frac{8P}{15}$



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$$\Rightarrow \quad P_{max} = \min \begin{cases} \left(\frac{15}{7} F_D\right)_{max} \\ \left(\frac{15}{8} F_A\right)_{max} \end{cases}$$

$$\Rightarrow \quad P_{max} = \min \begin{cases} \frac{15}{7} \times 480 \text{ N} \\ \frac{15}{8} \times 104.7 \text{ N} \end{cases}$$

$$\Rightarrow P_{max} = \min \begin{cases} 1028.57 \text{ N} \\ 196.31 \text{ N} \end{cases}$$

Hence max force that can be applied = 196.31 N

Hence spring force in $A = \frac{8P}{15} = 104.7 \text{ N}$

Spring force in $B = \frac{7P}{15} = 91.61 \text{ N}$

$F_A = 104.7 \text{ kN}$

$F_B = 91.61 \text{ N}$

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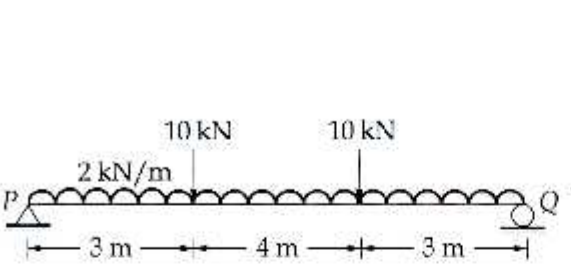
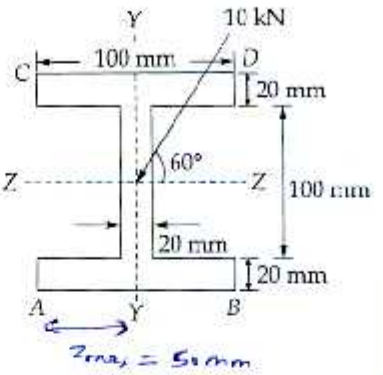
Q.3 (b) A simply supported beam of length 10 m is loaded as shown in figure. Determine the maximum bending stresses at points *A*, *B*, *C* and *D* on the cross-section shown below. Also determine the location of neutral axis on the cross-section.





(Neglect self weight of beam)

[20 marks]

$I_{yy} = \frac{20\times100^3}{12} + \frac{100\times20^3}{12} + \frac{20\times100^3}{12} = 34\times10^5\ mm^4$

$I_{zz} = \frac{100\times140^3}{12} - \frac{80\times100^3}{12} = 162\times10^5\ mm^4$

About Z-Z

10 sin60° = 8.66 kN

10 sin60° = 8.66 kN

2 kN/m

3

8.66 kN

18.66 kN

About Y-Y

10 cos60° = 5

10 cos60° = 5

5 kN

R_A

$R_B = 5$ kN

$R_A = R_B = \frac{2\times10 + 2\times8.66}{2} = 18.66$ kN

max. B.M at mid span

$m_y = 5\times5 - 5\times2$

$m_y = 15$ kNm

$(\text{max. B.M}) = 18.66\times5 - 8.66\times2 - 2\times5\times2.5$

mid point

$m_z = 50.98$ kNm

$\sigma_1 = \pm\frac{M_z y}{I_{zz}} = \pm\frac{50.98\times10^6\times70}{162\times10^5} = \pm 216.3$ mPa

$\sigma_2 = \pm\frac{m_y z}{I_{yy}} = \pm\frac{15\times10^6\times50}{34\times10^5} = \pm 220.6$ mPa

σ_1 loading will produce tension at A, B points

while σ_2 loading will produce tension at A & C points

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Hence stresses at corner points will be :-

At A $\quad \sigma_A = \sigma_1 + \sigma_2 = 436.9$ mPa (At A) 1

$\sigma_B = \sigma_1 - \sigma_2 = -4.3$ mPa (At B) 1

$\sigma_D = -\sigma_1 - \sigma_2 = -436.9$ mPa (At D) 1

$\sigma_C = -\sigma_1 + \sigma_2 = 4.3$ mPa (At C) 1

for N.A. (General eqn) $\quad \sigma = 0$ at N.A.

$$-\frac{M_z y}{I_{zz}} + \frac{M_y z}{I_{yy}} = 0$$

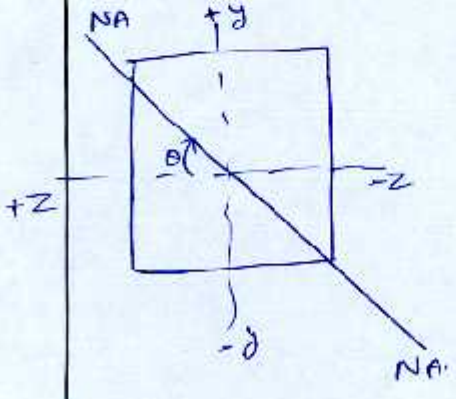
$$\Rightarrow \frac{M_z y}{I_{zz}} = \frac{M_y z}{I_{yy}}$$

$$\Rightarrow \frac{50.58 \times 10^6 \times y}{162 \times 10^5} = \frac{15 \times 10^6 \times z}{39 \times 10^5}$$

$$\Rightarrow y = 1.4z$$

$$\Rightarrow \theta = 54.5^\circ \quad 1$$

Hence N.A. is inclined at 54.5° to the (+z) to (+y) dirn



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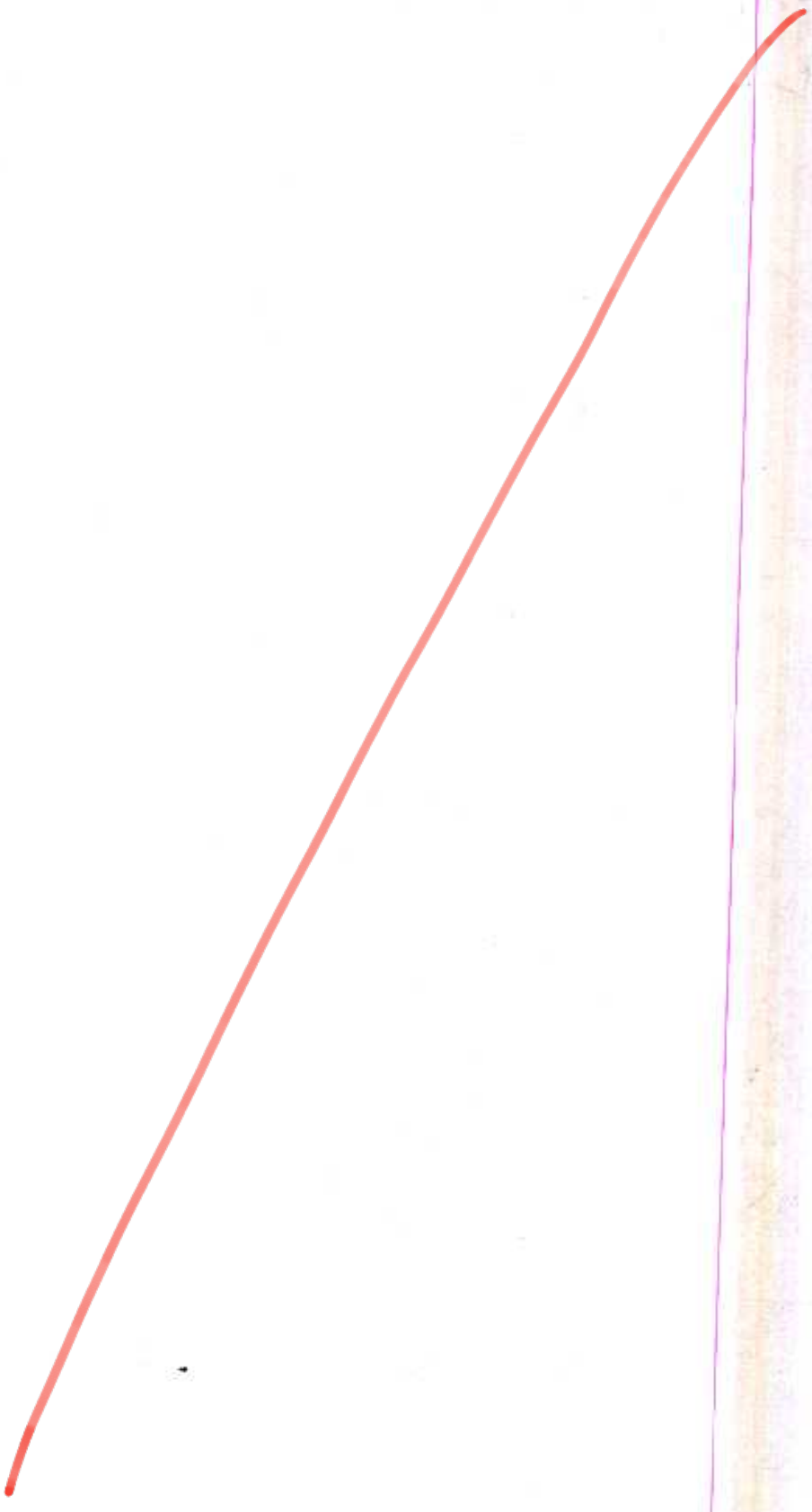

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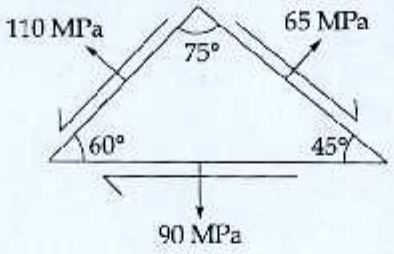
Q.3 (c) In a strained body, the normal stresses on three planes inclined as shown in figure are 65 MPa (Tensile), 90 MPa (Tensile) and 110 MPa (Tensile). Determine the shear stresses acting on these planes. Also find the principle stresses and draw the final stress element.



[20 marks]

$\sigma_y = 90$

At $\theta = 45°$

$$\sigma_n' = \left(\frac{\sigma_n+\sigma_y}{2}\right) + \left(\frac{\sigma_n-\sigma_y}{2}\right)\cos 90° + \tau_{xy}\sin 90°$$

$$65 = \left(\frac{\sigma_n+90}{2}\right) + \tau_{xy} \quad - (1)$$

At $\theta = -30°$

$$\sigma_n' = 110 = \left(\frac{\sigma_n+90}{2}\right) + \left(\frac{\sigma_n-90}{2}\right)\cos 60° - \tau_{xy}\sin 60°$$

$$\frac{2}{\sqrt{3}} \times 110 = \left[\frac{\sigma_n+90}{2} + \frac{\sigma_n-90}{4} - \frac{\tau_{xy}\sqrt{3}}{2}\right] \times \frac{2}{\sqrt{3}}$$

$$127 = \frac{\sigma_n+90}{\sqrt{3}} + \frac{\sigma_n-90}{2\sqrt{3}} - \tau_{xy} \quad - (2)$$

(1) + (2)

$$127+65 = \frac{\sigma_n+90}{2} + \frac{\sigma_n+90}{\sqrt{3}} + \frac{\sigma_n-90}{2\sqrt{3}}$$

$$192 = \sigma_n\left[\frac{1}{2}+\frac{1}{\sqrt{3}}+\frac{1}{2\sqrt{3}}\right] + 90\left[\frac{1}{2}+\frac{1}{\sqrt{3}}-\frac{1}{2\sqrt{3}}\right]$$

$\sigma_n = 88.6$ mpa

$\tau_{xy} = -24.3$ mpa

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Hence At $\theta = 45°$

$$\tau_{xy} = -\left(\frac{\sigma_x - \sigma_y}{2}\right)\sin 90° + \tau_{xy}\cos 90°$$

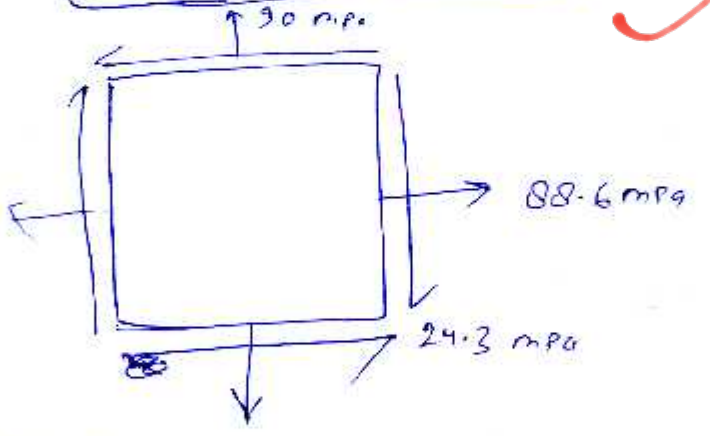
$$\boxed{\tau_{xy} = 0.7 \text{ mpa}}$$

At $\theta = -30°$

$$\tau_{xy} = -\left(\frac{\sigma_x - \sigma_y}{2}\right)\sin 60° + \tau_{xy}\cos 60°$$

$$= -\frac{0.7 \times \sqrt{3}}{2} - 12.15$$

$$\boxed{\tau_{xy} = -11.54 \text{ mpa}}$$



20

Draw final Stress element

Principal stresses

$$\sigma_1, \sigma_2 = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$= 89.3 \pm 24.31$$

$$= 113.61, 64.99$$

Hence major principal stress = 113.61 mpa

minor principal stress = 64.99 mpa

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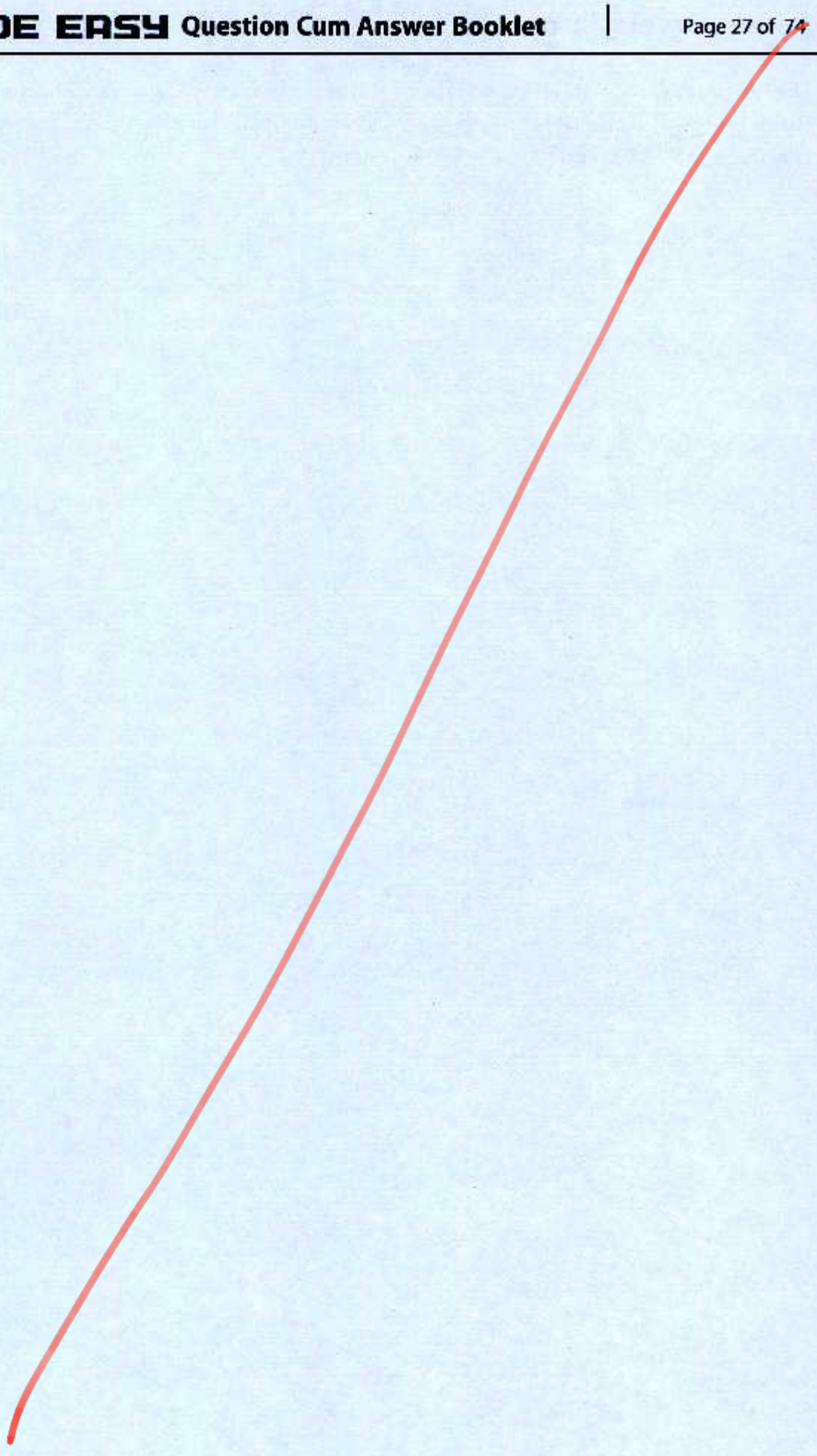

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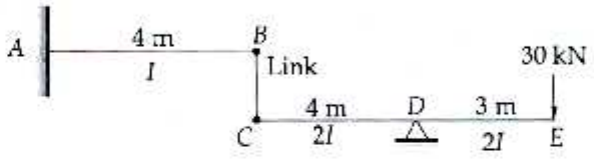
Q.4 (a) For the beam shown in figure; determine **(i)** the deflection at E; **(ii)** the deflection at B; **(iii)** the slope at B and **(iv)** the slope at C, using conjugate beam method.
[Take : $I = 8.30 \times 10^7$ mm^4 and $E = 200$ kN/mm^2]



[25 marks]

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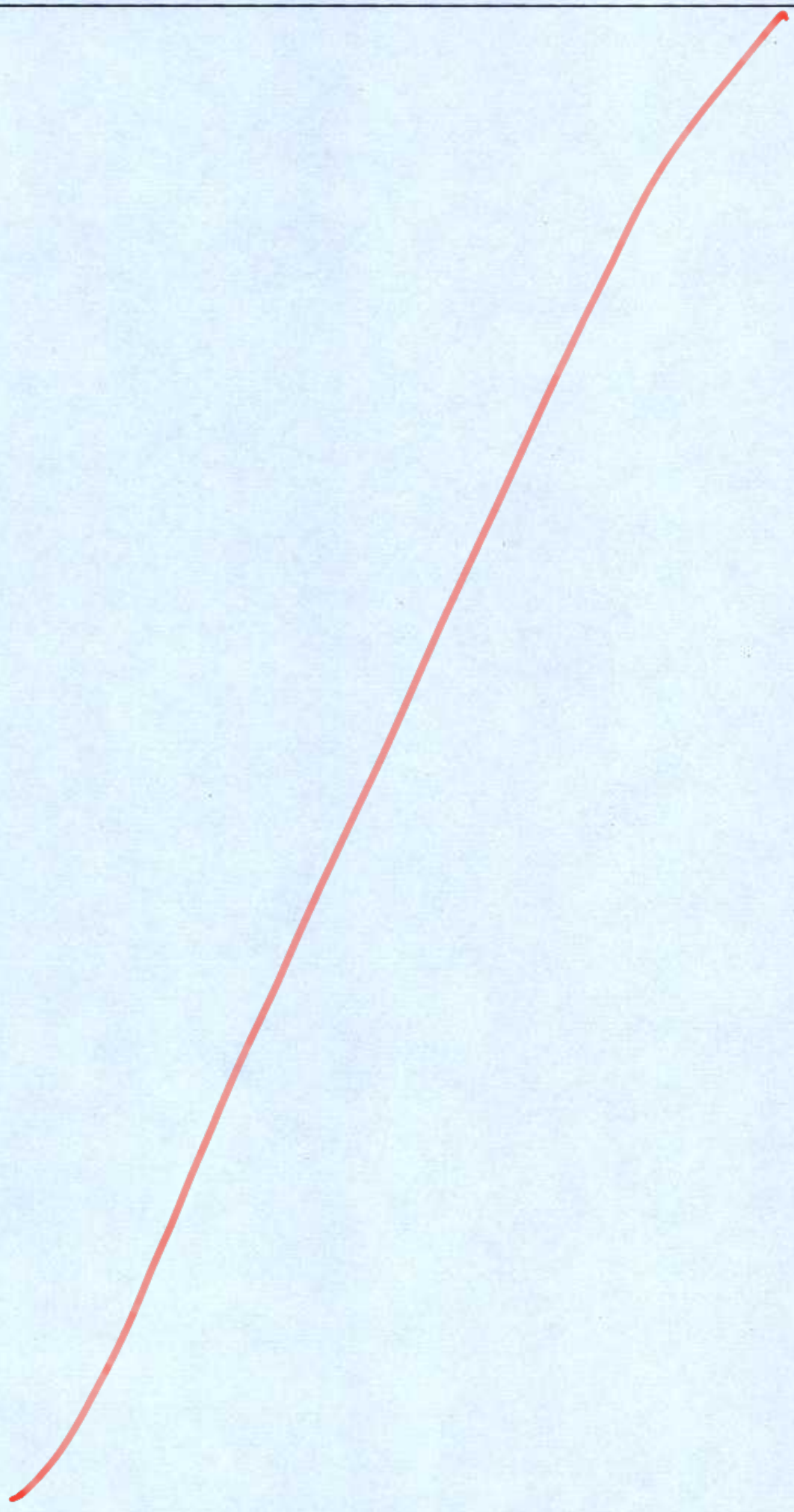

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Q.4 (b) A 15 mm diameter steel rod passes centrally through a copper tube of 50 mm external diameter and 38 mm internal diameter and is 3 m long. The tube is closed at each end by 25 mm thick steel plates which are secured by nuts. The nuts are tightened until the copper tube gets reduced by 0.635 mm in length. The whole assembly is then raised in temperature by 65° C. Calculate the stresses in copper and steel before and after the rise of temperature, assuming that the thickness of plates remains unchanged.

(Take $E_s = 2.1 \times 10^5$ N/mm^2 , $E_C = 1.05 \times 10^5$ N/mm^2 , $\alpha_S = 1.2 \times 10^{-5}$ per °C, $\alpha_C = 1.75 \times 10^{-5}$ per °C)

[20 marks]

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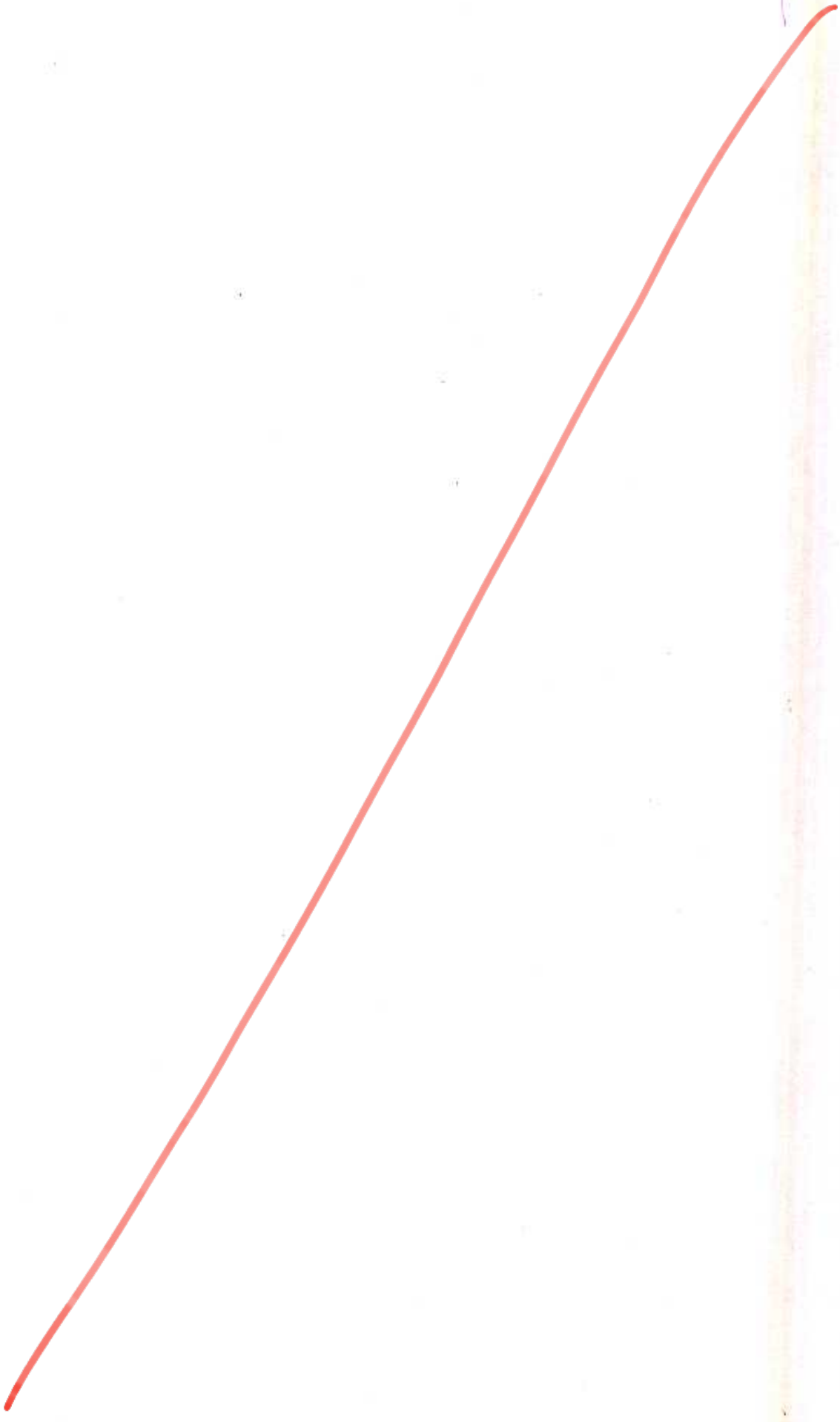

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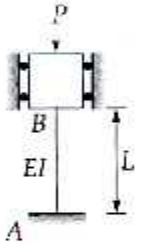
Q.4 (c) Determine the critical load P_{cr} and the equation of the buckled shape for an ideal column with both ends fixed against rotation (as shown in figure) by solving the differential equation of the deflection curve, such that the deflection at midpoint is 'δ'. (Assume single bow condition)



[15 marks]

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Section-B : Environmental Engineering

Q.5 (a) What do you mean by the term 'per capita demand'? For a town, what will be the total yearly water requirement in year 2025 if per capita demand is estimated as 250 lpcd? The population in the year 2025 can be estimated by using logistic curve method. The following data can be used for estimation of population:

Year	:	1965	1985	2005
Population	:	60,000	1,20,000	1,70,000

[12 marks]

'Per Capita demand' is demand exerted by a whole city for consumption, maintenance & providing various activities when divided by city population.

$t_1 = 20$ yrs

$P_0 = 60000$

$P_1 = 120000$

$P_2 = 170000$

$t = 60$ yrs

$$P = \frac{P_s}{1 + me^{nt}}$$

$$P_s = \frac{2P_0P_1P_2 - P_1^2(P_0 + P_2)}{P_0P_2 - P_1^2}$$

$$= \left[\frac{2448 - 144 \times 23}{102 - 144}\right] \times 10^4$$

$P_s = 270000$

$$m = \frac{P_s - P_0}{P_0}$$

$= 3.5$

$$n = \frac{1}{t_1} \ln \frac{P_0}{P_1} \frac{(P_s - P_1)}{(P_s - P_0)}$$

Calculation error

$$= \frac{1}{20} \ln \frac{6}{12} \times \frac{15}{21}$$

$n = -0.0515$

Hence $P_{2025} = \dfrac{270000}{1 + 3.5e^{-0.0515 \times 60}}$

$= 232908$

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Total yearly water requirement = 232908 × 250 × 365 litre

= 21253 ML

4

Q.5 (b) Design an oxidation pond for treating sewage from a hot climate residential colony with 10000 persons, contributing sewage at the rate of 135 litre per capita per day. The 5-day BOD of sewage is 250 mg/l. Assume suitable data if necessary.

[12 marks]

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Q.5 (c) The sound power from a source is 0.0018 W and is travelling in air of density 1.16 kg/m^3.

Determine:

(i) Sound intensity and sound intensity level at a distance of 10 m from source.

(ii) Sound pressure at a distance of 15 m from source.

(iii) Speed of sound in medium at distance 15 m from source.

(iv) Sound pressure level at a distance of 15 m (say N) if there is another sound source of 50 dB at N.

Assume that sound radiates from source in all directions.

[12 marks]

(i) Sound Intensity $= \frac{0.0018}{4\pi \times 10^2} = 1.43 \times 10^{-6} \frac{W}{m^2}$ A3

$$\text{Level} = 10 \log_{10} \frac{1.43 \times 10^{-6}}{10^{-12}}$$

Sound level $= 61.56$ dB A

(ii) $\text{Intensity} = \frac{0.0018}{4\pi \times 15^2} = 6.36 \times 10^{-7} \frac{W}{m^2}$

$$\text{Level} = 10 \log_{10} \frac{6.36 \times 10^{-7}}{10^{-12}} = 20 \log_{10} \left(\frac{P}{20 \times 10^{-6}} \right)$$

$$58.03 \text{ dB} = 20 \log_{10} \left(\frac{P}{20\mu} \right)$$

$$\Rightarrow P = 1594.9 \times 10^{-6} \text{ Pa}$$

$$P = 1594.9 \ \mu\text{Pa}$$ A

8

(iv) $L_1 = 58$ dB, $L_2 = 50$ dB

Second Pressure level $= 10 \log_{10} \left(10^{5.8} + 10^{5} \right)$

hence equivalent Sound level at 15m $= 58.64$ dB A

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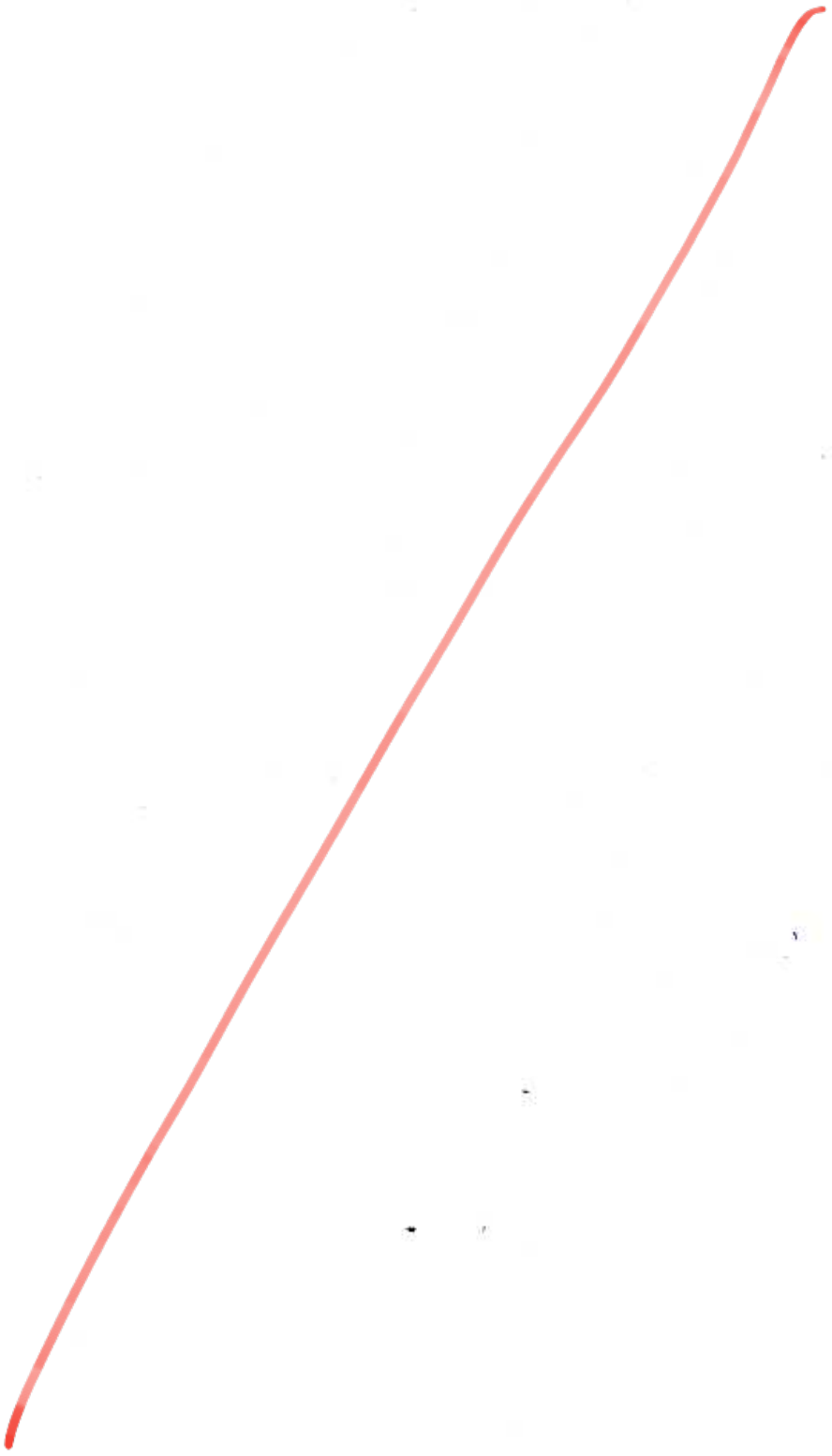

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Q.5 (d) **(i)** Explain the significance of COD and BOD in case of waste waters.

(ii) 5 ml of sample is diluted in a 300 ml incubation bottle. The initial and final D.O. of diluted sample are 8 mg/l and 4.5 mg/l respectively after (5 days of incubation). The temperature of incubation is kept as 20° C. When only seeded water is incubated in bottle for 5 days at the same temperature, then initial and final DO come out to be 8 mg/l and 7 mg/l respectively. Determine BOD_5 of sample.

[4 + 8 marks]

(i) COD is oxygen demand exerted ~~by [illegible]~~s for fully demposition of biodegradable & Non-biodegradable organic matter while BOD is oxygen demand exerted for fully decomposition of only biodegradible organic matter.

→ COD & BOD have significant Importance in Sewage treatment [In waste water industry]

COD → Chemical oxygen demand

BOD → Biochemical oxygen demand.

$COD \geq BOD$

3

(ii) $(BOD_5 \text{ of sample}) \times V_{sample} + BOD_5 \text{ of seed} \times V_{seed} + (BOD_5 \text{ of Diluted water} \times V_D) = 300 \times [8 - 4.5]$

$BOD \text{ of Sample} = \frac{300}{5} \times (8-4.5) - \frac{295}{5}(8-7)$

$BOD_5 \text{ of Sample} = 147.5 \text{ mg/l}$

2

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Q.5 (e) Explain Indore and Bangalore process of composting in details.

[12 marks]

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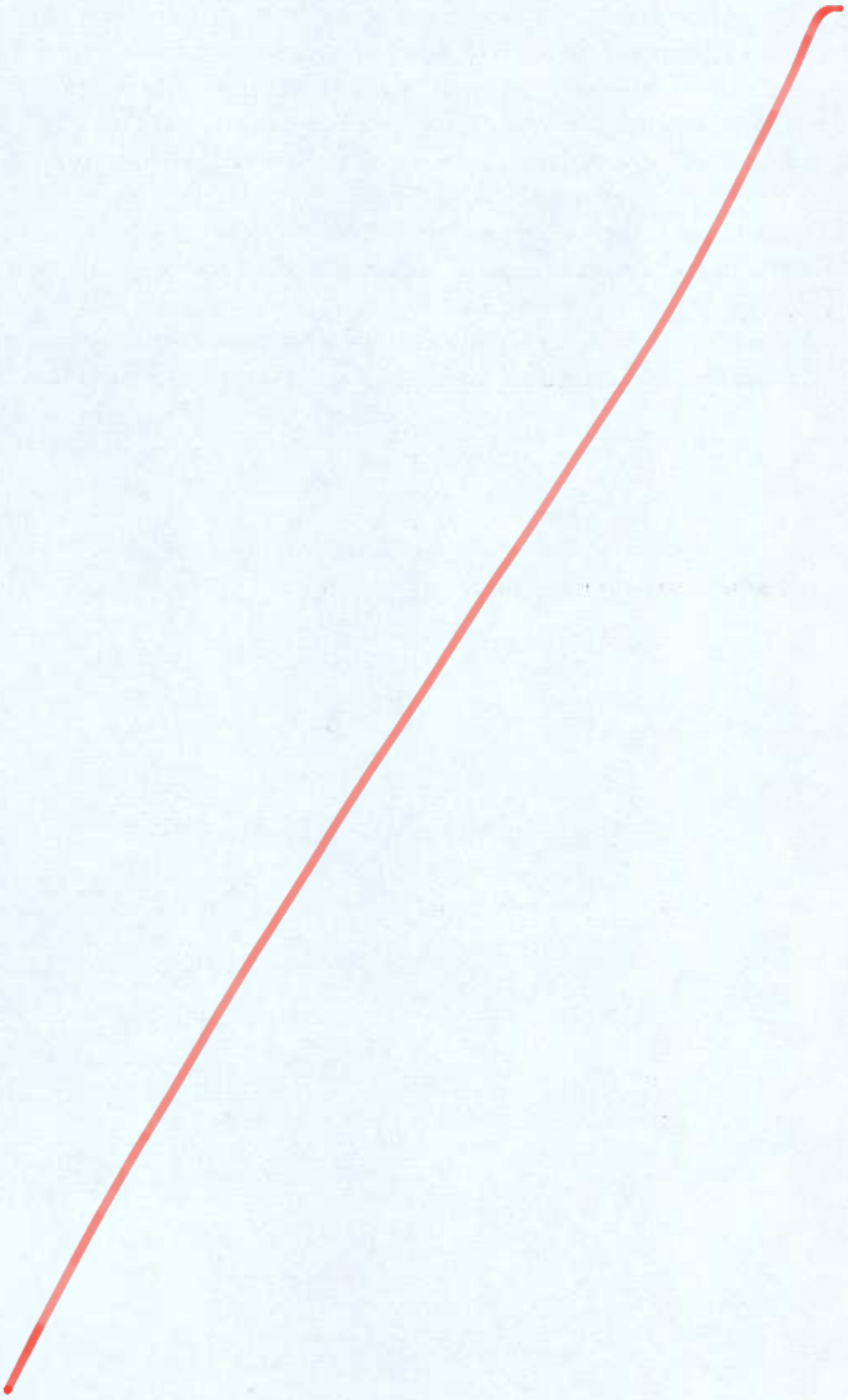

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Q.6 (a) **(i)** Explain the following terms in context of rapid gravity filters:

1. Formation of mud balls
2. Cracking of filters

(ii) A rapid sand filter is to be provided in a water treatment plant, to process the water for a town with a population of 3 lakh and average water demand for this town is estimated as 175 lpcd. The rate of filtration to be kept in filter is 24 $m^3/m^2/hr$. 5% of filtered water is to be provided for back washing which takes about 30 minutes daily. It is observed that during back washing, filter bed expands from 0.6 m to 0.66 m. Porosity of original bed is 0.5 m. Specific gravity of particles can be taken as 2.5. Drag coefficient is to be kept as 5.0.

1. Determine the number of beds (including stand by) if area of one filter is limited to 50 m^2.
2. What is effective diameter of particle if flow is assumed to be transitional during back washing and if the back washing upward velocity is kept as 18 cm/min?

[6 + 14 marks]

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Q.6 (b) **(i)** What do you understand by the term 'breakpoint' chlorination? If 0.8 mg/litre of total chlorine is required for satisfactory disinfection of water at pH = 7, then what chlorine dosage will be necessary at pH = 8? (Take $K_i = 2.7 \times 10^{-8}$ mol/lit)

[12 marks]

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Q.6 (b) (ii) Explain the effect of variations in demand on design component of a water supply scheme.

[8 marks]

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Q.6 (c) The chemical composition of a municipal solid waste (MSW) sample of 100 kg is given in table below:

Component	Wet mass, kg	Dry mass, kg	C	H	O	N	S	Ash
Food waste	25	7.5	3.6	0.48	2.82	0.19	0.03	0.38
Paper	60	56.4	24.54	3.38	24.82	0.17	0.11	3.38
Plastics	10	9.8	5.88	0.70	2.24	–	–	0.98
Wood	5	4	1.98	0.24	1.71	0.008	0.004	0.058

The chemical formula for this compound can be written as $C_aH_bO_cN_dS$.

Determine :

(i) The values of a, b, c, and d.

(ii) The energy content on wet basis and on dry basis of solid wastes if energy content on wet basis can be determined by the equation as:

Energy content (in kJ/kg) = $337C + 1428\left(H - \frac{O}{8}\right) + 9S$ where C, H, O and S are Carbon, Hydrogen, Oxygen and Sulphur in percent by mass.

[20 marks]

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Q.7 (a) **(i)** Calculate the maximum horizontal velocity that can be allowed in a gravitational settling chamber which is designed to remove particles of diameter 48 μm with 100% efficiency. Use the following data:

Length of chamber = 7.5 m
Height of chamber = 1.5 m
Mass density of particle = 2000 kg/m^3
Mass density of air = 1.2 kg/m^3
Correction factor = 1
Viscosity of air = 2.1×10^{-5} kg/m-s

[12 marks]

max. diameter which can be removed (100% efficiency) is given by

$$d = C\sqrt{\frac{18\,\mu V_H L}{(\rho_s - 1)\,\rho g H}}$$

$\rho_s = \frac{2000}{1000} = 2$

$C = 1$

$$48 \times 10^{-6} = \sqrt{\frac{18 \times 2.1 \times 10^{-5} \times V_H \times 7.5}{1 \times 1.2 \times 9.81 \times 1.5}}$$

4

$V_H = 1.435 \times 10^{-5}$ m/sec

$= 0.0861$ cm/min

Hence horizontal velocity required will be = 0.0861 $\frac{cm}{min}$

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Q.7 (a) **(ii)** An electrostatic precipitator is to be constructed to remove fly-ash particles from stack gases flowing at 15 m^3/s. Analysis of a similar system shows that drift velocity can be taken as 0.2 m/s. Determine the plate area required to collect 0.5 μm particles with 90 percent efficiency.

(iii) A fabric filter is to be constructed using bags that are 0.35 m in diameter and 5.8 m long. The bag house is to receive 12 m^3/s of air and filtering velocity has been determined to be 2.0 m/min. Determine the number of bags required for a continuously cleaned operation.

[4 + 4 marks]

(a) (ii)

$$\eta = 1 - e^{-wA/Q}$$

w = drift velocity
A = Area of Plates

$$0.9 = 1 - e^{-0.2 \times A/15}$$

$$\Rightarrow A = 172.7\ m^2$$

Hence plate Area required $= 172.7\ m^2$

4

(iii) Discharge that can pass through one bag

$$Q' = (\pi D H) \times V$$

$$= \pi \times 0.25 \times 5.8 \times \frac{2}{60}$$

$$= 0.2126\ m^3/sec.$$

$$\therefore \eta = \frac{Q}{Q'} = \frac{12}{0.2126} = 56.45 \approx 57$$

$\Rightarrow$ No. of bags required $= 57$

9

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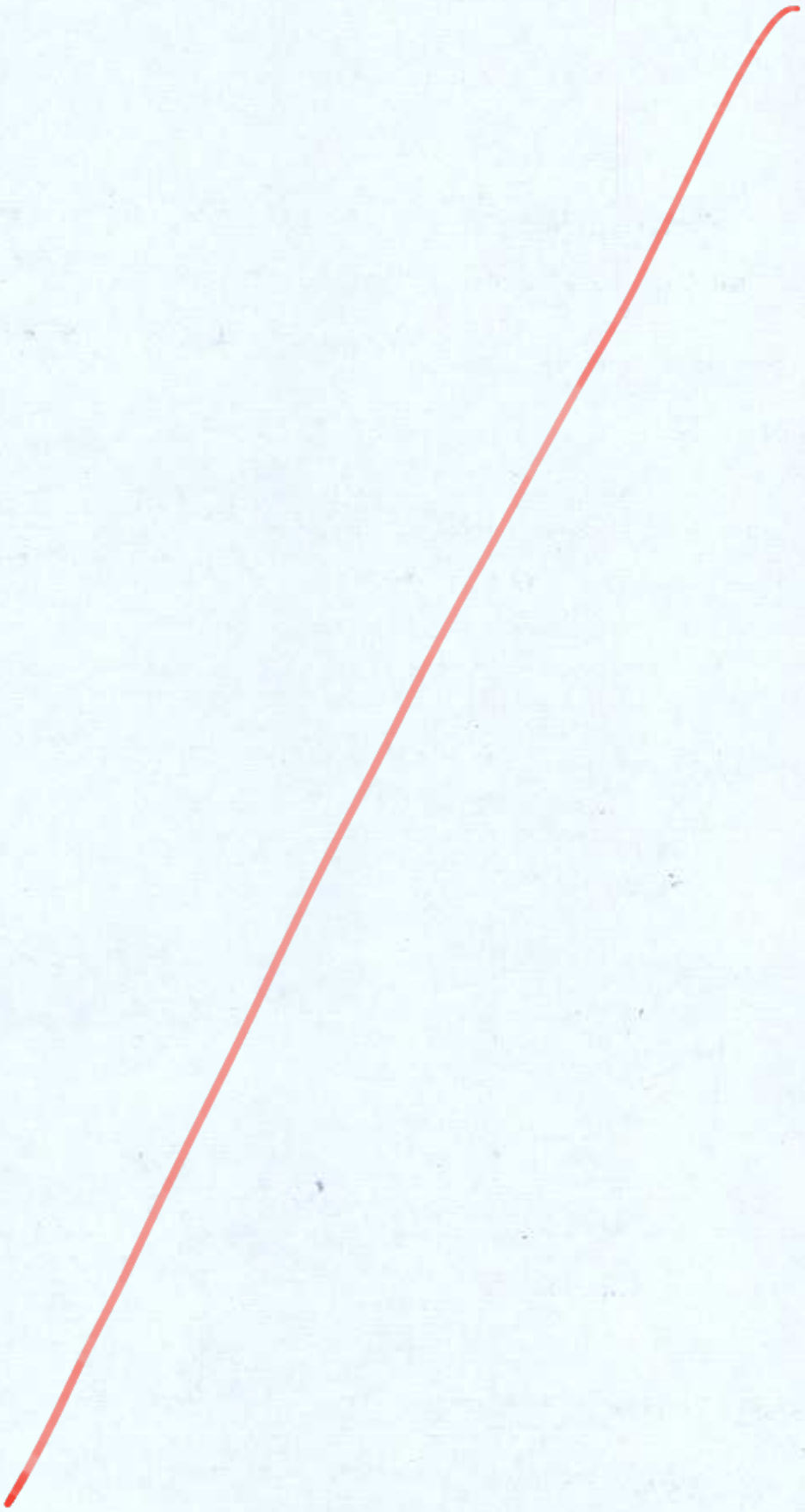

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Q.7 (b) (i) Explain the following terms in an activated sludge process along with their methods of measurement:

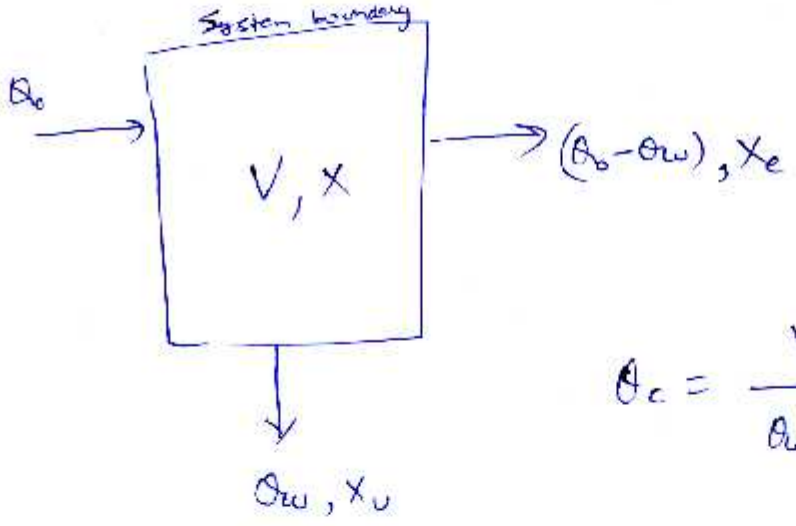
1. Sludge age
2. Sludge-volume index
3. Food to biomass ratio

[15 marks]

(i) Sludge age → It is the time which represents that how much time a biomass lives in system before being discharged.

It is avg. time in which biomass remains in system and contribute to the decomposition of organic matter.

Sludge age is calculated using mass balance eqn



$$\theta_c = \frac{VX}{Q_w X_u + (Q_o - Q_w) X_e}$$

(ii) Sludge volume index :- It is the characteristic of sludge which represent the settleability and flowability of sludge.

It is represented in ml/g.

If SVI is high ⇒ Sludge is poor settleable

& If SVI is lower ⇒ Sludge is poor flowable.

Usually range of SVI (100 - 150) $\frac{ml}{g}$

→ It is calculated by a 1 litre Jar in which Sludge is allowed to settle for 24 hrs after which we measure the vol. occupied by sludge.

(iii) F/m ratio → It is the most controlling factor in ASP process along with sludge age.

There should be optimum F/m in system so that decomposition is carried out effectively and endogeneous phase can be avoided.

$\frac{F}{m} > 0.3$ (for better performance)

$\frac{f}{m} = \frac{\theta_0 S_0}{VX}$ where θ_0 → incoming discharge

S_0 → incoming BOD_5

V → Vol. of Aerator

X → MLSS Conc

If $\frac{f}{m}$ is lower ⇒ operation trouble can occur.

15

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Q.7 (b) (ii) What are the advantages and disadvantages of an Activated Sludge Plants? **[5 marks]**

Advantages →

→ higher efficiency in BOD removal

→ ~~Sludge~~ recirculated sludge is more reactive toward organic matter.

→ decomposition carried out fastly & efficiently

→ sludge can be recycled

Dis advantage →

→ higher operation cost

→ maintenance requires skilled labour & supervision

→ operation trouble may occur if ~~Proper~~ parameters are not checked Properly.

→ sludge disposal problem.

3

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Q.7 (c) (i) Explain the mechanism of coagulation in detail.

[12 marks]

~~There are four step in~~

Coagulation is the process of destabilizing the particles by reducing repulsive forces in between them and allow them to attract each other thus making help in close contact.

There are 4 mechanism in Coagulation

(i) ~~Charge~~ Ionic layer Compression → when some Coagulent is added in the medium then it reduces the electrostatic force between particles thus reducing their charge cloud.

(ii) Absorption & charge Neutralization :-

furthermore Electro static force reduce and makes to Negligible and Vandewall forces of Attraction dominated Now Ionic layer disapear.

(iii) Sweep Coagulation → Coagulent makes ppt which is gelatinous in Nature and particle can ~~not~~ stick to that gelatinous ppt.

Thus they can be sweep out from mediom.

(Sufficient alkalinity is required)

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(iv) Inter particle bridging → Polymer or long chain molecule can attract various no. of particle in their space and thus help in removing the particle from medium. These are synthetics and are not used in regular treatments.

12

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Q.7 (c) (ii) A settling basin is designed to have a surface overflow rate of 32 m/day. Determine the overall efficiency of solids removal of basin with the help of table given below:

Particle size mm	0.1	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01
Weight fraction greater than stated size in percent (%)	10	15	35	65	75	80	85	95	90	100
Settling velocity, v_s in mm/s	1.06	0.88	0.72	0.65	0.37	0.25	0.17	0.10	0.04	0.01

[8 marks]

$SOR = 32\ m/day = \frac{32 \times 1000}{86400}$

$V_o = 0.37\ mm/sec.$

$\Rightarrow$ If $V_s = 0.37\ mm/sec.$ then efficiency will be just 100%.

If $V_s \geq V_o \Rightarrow \eta = 100\%$.

from table it can be clearly seen that

75% particle have $V_s > V_o$

$\therefore$ Hence 75% Particle will have $\eta = 100\%$.

for $V_s < V_o$

$\eta = \frac{V_s}{V_o} \times 100\%$.

Hence

Particle fraction range	mean velocity (V_s)	efficiency
5%	0.31 mm/sec.	83.78%.
5%	0.21 mm/s	56.76%.
5%	0.135 mm/s	36.48%.
5%	0.06 mm/sec	16.21%.
10%	0.025 mm/s	6.75%.

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Hence total efficiency (η)

$= 75 + 0.042 + 0.028 + 0.018 + 0.008 + 0.0067$

$\eta_{overall} = 75.1\ \%$

8

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Q.8 (a) **(i)** A milk products industry discharges its wastewater into a stream. Characteristics of the wastewater and stream are given below:

Parameter	Wastewater	Stream
Flow	1250 m^3/d	20,000 m^3/d
BOD_5 at 20° C	200 mg/l	2 mg/l
DO	0 mg/l	8 mg/l
Temperature °C	26	22
K_1 at 20° C(base e)	0.35 d^{-1}	-
K_2 at 20° C(base e)	-	0.55 d^{-1}

Equilibrium concentration of dissolved oxygen C_s for water is as follows:

Temperature °C	18	20	22	23	24	25	26
C_s (mg/l)	9.54	9.17	8.99	8.83	8.53	8.38	8.22

Temperature coefficients for K_1 and K_2 are taken as 1.04 and 1.02 respectively. If no treatment at all is given to wastewater, then what will be the lowest oxygen level in the stream as a result of discharge and its time of occurrence since mixing?

[15 marks]

$$(DO)_{mix} = \frac{1250 \times 0 + 20000 \times 8}{21250} = 7.53 \frac{mg}{l}$$

$$(Temp)_{mix} = \frac{1250 \times 26 + 20000 \times 22}{21250} = 22.235^{\circ}C$$

$$(BOD_5)_{mix} = \frac{1250 \times 200 + 20000 \times 2}{21250} = 13.647 \frac{mg}{l}$$

$$(DO)_{Sat \text{ at } 22.235^{\circ}} = 8.99 - 0.16 \times 0.235$$

$$= 8.95 \frac{mg}{l}$$

$$\therefore \text{ Initial deficit } = D_0 = 8.95 - 7.53$$

$$= 1.42 \frac{mg}{l}$$

$(BOD)_{ultimate}$

Incomplete Solution

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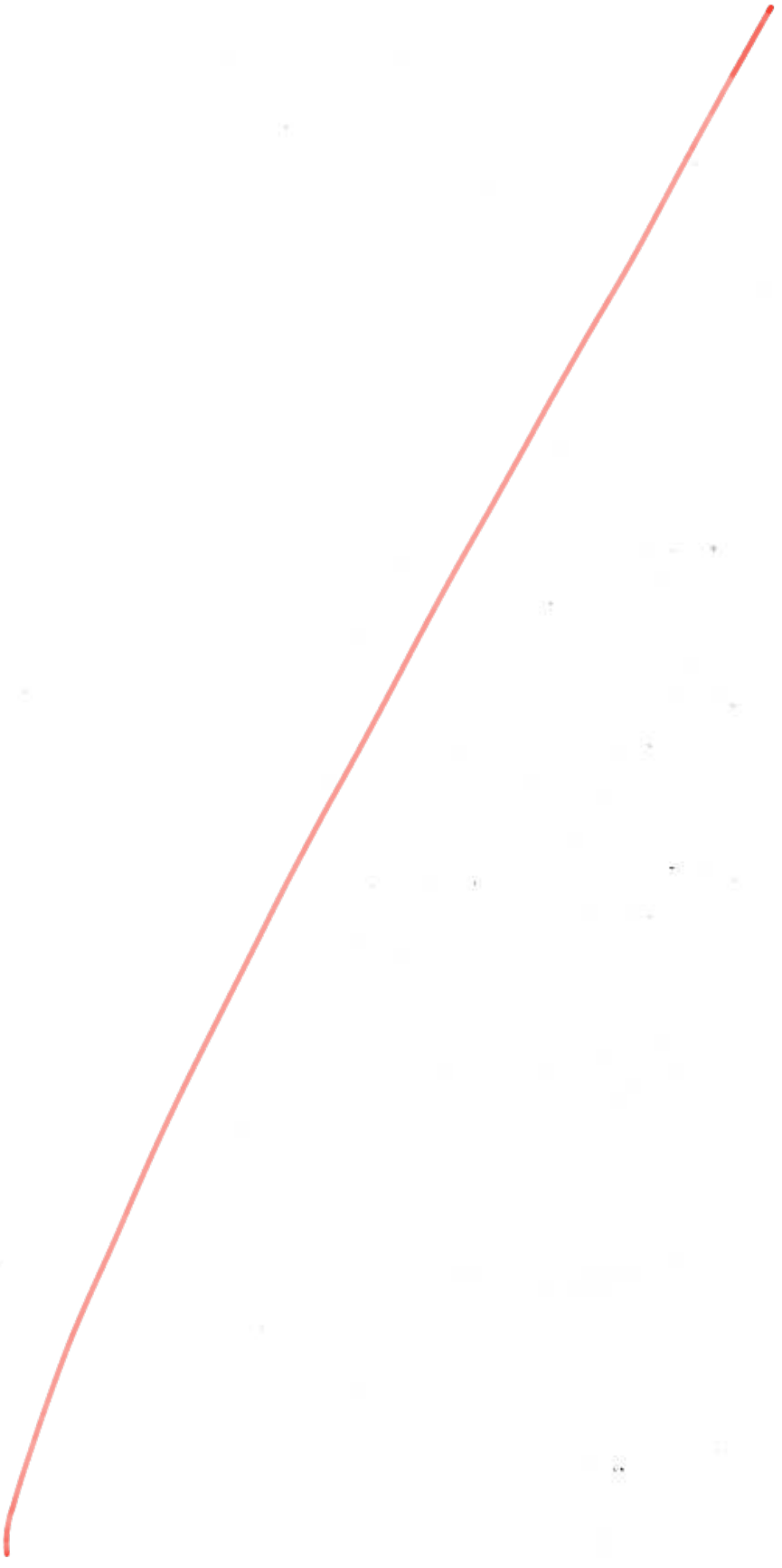

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Q.8 (a) (ii) Briefly describe population equivalent and relative stability.

[5 marks]

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Q.8 (b) **(i)** Explain the concept of L_{eq} in the context of noise pollution. Traffic noise data for a city is given in table below. Compute L_{eq} for the given data:

Time (in s)	10	20	30	40	50	60	70	80	90	100
Noise (dBA)	72	74	73	77	75	80	82	84	81	78

[8 marks]

$L_{eq} = 10 \log_{10} \sum 10^{L_i/10} \times t_i$

$\therefore L_{eq} = 10 \log_{10} \frac{10}{100} \left[10^{7.2} + 10^{7.4} + 10^{7.3} + 10^{7.7} + 10^{7.5} + 10^{8.0} + 10^{8.2} + 10^{8.4} + 10^{8.1} + 10^{7.8}\right]$

$L_{eq} = 79.25$ dB

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Q.8 (b) (ii) A wastewater treatment plant consists of primary treatment followed by a completely mix activated sludge secondary system. The primary and secondary sludge are mixed, thickened and treated by anaerobic digestion. The wastewater treatment plant and sludge characteristics are given below:

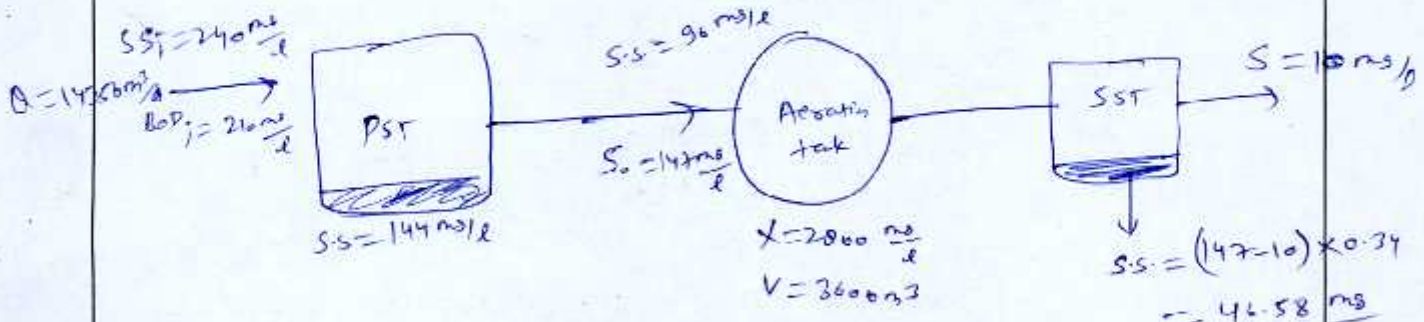
Wastewater	Treatment plant	Sludge
Influent suspended solids = 240 mg/l	Diameter of primary clarifier = 25 m	Primary sludge = 4% solids
Influent BOD = 210 mg/l	Aeration basin volume = 3600 m^3	Secondary sludge = 1% solids
Effluent BOD = 10 mg/l	MLSS in aeration tank = 2800 mg/l	Thickened sludge = 3% solids
Flow = 14350 m^3/d		Specific gravity of primary sludge = 1.02
		Specific gravity of secondary sludge = 1.03
		Specific gravity of thickened sludge = 1.3

Determine the following:

1. Solid loading to digesters.
2. Percent volume reduction in thickener.

Assume efficiency of primary clarifier in removal of suspended solids and BOD as 60% and 30% respectively. Ratio of solids formed in aerator to BOD consumed. i.e. biomass conversion factor is 0.34.

[12 marks]



Hence Solid loading to digestor

$= (144 + 46.58) \times 14350 \times 10^3 \times 10^{-6}$

$= 2734.8 \frac{kg}{day}$

Vol. of Primary sludge

Total sludge Solids = $\frac{144 \times 14350 \times 10^{-3}}{} \times \frac{100}{4}$

$= 51660 \text{ kg/d}$

$\therefore$ Vol. $= \frac{51660}{1020} = 50.647 \text{ m}^3/\text{d}$

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2° Sludge

Total sludge = $46.58 \times 14350 \times 10^{-3} \times \frac{100}{1}$

= 66842.7 kg/d

∴ Vol. = $\frac{66842.3}{1030}$ = 64.9 m^3/day

Thicked sludge (Assuming No solid loss)

Total solid = 2734.8 kg/d

∴ Total sludge = $2734.8 \times \frac{100}{3}$

= 91160 kg/d

∴ Vol. = $\frac{91160}{1300}$ = 70.123 m^3/d

Hence % reduction = $\frac{[50.647 + 64.9] - [70.123]}{[50.647 + 64.9]} \times 100$

= 39.3 %.

12

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Q.8 (c) (i) What are the different types of water distribution network? Explain the advantages and disadvantages of each system.

[12 marks]

(i) Open end or Tree System

Advantages
- Low cost
- Easy & Simple
- less length of Pipe

Disadvantages
- dead ends are there which become Zone of Stagnation
- Can cause diseases
- maintenance Can not carried out effectively.

(ii) Grid System → No. of inter Connected Pipes

advantage
- Supply Can reach from different Points.
- Not frequent shutdown

disadvantage
- high cost
- length of Pipe ↑
- Stagnation zones are removed

8

(iii) ring System outer periphery having main pipes & then supplied by means of outer to inner

(iv) radial & Zonal System → No. of Zone can be separated from a large area and then a tank is situated at Centre of those Area. Then supply is done through radial lines from that source.

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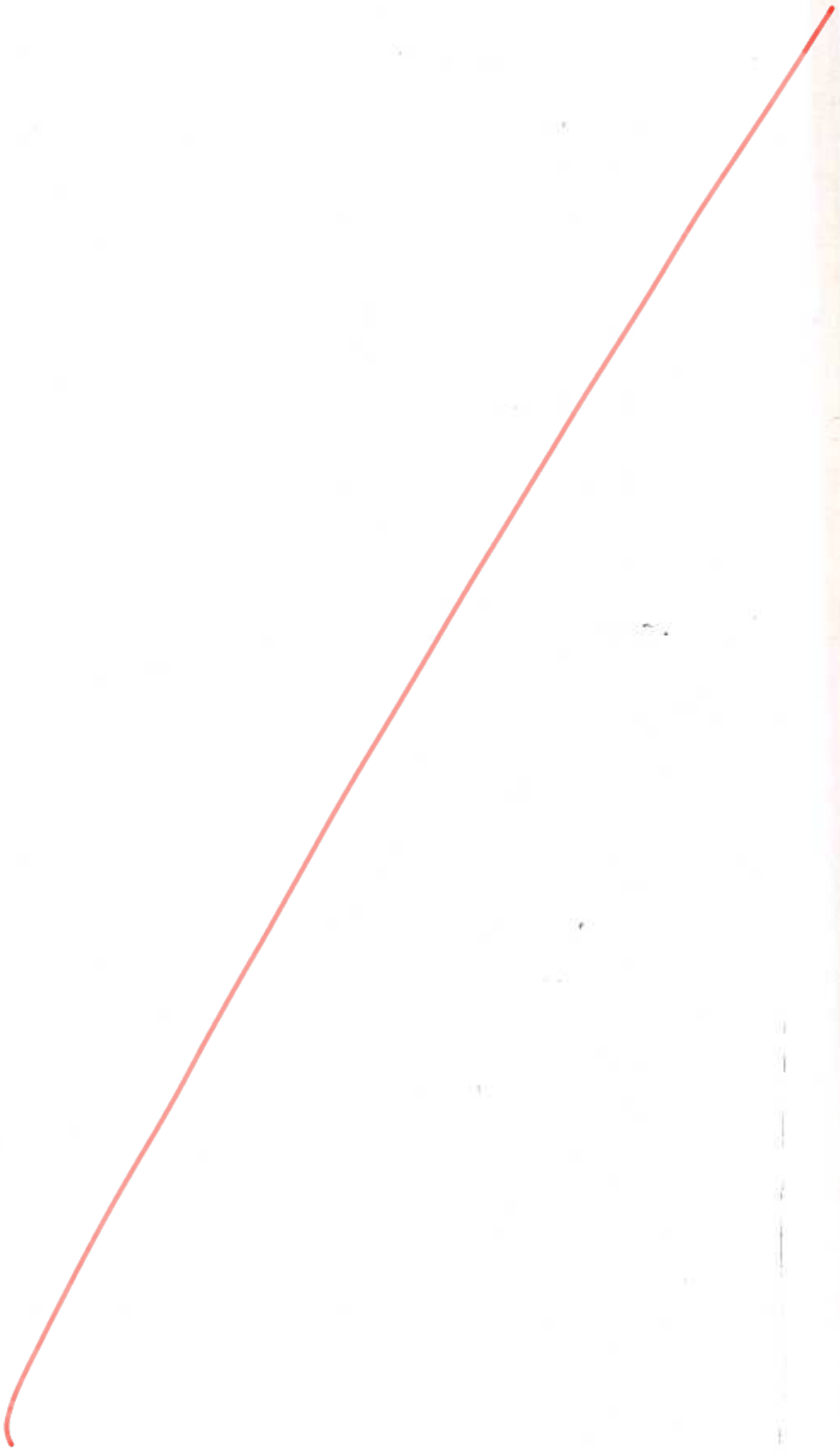

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Q.8 (c) (ii) Explain the functioning and applicability of the following:
1. Air valve 2. Reflux value 3. Flanged joint 4. Expansion joint

[8 marks]

(i) Air Valve
- Removes air from the System
- at Summit of Pipelines
- remove ~~the~~ less pressure Zones.

(ii) Reflux Valve
- Check value
- flow in one dirn only.

2

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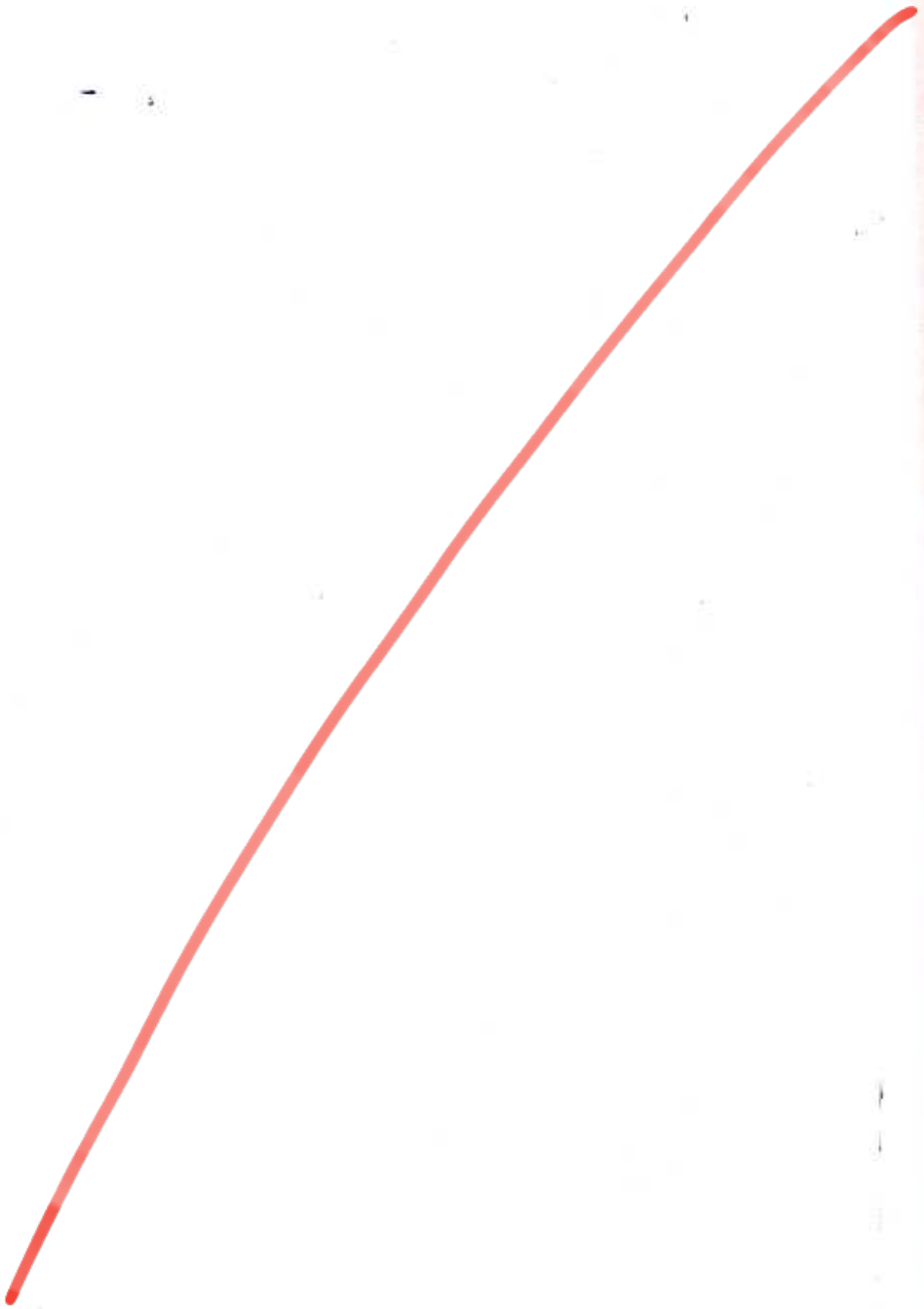

Space for Rough Work

Space for Rough Work

Space for Rough Work

Space for Rough Work