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$$\text{Stress} = \frac{\text{load (P)}}{\text{area (A)}} \quad \text{unit} = \text{Pascal}$$

(σ) Sigma

Internal resistance force / unit cross (x) section area

$$\sigma = \frac{P}{A} = \left(\frac{N}{m^2} \right) \quad , \quad \text{bar}$$

$$\left(\frac{N}{m^2} \right) = \text{Pa}$$

$$1 \text{ bar} = 10^5 \text{ Pascal} \left(\frac{N}{m^2} \right)$$

$$\text{Temperature} = ^\circ K$$

$$\text{Time} = \text{Second}$$

$$\text{velocity} = \text{m/s}$$

$$\text{acceleration} = \text{m/s}^2$$

$$\text{Force} = \text{Newton}$$

$$\text{Load} = \text{Newton}$$

Power = watt

work = Joule

Energy = Joule

Torque = N-m

Moment = N-m

Strain = unitless

Dimension = Meter

Mass = kg

Weight = N

Area = M^2

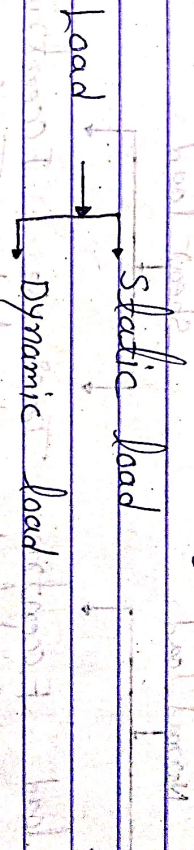
Volume = m^3

UNIT - 1

Simple Stress and Strain

Strain (ϵ) = Change in dimension (deformation)

$\epsilon = \frac{\text{change in dimension}}{\text{original dimension}}$



Magnitude Direction (4121101)

Static load :- whose magnitude and direction remain constant with respect to time is called static load.

[illegible]

Static load
Dynamic load

Types of Diffraction

[illegible]

$\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$
 $\frac{1}{4} \times \frac{1}{4} = \frac{1}{16}$
 $\frac{1}{16} \times \frac{1}{16} = \frac{1}{256}$
 $\frac{1}{256} \times \frac{1}{256} = \frac{1}{65536}$
 $\frac{1}{65536} \times \frac{1}{65536} = \frac{1}{4294967296}$

बैल्य बना के बिक्रीन एब उर बेल नु कयल गाना के लब
भा बउ बरु बरु दी देगी के अगेन आकार मे बाधुरी
बनी आ पाल के उर Plastic Deformation कहने के

॥ श्री गुरुः ॥

$\text{load}(\text{ETSL})$

Axial load :- Perpendicular to (x) cross section and passing through centroid

Eccentric Axial load :- Perpendicular to cross (x) section and away from



A horizontal beam is shown with three different loading conditions indicated by arrows pointing downwards:

- Centroid:** An arrow points to the center of the beam.
- Tensile load:** An arrow points to the left end of the beam.
- Compressive load:** An arrow points to the right end of the beam.

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Normal strain = $\frac{\text{change in dimension}}{\text{original dimension}}$

Longitudinal strain = Normal strain in the Direction of applied load

Lateral strain = Normal strain in the Direction Perpendicular to the applied load

Volume strain = $\frac{\text{change in volume}}{\text{original volume}}$

Shear strain = $\gamma_{\text{shear}} = \theta \text{ (rads)} = \frac{\delta}{L}$

Poisson's ratio (μ) = $\frac{\text{lateral strain}}{\text{longitudinal strain}}$

(u) = $\frac{\epsilon_{\text{lat}}}{\epsilon_{\text{long}}}$

$\epsilon_{\text{long}} = \frac{\Delta L}{L}$

$\epsilon_{\text{lat}} = \frac{\Delta b}{b} \quad \frac{\Delta h}{h} \quad \frac{\Delta t}{t}$

$\epsilon_v = \frac{\Delta V}{V}$

$0 < \mu < 0.5$

$\mu = 0$ is perfect elastic form

$\mu = 0.5$ is perfect plastic form

$\mu = \text{unitless}$

$\mu = \frac{\epsilon_{\text{lat}}}{\epsilon_{\text{long}}} \text{ unitless}$

$\mu = \text{unitless}$

Hook's law :- within elastic limit longitudinal stress is directly proportional to longitudinal strain

$\sigma \text{ (Sigma) long} \propto \epsilon_{\text{long}}$

$$\sigma = E \epsilon_{\text{long}}$$

$E = \text{constant} = \text{Young's modulus of elasticity}$

$$E = \frac{\sigma}{\epsilon_{\text{long}}}$$

Elastic constants

4 Elastic constants

1. Young's modulus of elasticity (E)

$$= \frac{\sigma}{\epsilon_{\text{long}}} \frac{\text{N}}{\text{m}^2}, (\text{Pa})$$

2. modulus of rigidity (G) = $\frac{\tau}{\gamma}$, N/m^2 (Pa)

3. Bulk modulus (K) = $\frac{\sigma_{\text{long}}}{\epsilon_v}$, N/m^2 (Pa)

4. Poisson's ratio (μ) = unitless

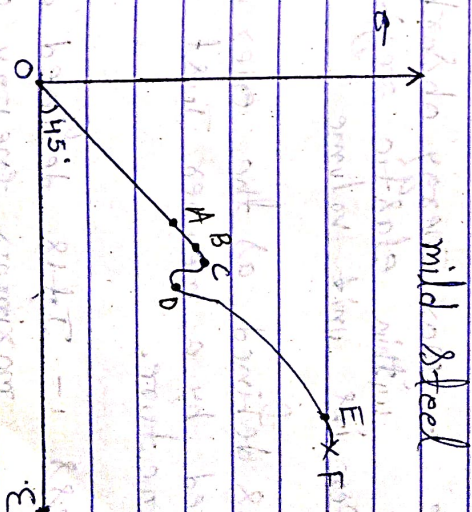
Relation b/w E, G, K & μ

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

$$E = 3K(1 - 2\mu)$$

$$E = \frac{9KG}{3K + G}$$

Stress, strain diagram for ferrous material



A = limit of proportionality

B = Elastic limit

C = lower yield point

D = lower yield point
 E = ~~ultimate~~ ~~stress~~ ~~point~~ Alternate stress point
 F = Fracture point / breaking point

Strain Energy

Resilience :- strain energy absorbed within elastic region

Proof Resilience :- maximum energy absorbed within elastic region

Modulus of resilience :- Max Energy absorbed within elastic region per its unit volume

Toughness :- It is defined as the energy absorbed by a member just before its fracture.

Modulus of Toughness :- It is defined as the maximum energy absorbed by a component just before fracture per its unit volume

(2) Stress :- it is defined as the magnitude of internal resisting force developed at a point in a member under loading

$$\sigma = \frac{\text{Load}}{\text{Section area}} = \frac{N}{m^2} \quad (Pa)$$

Types of Stress

1 Tensile stress :- σ_T

2. Compressive stress :- σ_c

3. Shear stress :- τ (N/m²)

(3) Strength :- It is defined as the magnitude of stress that a material can withstand

Example :- (σ_{max}) 200 GPa = 200×10^9 (Pa)
 mild strength

change in length $\Delta L = \frac{PL}{AE}$ (m)

$P =$ load, $L =$ length
 $A =$ Area of section, $E =$ modulus of elasticity

$$\Delta L_{\text{static}} = \frac{P}{A} \left(\frac{N}{m^2} \right)$$

$$E = \frac{1 - 2\mu}{E} (\sigma_x + \sigma_y + \sigma_z)$$

$$E = \frac{\sigma}{\epsilon}$$

$$P = 200 \text{ kN}$$

$$A = 30$$

$$E = \frac{\sigma}{\epsilon}$$

$\Delta L_{\text{static}} = \frac{PL}{AE}$, $h =$ height

$\sigma_{\text{impact}} = \text{I.f.} \times \sigma_{\text{static}}$

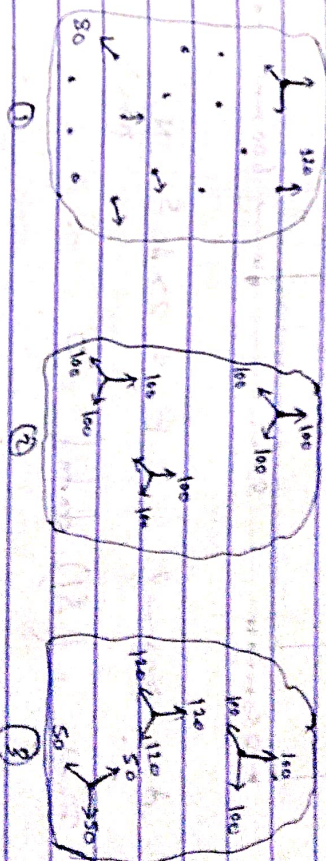
I.f. = impact factor

$$\text{I.f.} = 1 + \sqrt{1 + \frac{2h}{\Delta L_{\text{static}}}}$$

Homogeneous and isotropic material

any point in given direction

any direction at a given point



Impact load :- Short interval of time

$n \rightarrow \infty \Rightarrow$ Impact load $\Rightarrow$ Suddenly Applied load

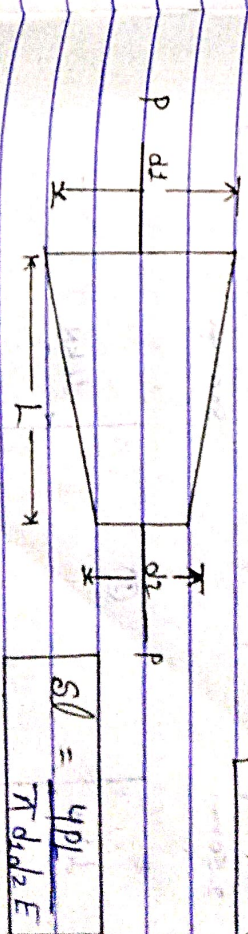
$$\text{I.f.} = 1 + \sqrt{1} = 2$$

$$\sigma_{\text{SAI}} = 2 \times \sigma_{\text{static}}$$

$$\Delta L_{\text{static}} = 2 \times \Delta L_{\text{static}}$$

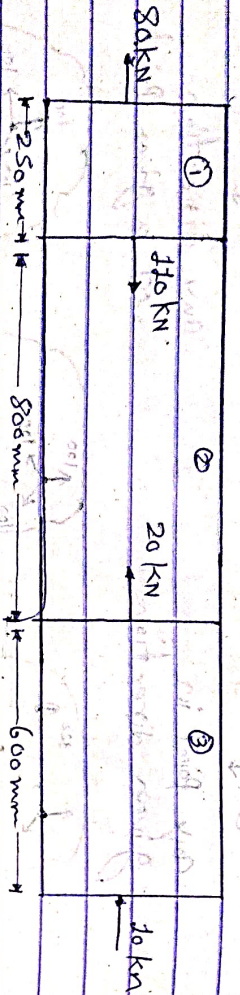
Elongation of a tapered bar :-

$$\sigma_{\text{max}} = \left(\frac{\text{change}}{\Delta L_{\text{static}}} \right)$$



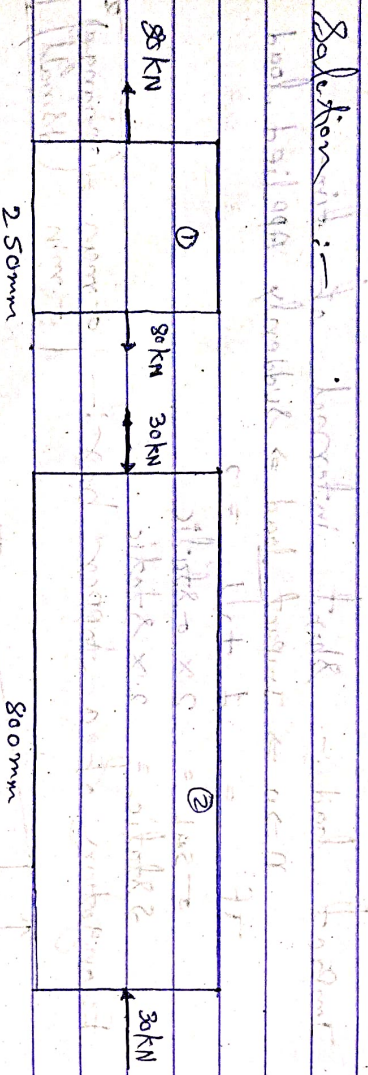
$$\Delta L = \frac{4PL}{\pi d_1 d_2 E}$$

Bay 1 in Series



$$A = 200 \text{ mm}^2 \quad E = 2 \times 10^5 \frac{\text{N}}{\text{mm}^2}$$

$$\text{Find } = (SL)_{\text{steel}} = ?$$



$$(SL)_{\text{steel}} = (SL)_1 + (SL)_2 + (SL)_3$$

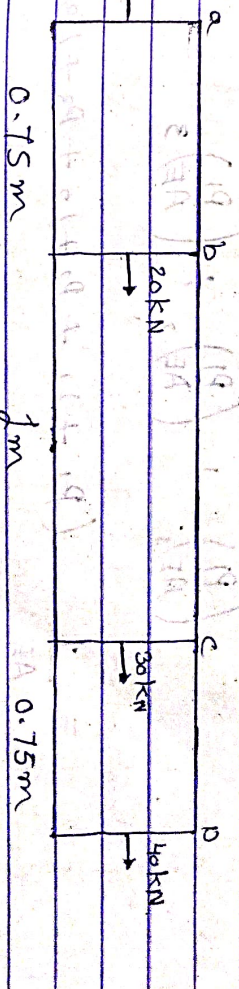
$$= \left(\frac{PL}{AE} \right)_1 + \left(\frac{PL}{AE} \right)_2 + \left(\frac{PL}{AE} \right)_3$$

$$= \frac{1}{AE} (P_1 L_1 + P_2 L_2 + P_3 L_3)$$

$$= \frac{1}{200 \times 2 \times 10^5} [80 \times 250 + 20 \times 200 + 10 \times 600]$$

$$(SL)_{\text{steel}} = 0.25 \text{ mm}$$

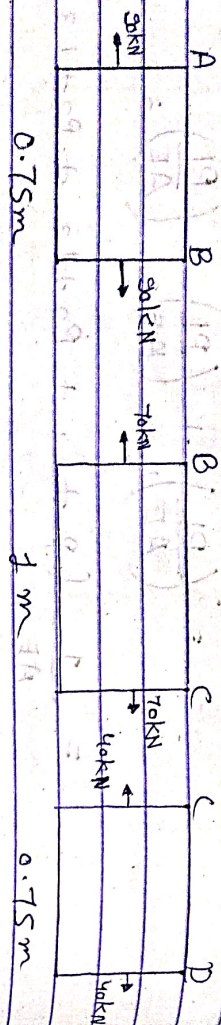
Q.2 Bay 3 in Series



$$A = 600 \text{ mm}^2 \quad E = 200 \text{ GPa}$$

$$(SL)_{\text{steel}} = ?$$

Solution :-



$$P_1 = 30 \text{ kN}$$

$$P_2 = 70 \text{ kN}$$

$$P_3 = 40 \text{ kN}$$

$$(SL)_{total} = (SL)_1 + (SL)_2 + (SL)_3$$

$$= \left(\frac{P_1}{AE_1} \right) + \left(\frac{P_2}{AE_2} \right) + \left(\frac{P_3}{AE_3} \right)$$

$$= \frac{1}{AE} (P_1 + P_2 + P_3)$$

$$= \frac{1}{AE} [30 \times 0.75 + 70 \times 1 + 40 \times 0.75]$$

$$= \frac{1}{600 \times 200 \times 10^{-6} \times 200 \times 10^{-3}} [30 \times 0.75 + 70 \times 1 + 40 \times 0.75]$$

$$(SL)_{total} = 1.4 \text{ mm}$$

Types of Strength

1. Yield Strength (σ_y) :- The stress at which the material begins to deform plastically.

Yield strength is the stress at which the material begins to deform plastically.

2. Ultimate Strength (σ_u) :- The maximum stress that a material can withstand before failure.

Ultimate strength is the maximum stress that a material can withstand before failure.

$$\sigma_{yield} = 0 \text{ Pascal} - 100 \text{ GPa}$$

$$\sigma_{ultimate} = 100 \text{ GPa} - 200 \text{ MPa}$$

Strength of material :- The ability of a material to resist deformation under load.

1. Ductile material :- A material that can undergo significant plastic deformation before failure.

2. Brittle material :- A material that fractures with little or no plastic deformation.

Strain :- The deformation of a body under loading.

Types of Strain :-

Normal strain (ϵ) :- The strain that occurs when a material is stretched or compressed.

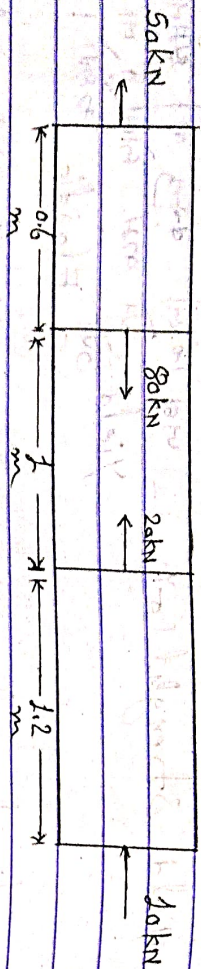
Longitudinal strain :- The strain that occurs along the length of a material.

(Elongation) Lateral strain :- The strain that occurs perpendicular to the direction of the applied stress.

(Contraction) Volumetric strain :- The strain that occurs in the volume of a material.

(Expansion)

Q.3 Bars in Series

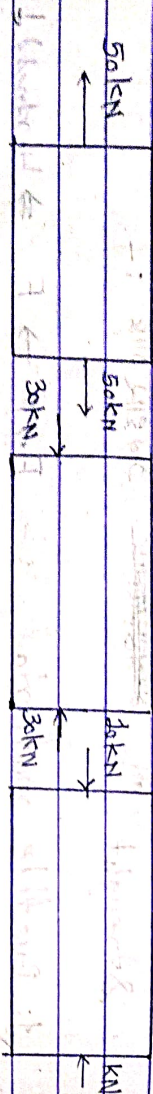


$$(S1)_{total} = ?$$

$$A = 1000 \text{ mm}^2$$

$$E = 200 \text{ GPa}$$

Solution :-



$$P1 = 50 \text{ kN}$$

$$P2 = 30 \text{ kN}$$

$$P3 = 20 \text{ kN}$$

$$(S1)_{total} = (S1)_1 + (S1)_2 + (S1)_3$$

$$= \left(\frac{P1}{AE} \right)_1 + \left(\frac{P1}{AE} \right)_2 + \left(\frac{P1}{AE} \right)_3$$

$$= \frac{1}{AE} (P1 + P2 + P3)$$

$$= \frac{1}{1000} (50 \times 0.6 + 30 \times 1 + 20 \times 1.2)$$

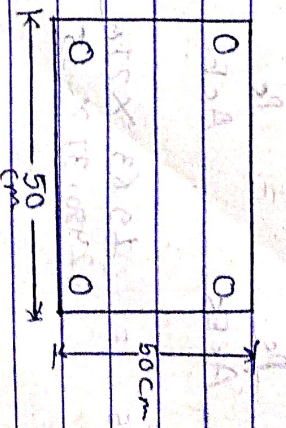
$$= \frac{1 \text{ kN}}{\text{mm}^2}$$

$$(S1)_{total} = -0.12 \text{ mm Ans}$$

Q.4 Bars in Parallel (11)

A reinforced concrete column 50 cm x 50 cm in section is reinforced with 4 steel bars of 25 cm diameter. one in each corner. The column is carrying a load of 300 kN. find the stresses in the concrete and steel bars take E for steel = 200 GPa and E for concrete = 15 GPa.

Solution :-



$A = 50 \text{ cm} \times 50 \text{ cm}$ $\therefore A_s = 3 \text{ steel}$

$D_s = 2.5 \text{ cm}$ $C = \text{concrete}$

$P = 900 \text{ kN}$

$E_s = 210 \text{ GPa}$

$E_c = 15 \text{ GPa}$

$\sigma_c, \sigma_s = \frac{P}{A}$

$A_s = \frac{4 \times \pi \times D_s^2}{4} \times 3 = \pi \times 2.5^2 = 19.63 \text{ cm}^2$

$A_c = 50 \times 50 - 19.63 = 2480.37 \text{ cm}^2$

$P_s + P_c = 900 \text{ kN}$ — eq (1)

$(\sigma_s)_s = (\sigma_c)_c$

$\left(\frac{P_s}{A_s E_s}\right)_s = \left(\frac{P_c}{A_c E_c}\right)_c$

$\frac{P_s}{A_s E_s} = \frac{P_c}{A_c E_c}$

$P_s = \frac{19.63 \times 210}{2480.37 \times 15} P_c$

$P_s = 0.11 P_c$

$0.11 P_c + P_c = 900$

$P_c (0.11 + 1) = 900$

$P_c = 810.8 \text{ kN}$

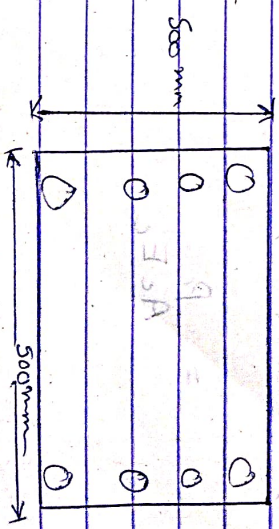
$P_s = 89.2 \text{ kN}$

$\sigma_s = \frac{P_s}{A_s} = \frac{89.2 \text{ kN}}{19.63 \text{ cm}^2} = 45 \text{ MPa}$

$\sigma_c = \frac{P_c}{A_c} = \frac{810.8 \text{ kN}}{2480.37 \text{ cm}^2} = 32 \text{ MPa}$

Q4 A Reinforced concrete column $500 \times 500 \text{ mm}$ in section is reinforced with 8 steel bars of 25 mm diameter. the column is carrying a load of 2000 kN . Find the stresses in the concrete and steel bars. Take E for steel = 210 GPa and E for concrete = 14 GPa .

Solution:-



$$A = 500 \text{ mm} \times 500 \text{ mm}$$

$$D_s = 25 \text{ mm}$$

$$P = 2000 \text{ kN}$$

$$E_s = 210 \text{ GPa}$$

$$E_c = 14 \text{ GPa}$$

$$\sigma_c, \sigma_s = \frac{P}{A}$$

$$A_s = \frac{8 \times \pi \times D_s^2}{4} = \frac{8 \times \pi \times 25^2}{4}$$

$$A_s = 3926.99 \text{ mm}^2$$

$$A_c = 500 \times 500 - 3926.99$$

$$A_c = 246073.01 \text{ mm}^2$$

$$P_s + P_c = 2000 \text{ kN} \quad \text{--- eq (1)}$$

$$\left(\delta l \right)_s = \left(\delta l \right)_c$$

$$\left(\frac{P L}{A E} \right)_s = \left(\frac{P L}{A E} \right)_c$$

$$\frac{P_s}{A_s E_s} = \frac{P_c}{A_c E_c}$$

$$P_s = \frac{3926.99 \times 210}{246073.01 \times 14} P_c$$

$$P_s = 0.2393 P_c$$

$$0.2393 P_c + P_c = 2000$$

$$P_c (0.2393 + 1) = 2000$$

$$P_c = 1613.81 \text{ kN}$$

$$P_s = 386.18 \text{ kN}$$

$$\sigma_s = \frac{P_s}{A_s} = \frac{386.18}{3926.99} \text{ kN/mm}^2$$

$$\sigma_s = 9.83 \text{ kN/mm}^2$$

$$\sigma_c = \frac{P_c}{A_c} = \frac{1613.81}{246073.01} \text{ kN/mm}^2$$

$$\sigma_c = 0.006 \text{ kN/mm}^2$$

$$0.006 \text{ kN/mm}^2$$

Q.5 A steel bar 50mm x 50mm in cross section is 1.2m long. it is subjected to an axial pull of 250 kN. what are the changes in length, width and volume of the bar if the value of Poisson's ratio is 0.3? Take E as 200 GPa.

Solution:-

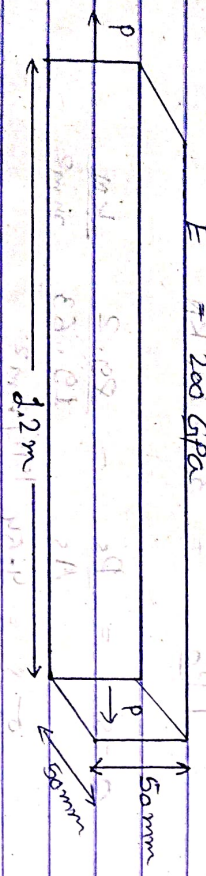
$$A = 50\text{mm} \times 50\text{mm}$$

$$l = 1.2\text{m}$$

$$P = 250\text{ kN}$$

$$\mu = 0.3$$

$$E = 200\text{ GPa}$$



To find Δl , Δb , Δv = ?

$$\Delta l = \frac{PL}{AE} = \frac{250 \times 1.2 \times 1000}{50 \times 50 \times 200}$$

$$= \frac{\text{KN} \times \text{mm}}{\text{mm}^2 \times \text{GN}} = \frac{\text{mm}}{\text{mm}^2}$$

$$\Delta l = 0.6\text{ mm}$$

$$\mu = \frac{\epsilon_{\text{lat}}}{\epsilon_{\text{long}}} \Rightarrow \epsilon_{\text{lat}} = \frac{\Delta b}{b}$$

$$\epsilon_{\text{long}} = \frac{\Delta l}{l}$$

$$\epsilon_{\text{lat}} = \mu \times \epsilon_{\text{long}}$$

$$\frac{\Delta b}{b} = -0.3 \times \frac{\Delta l}{l} \Rightarrow \frac{\Delta b}{50}$$

$$= -0.3 \times 0.6$$

$$1.2 \times 1000$$

$$\Delta b = -0.007\text{ mm}$$

$$\epsilon_v = \frac{\Delta v}{v} = \epsilon_x + \epsilon_y + \epsilon_z = \epsilon_{\text{long}} + 2\epsilon_{\text{lat}}$$

$$\epsilon_v = \epsilon_{\text{long}} + 2 \times (-0.3 \times \epsilon_{\text{long}})$$

$$= \epsilon_{\text{long}} - 0.6 \epsilon_{\text{long}}$$

$$\frac{\Delta v}{50 \times 50 \times 1200} = \frac{\Delta l}{1.2} (1 - 0.6)$$

$$\Delta v = 50 \times 50 \times 1200 \times 0.6 (1 - 0.3)$$

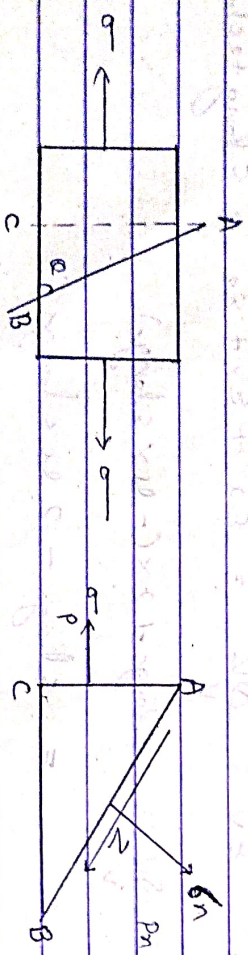
$$1200$$

$$\Delta v = 600\text{ mm}^3$$

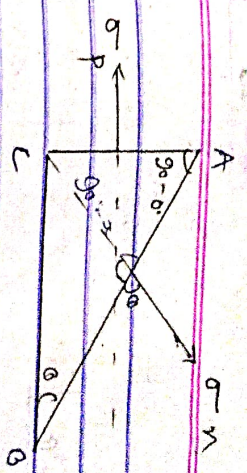
Principle Planes - There are three planes mutually perpendicular to each other which carry direct stress only and no shear stresses. The particular plane which have no shear stresses are known as principle planes.

Principle Stress :- The magnitude of direct stress across a principle plane is known as principle stress.

Stresses on a oblique of a body subjected to a direct stress in one plane



Horizontal force acting on face AC
force perpendicular to the section AB



$$\sigma = \frac{P}{A_c}$$

$$P = \sigma A_c$$

$$\text{Stress} = \frac{AC}{AB}$$

$$AB = \frac{AC}{\sin \theta}$$

Resolving forces perpendicular to the AB

$$P_n = P \cos (90 - \theta)$$

$$P_n = P \sin \theta = \sigma A_c \sin \theta$$

Resolving forces tangentially to the AB

$$P = P \cos \theta = \sigma A_c \cos \theta$$

Stress normal to AB

$$\tau_n = \frac{P_n}{AB} = \frac{\sigma A_c \sin \theta}{\frac{AC}{\sin \theta}}$$

$$= \sigma \sin^2 \theta$$

$$\sigma_n = \sigma \sin^2 \theta$$

Stress tangentially on AB = $\tau = \frac{\text{force}}{A_B}$

$$= \frac{\sigma A_C \cos \theta}{A_B \sin \theta}$$

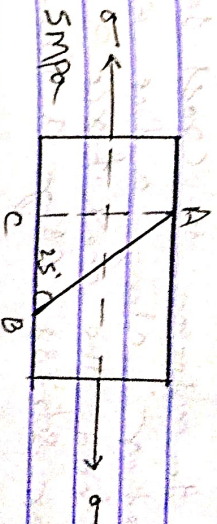
$$= \sigma \sin \theta \cdot \cos \theta$$

$$= \frac{\sigma}{2} \sin 2\theta$$

$$\sigma_R = \sqrt{\sigma_n^2 + \tau^2}$$

find resultant formula :-

A wooden bar is subjected to a tensile stress of 5 MPa what will the value of normal and shear stress across the section which made in angle of 25° with the direction of tensile strength



Solution :-

$$\sigma_n = \sigma \sin^2 \theta = \frac{\sigma}{2} (1 - \cos 2\theta)$$

$$\sigma = 5 \text{ MPa}$$

$$= \frac{5}{2} (1 - \cos (2 \times 25))$$

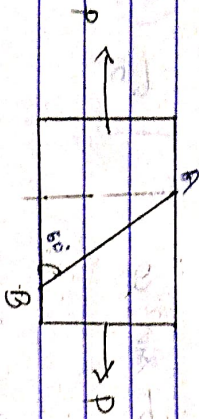
$$= 0.89 \text{ MPa}$$

$$\tau = \frac{\sigma}{2} \sin 2\theta = 0.89 \text{ MPa}$$

$$= \frac{5}{2} \sin (2 \times 25)$$

$$= 1.91 \text{ MPa}$$

Two wooden piece are joined together along a line AB shown figure find the max force P when applied if the shear stress along a joint AB is 1.3 MPa



Solution :- $A = 100 \times 100 \text{ mm}^2$

$$\tau = 1.3 \text{ MPa}$$

$$\tau = \frac{\sigma}{2} \sin 2\theta$$

$$1.3 = \frac{\sigma}{2} \times \sin 2 \times 60$$

$$1.3 = \frac{\sigma}{2} \times \sin 120$$

$$1.3 = \frac{\sigma}{2} \times \frac{\sqrt{3}}{2}$$

$$1.3 = \frac{\sigma}{4} \sqrt{3}$$

$$1.3 = \frac{\sigma}{4} \sqrt{3}$$

$$\sigma = \frac{1.3 \times 4}{\sqrt{3}}$$

$$\sigma = 3.00 \text{ kN}$$

$$\sigma = \frac{P}{A}$$

$$3.00 = \frac{P}{A}$$

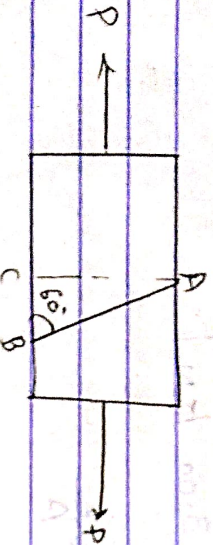
$$P = \sigma \times A$$

$$= \frac{3.00}{1000} \times 100 \times 100 \text{ mm}^2$$

$$= 30000 \text{ N} = 30 \text{ kN}$$

$$P = 30 \text{ kN} \text{ Any}$$

A wooden member is form by connecting two wooden member 200mm x 200mm as shown in figure determine the safe value of force P. If permissible normal stress and shear stress and joined are 0.5 MPa and 1.25 MPa respectively



Solution :- $\sigma_n = \sigma \sin^2 \theta = \frac{\sigma}{2} (1 - \cos 60^\circ)$

$$0.5 = \frac{\sigma}{2} (1 - \cos 60^\circ)$$

$$= \frac{\sigma}{2} (1 - \cos(120^\circ))$$

$$\sigma = \frac{0.5 \times 2}{1 - \cos(120^\circ)}$$

$$\sigma = 0.66 \text{ MPa}$$

$$1.25 = \frac{\sigma}{2} \sin(120^\circ)$$

$$\sigma = \frac{1.25 \times 2}{\sin(120^\circ)}$$

$$\sigma = 2.88 \text{ MPa}$$

The safe value of force

$$\sigma = \frac{P}{A}$$

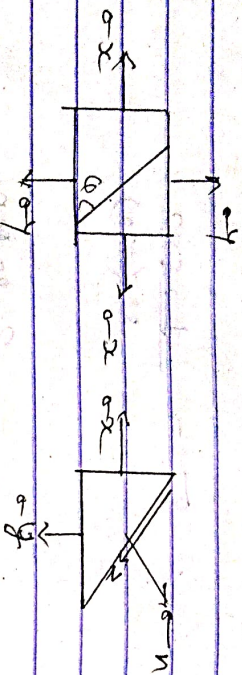
$$P = \sigma \cdot A$$

$$P = 0.66 \times 200 \times 100$$

$$P = 13200$$

$$P = 13.2 \text{ kN}$$

body subjected to direct stress in two mutually perpendicular direction



$$\sigma_n = \frac{\sigma_x + \sigma_y}{2} - \frac{\sigma_x - \sigma_y}{2} \cos 2\theta$$

$$\tau = \frac{\sigma_x - \sigma_y}{2} \sin 2\theta$$

Q.1 A point in a strained material is subjected to two mutually perpendicular tensile stresses of 200 MPa and 800 MPa. Determine the intensity of normal stress and resultant stress on a plane inclined at 30° with the axis of maximum tensile stress.

Solution:- $\sigma_n = \frac{\sigma_x + \sigma_y}{2} - \frac{\sigma_x - \sigma_y}{2} \cos 2\theta$

$$\sigma_n = \frac{200 + 800}{2} - \frac{200 - 800}{2} \cos 2(30)$$

$$\sigma_n = 125 \text{ MPa}$$

$$\tau = \frac{\sigma_x - \sigma_y}{2} \sin 2\theta$$

$$\tau = \frac{200 - 800}{2} \sin 2(30)$$

$$\tau = 43.30 \text{ MPa}$$

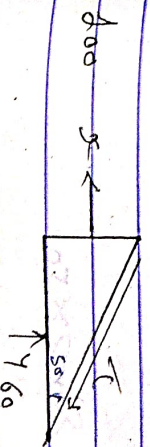
To find resultant

$$\sigma_R = \sqrt{\sigma_n^2 + \tau^2}$$

$$\sigma_R = \sqrt{125^2 + 43.30^2}$$

$$\sigma_R = 132.28 \text{ MPa}$$

Q.2 At a point in a stressed body the principal stresses are 800 MPa tensile and 600 MPa compressive. Determine the normal stress and shear stress on a plane inclined at 30° to the axis of major principal stress. Also calculate maximum shear stress at the point.



Solution:- given data

maximum principal $\sigma_x = 100 \text{ MPa}$

minimum principal $\sigma_y = -60 \text{ MPa}$

$\sigma_z = 50$

TS finding $\Rightarrow \sigma_n = ?$
 $\tau = ?$
 $\tau_{\text{max}} = ?$

$\sigma_n = \frac{\sigma_x + \sigma_y}{2} = \frac{100 - 60}{2} = 20$

$\sigma_n = \frac{100 - 60}{2} = 20 \cos 20^\circ$

$\sigma_n = \frac{100 - 60}{2} = 20 \cos 20^\circ$

$\sigma_n = 33.89 \text{ MPa}$

$\tau = \frac{\sigma_x - \sigma_y}{2} \sin 20^\circ$

$\tau = \frac{100 + 60}{2} \sin 20^\circ$

$\tau = 78.78 \text{ MPa}$

$\tau_{\text{max}} = \frac{\sigma_x + \sigma_y}{2} \sin 20^\circ$

value of $\sigma_z = 0$

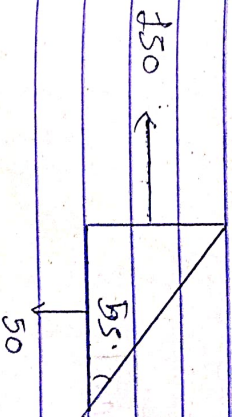
$\tau_{\text{max}} = \frac{\sigma_x - \sigma_y}{2} \sin 20^\circ$

$\tau_{\text{max}} = 100$

$\tau_{\text{max}} = 80 \text{ MPa}$

Q. The stress at a point of a machine component are 150 MPa and 50 MPa both tensile find the intensities of normal, shear resultant stress on a plane inclined at an angle of 50° with the axis of major tensile stress also find the magnitude of maximum shear stress in the component.

Solution:-



given data

maximum principle $\sigma_x = 150 \text{ MPa}$

minimum principle $\sigma_y = 50 \text{ MPa}$

$\theta = 55^\circ$

Find

$$\sigma_n = ?$$
$$\tau = ?$$

$$\sigma_n = \frac{\sigma_x + \sigma_y}{2} - \frac{\sigma_x - \sigma_y}{2} \cos 2\theta$$

$$\sigma_n = \frac{150 + 50}{2} - \frac{150 - 50}{2} \cos(2 \times 55)$$

$$\sigma_n = 117.10 \text{ MPa}$$

$$\tau = \frac{\sigma_x - \sigma_y}{2} \sin 2\theta$$

$$\tau = \frac{150 - 50}{2} \sin(2 \times 55)$$

$$\tau = 46.98 \text{ MPa}$$

$$\tau_{max} = \pm \frac{\sigma_x - \sigma_y}{2}$$

$$\tau_{max} = \frac{150 - 50}{2}$$

$$\tau_{max} = 50 \text{ MPa}$$

$$\sigma_R = \sqrt{\sigma_n^2 + \tau^2}$$

$$\sigma_R = \sqrt{(117.10)^2 + (46.98)^2}$$

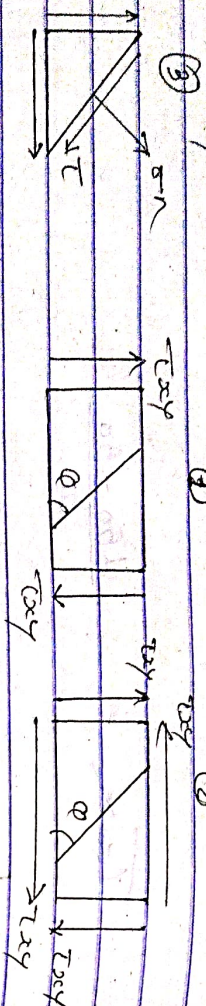
$$\sigma_R = 126.17 \text{ MPa}$$

Direction of Resultant Stress

$$\phi_n = \frac{\tau}{\sigma_n}$$

$$\theta = \tan^{-1} \frac{\tau}{\sigma_n}$$

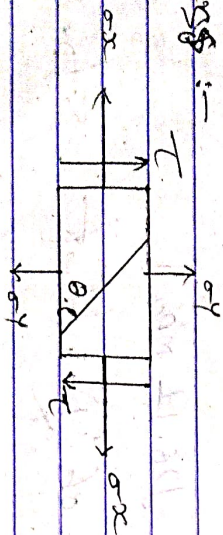
A body subjected to simple shear stress



$$\sigma_n = \tau_{xy} \sin 2\theta$$

$$\tau = -\tau_{xy} \cos 2\theta$$

A body subjected to direct stress into mutual perpendicular direction accompanied by simple shear stress :-



$$\sigma_n = \frac{\sigma_x + \sigma_y}{2} - \frac{\sigma_x - \sigma_y}{2} \cos 2\theta - \tau_{xy} \sin 2\theta$$

$$\tau = \frac{\sigma_x - \sigma_y}{2} \sin 2\theta - \tau_{xy} \cos 2\theta$$

Maximum Principle Stress $\sigma_1 = +$
Minimum Principle Stress $\sigma_2 = -$

$$\sigma_{\text{band 2}} = \frac{\sigma_x - \sigma_y}{2} + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + (\tau_{xy})^2}$$

$$\tan 2\theta_p = \frac{2\tau_{xy}}{\sigma_x - \sigma_y} \quad \text{direction of principle stress}$$

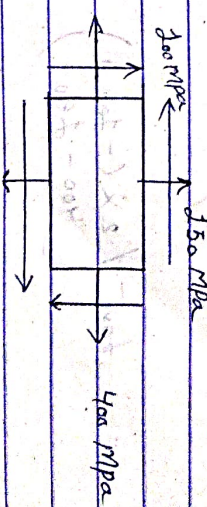
$$\text{max shear stress} = \tau_{\text{max}} = \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + (\tau_{xy})^2}$$

$$\tan 2\theta_s = \frac{\sigma_x - \sigma_y}{2\tau_{xy}} \quad \text{angle } \frac{\tau}{\sigma_n}$$

Q.1 A plan element in a boiler is subjected to a tensile stress of 40 MPa on 1 plan and 150 MPa on the other at right angle to the former each of the above stress is accompanied by a shear stress of 100 MPa such that when associated with the minor tensile stress tends to rotate and anticlockwise direction to find

- The principle stresses and their direction
- Maximum shear stress and the direction of the plan on which they act.

Solution :-



Given $\sigma_x = 400 \text{ MPa}$

$\sigma_y = 150 \text{ MPa}$

$\tau_{xy} = -100 \text{ MPa}$ (anticlockwise)

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

$\sigma_1 = \frac{400 + 150}{2} + \sqrt{\left(\frac{400 - 150}{2}\right)^2 + (-100)^2}$

$\sigma_1 = 435.07 \text{ MPa}$

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

$\sigma_2 = \frac{400 + 150}{2} - \sqrt{\left(\frac{400 - 150}{2}\right)^2 + (-100)^2}$

$\sigma_2 = 114.92 \text{ MPa}$

$\tan 2\theta_P = \frac{2\tau_{xy}}{\sigma_x - \sigma_y}$

$2\theta_P = \tan^{-1}\left(\frac{2 \times (-100)}{400 - 150}\right)$

$\theta_P = -38.65^\circ / 2$

$\sigma_P = -19.32^\circ$

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

$\tau_{max} = \pm \sqrt{\left(\frac{400 - 150}{2}\right)^2 + (-100)^2}$

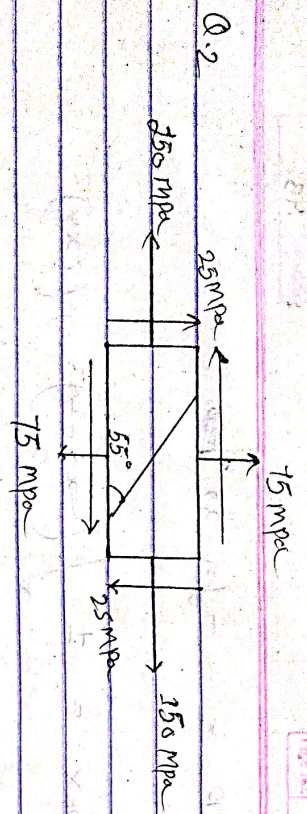
$\tau_{max} = 160.07 \text{ MPa}$

$\tan 2\theta_S = \frac{\sigma_x - \sigma_y}{2\tau_{xy}}$

$2\theta_S = \tan^{-1}\left(\frac{400 - 150}{2 \times (-100)}\right)$

$\theta_S = -51.34^\circ / 2$

$\theta_S = -25.67^\circ$



Solution:-

$$\sigma_x = 150 \text{ MPa}$$

$$\sigma_y = 75 \text{ MPa}$$

$$\tau_{xy} = 25 \text{ MPa}$$

$$\theta = 55^\circ$$

normal stress on $\theta = \frac{\sigma_x + \sigma_y}{2} - \frac{\sigma_x - \sigma_y}{2} \cos 2\theta$

$$\tau_{xy} \sin 2\theta$$

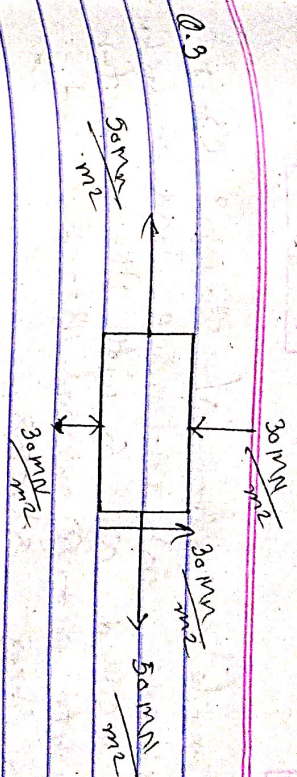
$$\sigma_n = \frac{150 + 75}{2} - \frac{150 - 75}{2} \cos 2(55) - 25 \sin 2(55)$$

$$\sigma_n = 101.83 \text{ MPa}$$

$$\tau = \frac{\sigma_x - \sigma_y}{2} \sin 2\theta - \tau_{xy} \cos 2\theta$$

$$\tau = \frac{150 - 75}{2} \sin 2(55) - 25 \cos 2(55)$$

$$\tau = 43.78 \text{ MPa}$$



Given

$$\sigma_x = 50 \text{ MN/m}^2 \text{ (T)}$$

$$\sigma_y = 30 \text{ MN/m}^2 \text{ (C)}$$

$$\tau_{xy} = -30 \text{ MN/m}^2$$

max principle stress $\sigma_1 \Rightarrow \frac{\sigma_x + \sigma_y}{2} + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$

and min principle stress $\sigma_2 = \frac{\sigma_x + \sigma_y}{2} - \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$

$$\sigma_{\text{max}} = \frac{50 + 30}{2} + \sqrt{\left(\frac{50 - 30}{2}\right)^2 + (-30)^2}$$

$$\sigma_1 = 60 \text{ MN/m}^2 \quad \sigma_2 = -40 \text{ MN/m}^2$$

max shear stress $= \tau_{\text{max}} = \frac{1}{2} \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + (\tau_{xy})^2}$

$$\tau_{\text{max}} = \frac{1}{2} \sqrt{\left(\frac{50 + 30}{2}\right)^2 + (-30)^2}$$

$$\tau_{\text{max}} = \pm 50 \text{ MN/m}^2$$

Q4 A Short metallic column of 500 mm^2 call section area and exerts compressive load of 100 kN for a plane inclined at 60° with the direction of load calculate (1) normal stress and (2) maximum shear stress.

Solution :- given

$$\times \text{Section area (A)} = 500 \text{ mm}^2$$

$$P = -100 \text{ kN}$$

$$P = -100 \times 10^3 \text{ N}$$

$$\theta = 60^\circ$$

$$\sigma = \frac{P}{A}$$

$$\sigma = \frac{-100 \times 10^3}{500}$$

$$\sigma = -200 \frac{\text{N}}{\text{mm}^2}$$

we know that,

$$\sigma_n = \frac{\sigma}{2} (1 - \cos 2\theta)$$

$$\sigma_n = \frac{-200}{2} (1 - \cos 2(60^\circ))$$

$$\sigma_n = -150 \text{ N/mm}^2$$

$$\tau = \frac{\sigma}{2} \sin 2\theta$$

$$\tau = \frac{-200}{2} \sin 2(60^\circ)$$

$$\tau = -86.60 \frac{\text{N}}{\text{mm}^2}$$

$$\tau_{\max} = \frac{\sigma}{2}$$

$$\tau_{\max} = \frac{-200}{2}$$

$$\tau_{\max} = -100 \frac{\text{N}}{\text{mm}^2}$$

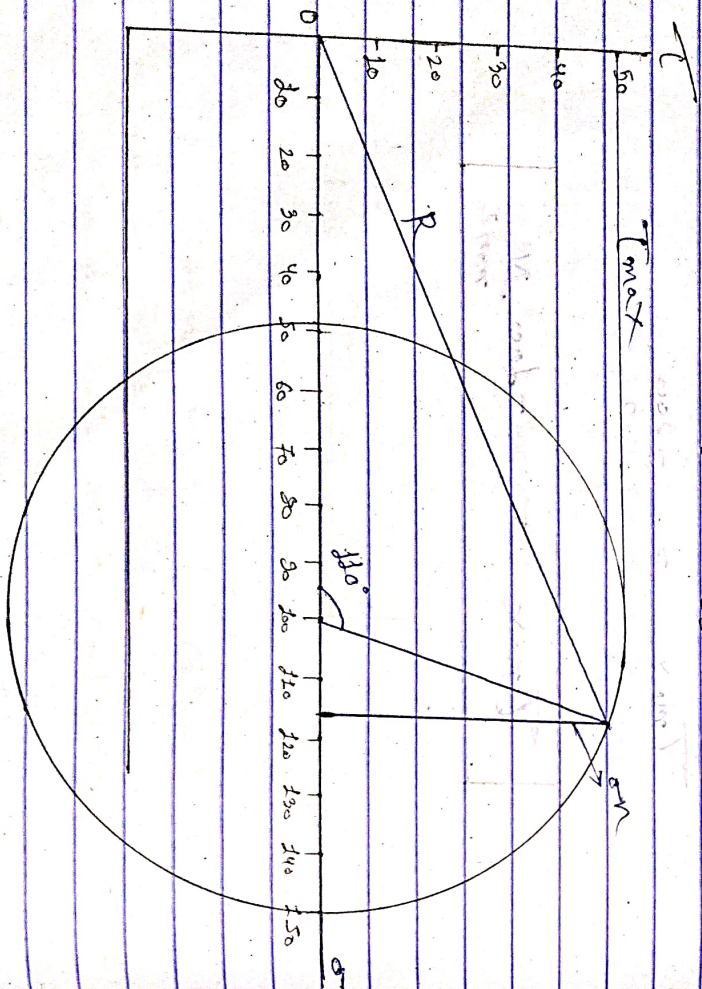
Mohr Circle

48

Q.1 The stress at a point of a machine component are 150 MPa and 50 MPa both tensile. Find the intensity of normal and shear stress on a inclined plane at an angle of 55° with the axis of major tensile stress also find the magnitude of max shear stress in the component.

Solution:- Given $\sigma_x = 150 \text{ MPa}$ (Tensile)
 $\sigma_y = 50 \text{ MPa}$ (Tensile)

$$\theta = 55^\circ$$



$$\text{radius } r = \frac{\sigma_x - \sigma_y}{2}$$

$$r = \frac{150 - 50}{2}$$

$$\text{radius} = 50 \text{ and radius} = 50$$

$$\text{centre of circle} = \frac{\sigma_x + \sigma_y}{2}$$

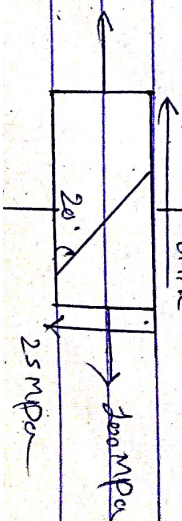
$$= \frac{150 + 50}{2}$$

$$= 100$$

Resultant	= 126 MPa
$\tau =$	47 MPa
$\tau_{\text{max}} =$	± 50 MPa
$\sigma_n =$	117 MPa

Q.2 A plane element in a body is subjected to a tensile stress of 100 MPa accompanied by a clockwise shear stress of 25 MPa. Find (i) normal and shear stress on plane inclined at an angle of 20° with the tensile stress (ii) maximum shear stress on a plane.

Solution:-

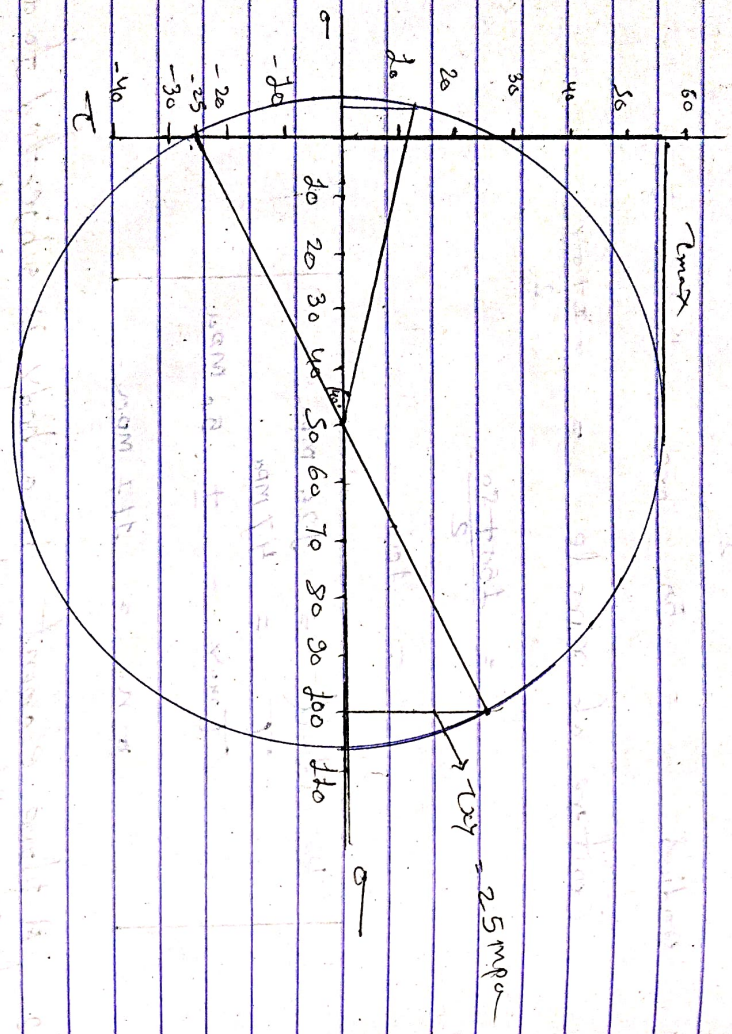


$\sigma_x = 100 \text{ MPa}$ (T)

$\sigma_y = 0 \text{ MPa}$

$\tau_{xy} = 25 \text{ MPa}$

$\theta = 20^\circ$

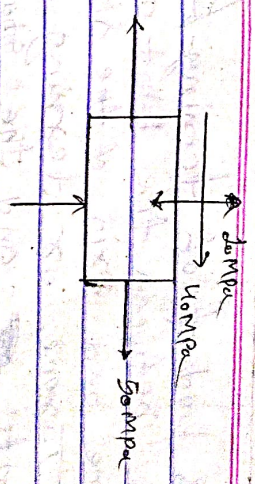


$\tau_{max} = 50.5 \text{ MPa}$

$\tau = 23 \text{ MPa}$

$\sigma_{min} = -5 \text{ MPa}$

Q.2



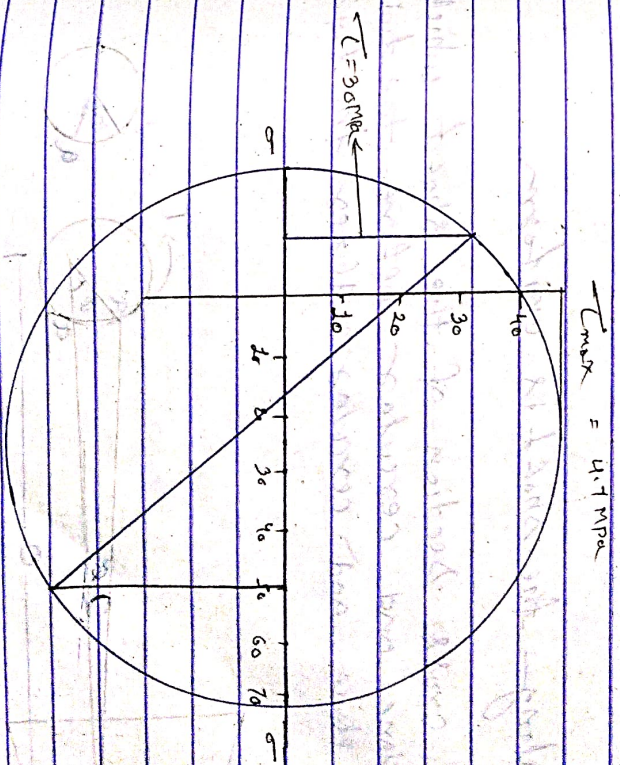
Solution is

Given data

$\sigma_x, \sigma_1 = 100 \text{ MPa}$

$\sigma_y, \sigma_2 = 50 \text{ MPa}$

$\tau_{xy} = 25 \text{ MPa}$



$\tau_{max} = 25 \text{ MPa}$

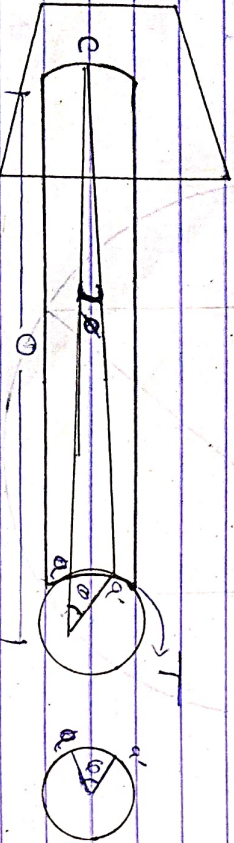
$\sigma_1 = 100 \text{ MPa}$

$\sigma_2 = 50 \text{ MPa}$

Torque :- It is product of turning force and distance between the point of application of the force and axis of the shaft is known as torque. Torque or turning moment or twisting moment and the shaft is best to be subjected to torsion.

Assumptions for shear stress in circular shaft subjected to torsion.

1. material of the shaft is uniform throughout
2. twist along the shaft is uniform
3. normal cross section of the shaft which were plane and circular before the twist remain plane and circular after the twist.



$$T = \text{Torque (N-m)} \Rightarrow J$$

l = length of shaft
 R = Radius of shaft
 τ = shear stress
 θ = twist in degree
 θ in radian
 C = modulus of rigidity
 J = Polar moment of inertia

we know that

$$\frac{T}{J} = \frac{\tau}{r} = \frac{C\theta}{l}$$

$$= \frac{A A'}{l} = \tan \theta$$

$$\frac{A A'}{l} = \theta \quad \left\{ \begin{array}{l} \theta \text{ is small} \\ \tan \theta = \theta \end{array} \right.$$

$$\text{arc } A A' = r \theta$$

$$80 \quad \theta = \frac{A A'}{l} = \frac{r \theta}{l} \quad \text{--- (1)}$$

we know that

$$\tau \propto \theta$$

$$\tau = C \theta$$

$$\theta = \frac{\tau}{C}$$

put θ in eqn (1)

$$\tau = \frac{C \theta}{l}$$

$$\tau = \frac{C \theta}{l}$$

$$\frac{T}{J} = \frac{T}{\rho} = \frac{C_0}{\rho}$$

$$T = \frac{M}{32(d)^4}$$



Now Consider an element of area dA of thickness dx at a distance x .

Area of element $dA = 2\pi x \cdot dx$

Shear stress of this section $T = \text{constant}$

$$\frac{T}{R} = \frac{T_x}{x} \Rightarrow T_x = \frac{T \cdot x}{R}$$

Shear force = Shear stress $\times$ cross section area

$$F = T_x \times 2\pi x \cdot dx$$

$$= \frac{T}{R} \cdot x \times 2\pi x \cdot dx$$

$$\text{Shear force} = \frac{2\pi T x^2 \cdot dx}{R}$$

Turning moment at this element

$$dT = \text{Shear force} \times \text{Radial distance}$$

$$= \frac{2\pi T x^2}{R} dx \times x$$

$$dT = \frac{2\pi T x^3}{R} dx$$

for shear torque integrate above eqn b/w 0 and R

$$\int_0^T dT = \int_0^R \frac{2\pi T x^3}{R} dx$$

$$\left[T \right]_0^T = \frac{2\pi T}{R} \left[\frac{x^4}{4} \right]_0^R$$

$$\left[T - 0 \right] = \frac{2\pi T}{R} \left[\frac{R^4}{4} - \frac{0^4}{4} \right]$$

$$T = \frac{2\pi T}{R} \times \frac{R^4}{4} \Rightarrow \frac{2\pi T R^3}{4}$$

$$\left\{ \therefore R = \frac{d}{2} \right\}$$

$$T = \frac{2\pi T \left(\frac{d}{2} \right)^3}{4}$$

$$T = \frac{\pi C d^3}{2 \times 8} \Rightarrow T = \frac{\pi C d^3}{16}$$

$$\boxed{T = \frac{16 T}{\pi d^3}} \quad \text{Imp} \quad \left\{ \because \frac{T}{R} = \frac{C \theta}{\rho} \right\}$$

$$\frac{16 T}{\pi d^3} = \frac{C \theta}{\rho} \quad \left\{ \because \rho = \frac{d}{2} \right\}$$

$$\frac{32 T}{\pi d^4} = \frac{C \theta}{\rho}$$

$$\frac{T}{\pi d^4} = \frac{C \theta}{\rho} \quad \left\{ \begin{array}{l} \text{Polar moment of inertia} \\ J = \frac{\pi d^4}{32} \end{array} \right\}$$

$$\frac{T}{J} = \frac{C \theta}{\rho}$$

$$\text{Twistion eqn} \quad \boxed{\frac{T}{J} = \frac{T}{\rho} = \frac{C \theta}{\rho}}$$

Q.1 A Circular shaft of diameter 50mm is required to transmit torque from one shaft another find the safe torque which the shaft can transmit if the shear stress is not to exceed 40 MPa.

Solution :- Given :- $d = 50 \text{ mm}$

$$\frac{50 \times 1 \text{ m}}{1000} = 0.05 \text{ m}$$

$$\tau = 40 \text{ MPa}$$

We know that torque can

$$\frac{T}{J} = \frac{C \theta}{\rho}$$

Applied Right Side eqn

$$\frac{T}{J} = \frac{C \theta}{\rho} \Rightarrow \frac{T}{\frac{\pi d^4}{32}} = \frac{C \theta}{\frac{d}{2}} \Rightarrow T = \frac{\pi C d^3}{32}$$

$$T = \frac{\pi C d^3}{32}$$

$$T = \frac{\pi \times 81.74 \text{ N-m}}{32 \times 1000} = \frac{40 \times 10^6 (50)^3 \times 10^6}{32 \times 1000} \text{ N-m}$$

$$T = 981.74 \text{ N-m}$$

Q.2 A Solid shaft is to transmit a torque of 20 kN-m. If the shear stress is not to exceed 45 MPa. Find the minimum diameter of the shaft.

Solution :- Given $T = 20 \text{ kN-m}$
 $\tau = 45 \text{ MPa}$

$$\frac{T}{J} = \frac{\tau}{r}$$

$$\frac{T}{\frac{\pi d^4}{32}} = \frac{\tau}{\frac{d}{2}} \Rightarrow T = \frac{\pi \tau d^3}{16}$$

$$d^3 = \frac{T \times 16}{\pi \tau}$$

$$d = \sqrt[3]{\frac{20 \times 16 \times 10^3}{\pi \times 45 \times 10^6}} \quad (\text{or}) \quad \left(\frac{10 \times 16 \times 10^3}{\pi \times 45 \times 10^6} \right)^{1/3}$$

$$d = 0.104 \text{ m}$$

Q.3 A Hollow shaft of External and internal diameter of 80mm and 60mm is required to transmit torque from one end to another what is the safe torque it can be transmit if the alloy steel is 45 MPa

Solution :- Given :- $d(\text{external}) = 80 \text{ mm}$
 $d(\text{internal}) = 60 \text{ mm}$
 $\tau = 45 \text{ MPa}$

$$k = \frac{d_i}{d_o} = \frac{60}{80} \quad \boxed{k = 0.75}$$

$$T = \frac{\pi \tau d_o^3}{32} (1 - k^4) \quad \boxed{\text{Hollow shaft to transmit}}$$

$$k = \frac{d_i}{d_o}$$

$$T = \frac{\pi \tau d_o^3}{32} (1 - k^4)$$

$$T = \frac{45 \times 10^6 \times \pi \times (80)^3}{32 \times (10)^3} (1 - 0.75^4)$$

$$T = 89.461 \text{ kN} \quad , \quad 89461.75 \text{ N-m} \quad \boxed{\text{Ans}}$$

Power transmitted by the shaft

$$P = \text{Power} = \frac{2\pi NT}{60} \text{ watt}$$

$$N = \text{rpm} \quad , \quad T = \text{N-m}$$

Q.4 A circular shaft of diameter 60mm is running at 150 RPM If the shear stress is not to exceed 50 MPa find the power which can be transmitted by the shaft.

Solution:- Given :- $d = 60\text{mm}$
 $N = 150\text{ RPM}$

$$\frac{T}{C} = \frac{\tau}{r} = \frac{50\text{MPa}}{30}$$

$$\tau = \frac{50 \times 30}{C}$$

$$T = \frac{\pi \tau d^3}{16}$$

$$T = \frac{\pi \times 50 \times 10^6 \times (60)^3}{16 \times (1000)^3}$$

$$T = 2120.57 \text{ N-m}$$

$$\therefore \text{Power} = \frac{2\pi NT}{60}$$

$$P = \frac{2 \times \pi \times 150 \times 2120.57}{60}$$

$$P = \frac{33309.83 \text{ watt}}{1000} = 33.309 \text{ kWatt}$$

Q.5 A solid circular shaft of 60mm diameter is transmitting 20 kWatt at a 150 RPM find the intensity of shear stress in the shaft.

Solution:- Given :- $d = 60\text{mm}$
 $\text{Power} = 20 \text{ kWatt}$
 $N = 150 \text{ RPM}$

$$\frac{T}{C} = \frac{\tau}{r} = \frac{P \times 60}{2\pi N}$$

$$\tau = \frac{P \times 60}{2\pi N \times C}$$

$$P = \frac{2\pi NT}{60} \Rightarrow T = \frac{P \times 60}{2\pi N}$$

$$T = \frac{20 \times 60 \times 10^3}{2 \times \pi \times 150} \quad T = 7639.43 \text{ N-m}$$

$$T = \frac{\tau \times d}{16} \Rightarrow \tau = \frac{7639.43 \times 16 \times 1000^3}{\pi \times (60)^3}$$

$$T = \frac{38307297.5 \text{ N}}{1000}$$

$$T = 38.307297 \text{ MPa}$$

Q.6 A shaft is transmitting power at 80 RPM If the shear stress is not to exceed 60 MPa and internal dia is 0.6 of the external diameter find the diameter of shaft

Solution :- Given by $P = 200 \text{ kW}$
 $N = 80 \text{ rpm}$

$$\tau = 60 \text{ MPa}$$

$$K = \frac{d_i}{d_o} = 0.6$$

$$\tau = ? \quad d = ?$$

$$\therefore P = \frac{200 \text{ kNT}}{60} \Rightarrow \tau = \frac{P \times 60}{200 \text{ N}}$$

$$\tau = \frac{200 \times 10^3 \times 60}{200 \times 80} \Rightarrow \tau = 23873.24 \text{ N-m}$$

$$\therefore \tau = \frac{T}{J} \frac{16}{d_o^3 \pi (1-K^4)}$$

$$d_o^3 = \frac{16T}{\pi \tau (1-K^4)}$$

$$d_o = \sqrt[3]{\frac{16 \times 23873.24}{\pi \times 60 \times 57 \times (1-0.6^4)}}$$

$$d_o = 0.13 \text{ m}$$

$$\frac{d_i}{d_o} = 0.6 \Rightarrow d_i = 0.6 \times 0.13$$

$$d_i = 0.078 \text{ m}$$

Q.7 A solid steel shaft has to transmit power at 800 rpm taking allowable shear stress as 70 MPa. Find the suitable diameter of the shaft the maximum torque transmitted in each revolution Exceed the mean by 20%.

Solution :- Given :-

$$P = 200 \text{ kW}, \quad \tau = 70 \text{ MPa}$$

$$N = 160 \text{ rpm}, \quad \tau = ? \quad d = ?$$

$$\therefore P = \frac{200 \text{ kNT}}{60} \Rightarrow \tau = \frac{P \times 60}{200 \text{ N}}$$

$$\tau_{\text{min}} = \frac{200 \times 10^3 \times 60}{200 \times 160} \Rightarrow \tau_{\text{min}} = 5968.31 \text{ N-m}$$

$$\tau_{\text{max}} = \tau_{\text{minimum}} + \tau_{\text{min}} \times 20\%$$

$$\tau_{\text{max}} = 5968.31 + 5968.31 \times 20\%$$

$$\tau_{\text{max}} = 7161.972 \text{ N-m}$$

$$\therefore \tau = \frac{16T}{\pi d^3} \Rightarrow d^3 = \frac{16 \tau_{\text{max}}}{\pi \tau}$$

$$d = \left(\frac{16 \times 7161.972}{\pi \times 70 \times 10^6} \right)^{1/3}$$

$$d = 0.080 \text{ m}$$

$$d = 80 \text{ mm}$$

Q.2 Calculate the max length of shaft of 425 mm diameter can transmit if max angle of twist is 1° in a length of 1.5 m take $C = 70 \text{ GPa}$

Solution :- Given :-

$$d = 425 \text{ mm} = 0.425 \text{ m}$$

$$\theta = 1^\circ$$

$$\text{Modulus of rigidity } C = 70 \text{ GPa} = 70 \times 10^9 \frac{\text{N}}{\text{m}^2}$$

$$\text{Polar moment of inertia } J = \frac{\pi}{32} d^4$$

$$\text{angle of twist} = 1^\circ$$

$$= \frac{\theta \times J}{180} = 0.0774$$

$$= J / 180$$

$$J = \frac{\pi}{32} d^4$$

$$J = \frac{\pi}{32} \times (0.425)^4$$

$$\frac{T}{J} = \frac{\tau}{r} = \frac{C\theta}{l}$$

$$\frac{T}{\frac{\pi}{32} d^4} = \frac{70 \times 10^9 \times \frac{1}{180} \times \frac{\pi}{32} \times (0.425)^4}{1.5}$$

$$T = 19521.99 \text{ N-m}$$

$$T = 19521.99$$

find the maximum torque

$$T = 19.52 \text{ kNm}$$

A Solid shaft 425 mm diameter is required to transmit 200 kW at 200 RPM. If the angle of twist is not to exceed 2° find the length of the shaft take modulus of rigidity for the shaft is 70 GPa.

Solution :- given :- $d = 120 \text{ mm}$
 $= .12 \text{ m}$

$N = 1600 \text{ rpm}$

$P = 200 \text{ kW}$

$G = 80 \text{ GPa} = 80 \times 10^9 \frac{\text{N}}{\text{m}^2}$

$\phi = 20 = 2 \times \frac{\pi}{180} = \frac{\pi}{9}$

$l = ?$

$P = \frac{2\pi NT}{60}$

$P = \frac{2\pi \times 1600 \times T}{60}$

$200 \times 1000 = \frac{2\pi \times 1600 \times T}{60}$

$T = \frac{60 \times 200 \times 1000}{2\pi \times 1600}$

$T = 119098.59 \text{ N}\cdot\text{m}$

$\frac{T}{J} = \frac{\phi}{l} \left[J = \frac{\pi}{32} \times (d)^4 \right] \left[\phi = \frac{\theta}{2} \right]$

$\frac{119098.59}{\frac{\pi}{32} (120)^4} \times \frac{20 \times 10^{-3} \times 2 \times \pi \times 1180}{l}$

$l = \frac{20 \times 10^3 \times 2 \times \pi \times 1180}{\frac{\pi}{32} (120)^4} \times \frac{\pi}{32} (120)^4$

$l = 3.3486 \text{ m}$

Q. Find the max torque that can be safely applied to a shaft of 80mm diameter permissible angle of twist 18.45° in a length of 5m and shear stress not to exceed $42 \frac{\text{N}}{\text{mm}^2}$

Take $C = 84 \times 10^3 \frac{\text{N}}{\text{mm}^2}$

Solution :- given :-

$C = \frac{84 \times 10^3 \text{ N}}{\text{mm}^2} = 84 \times 10^3 \frac{\text{N}}{\text{mm}^2}$

angle $(\theta) = 18.5^\circ = 18.5 \times \frac{\pi}{180}$

$d = 80 \text{ mm} = 0.08 \text{ m}$

$l = 5 \text{ m} = 5000 \text{ mm}$

Find Torque = ?

$$\frac{T}{J} = \frac{T}{R}$$

$$\frac{T}{32} = \frac{42 \times 90}{2}$$

$$T = \frac{42 \times 2 \times \frac{T}{32} \times (80)^4}{(80)}$$

$$T = 4222.300, 926 \text{ N-mm}$$

$$= 4222.300 \text{ KN-mm}$$

$$\frac{T}{J} = \frac{T}{r}$$

$$= \frac{4222.300}{32} = \frac{84 \times 10^3 \times 1.5 \times \frac{T}{180}}{5000}$$

$$T_{max} = \frac{84 \times 10^3 \times 1.5 \times \frac{T}{180} \times \frac{T}{32} (80)^4}{5000}$$

$$T_{max} = 1768639.109 \text{ N-mm} \Rightarrow 1768 \text{ KN-mm}$$

Q.2 Find the angle of twist per meter length of hollow shaft of 100mm external and 60mm internal diameter of the shear stress not to exceed 35 mpa and take $C = 85 \text{ GPa}$.

Solution:- Given :-

d_o length = 100mm
 d_i = 60mm

$\tau = 35 \text{ mpa}$
 $C = 85 \text{ GPa}$

angle $\theta = ?$

we know that

$$\frac{T}{J} = \frac{T}{r} = \frac{G\theta}{L}$$

$$\text{Taking } \left[\frac{T}{J} = \frac{T}{r} \right] \left[d = \frac{d}{2} \right]$$

$$\frac{T}{J} = \frac{T}{r} \Rightarrow \frac{T}{32} = \frac{35 \times 10^6 \times 2}{\frac{T}{32} (d_o - d_i)}$$

$$\Rightarrow T = \frac{35 \times 10^6 \times 2 \times 100}{2 \times (100^4 - 60^4)}$$

$$\Rightarrow 5981.5924 \text{ N} = \text{mm} \Rightarrow 5981592.412 \text{ N-mm}$$

$$\Rightarrow 5981.59 \text{ N-mm} \Rightarrow 5981.59 \text{ N-mm}$$

$$Q = ?$$

$$\frac{T}{J} = \frac{G\theta}{L}$$

$$\frac{5981.59}{32(0.1^4 - 0.06^4)} = \frac{85 \times 10^9 \times \theta}{1}$$

$$\theta = \frac{5981.59 \times 1}{32(0.1^4 - 0.06^4)} \times 85 \times 10^9$$

$$\theta = 0.00823 \text{ Radian}$$

$$\theta = 0.4715^\circ$$

Q. A Solid Circular shaft transmit 75 kW power at 20/3 RPS. Calculate shaft dia if angle twist in the shaft is not to exceed 2° in 200 mm length of shaft 3 shear stress is limited to 50 N/mm² take $G = 80 \times 10^9 \text{ N/mm}^2$

Solution:- $P = 70 \text{ kW}$
 $N = 20/3 \text{ RPM}$

$$Q = \frac{P}{\omega} = \frac{70 \times 10^3}{2\pi \times 20/3} = 1650 \text{ Nm}$$

To find diameter of shaft

$$P = \frac{2\pi NT}{60} \quad [\text{in Sec 60 not used}]$$

$$T = \frac{P}{2\pi N} = \frac{70000 \times 3}{2\pi \times 20}$$

$$\frac{T}{J} = \frac{G\theta}{L} \Rightarrow \frac{16T}{\pi d^3} = \frac{85 \times 10^9 \times 0.00823}{1} \Rightarrow d^3 = \frac{16T}{\pi \times 85 \times 10^9 \times 0.00823}$$

$$d = \sqrt[3]{\frac{16 \times 3580.98}{\pi \times 85 \times 10^9}}$$

$$d = 0.071 \text{ m}$$

$$\frac{T}{J} = \frac{C\theta}{L} \Rightarrow \frac{2T}{d^3} = \frac{C\theta}{L}$$

$$d = 2T \times L$$

$$\Rightarrow 2 \times 50 \times 10^9 \times 0.2$$

$$d = 0.114 \text{ m}$$

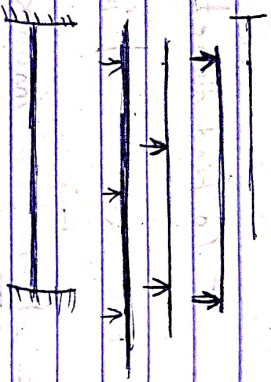
$$d = 114.59 \text{ mm}$$

Ans

SMD and BMD Diagram

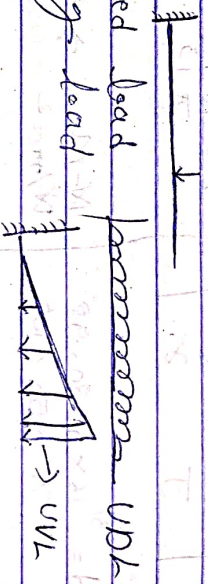
Types of beam

- 1) Cantilever beam
- 2) Simply supported beam
- 3) Overhanging beam
- 4) Continuous beam
- 5) Fixed beam



Types of load

- 1) Point load
- 2) Uniformly distributed load
- 3) Uniformly varying load



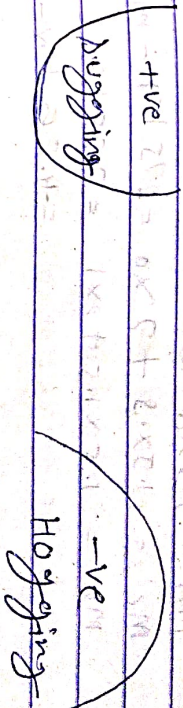
Shear force :- Shear force at the cross section of beam is define as the unbalance vertical force to the right or left of the section

Bending moment :- Bending moment at the cross section of beam is define as the algebraic sum of the moments of the force to the right or left of the section.

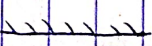


-ve Shear

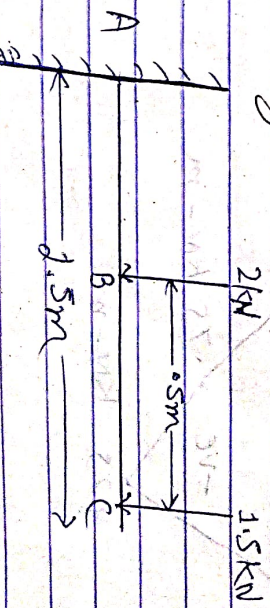
+ve Shear



(1) A cantilever beam



at Draw the shear force and bending moment diagram for a cantilever beam of span 1.5 carrying point load 2kN and 1.5kN shown figure.



Solution :-

Given :-

$$f_B = 1.5$$

$$f_C = 3.5$$

$$f_A = 3.5$$

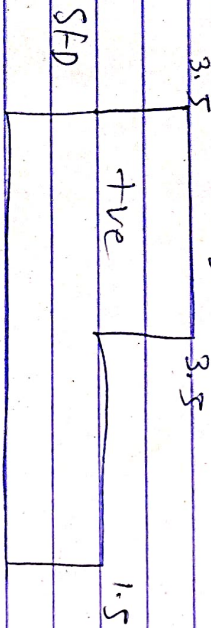
(BM) Bending moment

$$M_B = 1.5 \times 0 = 0$$

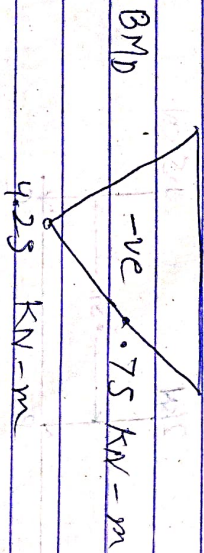
$$M_C = 1.5 \times 3.5 + 2 \times 0 = 5.25 \text{ KN-m}$$

$$M_A = 1.5 \times 1.5 + 2 \times 1 = 4.25 \text{ KN-m}$$

Shear force diagram (SFD)

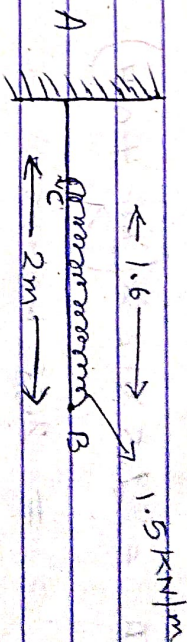


BMD Bending moment diagram



Solution :-

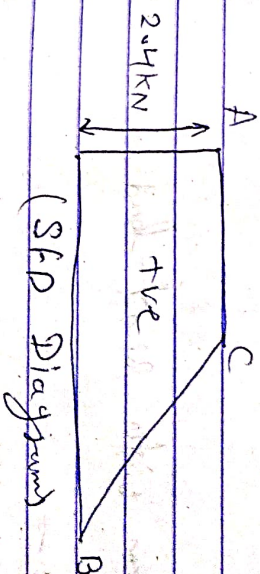
Q2 A cantilever beam AB 2m long carries a u.n.l. load of 1.5 kN/m over a length of 1.6m from the free end draw SFD and BMD for the beam?



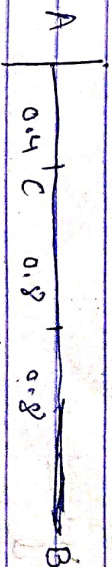
$$Sf_B = 1.5 \times 0 = 0$$

$$Sf_C = 1.5 \times 1.6 = 2.4 \text{ kN}$$

$$Sf_A = 1.5 \times 1.6 = 2.4 \text{ kN}$$



Bending moment diagram (BMD)



$$BM_B = 0$$

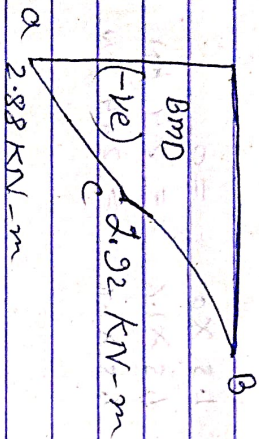
$$BMC = w \times l \times \frac{l}{2}$$

$$= 1.5 \times 1.6 \times \frac{1.6}{2}$$

$$= 1.92 \text{ KN-m}$$

$$BMA = 1.5 \times 1.6 \times \left(\frac{1.6}{2} + 0.4 \right)$$

$$= 2.88 \text{ KN-m}$$



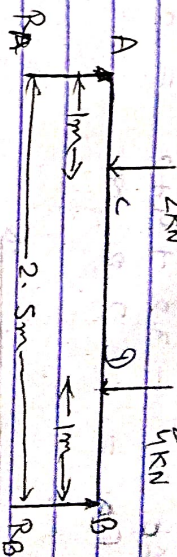
Simply supported beam with point load

formula :-

$$R_A = \frac{w \times l}{2}$$

$$R_B = \frac{w \times l}{2}$$

Q. A simply supported beam of span 2.5 m is carry to point load shown in figure. Draw SFD and BMD



Solution :-

$$\sum F_y = 0$$

$$R_A + R_B = 2 + 4 = 6 \text{ kN} \quad \text{--- (1)}$$

$$\sum M_x = 0$$

$$R_A \times 2.5 - 4 \times 1.5 - 2 \times 1 = 0$$

$$R_B \times 2.5 - 4 \times 1.5 + 2 \times 1 = 0$$

$$R_B = \frac{8}{2.5} = 3.2 \text{ kN}$$

Now put value eq(1)

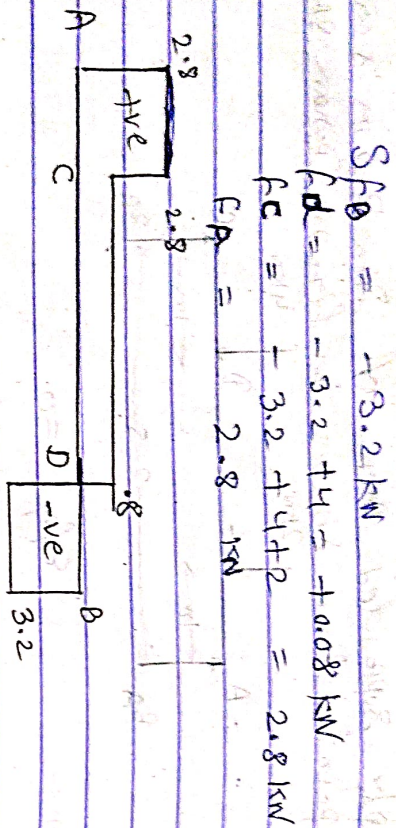
$$R_A + R_B = 6$$

$$R_A + 3.2 = 6$$

$$R_A = 6 - 3.2$$

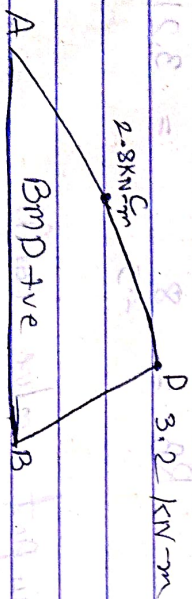
$$R_A = 2.8 \text{ kN}$$

Values calculated for SFD and BMD



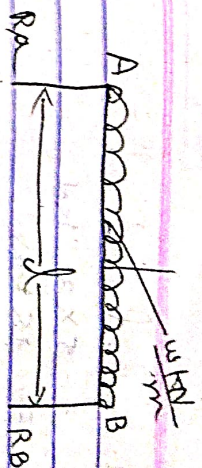
values substituted for BMD

$M_B = 0$
 $M_D = 3.2 \times 1 - 4 \times 0 = 3.2$
 $M_C = 3.2 \times 1.5 - 4 \times 1.5 = 2.8$
 $M_A = 3.2 \times 2.5 - 4 \times 1.5 - 2 \times 1 = 0$



Anticlockwise = +ve
 Clockwise = -ve

for Bending moment



$\sum F_y = 0$

$R_A + R_B = wl$

$\sum \text{Comp} = 0$

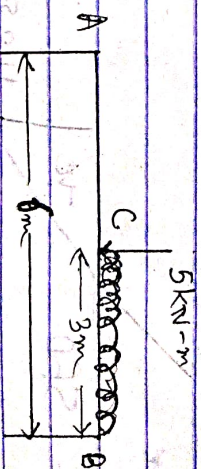
$R_B \times l - w \times l \times \frac{l}{2} = 0$

$R_B \times l = \frac{wl^2}{2}$

$R_B = \frac{wl}{2}$

A simply supported beam 6m long is carrying uniformly distributed load of 5 kN/m over its entire length. Draw the shear force and bending moment diagrams for the beam and also calculate the maximum bending moment on the section.

Solution :-



$R_A + R_B = \text{wL}$

$$R_A + R_B = 5 \times 3 \text{ kN} = 15 \text{ kN}$$

→ Taking moment about A

$$R_B \times 6 - 5 \times 3 \times \left(\frac{3}{2} + 3 \right) = 0$$

$$R_B = 11.25 \text{ kN}$$

Putting the value of R_B in eqn ①

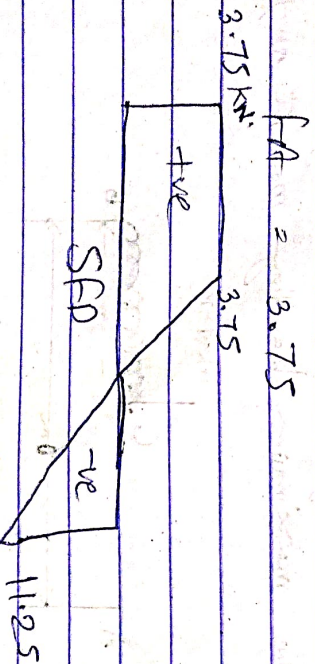
$$R_A = 15 - 11.25 = 3.75 \text{ kN}$$

Calculate the value for SF

$$F_B = -11.25$$

$$F_{CB} = -11.25 + 15 = 3.75$$

$$F_A = 3.75$$



Calculate the value for BM

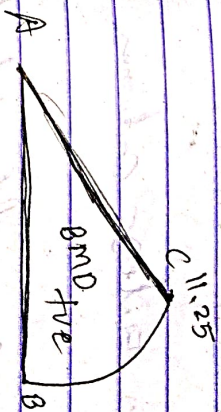
$$B_{MA} = 0$$

$$B_{MB} = 0$$

$$B_{MC} = 11.25 \times 3 \times \frac{1}{2} \times \frac{1}{2} = 11.25 \times 3 - 5 \times 3 \times \frac{3}{2}$$

$$= 11.25 \times 3 - 15 \times 1.5$$

$$= 11.25 \text{ kNm}$$



Column and strut

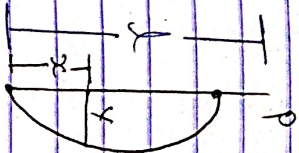
Strut:- A structural member subjected to an axial compressive force is called a strut. Strut may be horizontal, vertical, or inclined.

Column:- A vertical strut used in building or frame is called column.

Theory Assumptions in Euler column

- 1) Initially the column is perfectly straight and load applied evenly axial
- 2) Cross section of the column is uniform through out the length
- 3) Column material is perfectly elastic homogeneous and isotropic and there are no loads or moments
- 4) The failure of column occurs due to buckling only

Column with both ends hinged



$P =$ Critical load
 $y =$ Deflection of the column at x

$$M = Px$$

$$EI \frac{d^2 y}{dx^2} = -Px$$

$$EI \frac{d^2 y}{dx^2} + Px = 0$$

$$EI \frac{d^2 y}{dx^2} = M$$

The general solution of above differential is

$$y = A \cos \left(x \sqrt{\frac{P}{EI}} \right) + B \sin \left(x \sqrt{\frac{P}{EI}} \right)$$

$$A \cos x \sqrt{\frac{P}{EI}} = 0$$

$$x=0, y=0, A=0$$

$$x=l, y=0$$

$$0 = B \sin l \sqrt{\frac{P}{EI}}$$

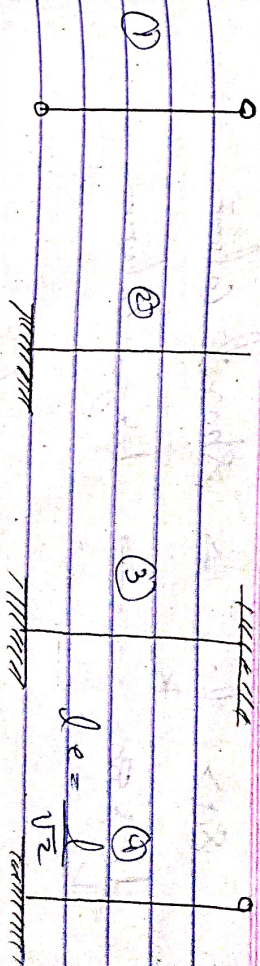
$$\sin l \sqrt{\frac{P}{EI}} = 0$$

$$0, \pi, 2\pi, 3\pi$$

$$\frac{y}{EI} = \frac{P}{EI} = \pi$$

$$\frac{P}{EI} = \frac{\pi^2}{l^2}$$

$$P = \frac{\pi^2 EI}{l^2}$$



(1) Both ends hinged (2) one end fixed and other hinged (3) both ends fixed (4) one end fixed and other hinged

(1) $l_e = l$ (2) $l_e = \frac{l}{2}$ (3) $l_e = \frac{l}{2}$ (4) $l_e = \frac{l}{\sqrt{2}}$

$$P = \frac{\pi^2 EI_{\min}}{l_e^2} \quad (1) P = \frac{\pi^2 EI}{l^2} \quad (2) P = \frac{4\pi^2 EI}{l^2} \quad (3) P = \frac{4\pi^2 EI}{l^2} \quad (4) P = \frac{2\pi^2 EI}{l^2}$$

$$(4) P = \frac{2\pi^2 EI}{l^2}$$

$$P = \frac{\pi^2 EI}{l^2}$$

Area of $\sqrt{AK^2}$ Radius of gyration r

$$P = \frac{\pi^2 EAK^2}{l^2}$$

$$= \frac{\pi^2 EA}{\left(\frac{l}{r}\right)^2} \quad \frac{l_e}{r} = \text{Slenderness ratio}$$

80 > $k_e \rightarrow$ Short column
 $k_e < 80 \rightarrow$ Long column

Q A Steel rod 5m long and 4mm diameter is used as a column with one end fixed and other free determine the crippling load by Euler's formula take $E = 200 \text{ GPa}$

Solution :- Given condition one end fixed and other free

$$l_e = 2l$$

$$P = \frac{\pi^2 EI}{4l^2}$$

$$P = \frac{\pi^2 \times 200 \times 10^9 \times 12.56637 \times 10^{-12}}{4 \times 5000^2}$$

$$P = 2.480 \text{ kN}$$

Q A Hollow alloy tube 7m long with external and internal diameters of 40mm and 25mm respectively was found to extend 4.8mm under tensile load of 60kN find the buckling load for the tube with both ends pinned also find the same load on the tube taking factor of safety as 5

Solution :- Given :-

$$d_o = 25 \text{ mm} \Rightarrow 0.025 \text{ m}$$

$$d_i = 40 \text{ mm} \Rightarrow 0.04 \text{ m}$$

$$l = 4 \text{ m} \Rightarrow 4000 \text{ mm}$$

$$\Delta l = 4.8 \text{ mm}$$

$$P = 60 \text{ kN}$$

$$\text{Safety factor} = 5$$

$$P = \frac{\pi^2 EI}{l_e^2}$$

$$I = \frac{\pi}{64} (d_o^4 - d_i^4)$$

$$I = \frac{\pi}{64} (0.025^4 - 0.04^4)$$

$$I = 1.064 \times 10^{-7} \text{ m}^4$$

$$P = \pi^2 \times$$

Q.2 Calculate the safe compressive load on a hollow shaft cast iron column one end fixed and other end hinged of 150mm Extnd dia and 100mm internal diameter and 2m length use Euler formula with a factor of safety 5 and $E = 95 \text{ GPa}$

for solution :- given :- $d_o = 150 \text{ mm} \rightarrow .15 \text{ m}$
 $d_i = 100 \text{ mm} \rightarrow .1 \text{ m}$
 $E = 95 \text{ GPa} \times 10^9$
 $l = 2 \text{ m}$
 Safety = 5

as euler formula

$$\text{Buckling load } P_c = \frac{\pi^2 EI}{l_e^2}$$

for one end fixed and one end hinged

$$P = \frac{2\pi^2 EI}{l^2}$$

$$I = \frac{\pi}{64} (d_o^4 - d_i^4)$$

$$I = \frac{\pi}{64} (.15^4 - .1^4)$$

$$I = 1.994 \times 10^{-5}$$

$$P = \frac{2 \pi^2 \times 95 \times 10^9 \times 1.994 \times 10^{-5}}{10^2}$$

$$P = 373919.8323 \text{ N}$$

$$\text{for } kN = 373.91 \text{ kN}$$

$$\begin{aligned} \text{working stress} &= \frac{373.91}{5} \\ &= 74.782 \text{ ~~N/mm}^2 \end{aligned}~~$$

A solid bar 60 mm in diameter and 2.5 m length is used as a strut one end of the strut is fixed and other is free find the safe load for this strut using Euler formula $E = 200 \text{ GPa}$ and factor is 3

Solution :- given :- $d = 60 \text{ mm } 0.06 \text{ m}$
 $l_e = 2.5$
 $E = 200 \text{ GPa } \times 10^9$
 safety factor = 3
 $l_e = 2l$

we know that Euler formula

$$P = \frac{\pi^2 EI}{4L^2}$$

$$I = 6.362 \times 10^{-5}$$

$$P = \frac{\pi^2 \times 200 \times 10^9 \times 6.362 \times 10^{-5}}{4 \times 2.5^2}$$

$$P = 50224.44 \text{ N}$$

$$P = 50.224 \text{ kN}$$

$$\text{working stress} = \frac{50.22}{3} \times \text{safety factor}$$
$$= 26.74$$

UNIT - 5

Helical Springs

Formula :-

$$\frac{T}{J} = \frac{T}{\rho} = \frac{G\theta}{l}$$

$$\theta = \frac{64WR^2N}{Gd^4}$$

Deflection (S) = $R\theta$

$$S = \frac{64WR^3N}{Gd^4}$$

$$\text{Stored energy} = U = \frac{1}{2} Sw$$

Stiffness = $\frac{W}{S}$

$$S = \frac{Gd^4}{64R^3N}$$

$$T = \frac{dG\tau}{\pi d^3}$$

$$\tau = \frac{16 \times W \times R}{\pi d^3}$$

Q. A Helical Compression Spring is made of 12mm diameter steel wire ~~is~~ wound on a 120mm diameter mandrel. The force must be applied to the spring to elongate it by 40mm. Take mod of Active coil as $G = 82 \text{ GN/m}^2$?

Solution :- Given: Number of Active coil = 40
modulus of rigidity (G) = 82 GN/m^2 (GPa)

Applied load (W) = ?

(R) radius of coil = 120mm

dia of wire (d) = 12mm

Deflection (S) = 40mm

$$S = \frac{64WR^3N}{Gd^4}$$

$$R = \frac{120 + 12}{2} = 132$$

$$R = \frac{132}{2} = 66$$

$$\frac{40}{1000} = \frac{64 \times W \times 0.066^3 \times 10}{82 \times 10^9 \times 0.012^4}$$

$$W = \frac{0.04 \times 82 \times 10^9 \times 0.012^4}{64 \times 0.066^3 \times 10}$$

$$W = 369.64 \text{ N}$$

$$\text{Stiffness} = \frac{W}{S}$$

$$= \frac{389.64}{40} = 9.741 \text{ kN/mm}$$

A closed coil spring is made of 6mm diameter steel rod the coil consist of 10 turns and axial pull of 200N find the maximum shear stress induced in the section of rod if ~~the~~ find Deflection, stiffness and average in the spring

Solution:- Given :- $d = 6\text{mm}$

$$W = 200\text{N}$$

$$C = 80 \text{ GN/cm}^2$$

$$n = 10$$

$$(R) = 60\text{mm}, 6\text{cm}$$

$$S = \frac{64WR^3}{Gd^4}$$

$$S = \frac{64 \times 200 \times 60^3 \times 10}{80 \times 10^9 \times 10^4}$$

$$S = 3.456 \times 10^{-4} \text{ cm}$$

$$U = \frac{1}{2} \times 200 \times 3.456 \times 10^{-4}$$

$$U = 0.034 \text{ N-cm}$$

$$\text{Stiffness} = \frac{W}{S}$$

$$= \frac{200}{3.456 \times 10^{-4}}$$

$$= 578703.70 \frac{\text{N}}{\text{cm}}$$

$$= 578.70 \text{ kN/cm}$$

$$C = \frac{26 \times W \times R}{\pi d^3}$$

$$= \frac{26 \times 200 \times 6}{\pi \times 10^3}$$

$$C = 6111.54 \frac{\text{N}}{\text{cm}^2}$$

$$C = 6.111 \frac{\text{kN}}{\text{cm}^2}$$

Leaf Spring

Formula :-

$$S = \frac{3wl^3}{8Enbt^3}$$

$$\sigma = \frac{3wl}{2nbt^2}$$

w = load acting on the spring

b = width of plate

t = thickness of plate

n = no of plate

E = Young's modulus of elasticity (Elasticity)

σ = bending stress

Q. A leaf spring is to be made of 7 steel plates 65 mm width and 6.5 mm thick. Calculate the length of spring so that it may carry a central load of 2.75 kN. The bending stress limited to 160 mpa. also calculate Deflection at the centre of the spring. $E = 200 \text{ GPa}$

Solution :- given that

modulus of Elasticity = $200 \text{ GPa} = 200 \times 10^9$

No of plates, $n = 7$

width (b) = 65 mm

thickness (t) = 6.5 mm

load (W) = 2.75 kN

bending stress (σ) = 160 mpa

$$S = \frac{3wl^3}{8Enbt^3}$$

$$S = \frac{3 \times 2.75 \times 7.456^3}{8 \times 200 \times 10^9 \times 7 \times 65 \times 6.5^3}$$

$$S = 1.716 \text{ mm}$$

$$S = 0.171 \text{ m}$$

$$\sigma = \frac{3wL}{2nbL^2}$$

$$160 \times 10^6 = \frac{3 \times 2.75 \times L}{2 \times 7 \times 65 \times 6.5^2}$$

$$L = \frac{160 \times 10^6 \times 2 \times 7 \times 65 \times 6.5^2}{3 \times 2.75}$$

$$L = 7.456 \text{ mm} \Rightarrow 0.745 \text{ m}$$

A leaf spring 300mm long is to support a central load 6kN. If the maximum deflection of the spring is not to exceed 5mm and max stress is limited to 300N/mm² calculate the thickness and width of the plate the no of plates and $E = 210 \text{ kN/mm}^2$

Selection:- given

$$\text{modulus of Elasticity} = 210 \text{ kN/mm}^2$$

$$\text{load (w)} = 6 \text{ kN}$$

$$\text{length } L (\text{m}) = 300 \text{ mm} \Rightarrow 0.3 \text{ m}$$

$$\text{Deflection } \delta = 50 \text{ mm} \Rightarrow 0.05 \text{ m}$$

$$\text{max stress } \sigma = 300 \text{ N/mm}^2 \Rightarrow 300 \times 10^6$$

$$\text{no of plate (n)} = 6$$

$$S = \frac{3wL^3}{8EnbL^3}$$

$$50 = \frac{3 \times 6 \times 900^3 \times 10^3}{8 \times 210 \times 10^9 \times 6 \times 10^6 \times 4.5 \times 10^{-6} \times L^3}$$

$$L = \frac{3 \times 6 \times 900^3 \times 10^3}{8 \times 210 \times 10^9 \times 6 \times 10^6 \times 4.5 \times 10^{-6} \times 50}$$

$$L = 5.7857 \text{ mm}$$

$$\sigma = \frac{3wL}{2nbL^2}$$

$$\sigma = 300 \times 10^6$$

$$300 \times 10^6 = \frac{3 \times 6 \times 10^3 \times 10^3}{2 \times 6 \times (b \times L^2)}$$

$$bL^2 = \frac{3 \times 6 \times 10^3 \times 10^3}{2 \times 6 \times 300 \times 10^6}$$

$$bL^2 = 4.5 \times 10^{-6}$$

$$L = 0.0021 \text{ m}$$

$$\sigma = \frac{3wl}{2nb^2t^2} \Rightarrow b = \frac{3wl}{2\sigma t^2}$$

$$b = \frac{3 \times 6 \times 10^3 \times 0.9}{2 \times 6 \times 300 \times 10^6 \times 5.7857^2}$$

$$b = 1.34 \text{ m} \quad 134.4 \text{ mm}$$

A leaf spring 1m long is made up of plates each 5mm wide and 15mm thick the bending stress in the spring is limited to 300mpa how many plates are required to enable the spring to carry a central load of 4kN also calculate the Deflection take $E = 2 \times 10^5 \text{ mpa}$

Solution :- given that

$$L = 1 \text{ m} \quad E = 2 \times 10^5 \text{ mpa} \quad 2 \times 10^5 \times 10^6$$

$$\text{Length} = 1 \text{ m}$$

$$b = 9 \text{ mm} \Rightarrow 0.09 \text{ m}$$

$$t = 15 \text{ mm} \Rightarrow 0.015 \text{ m}$$

$$\sigma = 300 \text{ mpa} \Rightarrow 30 \times 10^6$$

$$W = 4 \text{ kN} \Rightarrow 4 \times 10^3$$

$$S = ?$$

$$N = ?$$

$$\sigma = \frac{3wl}{2nb^2t^2}$$

$$30 \times 10^6 = \frac{3 \times 4 \times 10^3 \times 1}{2 \times n \times 0.09 \times 0.015^2}$$

$$n = \frac{3 \times 4 \times 10^3 \times 1}{2 \times 30 \times 10^6 \times 0.09 \times 0.015^2}$$

$$n = 9.87 \quad \text{Approx} = 10$$

$$S = \frac{3wl^3}{8Embt^3}$$

$$S = \frac{3 \times 4 \times 10^3 \times 1^3}{8 \times 2 \times 10^5 \times 10^6 \times 9.87 \times 0.09 \times 0.015^3}$$

$$S = 2.501 \times 10^{-3} \text{ m}$$

$$S = 2.501 \times 10^{-3} \text{ mm}$$