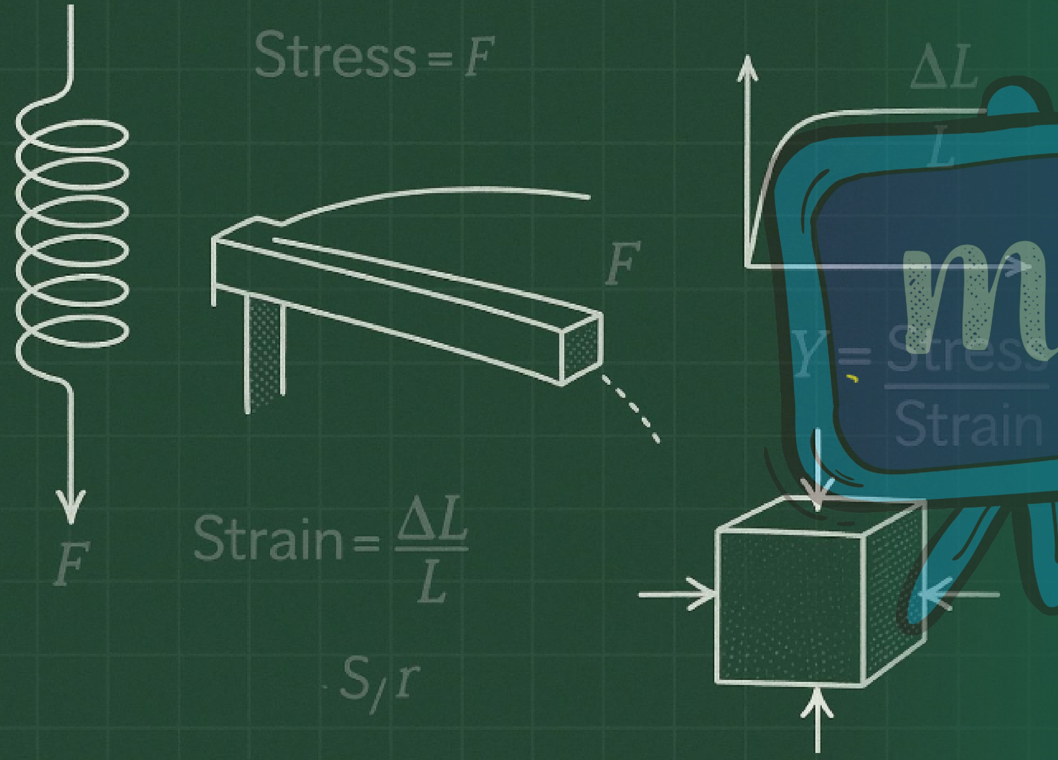


CLASS – 11

PHYSICS

Chapter – 8

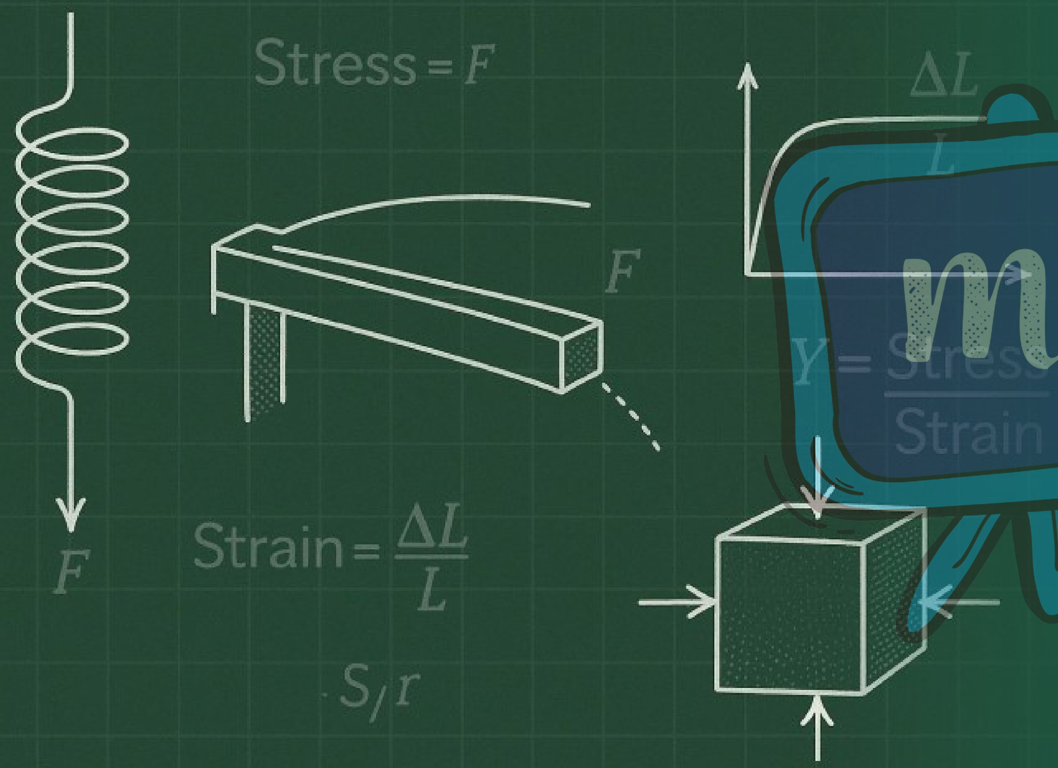
Mechanical Properties of Solid

Part – 3

Stress – Strain Curve

Alok Gaur

OVERVIEW



1. Stress and Strain
2. Elastic Moduli
3. Stress – Strain Curve

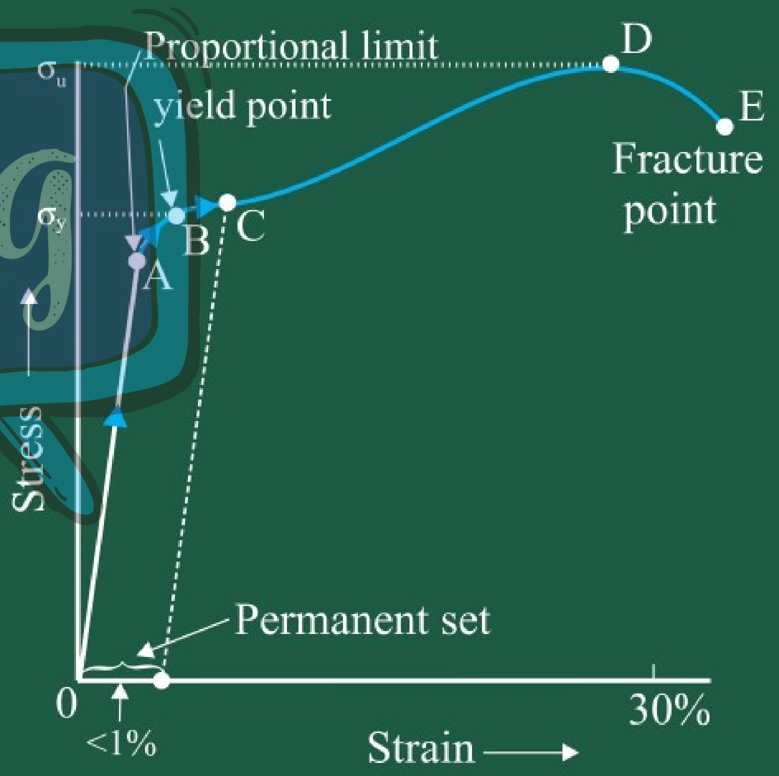
STRESS – STRAIN CURVE

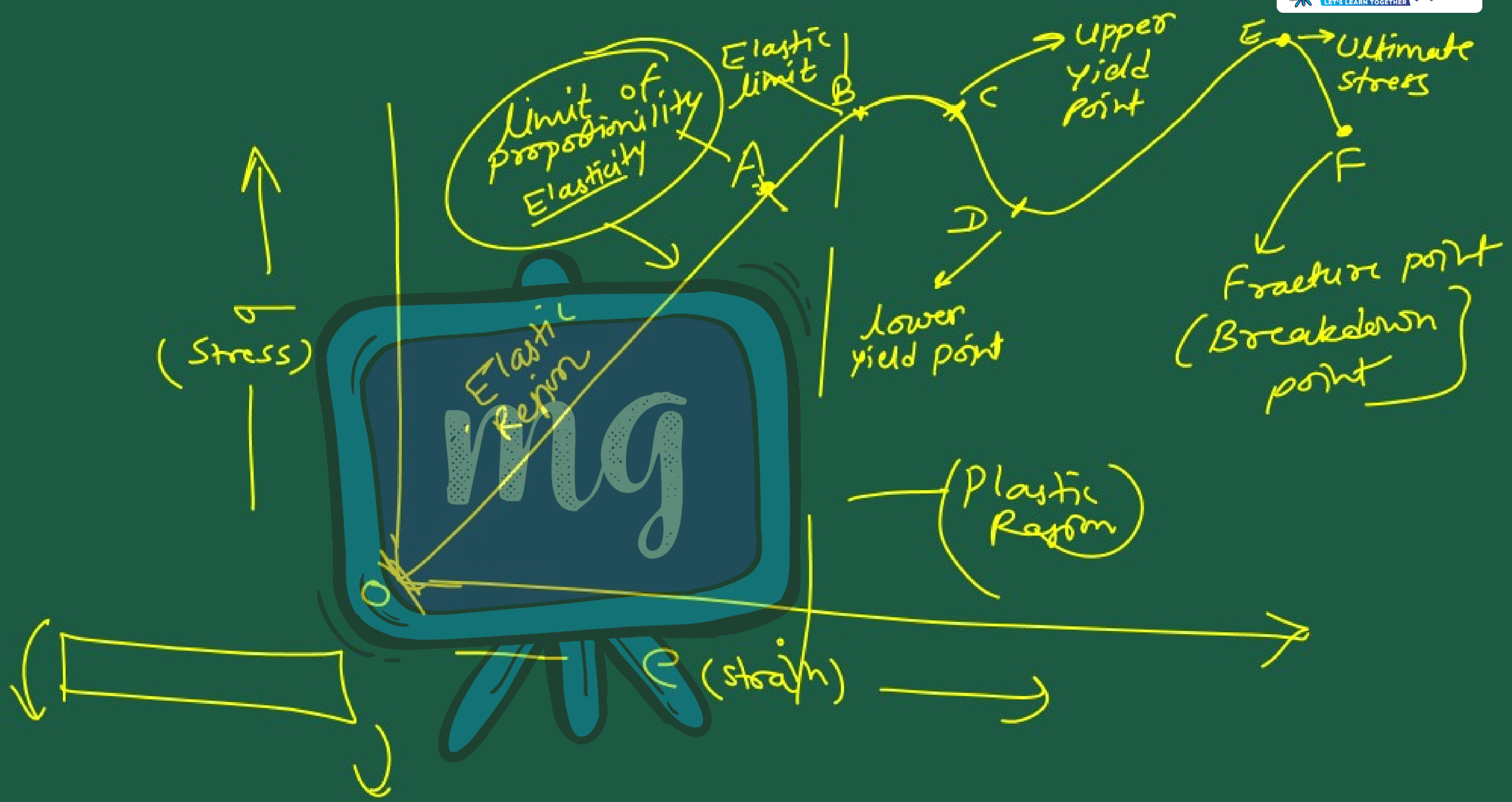
Stress $\propto$ strain

stress $\propto$ strain

$\sigma \propto e$

Under the limit of elasticity



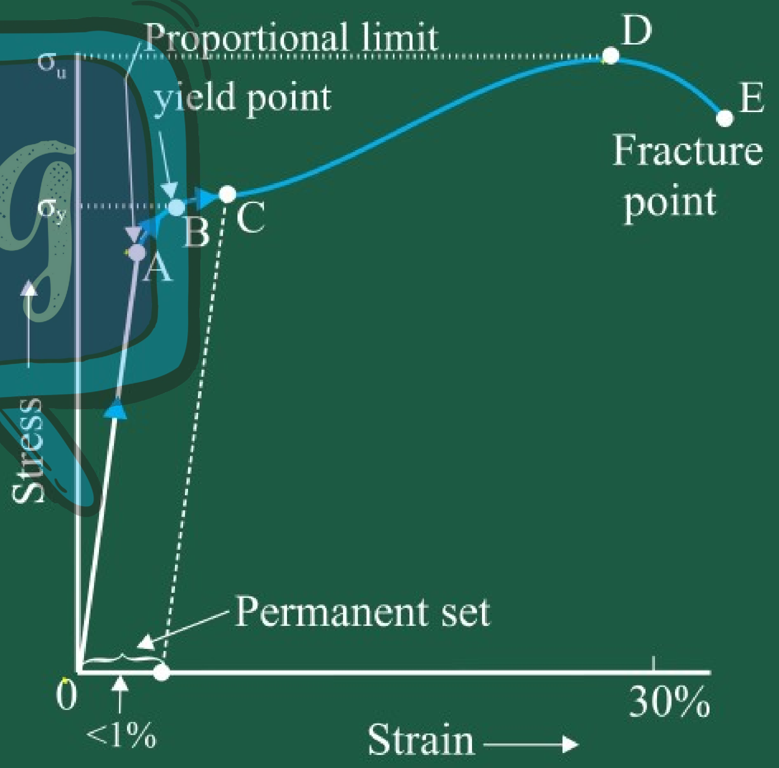

Limit of proportionality
Elasticity
Elastic limit
A
B
C
upper yield point
D
lower yield point
E
Ultimate stress
F
Fracture point
(Breakdown point)
σ
(Stress)
Elastic Region
Plastic Region
O
ϵ (strain)

- The relation between the stress and the strain for a given material under tensile stress can be found experimentally.
- In a standard test of tensile properties, a test cylinder or a wire is stretched by an applied force.
- The fractional change in length and the applied force needed to cause the strain are recorded.

- The applied force is gradually in creased is steps and the change in length is noted.
- A graph is plotted between the stress and the strain produced-where stress is equal in magnitude to the applied force per unit area.

- The stress-strain curves help us to understand how a given material deforms with increasing loads.

FROM THE GRAPH



i. **O A Curve :** We can see that in the region between O to A, the curve is linear. In this region. Hooke's law is obeyed. The body regains its original dimensions when the applied force is removed. In this region, the solid behaves an elastic body.

ii. **AB Curve :** In the region from A to B, stress and strain are not proportional Never the less, the body still returns +a, it's original dimension when the load, is removed. The point B in the curve is known as yield point (also known as elastic limit) and the corresponding stress is known, as yield strength (σ_u) of the material.

iii. **BCD Curve :** If the load is increased further, the stress developed exceeds the yield strength and strain increases rapidly even for a small change in the stress.

The portion of the curve between B and D shows this. When the load is removed, say at some point C and B and D, the body does not regain its original dimension.

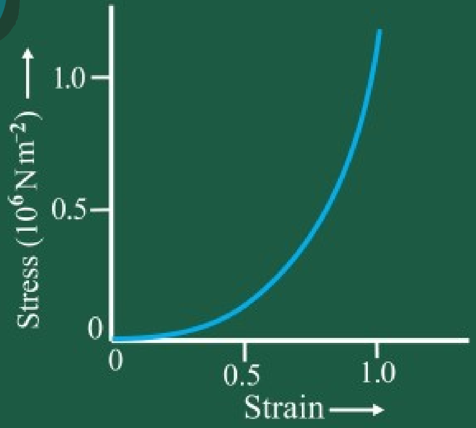
In this case, even when the stress is zero, the strain is not zero. The material is said to have a permanent set. The deformation is said to be plastic deformation. The point D on the graph is the ultimate tensile strength (σ_u) of the material.

iv. **DE Curve :** Beyond pint D, additional strain is produced even by a reduced applied force and fracture occurs at point E. Breakdown point

If the ultimate strength and fracture points D and E are close, the material is said to be brittle.

If they are for apart, the material is said to be ductile.

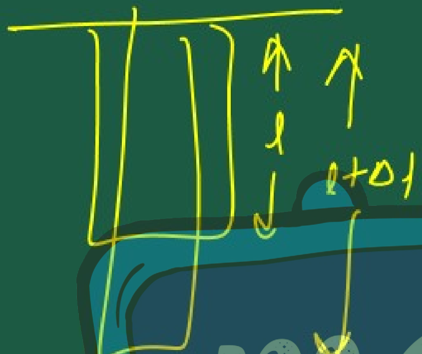
- As started earlier, the stress-strain behavior varies from material to material, for example, rubber can be pulled to servel times its original length and still returns to its original shape.



- Substances like tissue of aorta, rubber etc. which can be stretched to cause large strains are called elastomers.

ELASTIC POTENTIAL ENERGY IN A STRETCHED WIRE

- When a wire is stretched interatomic force come into play which oppose the change. Work has to be done against these restoring forces. The work done is stretching the wire is stored in it as its elastic potential energy.



$F_{initial} = 0$

$F_{final} = F$

$F_{avg} = \frac{F+0}{2}$

$= F/2$

$W = F_{avg} \times \Delta l$

$W = \frac{F}{2} \Delta l$

$W = U$

$U = \frac{F}{2} \Delta l$

$Y = \frac{F l}{A \Delta l}$

$F = \frac{Y A \Delta l}{l}$

$U = \frac{Y A \Delta l}{2 l}$

$U = \frac{F l}{2} \frac{\Delta l}{l}$

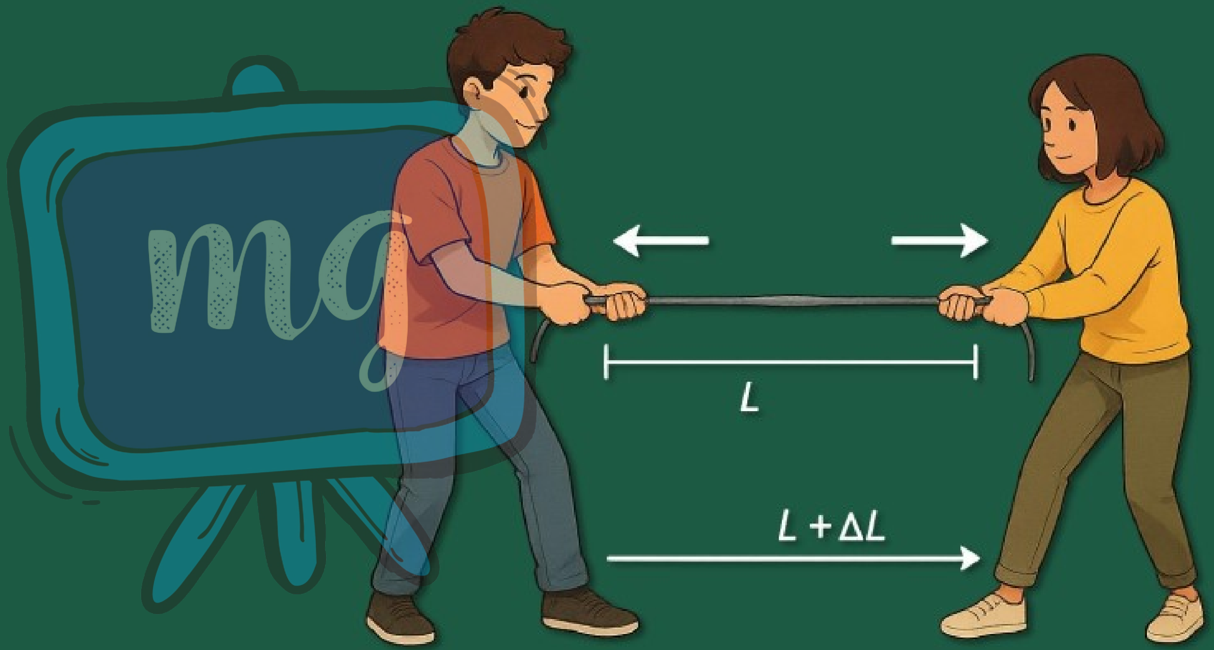
$U = \frac{F l}{2} \times strain$

$= \frac{F l A}{2 A} \times strain$

$U = \frac{Stress \times Vol \times strain}{2}$

$\frac{U}{Volume} = \frac{1}{2} \times stress \times strain$

$U = \frac{1}{2} \sigma e$


L
L + ΔL

- Suppose a force F applied on a wire of length increases it's length by Δl. Initially, the internal restoring force in the wire is zero.
- When the length is increased by Δl, the internal force increases from zero to F.

Average internal force $= \dfrac{0 + F}{2} = \dfrac{F}{2}$

Work done

w = Average force × increase in length

$$= \frac{F}{2} \times \Delta l$$

$$\text{P.E. } u = \frac{1}{2} . F\Delta l$$

$$= \frac{1}{2} \times \text{stretching force} \times \text{increasing in length}$$

$$U = \frac{1}{2} \frac{F}{A} \frac{\Delta l}{l} \times Al$$

$$= \frac{1}{2} \text{ stress} \times \text{strain} \times \text{volume of wire}$$

Elastic energy density $u = \frac{U}{V}$

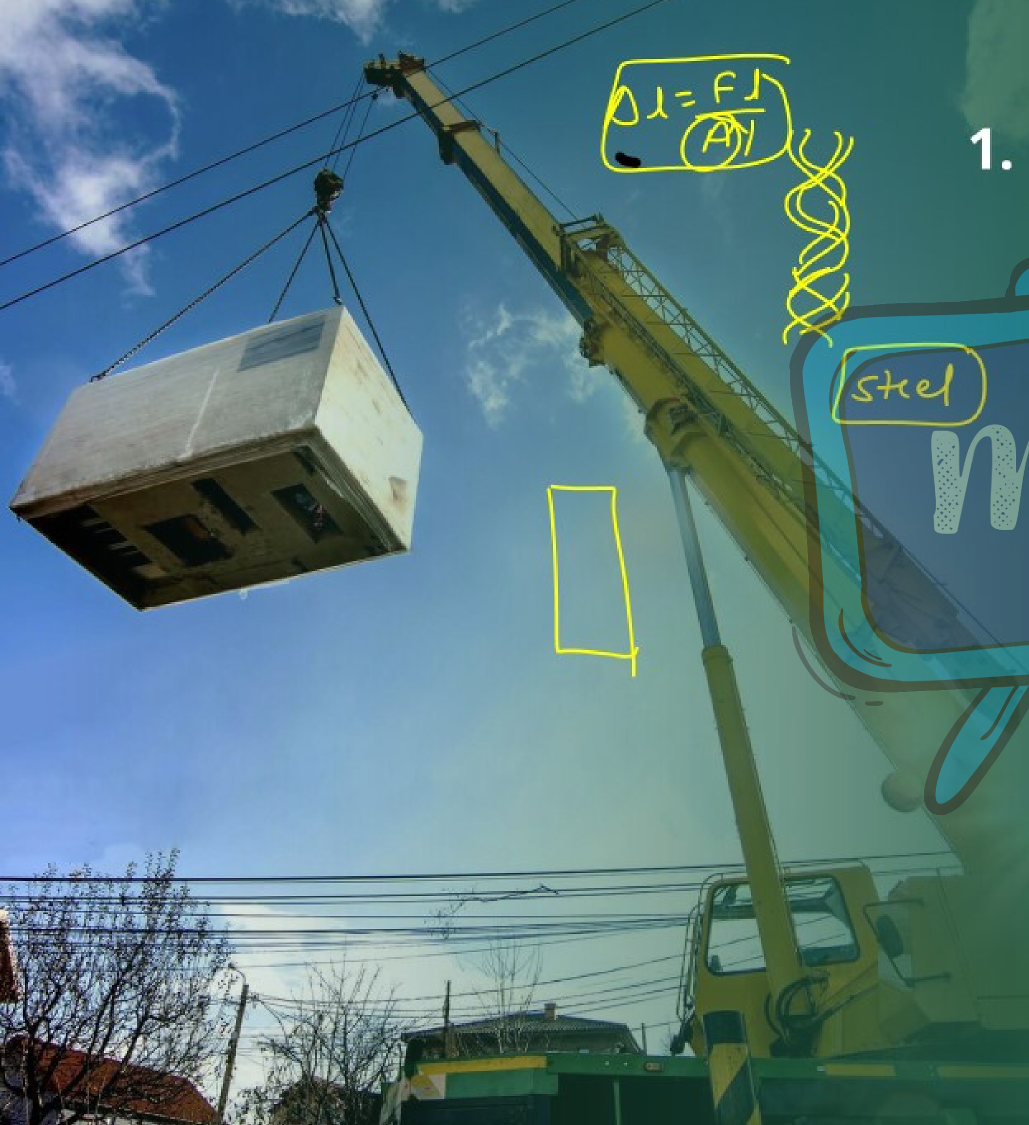
$$u = \frac{1}{2} \times \text{stress} \times \text{strain}$$

Stress = Young's modulus × strain

$$u = \frac{1}{2} \text{ Young's modulus} \times \text{strain}^2$$

APPLICATIONS OF ELASTIC BEHAVIOR OF MATERIALS

All engineering designs require precise knowledge of the elastic behavior of materials for example while designing a building, the structural design of the columns, beams and supports require knowledge of strength of materials used.



1. Cranes are used for lifting heavy objects from one place to another. In cranes a thick metallic rope is used. It is important to estimate the weight to be lifted by metallic rope.

   The maximum weight should be within the elasticity limit of the material of the rope.

For example :

The rope is made of steel and the crane can lift a maximum weight of 10^5 kg. The limit of elasticity of steel is 3×10^8 N/m^2.

$$\text{Stess} = \frac{\text{Weight}}{\text{Area}} \leq \text{Elasticity limit}$$

$$\text{Area of rope } A \geq \frac{Mg}{\text{Elasticity limit}}$$

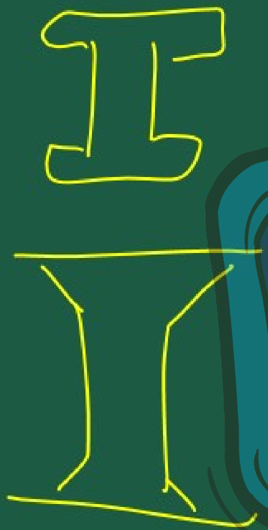
$$\pi r^2_{min} = 3.3 \times 10^{-3}$$

$$r_{min} = \sqrt{\frac{3.3}{3.14} \times 10^{-3}} = 0.032 \text{ m}$$

$= 32$m

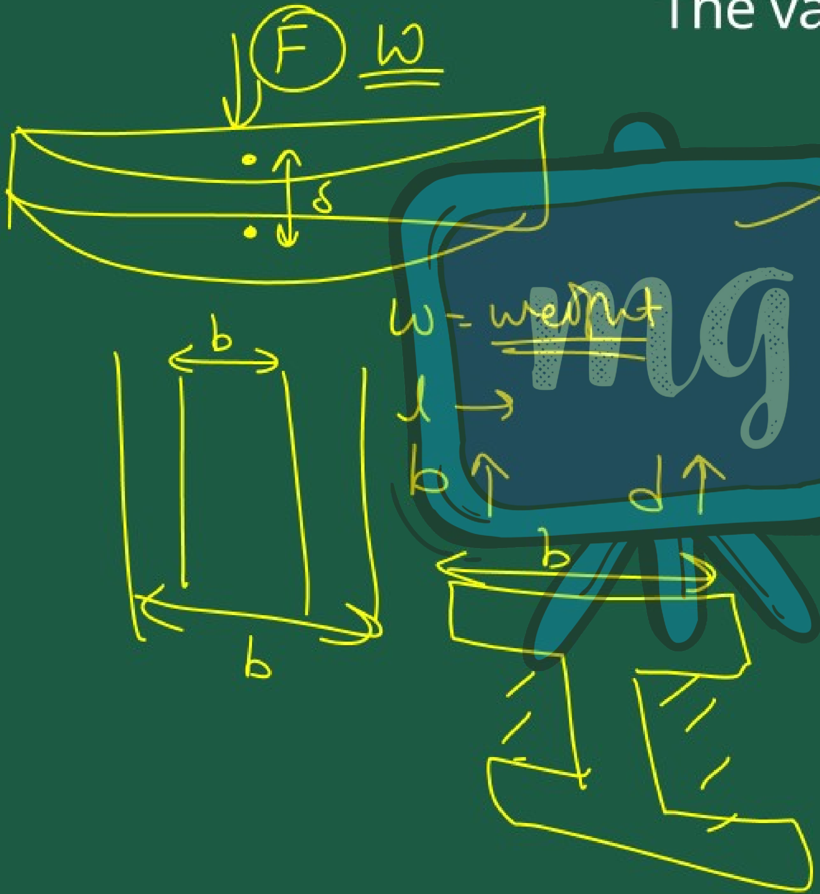
Thus to lift a weight of 10^5 kg the radius of the rope of steel should be around 3 cm.

- For safety the thickness of the rope is kept more (radius 10 cm)
- For flexibility, strength and convenience of construction the rope is made by coiling many thin wires with each other.



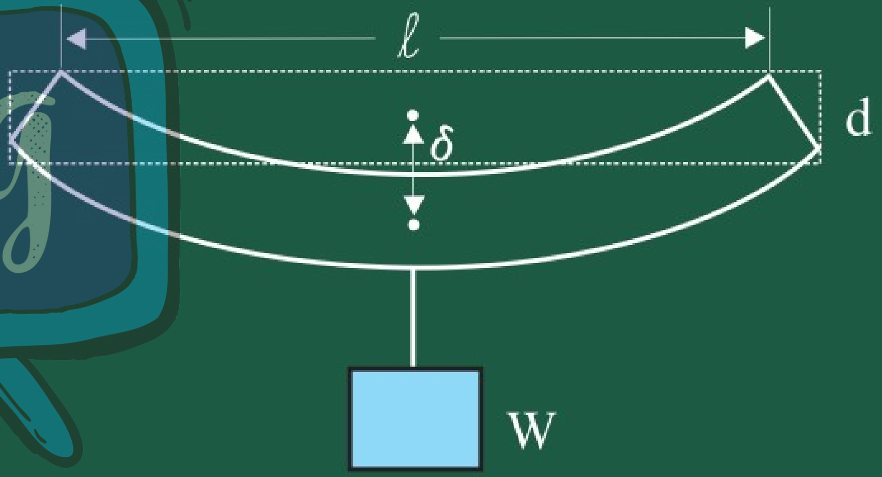
2. When a horizontal rod which is placed on rigid supports at both ends and has a weight w in the middle then there is depression in the rod. The magnitude of depression depends upon the materials of the rod, its length, thickness and depth.

The value of depression angle δ is

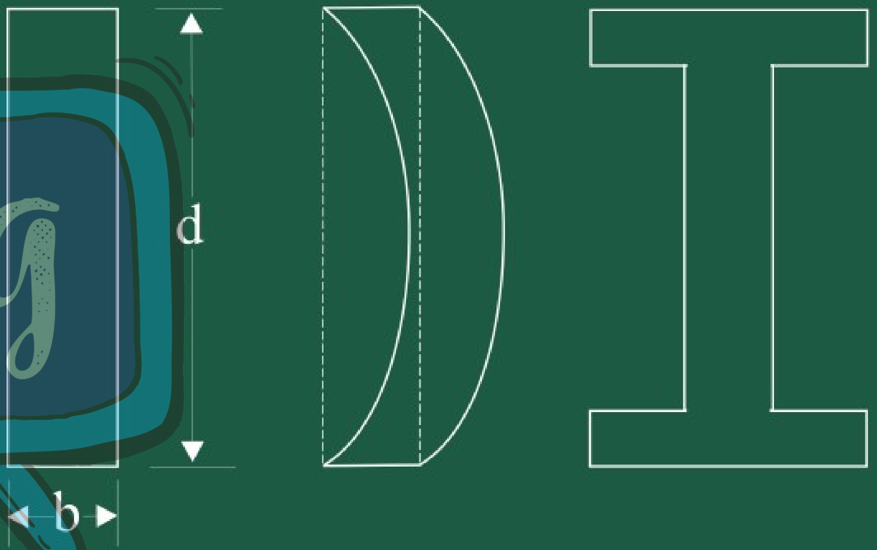


$$\delta = \frac{Wl^3}{4bd^3Y}$$

$$\therefore \delta \propto \frac{1}{d^3}$$


ℓ
d
δ
W

- For lesser bend of a beam instead of breadth (b), depth (d) should be increased. But increasing the depth too much would cause the beam to bend as in the figure.



(a) (b) (c)

- This is called buckling. To reduce this buckling beam is given the shape of I.

3. For estimating the height of a mounting the property of elasticity of the earth is useful.

Pressure at the base of the mountain

$P = h\rho g = \text{stress}$

Elasticity limit of rocks is $3 \times 10^8\ N/m^2$

$h\rho g = 3 \times 10^8$

$$h = \frac{3 \times 10^8}{3 \times 10^3 \times 10} = 10^4\ m = 10\,km$$

Which is more than the height of Mount Everest.

4. Shaft is a cylindrical rod used to give rotational motion to other machines. If one end of the shaft is tightly fixed and torsion force is applied on the other end then shearing strain would be obtained in the rod.

$$\tau = \frac{\eta \pi r^4 \theta}{2l}$$

$$\tau_{hollow} > \tau_{solid}$$

LEARNING OUTCOMES

1. To study for stress-strain curve
2. To study for elastic potential energy
3. To study for elastic behavior of martials

ASSESSMENT

1 Select the correct order with regard to elasticity of materials.

A Steel > Glass > Rubber

B Glass > Rubber > Steel

C Rubber > Glass > Steel

D Rubber > Steel > Glass

ASSESSMENT

2 | ________ is the property of metals due to which they can be drawn into thin wires.

A Malleability

B Conductivity

C Refinement

D Ductility