NCERT-XI / Unit- 9 – Mechanical properties of solid

The elastic behaviour of materials plays an important role in engineering design, like designing a building ,bridges, automobiles, ropeways etc.

Origin of elasticity

In a solid, each atom is surrounded by neighbouring atoms and bonded together by interatomic forces and stay in a stable equilibrium position. When a solid is deformed, the atoms are displaced from their equilibrium positions causing a change in the interatomic distances. When the deforming force is removed, the interatomic forces tend to drive them back to their original positions. A restoring force is developed , with the help of which the body regains its original shape and size. The restoring force is equal in magnitude and opposite in direction to the deforming forces .

Elasticity

The phenomenon by virtue of which a body can regain its initial shape after the removal deforming force is known as elasticity.

Difference between elastic & plastic body.

1) A body which can regain its initial shape after the removal of the deforming force is known as elastic body. Example best elastic body -a fibre of quartz crystal

2) A body which can't regain its original shape completely is known as plastic body. e. g. – putty ,wood ,mud.

Stress :-

The restoring force acting per unit area of a body is known as stress.

If 'F' be the restoring force acting in an area 'A' of the body then

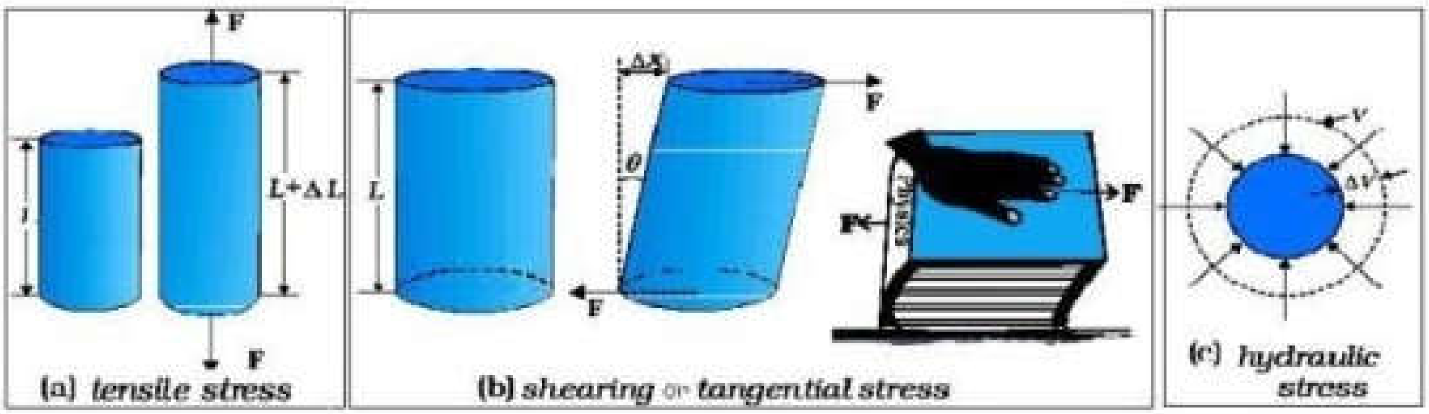
Stress = F / A

SI unit :- N/m^2 **[stress]= $[M^1L^{-1}T^{-2}]$**

Types of stress

By three ways in which a solid may change its dimensions when an external force acts on it.

(i) Longitudinal stress **(ii) Tangential or shearing stress** **(iii)Hydraulic stress**



(i)A cylinder is stretched by two equal forces applied normal to its cross-sectional area. The restoring force developed per unit area in this case is called **tensile stress**.

If the cylinder is compressed under the action of applied forces, the restoring force per unit area is known as **compressive stress**.

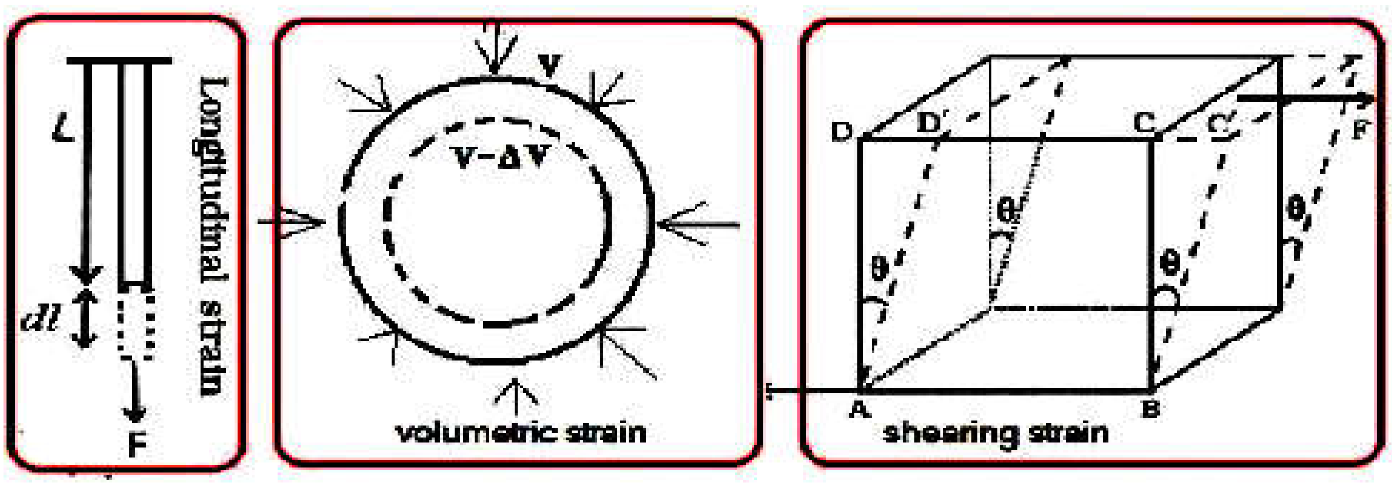
Tensile or compressive stress can also be termed as **longitudinal** stress.

(ii) If two equal and opposite deforming forces are applied parallel to the cross-sectional area of the cylinder, there is relative displacement between the opposite faces of the cylinder. The restoring force per unit area developed due to the applied tangential force is known as **tangential or shearing stress**.

(iii)If a solid sphere placed in the fluid under high pressure is compressed uniformly on all sides. The force applied by the fluid acts in perpendicular direction at each point of the surface and the body is said to be under hydraulic compression. This leads to decrease in its volume without any change of its geometrical shape. The body develops internal restoring forces that are equal and opposite to the forces applied by the fluid. The internal restoring force per unit area in this case is known as **hydraulic stress** and in magnitude is equal to the hydraulic pressure .

The strain

It is defined as the ratio of change in configuration to the original configuration. There are three types of strain.



<u>i) Longitudinal strain</u> :- It is defined as the ratio of change in length to the original length of the body.

Longitudinal strain = ΔL/L

<u>ii) Volumetric strain</u> :- It is defined as the ratio of change in volume of the original volume.

volumetric strain= ΔV/V

<u>iii) Shearing strain :-</u> It is defined as the angle by which the plane perpendicular to the fixed surface of block is rotated under the action of a tangential force.

It is denoted by θ

<u>Elastic limit</u>

The maximum value of stress beyond which a body can't regain its initial shape is known as elastic limit.

Hooke's law

" Within elastic limit applied stress is directly proportional to strain produced ".

i.e **Stress a strain ,**

Strain / stress = E , where E is a constant , known as co-efficient of elasticity.

Co-efficient of elasticity is defined as the ratio of applied stress and strain produced in a body within elastic limit.

There are three types of co-efficient of elasticity.

i) Young's modulus of elasticity (Y)

ii) Bulk modulus of elasticity (B)

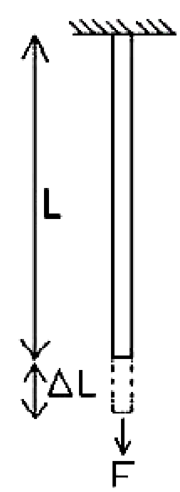
iii) Rigidity modulus of elasticity (η)

i) Young's modulus of elasticity

:- It is defined as the ratio normal stress to the longitudinal strain produced in a linear body.

Let us consider a wire of length L and cross sectional area A , suspended from a rigid support . Let it be elongated by a small length ΔL under the action of force 'F' which is acting vertically downward.

By the definition of Young's modulus –



Y = **Normal stress / Longitudinal stress**

= **(F/A) / (ΔL /L)**

Y = (F L) / (A ΔL) 1

If r be the radius of the wire and m be the mass of the load attached to the free end of the wire **,**

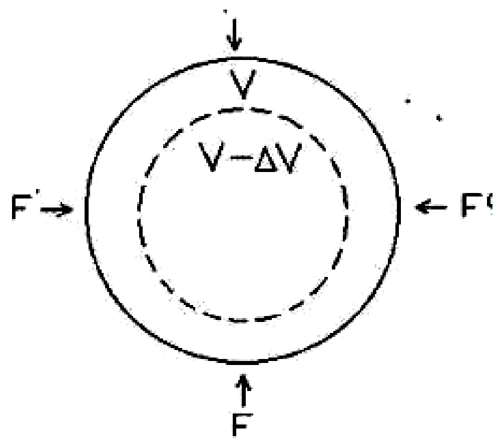
F = mg and A = π r ^{2}

Y = mgL / π r ^{2} ΔL 2

Unit of Y – N/m^2 and Dimensional formula.- [Y] = [$M^1L^{-1}T^{-2}$]

(ii) Bulk modulus of elasticity

It is defined as the ratio of normal stress and volumetric strain.



Let us consider a hollow sphere of surface area 'A' and volume 'V' whose volume decreases by 'ΔV' under the action of normal force 'F'.

By the definition of Bulk modulus of elasticity

B = Normal stress / volumetric Strain

$= (F / A) / (\Delta V / V)$

$= – P / (\Delta V / V)$,

where P is the pressure in the sphere.

Negative sign indicates that with increase in pressure volume decreases ,

Unit of K= N/m^2 and

Dimensional formula of [B] = $[M^1L^{-1}T^{-2}]$

Compressibility :– It is defined as the reciprocal of Bulk modulus of elasticity.

Compressibility = **$\Delta V/PV = N^{-1} m^2$**

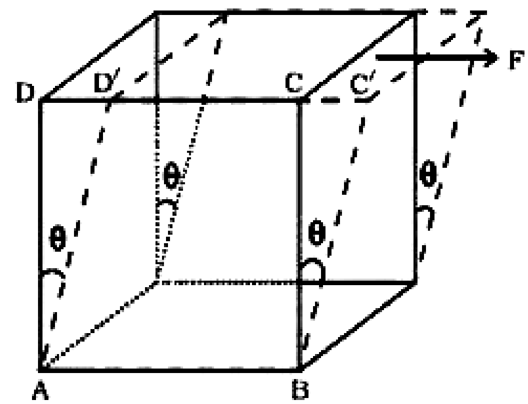
(iii) Rigidity modulus of elasticity

It is defined as the ratio of tangential stress to the shearing strain. It is denoted by η

Let ABCD be the perpendicular surface of a cube of side L , whose lower surface is fixed .Let 'F' be the tangential force applied to it , so that a shearing strain θ is produced on it.

The rigidity modulus is given as $\eta = (F/a)/\theta = F / a\theta$……………………….**…1**

where a is the surface area of the perpendicular face of the cube. If x be the displacement of the normal face then



$\theta = \tan\theta = A'A / AB = x / L$

So $\eta = (F/a) /(x/L) = (FL) / (ax)$……..**2**

Unit of η = N/m^2

$[\eta] = [M^1L^{-1}T^{-2}]$

Q. which one is more elastic steel or rubber ?

Ans :- Let us consider a steel wire and a rubber strip of same length and cross-sectional area , suspended under same load .Let ΔL_S & ΔL_R be the elongation of steel & rubber strip .The Young's modulus of elasticity is

$Y = (F L)/(A \Delta L)$ ……………………….1

Since F, L & A are constant,

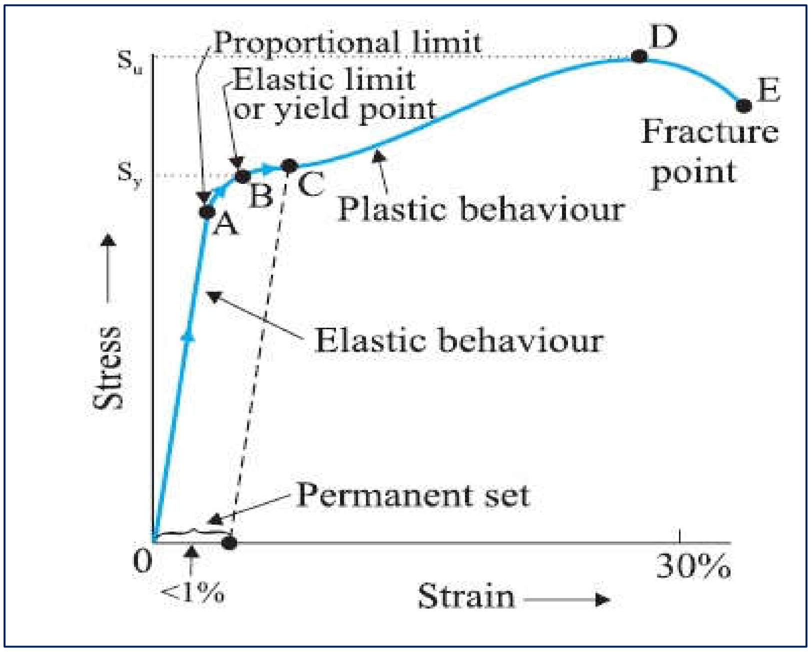
so $Y \propto 1/\Delta L$

Since $\Delta L_R >> \Delta L_S$,

so for same load $Y_S >> Y_R$ **So, steel is more elastic than rubber.**

STRESS-STRAIN CURVE

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



1. In the region between O to A, the curve is linear. In this region, Hooke's law is obeyed and the body regains its original dimensions when the applied force is removed. In this region, the solid behaves as an elastic body.

2. In the region from A to B, stress and strain are not proportional. Nevertheless, the body still returns to its 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 (**S_y**) of the material.

3. 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 between 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 (S_u**) of the material.

4. Beyond this point, additional strain is produced even by a reduced applied force and **fracture occurs at point E**.

5. If the ultimate strength and fracture points **D and E are close, the material is said to be brittle** and if they are**far apart, the material is said to be ductile**..