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Department of Civil Engineering

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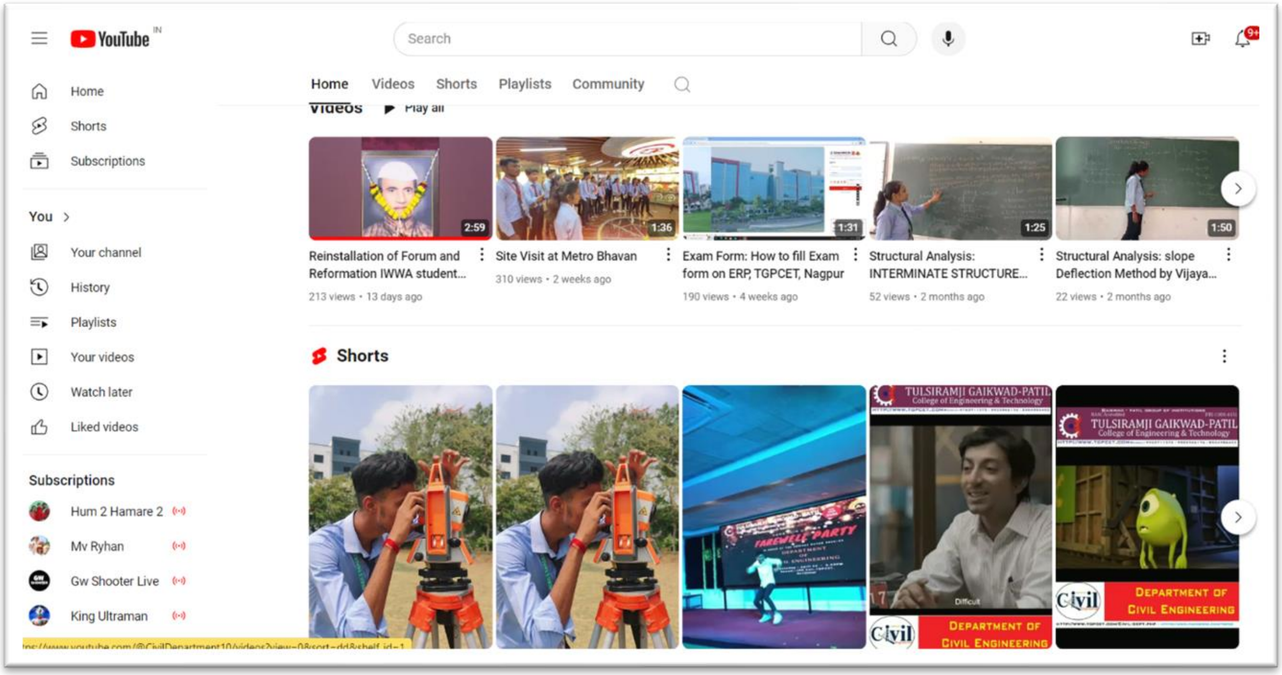

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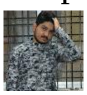
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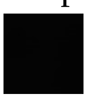
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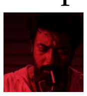

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What method is this sir LSM OR WSM?

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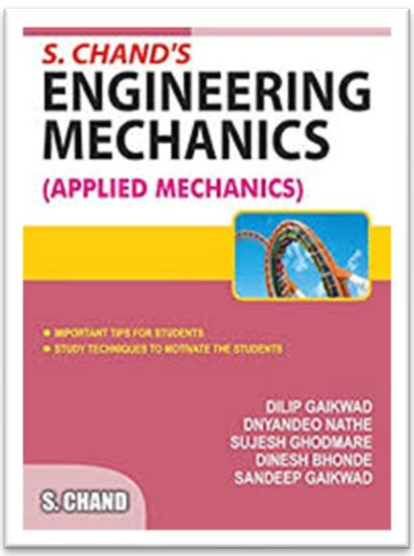
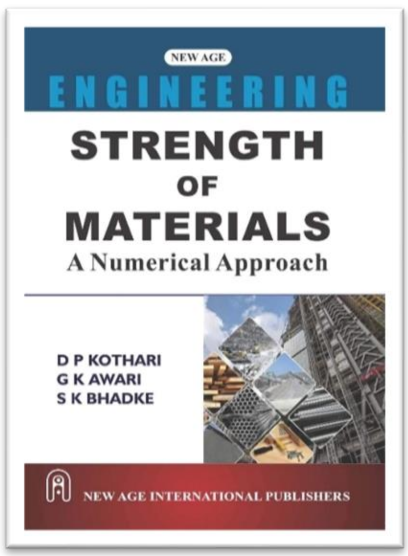




2.1 Introduction
Simple Stresses and Strains

In this chapter general meaning of stress is explained. Expressions for stresses and strains are derived with the following assumptions: For the range of forces applied the material is elastic *i.e.* it can regain its original shape and size, if the applied force is removed .Material is homogeneous *i.e.* every particle of the material possesses identical mechanical properties. Material is isotropic *i.e.* the material possesses identical mechanical property at any point in any direction. Presenting the typical stress-strain curve for typical steel, the commonly referred terms like limits of elasticity and proportionality, yield points, ultimate strength and strain hardening are explained. Linear elastic theory is developed to analyse different types of members subject to axial, shear, thermal and hoop stresses.

2.2 MEANING OF STRESS

When a member is subjected to loads it develops resisting forces. To find the resisting forces developed a section plane may be passed through the member and equilibrium of any one part maybe considered. Each part is in equilibrium under the action of applied forces and internal resisting forces. The resisting forces may be conveniently split into normal and parallel to the section plane. The resisting force parallel to the plane is called shearing resistance. The intensity of resisting force normal to the sectional plane is called intensity of Normal Stress

Stress:

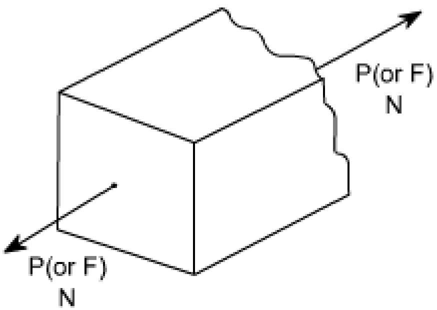
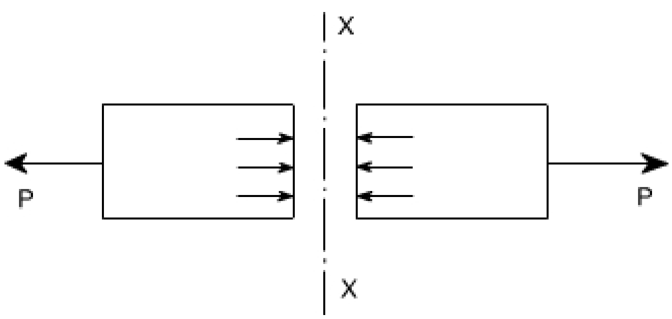


Fig 2. 1 Member subjected to load

Let us consider a rectangular bar of some cross – sectional area and subjected to some load or force (in Newton's). Let us imagine that the same rectangular bar is assumed to cut into two halves at section XX. The each portion of this rectangular bar is in equilibrium under the action of load P and the internal forces acting at the section XX has been shown in fig 2.2



Let us consider a rectangular bar of some cross – sectional area and subjected to some load or force (in Newton's). Let us imagine that the same rectangular bar is assumed to cut into two halves at section XX. The each portion of this rectangular bar is in equilibrium under the action of load P and the internal forces acting at the section XX has been shown in fig 2.2

Now stress is defined as the force intensity or force per unit area. Here we use a symbol s
to represent the stress.

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

Where A is the area of the X – section

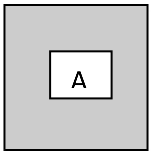


Fig 2.3 Cross section area

Here we are using an assumption that the total force or total load carried by the Rectangular bar is uniformly distributed over its cross – section. But the stress distributions may be for from uniform, with local regions of high stress known as stress concentrations. If the force carried by a component is not uniformly distributed over its cross – sectional area, A, we must consider a small area, ‘dA' which carries a small load dP, of the total force ‘P', Then definition of stress is

$$\sigma = \frac{\delta F}{\delta A}$$

As a particular stress generally holds true only at a point, therefore it is defined Mathematically as

$$\sigma = \lim_{\delta A \to 0} \frac{\delta F}{\delta A}$$

Units :

The basic units of stress in S.I units i.e. (International system) are N/m2 (or Pa)

MPa = 10^6 Pa

GPa = 10^9 Pa

KPa = 10^3 Pa

Some times N/mm^2 units are also used, because this is an equivalent to MPa. While US Customary unit is pound per square inch psi.

2.3 TYPES OF STRESSES:

Only two basic stresses exist: (1) Normal stress and (2) Shear stress. Other stresses either similar to these basic stresses or a combination of these e.g. bending stresses are a combination tensile, compressive and shear stresses. Torsional stress, as encountered in twisting of a shaft is a shearing stress.

Let us define the normal stresses and shear stresses in the following sections.

Normal stresses: We have defined stress as force per unit area. If the stresses are normal to the areas concerned, then these are termed as normal stresses. The normal stresses are generally denoted by a Greek letter (б)

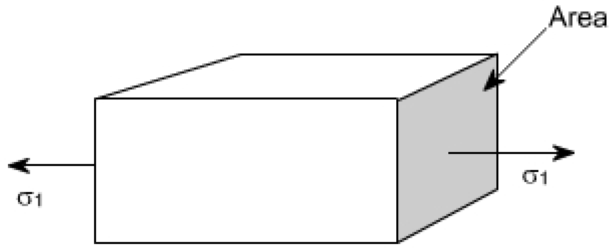


Fig 2.4 Tensile stresses

This is also known as uni-axial state of stress, because the stresses acts only in one direction however, such a state rarely exists, therefore we have biaxial and tri axial state of stresses where either the two mutually perpendicular normal stresses acts or three mutually perpendicular normal stresses acts as shown in the figures below :

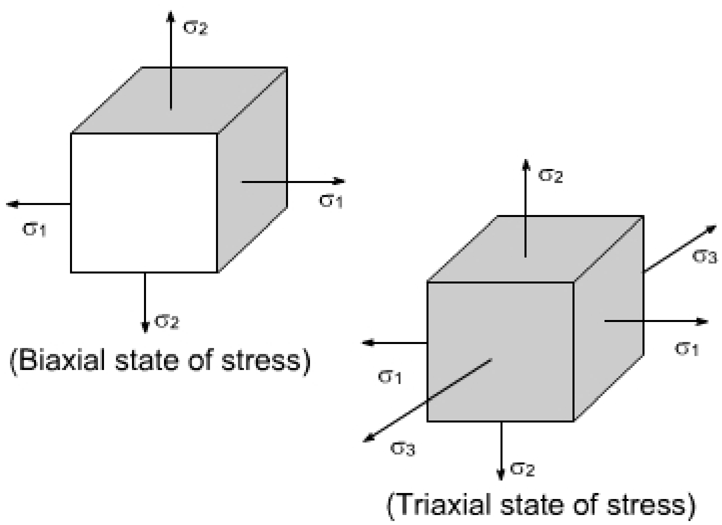


Fig 2.5 Stresses in various direction

Tensile or compressive stresses:

The normal stresses can be either tensile or compressive whether the stresses acts out of the area or into the area

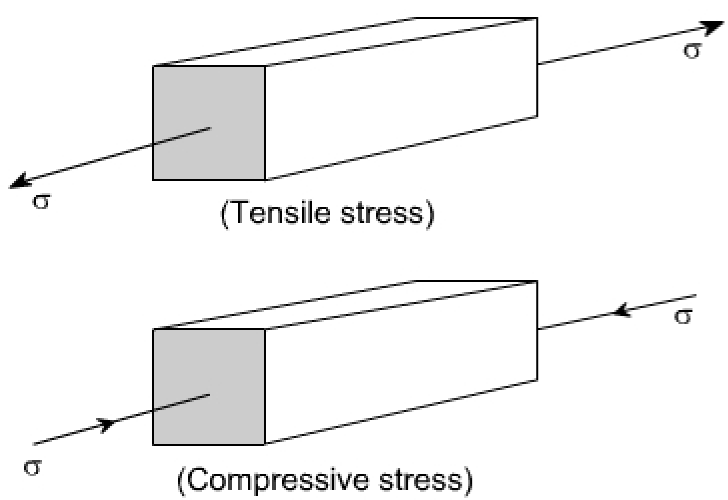


Fig 2.6 Tensile and compressive stresses

Bearing Stress: When one object presses against another, it is referred to a bearing stress (They are in fact the compressive stresses)

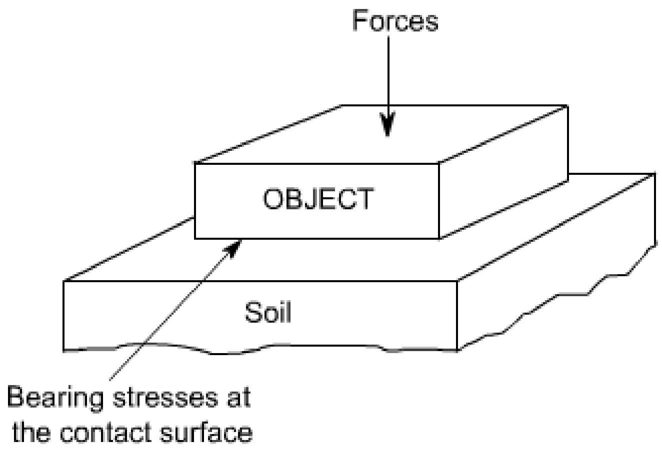


Fig 2.7 Bearing stresses

Shear stresses:

Let us consider now the situation, where the cross– sectional area of a block of materials subject to a distribution of forces which are parallel, rather than normal, to the area concerned. Such forces are associated with a shearing of the material, and are referred to as shear forces. The resulting force interest is known as shear stresses.

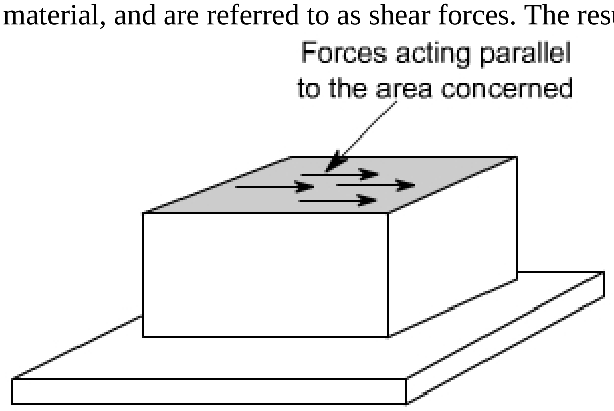


Fig 2.8 Shear stresses

The resulting force intensities are known as shear stresses, the mean shear stress being equal to
$\tau = F/A$

Where F is the total force and A the area over which it acts.

As we know that the particular stress generally holds good only at a point therefore we can define shear stress at a point as

$$\tau = \lim_{\delta A \to 0} \frac{\delta F}{\delta A}$$

The Greek symbol τ (tau) (suggesting tangential) is used to denote shear stress.

However, it must be borne in mind that the stress (resultant stress) at any point in a body is basically resolved into two components s and t one acts perpendicular and other parallel to the area concerned, as it is clearly defined in the following figure.

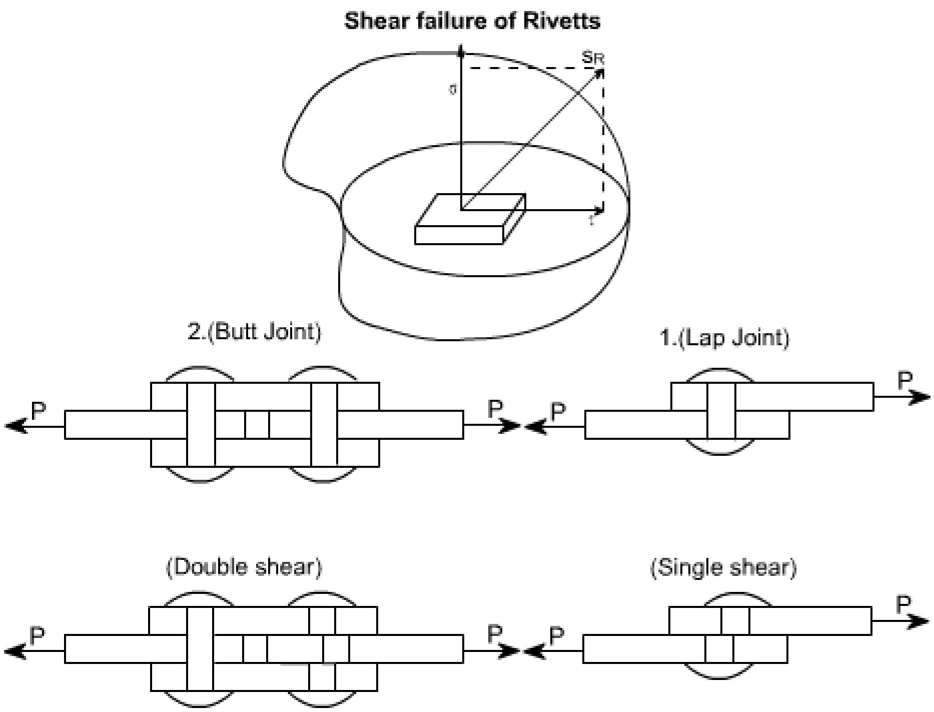


Fig2. 9 shear failure of rivet

The single shear takes place on the single plane and the shear area is the cross - sectional of the rivet, whereas the double shear takes place in the case of Butt joints of rivet and the shear area is the twice of the X - sectional area of the rivet

2.4 CONCEPT OF STRAIN

Concept of strain: if a bar is subjected to a direct load, and hence a stress the bar will change in length. If the bar has an original length L and changes by an amount dL, the strain produce is defined as follows:

$$\text{strain}(\varepsilon) = \frac{\text{change in length}}{\text{orginal length}} = \frac{\delta L}{L}$$

Strain is thus, a measure of the deformation of the material and is a non dimensional Quantity i.e. it has no units. It is simply a ratio of two quantities with the same unit.

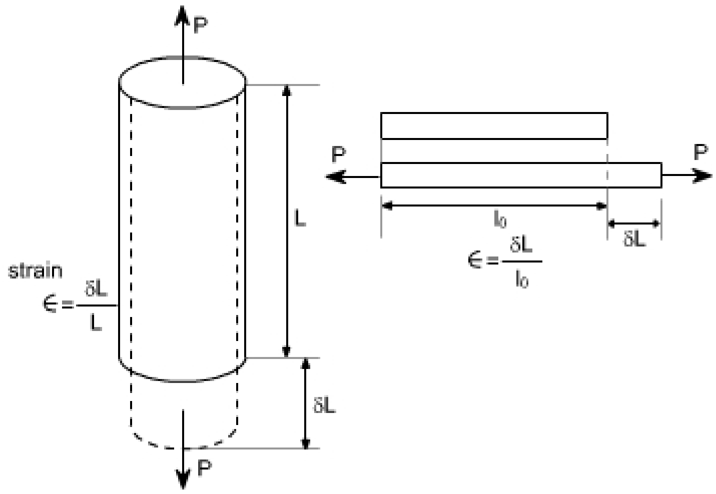


Fig 2.10 Concept of strain

Since in practice, the extensions of materials under load are very small, it is often convenient to measure the strain in the form of strain x 10^{-6} i.e. micro strain, when the symbol used becomes €

Sign convention for strain:

Tensile strains are positive whereas compressive strains are negative. The strain defined earlier was known as linear strain or normal strain or the longitudinal strain now let used fine the shear strain.

Definition: An element which is subjected to a shear stress experiences a deformation as shown in the figure below. The tangent of the angle through which two adjacent sides rotate relative to their initial position is termed shear strain. In many cases the angle is very small and the angle it self is used, (in radians), instead of tangent, so that g = Ð AOB - Ð A'OB' = f

Shear strain: As we know that the shear stresses acts along the surface. The action of the stresses is to produce or being about the deformation in the body considers the distortion produced b shear sheer stress on an element or rectangular block.

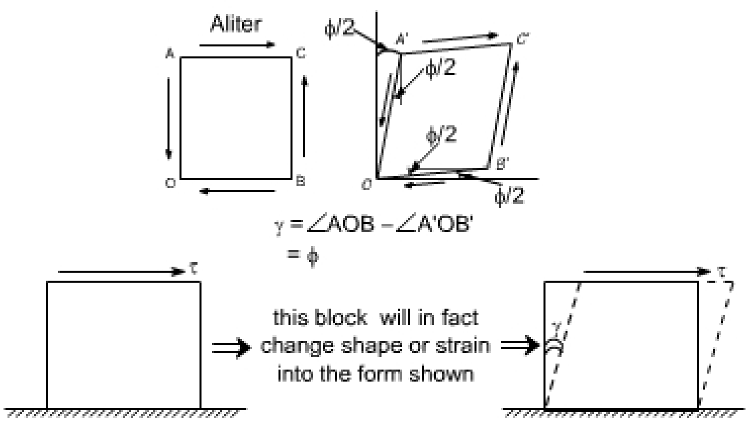


Fig 2.11 Shear strain

This shear strain or slide is f and can be defined as the change in right angle. or The angle deformation g is then termed as the shear strain. Shear strain is measured in radians & hence is non – dimensional i.e. it has no unit. So we have two types of strain i.e. normal stress & shear stresses.

2.5 STRESS-STRAIN RELATION The stress-strain relation of any material is obtained by conducting tension test in the laboratories on standard specimen. Different materials behave differently and their behaviour in tension and in compression differs slightly.

2.6 Behaviour in Tension

Mild Steel. Figure shows a typical tensile test specimen of mild steel. Its ends are gripped into universal testing machine. Extensometer is fitted to test specimen which measures extension over the length *L*, shown in Fig.2.12 The length over which extension is measured is called gauge *length.* The load is applied gradually and at regular interval of loads extension is measured. After certain load, extension increases at faster rate and the capacity of extensometer to measure extension comes to an end and, hence, it is removed before this stage is reached and extension is measured from scale on the universal testing machine. Load is increased gradually till the specimen breaks.

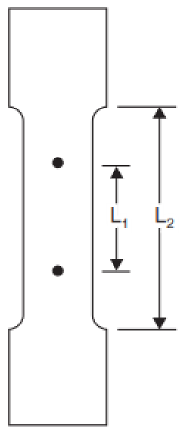


Fig. 2.12 Tension Test Specimen

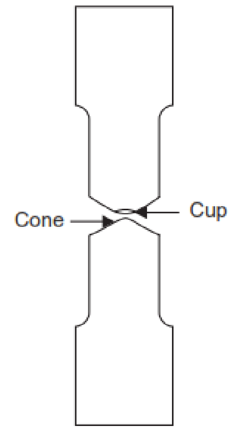
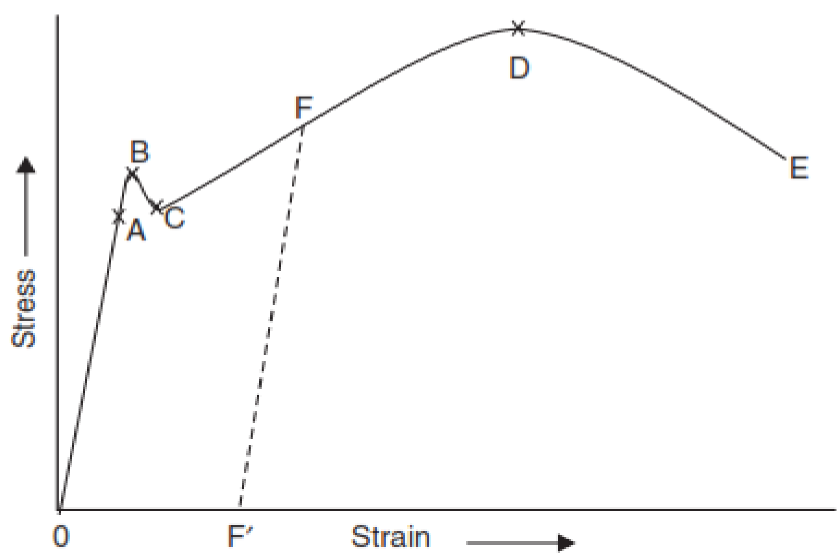


Fig. 2.12a Tension Test Specimen after Breaking



Load divided by original cross-sectional area is called as nominal stress or simply as stress. Strain is obtained by dividing extensometer readings by gauge length of extensometer (*L*)
and by dividing scale readings by grip to grip length of the specimen (*L*). Figure shows stress *vs* strain diagram for the typical mild steel specimen. The following salient points are observed on stress-strain curve:

(a) **Limit of Proportionality (A):** It is limiting value of the stress up to which stress is proportional to strain.
(b) **Elastic Limit:** This is the limiting value of stress up to which if the material is stressed and then released (unloaded) strain disappears completely and the original lengths regained. This point is slightly beyond the limit of proportionality.

(c) **Upper Yield Point (B):** This is the stress at which, the load starts reducing and the extension increases. This phenomenon is called yielding of material. At this stage strain is about 0.125per cent and stress is about 250 N/mm^2.

(d) **Lower Yield Point (C):** At this stage the stress remains same but strain increases for some time.

(e) **Ultimate Stress (D):** This is the maximum stress the material can resist. This stress is about 370–400 N/mm^2. At this stage cross-sectional area at a particular section starts reducing very fast (Figure) This is called neck formation. After this stage load resisted and hence the stress developed starts reducing.
(f) **Breaking Point (E):** The stress at which finally the specimen fails is called breaking point.At this strain is 20 to 25 per cent.

If unloading is made within elastic limit the original length is regained *i.e.*, the stress-strain curve follows down the loading curve shown in Figure If unloading is made after loading the specimen beyond elastic limit, it follows a straight line parallel to the original straight portion as shown by line *FF*' in Figure Thus if it is loaded beyond elastic limit and then unloaded a permanent strain (*OF*) is left in the specimen. This is called permanent set.

Stress-strain relationship in aluminium and high strength steel. In these elastic materials there is no clear cut yield point. The necking takes place at ultimate stress and eventually the breaking point is lower than the ultimate point. The typical stress-strain diagram is shown in Figure2.14 The stress *p* at which if unloading is made there will be 0.2 per cent permanent set is known as 0.2 percent proof stress and this point is treated as yield point for all practical purposes.

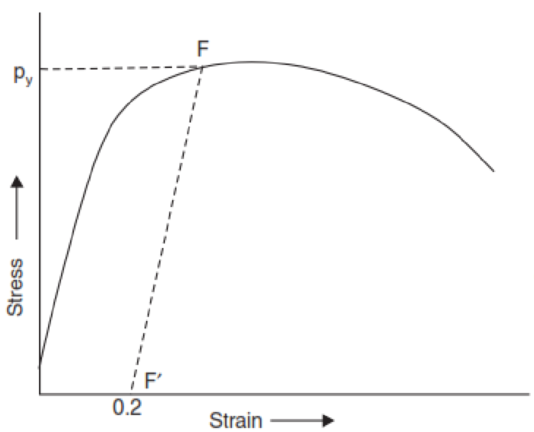


Figure 2.14. Stress-Strain Relation in Aluminium and High Strength Steel

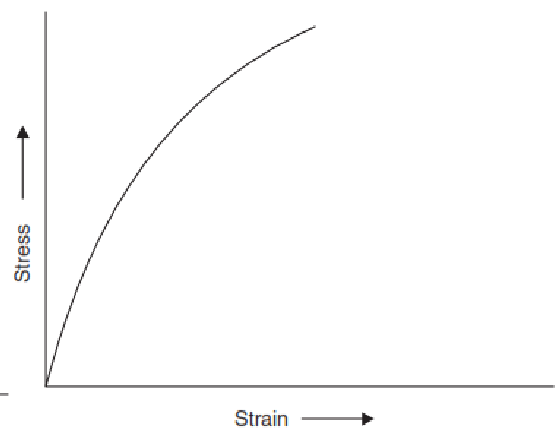


Figure. Fig 2.14 a Stress-Strain Relation for Brittle Material

Stress-strain relation in brittle material. The typical stress-strain relation in a brittle material like cast iron, is shown in Figure.2.14 In these material, there is no appreciable change in rate of strain. There is no yield point and no necking takes place. Ultimate point and breaking point are one and the same. The strain at failure is very small.

Percentage elongation and percentage reduction in area. Percentage elongation and percentage reduction in area are the two terms used to measure the ductility of material.

(a) **Percentage Elongation:** It is defined as the ratio of the final extension at rupture to original length expressed, as percentage. Thus,

$$\text{Percentage Elongation} = \frac{L' - L}{L} \times 100$$

where L – original length, L'– length at rupture.

The code specify that original length is to be five times the diameter and the portion considered must include neck (whenever it occurs). Usually marking are made on tension rod at every '2.5 *d*' distance and after failure the portion in which necking takes place is considered. In case of ductile material percentage elongation is 20 to 25.

(b) **Percentage Reduction in Area:** It is defined as the ratio of maximum changes in the cross sectional area to original cross-sectional area, expressed as percentage. Thus,

Percentage Reduction in Area = $\frac{A-A}{A}$ x 100

Where A–original cross-sectional area, A'–minimum cross-sectional area. In case of ductile material, *A*' is calculated after measuring the diameter at the neck. For this, the two broken pieces of the specimen are to be kept joining each other properly. For steel, the percentage reduction in area is 60 to 70.

2.7 Behaviour of Materials under Compression

As there is chance to bucking (laterally bending) of long specimen, for compression tests short specimens are used. Hence, this test involves measurement of smaller changes in length. It results into lesser accuracy. However precise measurements have shown the following results:(*a*) In case of ductile materials stress-strain curve follows exactly same path as in tensile test up to and even slightly beyond yield point. For larger values the curves diverge. There will not be necking in case of compression tests.

(*b*) For most brittle materials ultimate compressive stress in compression is much larger than in tension. It is because of flows and cracks present in brittle materials which weaken the material in tension but will not affect the strength in compression.

2.8 Hook's Law and numericals

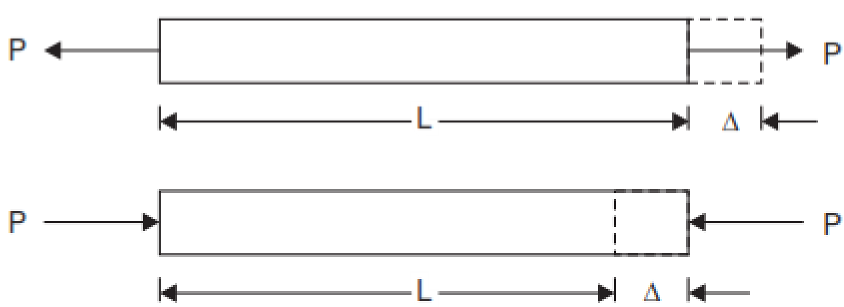
A material is said to be elastic if it returns to its original, unloaded dimensions when load is removed. Hook's law therefore states that

Stress (σ) a strain(e)

$$\frac{\text{stress}}{\text{strain}} = \text{constant}$$

EXTENSION/SHORTENING OF A BAR

Consider the bars shown in Figure 2.15.



From equation , Stress σ = $\frac{P}{A}$

Fig 2.15 Bar subjected to tension and compression

From equation , Strain, e = Δ/L

From Hooke's Law we have,

$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{\sigma}{e} = \frac{P/A}{\Delta/L} = \frac{PL}{A\,\Delta}$$

$$\Delta = \frac{PL}{A\,E}$$

Numerical:

2.1. A circular rod of diameter 16 mm and 500 mm long is subjected to a tensile force 40kN. The modulus of elasticity for steel may be taken as 200 kN/mm^2. Find stress, strain and elongation of the bar due to applied load.

Solution: **Given Data:** Load P = 40 kN = 40 × 1000 N

E = 200 kN/mm= 200 × 10^3 N/mm^2

L = 500 mm

Diameter of the rod d = 16 mm

Therefore, sectional area $A = \frac{\pi d^2}{4} = \frac{\pi}{4} \times 16^2$

= = 201.06 mm^2

$$\text{Stress } \sigma = \frac{P}{A} = \frac{40 \times 1000}{201.06} = 198.94 \text{ N/mm}^2$$

$$\text{Strain } e = \frac{P}{E} = \frac{198.94}{200 \times 103} = 0.0009947$$

$$\text{Elongation } \Delta = \frac{PL}{AE} = \frac{4 \times 1000 \times 500}{201.06 \times 200 \times 10^3} = 0.497\text{mm}$$

2.2. A Surveyor's steel tape 30 m long has a cross-section of 15 mm × 0.75 mm. With this,line AB is measure as 150 m. If the force applied during measurement is 120 N more than the force applied at the time of calibration, what is the actual length of the line?

Take modulus of elasticity for steel as 200 kN/mm^2

Solution: **Given Data:** A = 15 × 0.75 = 11.25 mm^2

P = 120 N, *L* = 30 m = 30 × 1000 mm

E = 200 kN/mm^2 = 200 × 10^3 N/mm^2

$$\text{Elongation } \Delta = \frac{PL}{AE} = \frac{120 \times 30 \times 1000}{11.25 \times 200 \times 10^3} = 1.600 \text{ mm}$$

Hence, if measured length is 30 m.
Actual length is 30 m + 1.600 mm = 30.001600 m

∴ **Actual length of line *AB*** $= \frac{150}{30} \times 30.001600 =$ **150.008 m**

2.3. A specimen of steel 20 mm diameter with a gauge length of 200 mm is tested to destruction. It has an extension of 0.25 mm under a load of 80 kN and the load at elastic limit is 102 kN. The maximum load is 130 kN.

The total extension at fracture is 56 mm and diameter at neck is 15 mm. Find

(i) The stress at elastic limit.
(ii) Young's modulus.
(iii) Percentage elongation.

(iv) Percentage reduction in area.
(v) Ultimate tensile stress.

Solution: **Given Data:** Diameter d = 20 mm

Area A = $\frac{\pi d^2}{4}$ = 314.16 mm^2

i. Stress at elastic limit = $\frac{\text{Load at elastic limit}}{\text{Area}}$

$$= \frac{102 \times 10^3}{314.16} = 324.75 \text{ N/mm}^2$$

ii. Young's modulus E = $\frac{\text{Stress}}{\text{Strain}}$ within elastic limit

$$= \frac{P/A}{\Delta/l} = \frac{80 \times 10^3/314.16}{0.25/200} = 203718 \text{ N/mm}^2$$

iii. Percentage elongation = $\frac{\text{Final Elongation}}{\text{Original Length}}$

$$= \frac{56}{200} \times 100 = 28$$

iv. Percentage reduction in area = $\frac{\text{Initial area} - \text{Final area}}{\text{Initial area}}$ x 100

$$= \frac{\frac{\pi}{4} \times 20^2 - \frac{\pi}{4} \times 15^2}{\frac{\pi}{4} \times 20^2} \times 100 = 43.75$$

v. Ultimate Tensile Stress = $\frac{\text{Ultimate Load}}{\text{Area}}$

$$= \frac{130 \times 10^3}{314.16} = 413.80 \text{ N/mm}^2$$

2.9 BARS WITH CROSS-SECTIONS VARYING IN STEPS

A typical bar with cross-sections varying in steps and subjected to axial load is as shown in Fig2.16.a Let the length of three portions be L_1, L_2 and L_3 and the respective cross-sectional areas of the portion be A_1,A_2,A_3 and E be the Young's modulus of the material and P be the applied axial load.

Fig2.16.(*b*) shows the forces acting on the cross-sections of the three portions. It is obvious that to maintain equilibrium the load acting on each portion is P only. Hence stress, strain and extension of each of these portions are as listed below:

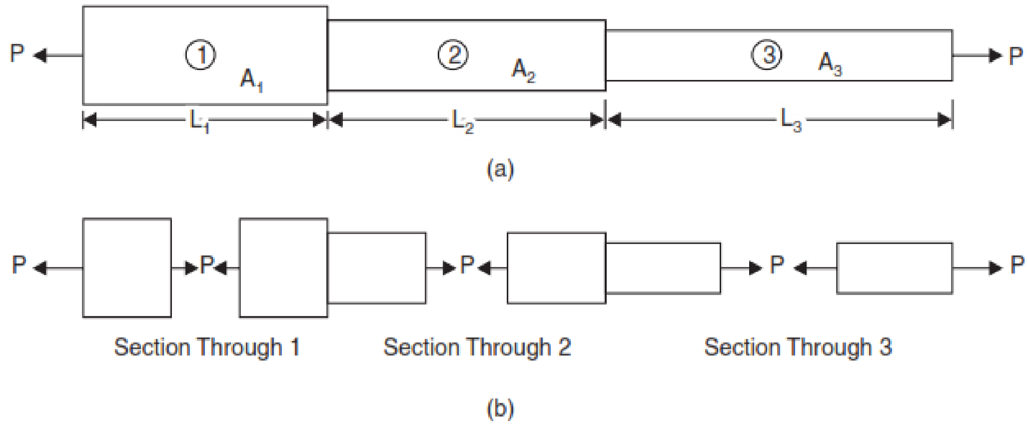


Fig. 2.16 Typical Bar with Cross-section Varying in Step

Portion	*Stress*	*Strain*	*Extension*
1	$p_1 = \frac{P}{A_1}$	$e_1 = \frac{p_1}{E} = \frac{P}{A_1 E}$	$\Delta_1 = \frac{PL_1}{A_1 E}$
2	$p_2 = \frac{P}{A_2}$	$e_2 = \frac{p_2}{E} = \frac{P}{A_2 E}$	$\Delta_2 = \frac{PL_2}{A_2 E}$
3	$p_3 = \frac{P}{A_3}$	$e_3 = \frac{p_3}{E} = \frac{P}{A_3 E}$	$\Delta_3 = \frac{PL_3}{A_3 E}$