Experiment No. 1

STATIC TENSION TEST OF MILD STEEL SPECIMEN

1.1 Introduction

In static tension test, attempt is made to apply an axial load to a test specimen so that uniform stress distribution can be ensured over the critical section. In such tests the specimen is subjected to a gradually increasing (i.e. *static*) uniaxial load until failure occurs. The static tension tests are the most commonly made and are among the simplest of all the mechanical tests. These tests provide almost all the fundamental mechanical properties for use in design. The use of the tension test is largely determined by the type of service to which a material is to be subjected. Metals, for example, generally exhibit relatively high tenacity and are therefore better suited to and are more efficient for resisting tensile loads than materials of relatively low tensile strength. For brittle materials such as mortar, concrete, brick, and ceramic products, whose tensile strengths are low compared with their compressive strengths, and which are principally employed to resist compressive forces, the compression test is more significant and finds greater use.

1.2 Important Terminology

Fundamental to the understanding of the tests in this chapter and also in subsequent chapters is a clear concept about the various terms used. This section, therefore, describes the important terms used in connection with the physical testing of material.

Gage length is the length over which deformation measurement is made.

Elasticity is that property of a material by virtue of which deformations caused by stress disappear upon the removal of stress. A perfectly elastic body is the one which completely recovers its original shape and dimensions after release of stress. No materials are known which are perfectly elastic throughout the entire range of stress up to rupture, although some materials, such as steel, appear to be elastic over a considerable range of stress.

Plasticity is the property by virtue of which a material can undergo permanent deformation without rupture.

Permanent Set* or *Set is defined as the amount of plastic deformation that remains even after the removal of load (see Fig.1.1)

Elastic Limit is defined as the maximum stress that a material is capable of developing without a permanent set remaining upon complete release of stress.

Proportional Limit **(σ_{pl})** is defined as the maximum stress a material is capable of developing without deviation from straight-line proportionality between stress and strain.

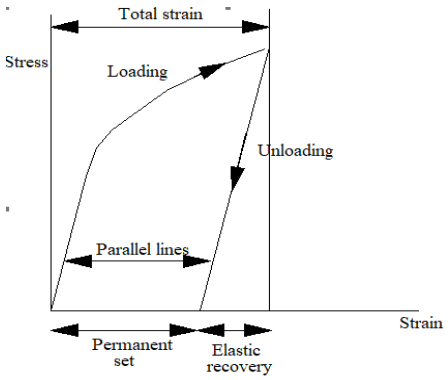


Fig. 1.1 Definition of permanent set on unloading

Modulus of Elasticity **(E)** is defined as the ratio of stress to corresponding strain under normal (axial) stress within the proportional limit. It is a measure of stiffness - the greater the stress required to produce a given strain, the stiffer the material is said to be. For material whose stress-strain relationship is not linear, the above definition of modulus of elasticity is clearly inadequate. However, in such case the concept of *initial tangent stiffness* (slope of the stress-strain curve at origin) or *secant stiffness* (slope of a line connecting the origin and a point on the stress-strain curve at any specified stress level) or *tangent stiffness* (slope of the tangent to the stress-strain curve at the average allowable stress) is utilized.

The term ***modulus of rigidity*** (also termed as shearing *modulus of elasticity*) is the ratio of stress to corresponding strain under shearing stress. Modulus of rigidity (G), and modulus of elasticity (E) of a material is related by the following relationship:

$$G = \frac{E}{2(1+\mu)}$$; where μ is the Poisson's ratio.

Energy Capacity: The amount of energy that can be recovered on removal of stress form the elastic limit is called elastic resilience. The energy stored per unit volume at the elastic limit is the *modulus of resilience* and it is the area under the stress-strain diagram up to the elastic limit (Fig.1.2). It is a measure of elastic energy strength of the material and is of importance in the selection of materials for service where the stresses must be kept within the elastic limit.

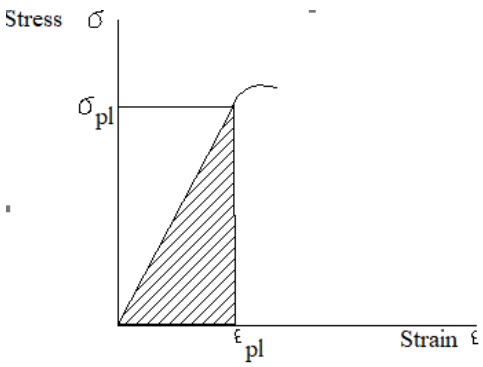


Fig. 1.2 Elastic Resilience or Modulus of Resilience

Toughness is the energy required to rupture a material. It is measured by the amount of work per unit volume of a material required to carry the material to failure under static loading, called the modulus of toughness and represented by the area under the complete stress-strain diagram.

Yield Point **(σ_y)** exists only for ductile materials such as mild steel. Yield point is defined as the stress at which there occurs a marked increase in strain without increase in stress.

Yield Strength **(σ_y)** is the practical and most commonly used measure of elastic strength. It is the value of stress at which inelastic action begins. The beginning of inelastic action (yielding) is a very localised action and yielding becomes measurable only after many local internal adjustments have occurred and after a considerable portion of the piece is affected by yielding. It is, therefore, necessary to specify a certain measurable amount of yielding as the beginning of yielding.

Ductility is a special way of expressing plasticity (the general term to indicate the ability of a material to deform in the inelastic or plastic range without rupture) of a material. Ductility is that property of a material which enables it to be drawn-out to a considerable extent before rupture and at the same time to sustain appreciable load. Mild steel is an example of ductile materials. A non-ductile material is called brittle material which fractures at relatively little or no elongation. Cast iron and concrete are examples of brittle materials, which characteristically have low tensile strength (fig.1.3)

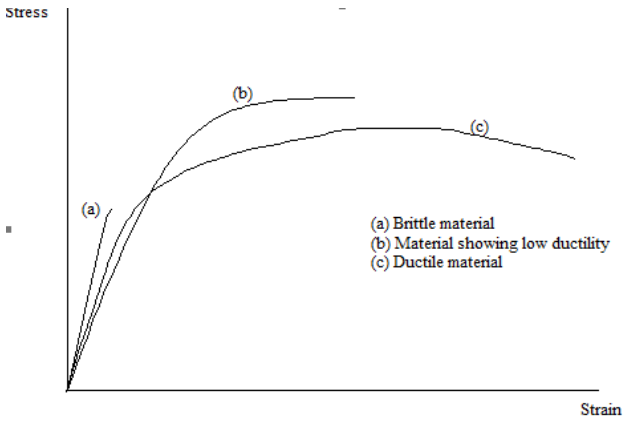


Fig. 1.3 Typical stress-strain diagram for different materials

1.3 Stress-Strain Diagram of Mild Steel

Figure 1.4 shows one such diagram which introduces the various terminology defined in the previous section.

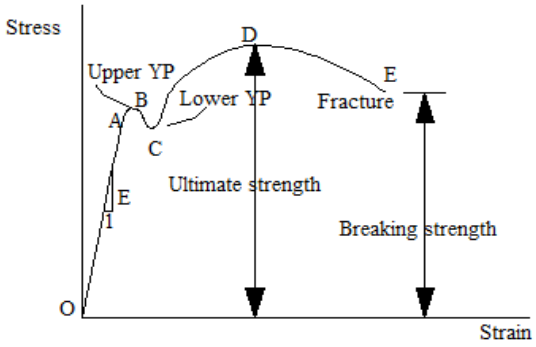


Fig. 1.4 Stress-Strain Diagram of Mild Steel

The initial OA segment of the stress-strain curve is linear, indicating that stress and strain are proportional up to point A, the proportional limit. Stresses not exceeding the proportional limit results in practically elastic deformation only i.e. the strain that disappears when the load is removed. For this reason the proportional limit is frequently

identified with the elastic limit. This is not correct although this should be accurate enough for most practical purposes. Usually the elastic limit is defined as the stress at which the permanent set is of the order of 0.005 per cent strain.
If the load is increased beyond the elastic limit a point is reached where sudden extension takes place with no increase in load. This is known as the `*yield point*' (YP). In some materials the onset of plastic deformation is denoted by a sudden drop in load indicating both an upper and a lower yield point. In Fig. 1.4, the *upper YP* is the highest stress before sudden extension occurs and its value is affected by surface finish, shape of test piece and rate of loading. The *lower YP*, which is normally measured in commercial testing is the stress producing the large elongation.

The stress-strain diagram for this type of behaviour is a discontinuous curve and is characteristic of mild steel. Other materials which sometimes yield discontinuously include molybdenum, cadmium, brass, aluminium and zinc. The reason of such discontinuous yielding is attributed to the presence of small amount of impurities e.g., foreign atoms in the material, usually carbon and nitrogen (as little as 0.003 per cent nitrogen or carbon is sufficient for this effect to take place). The foreign atoms, in solution, occupy more-or-less unstable interstitial positions in the lattice. These foreign atoms naturally tend to migrate to vacancies in the lattice or to regions of higher energy such as dislocations. Many of them find stable positions in the space just below the extra planes of atoms in edge dislocations. Therefore, they line up in these spaces and effectively anchor the dislocations against movement.

Such a line of foreign atoms is called an atmosphere (Fig. 1.5). When a shear stress is applied on a slip plane in mild steel, it must pull the dislocations away from their atmospheres before slip can take place. Figure 1.6 illustrates the variation of stress with the displacement, where the stress is largest when the dislocation has been displaced $r_0/\sqrt{3}$, where r_0 is a constant of the order of one atomic spacing, τ is the applied stress and x is the displacement. As the dislocation moves further away, it does so at a decreased stress. Thus a high stress is required to initiate yielding but a low stress will continue it and we have the upper and lower yield points. After this point, the specimen stretches plastically and the stress to produce continued plastic deformation increases with increasing strain i.e. the metal *strain-hardens*. This strengthening mechanism is related to an increase in deformation. The increase in external stress is due to the interaction of the moving dislocation with existing dislocations.

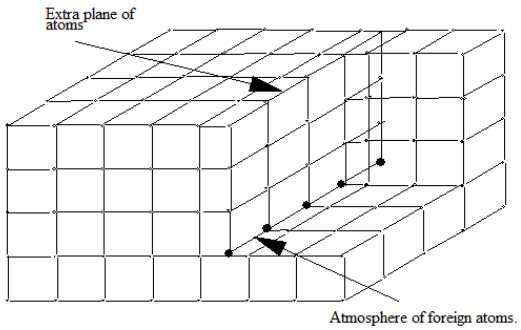


Fig. 1.5 Cutway view of dislocation, showing row, or atmosphere, of foreign atoms

As the specimen elongates, it decreases uniformly along the gage length in cross-sectional area. Initially, the strain-hardening more than compensates for this decrease in area and the engineering stress continues to rise with increasing strain. Eventually a point is reached where the decrease in specimen cross-sectional area is greater than the increase in deformation load arising from strain hardening.

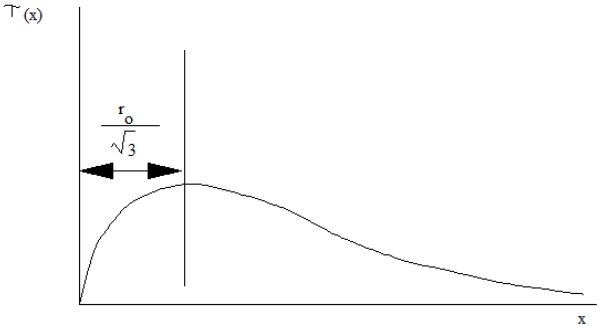


Fig 1.6 Variation of stress on an anchored dislocation

This condition will be reached first at some point in the specimen that is slightly weaker than the rest. All further plastic deformation is concentrated in this range and the specimen begins to neck or thin down locally (fig.1.7). Because the cross-sectional area now is decreasing far more rapidly than the deformation load is increased by strain-hardening, the actual load required to deform the specimen falls off and the engineering stress continues to decrease until fracture occurs.

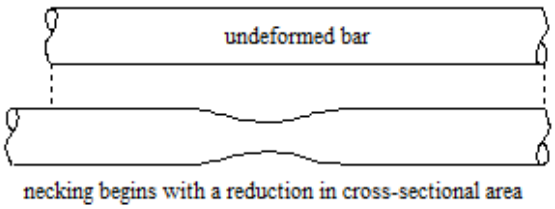


Fig 1.7 Necking of mild-steel bar in tension

1.4 Measurement of Ductility

When a tension test is performed, ductility is measured by *Percentage elongation* (note that percentage elongation depends on the gage length used) and/or *percentage reduction in the x-sectional area.* The percentage elongation is usually based on a 2 in. gage length, but other lengths are also used. Since the largest part of the plastic strain is localised in the neck with relatively little in other parts of the specimen, the percentage elongation varies with the length used.

The percentage reduction in area is found by measuring the cross-sectional area of the member before loading (A_0) and that of the neck after fracture (A). The differences between these two areas expressed as percentage of the original area, is the reduction of area.

$$\text{Percentage reduction in area} = \frac{A_0 - A}{A_0} \times 100$$

For specimens of the same size and shape this quantity provides a good ductility rating, since this is not subjected to any ambiguity as in percentage elongation.

1.5 Engineering Stress and True Stress

It must be emphasised at this stage that the stress that is normally reported is the engineering stress (also known as conventional stress or nominal stress) obtained by dividing the applied force by original (undeformed) cross-sectional area of the specimen. The true stress, on the other hand, is obtained as the ratio of the applied load to the corresponding reduced area (instantaneous area) of the cross section of the specimen. In the elastic range the reduction in area is very small (for steel, with Poison's ratio, =0.3 and 50,000 psi, the reduction is only 0.1 per cent) and the original area of the cross-section may be used without losing any significant accuracy.

Similarly engineering (also known as conventional or nominal) strain is the term given when original length of the specimen is used for computing strain, In the plastic range, however, it must be recognised that both the reduction in area and the strain can become very large and the use of instantaneous area and instantaneous gage length becomes more important in calculating the stress and strain. These are called true stress and true strain (also called natural strain) Figure 1.8 compares true stress with conventional stress, both plotted against conventional strain. The monotonic increase of true stress up to the breaking point illustrates that strain-hardening continues throughout the plastic range.

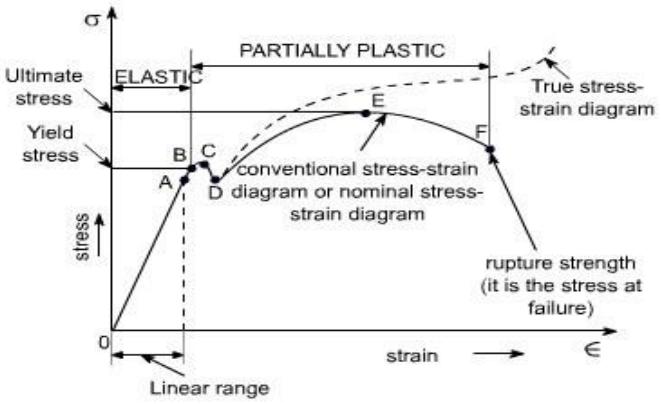


Fig 1.8 Comparisons of True Stress and Conventional Stress

1.6 The Standard Tension Test

The tension test is the most widely used experiment for the study of mechanical behaviour of a material. It is often called the basic mechanical test. In the idealised state of static tension it is assumed that (a) the load is applied axially, (b) the stress is constant at cross-sections along the length of the member, and (c) the load changes so slowly that no dynamic effects are present. In the standard tension test these conditions are approached as closely as possible within the practical limitations of the equipment available. A standard specimen is loaded slowly with an axial load, and a series of observations of load and deformation are made.

Deformation may be axial elongation or lateral contraction (or both). In the tension test for conventional stress and strain, it is necessary only to measures the elongation with an extensometer. The true stress-strain tension test, on the other hand, requires the lateral contraction to be measured, in addition to the measurement of the elongation. This makes the conventional stress-strain test of widespread use. In fact all standardised tension tests are for conventional stress and strain and this is why the procedure for this test only will be described here.

1.7 Tests for Conventional Stress and Strain

The test methods for obtaining information about stress and strain differ from material to material. The ASTM Standard E8 covers such test for metallic materials. The method used for metallic materials, however, applies also to others, and consequently this method will be discussed in details.

Specimen

Specimens, are almost always cylindrical or prismatic, with substantially constant cross-sectional area for uniformity of stress. The ends are usually enlarged for added strength so that rupture wilt not take place near the grips, where the stress distribution is complicated. The experimental measurements are all made on the central portion (i.e. the reduced section). In cylindrical specimens this portion is commonly 0.5 inch in diameter and 2.25 inches long. The ends are 0.75 inch in diameter and are threaded to screw into specimen holders on the testing machine. Since abrupt changes in cross-section cause stress concentrations, the transition from the central portion to the larger ends must be made by fillet of large radius (Fig. 1.9). The 2.25 inch central portion allows the use of a 2-inch gage length. It is often tapered very slightly (0.003-0.005 inch) toward the centre to help ensure rupture near the centre. Rectangular specimens are used for plate or sheet materials. Their proportions are similar to those of the cylindrical type. The ends are gripped by jaws in the testing machine. A number of other types and sizes are in common use for various purposes. Details are given in the appropriate ASTM Standards.

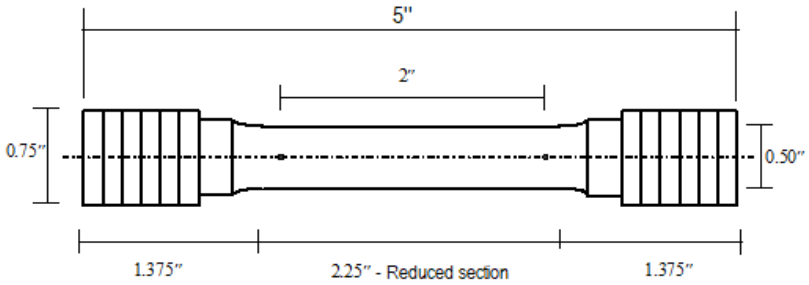


Fig. 1.9 Mild Steel Test Specimen

Loading

Before the specimen is placed in the testing machine its dimensions must be measured with care. The diameter of a V2 inch specimen is usually measured to the nearest 0.001 inch (for more detailed instructions see ASTM E8). The gage length is fixed by the extensometer, the gage points or knife edges of which are at the proper spacing. A pair of gage marks is usually punched on the surface of the specimen so that changes in their spacing can be measured with dividers for large elongation. These gage marks are also necessary if the final elongation is to be obtained.

After the specimen is properly aligned, a small initial load is usually applied to hold it firmly while the extensometer is being attached. The type of extensometer used depends on the gage length of the specimen, the accuracy and range desired, and whether the strains are to be recorded autographically. In order to plot a stress-strain diagram, the load and extensometer readings must be obtained at regular intervals. Intervals of load or extensometer reading are chosen before the start of the test to provide the desired number of readings. As soon as it nears the end of its operating range the extensometers should be removed (before this if there is any reason to believe that the specimen might rupture

prematurely). Observations of strain can then be continued with the dividers and gage points, using a magnifying glass if necessary.

Particular loads, such as yield point load (if any), ultimate (maximum) load, and breaking load, are recorded during the progress of the experiment. If it is carried all the way to rupture, the final elongation and cross-sectional area can be measured. The character of the fracture is often a revealing piece of information and should be described. The extensometer readings must be converted to strain by multiplying the gage factor and dividing by the gage length.

1.8 Apparatus

Universal Testing Machine:

A universal testing machine (UTM) is used to test the shear strength of materials (see Fig.2.5). The "universal" part of the name reflects that it can perform many standard tests on materials, components, and structures (in other words, that it is versatile).



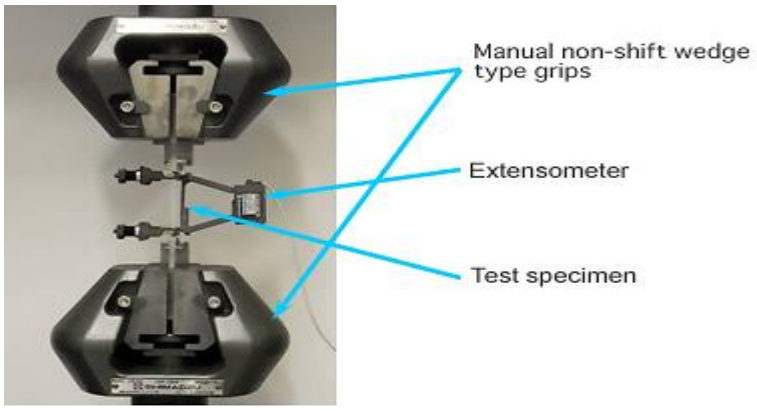
Fig 1.10: Universal Testing Machine

Slide callipers:

A slide calliper is used to measure the dimensions of the test specimens.

Extensometer:

An extensometer is a device that is used to measure changes in the length of an object. It is useful for stress-strain measurements and tensile tests.



1.9 Test Procedure

1. Measure the diameter of the specimen by slide calipers.
2. Record extensometer constant and gage length.
3. Fix the specimen in position.
4. Fix the extensometer with the specimen.
5. Apply load and read the extensometer at a convenient interval of load (say 500 lbs).
6. When yield point is reached, stop loading and remove the extensometer (since extensometer would have reached its maximum dial reading by now; elongation beyond this point (YP) is taken by means of an elongation scale).
7. Start loading again and take reading by the elongation scale at regular intervals. In this way, increase load gradually till a waist is formed in between the marked points and the specimen breaks.
8. Record the maximum and the breaking load.
9. Remove the broken specimen and measure smallest cross-sectional area and the final length (Lf) between the gage marks (see figure below) by fitting the two ends of the broken test piece together.
10. Note the characteristics of the fractured surfaces and draw a sketch of the failed specimen.

1.10 Calculations and Reports

1. Draw the complete stress-strain diagram of the mild steel specimen.
2. Draw the stress-strain diagram upto the yield point in an enlarged scare identifying the major points of the graph.
3. Determine the following parameters - proportional limit, yield stress, ultimate strength, breaking stress, modulus of elasticity, and modulus of resilience.
4. Determine the percentage elongation, percentage reduction in area and comment on the ductility of the specimen.

Experiment No. 2

Direct Shear Test of Metal Specimens

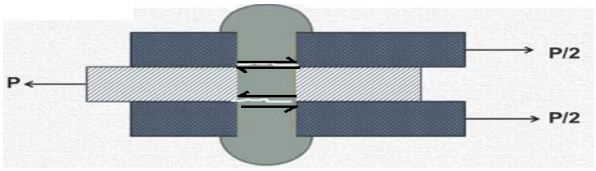
2.1 Introduction

A shearing stress is one that acts parallel to a plane as distinguished from the tensile and compressive stresses that act normal to a plane. It resists the tendency of the part of the body on one side of the plane to slide relative to the part of the body on the other side of the same plane. Following types of loading produce shear in material:

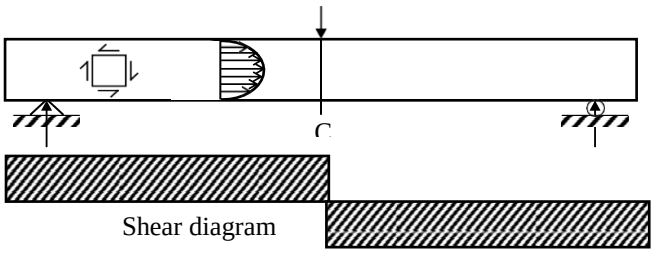
(i) The resultants of parallel but opposed forces act through the centroid of sections that are spaced infinitesimal distances apart. In such cases the shearing stresses over the sections should be uniform and the state of pure direct shear would exist (Fig. -2.1-a). This condition may be approached but is never realized practically.

(ii) The applied opposed forces are parallel, act normal to a longitudinal axis of the body, but are spaced finite distances apart. In such case, in addition to the shearing stresses produced, bending stresses are also set up. In the case of a rectangular beam subjected to transverse loads [Fig 2.1(b)], the intensity of shearing stresses on any cross-sections vary parabolically from zero at the upper and lower surfaces of the beam to a maximum at the neutral axis.

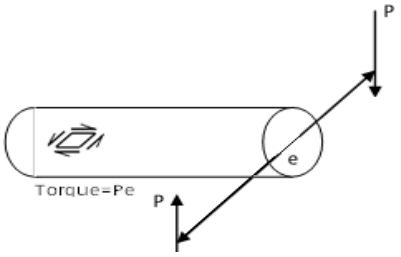
(iii) The applied forces are parallel and opposite but do not lie in a plane containing the longitudinal axis of the body; here a couple is set up which produces a twist about a longitudinal axis. This twisting action of one section of a body with respect a contiguous section is termed as torsion as shown in Fig 2.1(c). Torsional shearing stresses on circular cross-sections vary linearly from zero at axis of twist to a maximum at the extreme fibres. If no bending is present, 'pure shear' exists.



(a) Direct shear in a rivet



b) Shear in a homogeneous beam of rectangular section.



(c) Shear produced by torsional loading

Fig 2.1: Loading producing shear

2.2 Shear Stress Distribution in Beams

The shear force and the bending moment acting at a cross-section of a beam are closely interrelated. Let us consider an element of a beam of length dx (Fig. 2.2). The bending moment to the left of the element is M, and to the right it is slightly larger, M+dM. Let us now cut the beam horizontally at a distance y above the neutral axis, and consider the equilibrium of the element of width b (at right angles to the sketch), of length dx, and of depth (Fig.2.3). Since the compressive stresses due to the bending moment M+dM are greater than those due to the moment M, there is a resultant force tending to push the element to the right. This is resisted by the horizontal shear force V, acting along the cut which we made at a distance y above the neutral axis. There can be no shear at the top face of the beam, because at a free horizontal surface there is nothing to offer resistance to a horizontal shear force.

The shear force V=vbdx; where v is the shear stress, b the width of the section, and dx the length of the element. The shear stress builds up with depth from the free surface, as the difference between the direct compressive forces increases. Since this shear stress is the sum (or integral) of the difference in compressive stress over the depth (which is a linear or first -order function), the shear stress varies parabolically with depth. The total shear force V equals the area of this diagram, and a parabola has an area two-thirds that of the enclosing rectangle. In a rectangular section of width b and depth d, the maximum shear stress (which occurs at the neutral axis) is therefore,

$$\mathrm{v}_{\max} = \frac{\mathrm{V}}{2/3\mathrm{bd}}$$

A rigorous proof of this formula is given in many textbooks on the strength of materials is therefore is not included here. In the case of an I-beam, there is a sharp change in shear stress at the junction of the flanges with the web, since v is inversely proportional to b. The shear stress distribution diagrams thus almost rectangular (Fig. 2.4), and the maximum shear stress in a steel I-section is approximately

$$\mathrm{v} = \frac{V}{b_w d}$$

where, b_w is the width of the web.

Evidently an I-section divides itself into the flanges, which resist practically the whole of the bending moment, and the web, which resists practically the whole of the shear. However, it should be noted that in most practical cases the shear stress is computed by dividing the shear force acting on the cross-section by the area of the cross-section. This represents the average shear stress in the cross-section and is satisfactory for practical purposes.

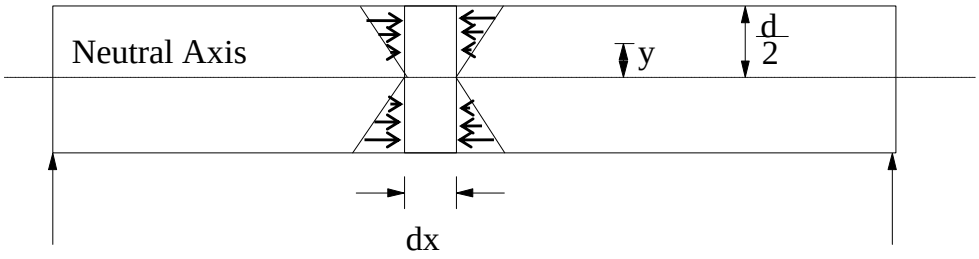


Fig.- 2.2 Direct stresses acting on an infinitesimally short length of beam, dx.

The bending moment increases over the length dx from M to M+dM, and the direct stresses increases proportionately.

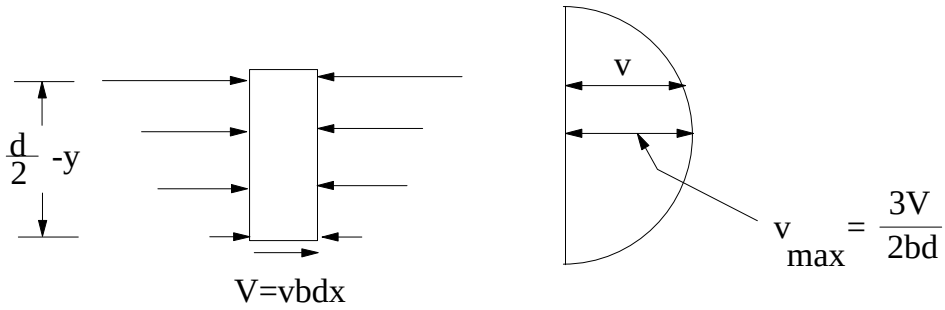


Fig.- 2.3 Horizontal shear force in a beam

Since the direct stresses increase over the length dx (Fig.3.2), a shear force V is required to balance the forces acting on the element of the beam dx long and b wide. The shear stress acting on this area, v, increases parabolically from zero at the free surface to a maximum at the neutral axis.

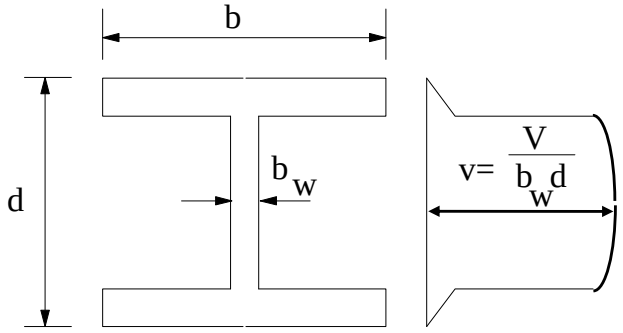


Fig.- 2.4 Shear stress distribution in I-sections.

The shear stress is invariably proportional to the width,b. Since the width changes abruptly in an I-section at the junction of the web and the flange, the shear stress changes in the proportion of b to b_W. Since the flange width, b is so much greater than the thickness of web, b_W, the shear force is almost entirely resisted by the web.

Two types of shear test are in common use; they are:

(i) The direct shear test

(ii) The torsion test

The direct shear test (also called transverse shear test) gives an approximation to the correct values of shearing strength.

2.3 Single Shear and Double Shear

Many of the circumstances that can be characterized as direct shear may be further classified as – i. single shear or as ii. double shear. This applies particularly to connections such as pinned, bolted, or welded joints. A single-shear connection is one where there is a single plane on which shear stress acts to transfer load from one member to the adjacent member. The pin of the pliers in Fig.- 2.5 is one example of a single-shear connection

$$\text{Single shear, } S_S = \frac{P}{A} \qquad (2.1)$$

Here A = the overlapped area

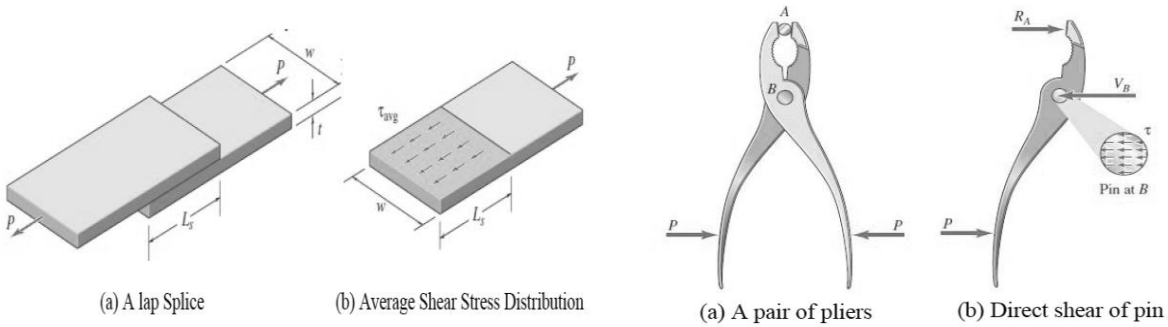


Fig. -2.5: Examples of single shear

Whereas double shear is the simultaneous shear across two usually parallel planes - as shown in figure below

$$\text{Double shear, } S_D = \frac{P}{2A} \qquad (2.2)$$

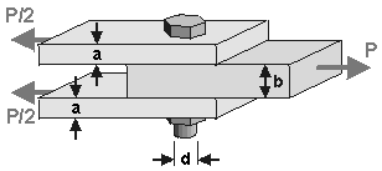


Fig. -2.6: Example of double shear

The specimens used in the direct shear tests in the laboratory are made of mild steel and brass. The shear strength of mild steel specimens typically vary between 30~80 ksi. On the other hand brass has lower strength compared to MS.

2.4 Failure Plane:

The failure surfaces for single shear is accompanied by bending moment across the shearing surface (as the specimen is a cantilever beam), the failure surface is also bent, i.e., it is inclined to the original surface. But the bending moment across the shearing surface for double shear is negligible as the specimen is a simply supported/partially clamped beam - the failure surface is almost plane. However for both cases, failure through shearing is ensured by minimizing the unsupported length of the specimens.

2.5 Experimental Setup

This test is usually done in a Johnson type of shear tool by clamping a portion of the material so that bending stresses are minimized across the plane along which the shearing load is applied. Because of inevitable bending and friction between parts of the tool it gives

an indication of the shearing resistance of the material. The transverse-shear test has the further limitation of being useless for the determination of the elastic strength or of the modulus of rigidity, owing to the impossibility of measuring strains

.

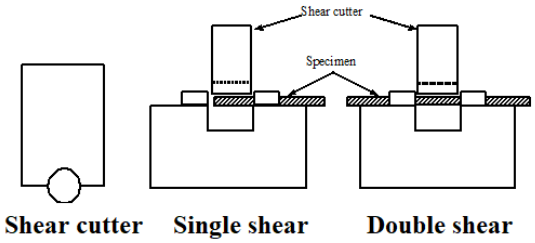


Fig. -2.7: Direct Shear test setup for single and double shear

2.6 Apparatus

Universal Testing Machine:

See experiment -1 (article-1.8)

Johnson's shear tool:

A shearing tool named “Johnson’s Shear Tool” is used to apply both the single and double shear load to the specimen (see Fig.2.8).

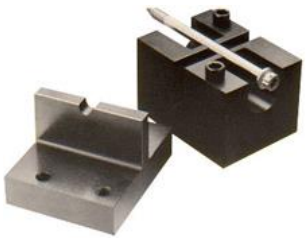


Fig 2.8: Johnson's shear tool

Slide callipers:

A slide calliper is used to measure the dimensions of the test specimens.

2.7 Test Specimens

Two types of test specimens are used in this experiment:

i) Brass rod ii) Mild steel rod

2.8 Test Procedure

i. Measure the diameter of the specimen with a slide calliper.
ii. Fix the specimen in the shear tool such that it is in single shear and apply load until rupture takes place.
iii. In the same way test the specimen for double shear.
iv. Repeat the experiment two more specimen.

2.9 Calculation

Calculate single and double shear using equation – 2.1 and 2.2.

Experiment No. 3

HARDNESS TEST OF METALS

3.1 Introduction

Hardness is defined as the resistance of a material to permanent deformation. The principal purpose of the hardness test is to determine the suitability of a material for a given application, or the particular treatment to which the material has been subjected. The ease with which the hardness test can be made has made it the most common method of inspection for metals and alloys. For example, both the hardness test and the tensile test measure the resistance of a metal to plastic flow, and results of these tests may closely parallel each other. The hardness test is preferred because it is simple, easy, and relatively non-destructive.

There are many hardness tests currently in use. The necessity for all these different hardness tests is due to the need for categorizing the great range of hardness from soft rubber to hard ceramics Depending on the particular deformation type (or for that matter particular type of stressing) hardness may be of the following types:

i. Indentation hardness test (by indenting)
ii. Scratch hardness test (by scratching)
iii. Dynamic hardness test (by impact)
iv. Rebound hardness test (by the rebound of a falling ball)
v. Wear hardness (by abrasion)
vi. Machinability (by cutting or drilling)

In this chapter, hardness test by indentation has been discussed. In indentation hardness test, a surface may be deformed is by indentation, in which a permanent deformation is produced by pressing an indenter of harder material into the surface of any material. Typical indenters are hardened steel and diamond depending upon the material tested and the type of the test. The depth of penetration and the force required are measured which provides an indication of hardness (indentation hardness). Indentation hardness is the most commonly used hardness test and different forms of this hardness test are in use. Current practice divides indentation hardness testing into two categories: macrohardness and microhardness. Macrohardness refers to testing with applied loads on the indenter of more than 1 kg and covers, for example, the testing of tools, dies, and sheet material in the heavier gages. In microhardness testing, applied loads are 1 kg and below, and material being tested is very thin (down to 0.0125 mm, or 0.0005 in.). Applications include extremely small parts, thin superficially hardened parts, plated surfaces, and individual constituents of materials.

i. Macro Hardness Testers Loads > 1 kg
    a. Rockwell
    b. Brinell
    c. Vickers
ii. Micro Hardness Testers < 1 kg
    a. Knoop diamond
    b. Vickers diamond pyramid

A general description of some of the common form of indentation hardness tests are given here:

3.1.1 Pyramid Hardness

The most versatile hardness measurement makes use of diamond points, ground in the shape of a pyramid, as indenter. The indenter is forced into the surface, leaving an impression, the size of which is measured by the length of the diagonal 'd'. The hardness number (H) is then defined as the ratio of the load (P) to the area of the impression (A):

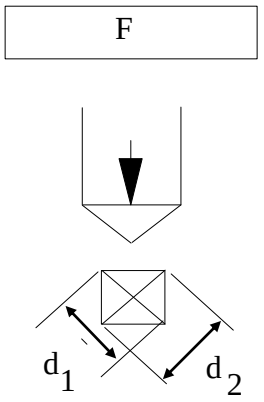
$$H = P/A \quad . \quad . \quad (3.1)$$

It has been found experimentally that for pyramid indentors, the load varies as the square of the diagonal, 'd'.

Therefore, $P = \lambda d^2$; where 'λ' is a constant. and $A = \beta d^2$; depending on the material and shape of pyramid. Constant 'β' depends on the shape of the pyramid. Substituting these expression in (3.1) we have

$$H = \lambda/\beta \quad . \quad . \quad (3.2)$$

It can be seen that H is independent of both load and size of indentation. This equation has a very important meaning. Within certain limits, the hardness number for a given shape of pyramid is the same regardless of the load used. The hardness measured by a square based pyramid is the 'Vicker's hardness' and is standardised by ASTM under the more general name 'Diamond Pyramid Hardness' (DPH).



F = Load (kgf)

$$d = \frac{d_1 + d_2}{2} \text{ (mm)}$$

$$H_V = 1.854 \frac{F}{d^2}$$

H_V = Vickers hardness

Fig. 3.1 Vickers Hardness

3.1.2 Brinell Hardness

Brinell developed one hardness measurement using a hardened steel ball. The indentation is a circular depression and the Brinell hardness number is defined as:

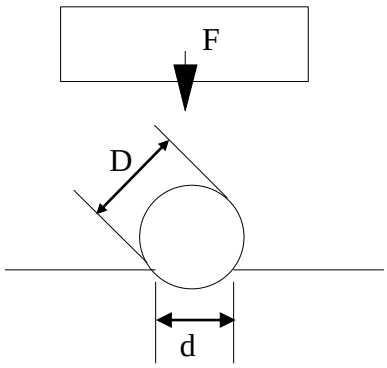
$$H_B = P/A \quad . \quad . \quad (3.3)$$

where, A= area of contact in sq. mm. between the ball and the indentation and P= applied load in kgf.

Therefore, Brinell hardness number is measured as the load in kilograms per square millimetre of spherical impression made in the test as shown in Figure 3.2.

In Brinell hardness test, the selection of the load (P) and the diameter (D) of the ball (penetrator) is quite important. Injudicious selection of these parameters may lead to meaningless results. Fig.-3.3 shows the importance of the use of appropriate load and

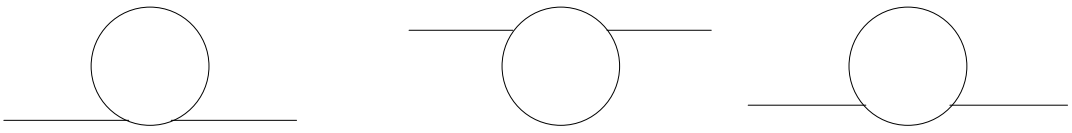
penetrator. Fig.-3.3(b), for example, shows a case where too great a load compared to the diameter of the ball has been applied on a relatively soft metal. As a result the ball has sunk to its full diameter and the result is obviously meaningless. For different materials, therefore, the ratio of P/D^2 has been standardised as shown in Table 3.1.



F = Load (kgf)
D = ball diameter (mm)
d = mean diameter of indentation (mm)
H_B = Brinell hardness

$$H_B = \frac{2F}{\pi D[D-\sqrt{(D^2-d^2)}]}$$

Fig. 3.2: Brinell Hardness



(a) Depth of impression too shallow which may lead to inaccurate dtermination of diameter and hence of hardness. (b) The ball has sunk to its full diameter and hence determination of hardness from this is meaningless. (c) Depth of impression is satisfactory

Fig.3.3 Depth of impression and accuracy of hardness determination.

Table 3.1 Brinell hardness test conditions for different materials

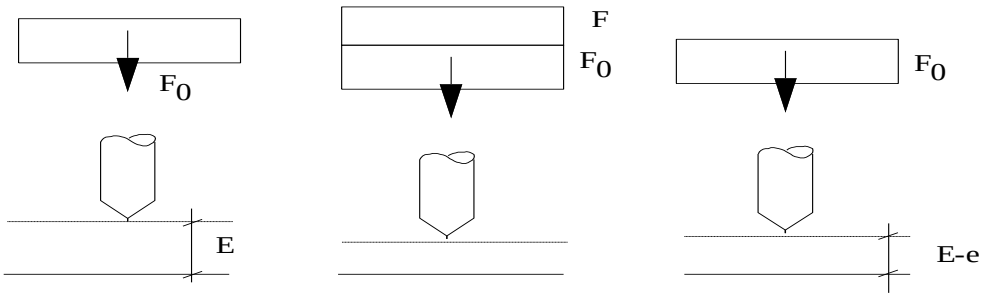
Specimen		Standard conditions for Brinell Test		P/D^2 for other penetrator size	Range of HB
Material	Min. thickness	Load (P) kg	Ball dia (D) mm		
Steel	—	3,000	10	30	
Grey cast Iron	>15 mm	1,000	10	10	<140
	5-15 mm	750	5	30	140~500
	<5 mm	120	2	–	
Copper & its alloys	—			10	25~200
	—			5	<40
	—			30	>190
Light metals and alloys	—			5	<55
	—			5~15	55~80
	—		10	15	80

3.1.3 Rockwell Hardness

The Rockwell hardness is measured by use of a steel ball or a cone shaped diamond point. It differs from measurements already discussed in that the depth of the impression is

measured instead of its diameter. However, since the two are always geometrically related, the hardness measurement is the same in principle.

Generally a minor load (F_0) is applied first. Application of the minor load is always made in order to sink the penetrator below the surface of the test specimen. The remaining portion of the loading force (the major load, F) is then used to make a hole whose depth will be the inverse measure of the hardness. This feature of first applying a small part of the force, as a means of embedding the penetrator below the surface of the test specimen, gives much more reliable and reproducible results .It almost entirely eliminates the effect of surface finish differences by smoothening out irregularities .The depth of penetration is measured from this smooth surface created by the minor load .This method of hardness testing consists of measuring the increment of depth of the penetrator that was forced into the metal by a primary and a secondary load and is also known as "differential depth measurement method". Consequently, the Rockwell hardness value is defined (see Fig. 3.4):



Rockwell hardness H_R =E-e

Where, E=100 (diamond brale) for C scale.
E=130 (steel ball) for B scale
e= permanent increase in depth of penetration due to load F (kgf), measured in units of 0.002 mm

Fig. 3.4 Rockwell Hardness

The Rockwell hardness value (H_R), which is a dimensionless index, is read directly from a specially graduated dial indicator. The readings taken after the major load is applied and removed while the minor load is still in position. Two types of indentor are used in the Rockwell test:

(i) a steel ball of 1/16 inch in diameter (other diameters are also used) and

(ii) a diamond brale (a diamond cone with 120° apex angle).

The steel ball indentor is used with softer metals whereas the diamond brale is used for harder metals. The major and minor load to be used in either case appear in Table 3.2.

The dial of the Rockwell hardness tester has two sets of figures, one red and the other black. In the designation of scales, it should be noted that the red figures are used for readings obtained with ball indentor regardless of the size of the ball or magnitude of major load and that black figures are used only when the brale indentor is in use. These two scales are separated by 30 Rockwell units. This is done to avoid a negative reading for the

relatively softer materials. The red and black figures correspond to the B and C scales respectively when used with the load and penetrator size as specified in Table 3.2.

Table 3.2 Relevant details for using with a steel ball (1/16") or brale indentor in a Rockwell tester.

Type of indentor	Scale to be used	Minor load (F_0) kg	Major load (F) kg
Steel ball $\frac{1}{16}$" dia	B	10	100
Diamond brale	C	10	150

Other scales are also used with the Rockwell machine (see Figure 3.5). Each of these scale is indicated by a symbol (A,D,E,F,G,H,K,L,M,P,R,S,and V), which denotes the sizes of the penetrator and the load. However, Rockwell B and C are the most commonly used scales. In reporting the Rockwell hardness values, it is important to mention the scale used. For example, a hardness measurement reported merely as a number as read form the instrument dial, say 50, has no meaning whatsoever. In other words the hardness scale is not defined. Thus the hardness numbers must be prefixed by the letter B or C as appropriate i.e., 50 HRB, 96 HRC.

3.2 Apparatus

Rockwell Hardness Tester:

The Rockwell Hardness Tester machine measures hardness by determining the difference in penetration depths of an indenter under two specified forces. The unit measurement for depth of penetration is .002mm.

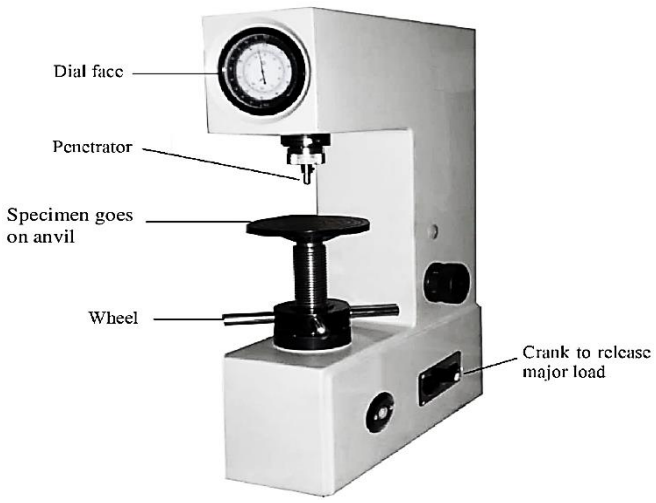


Fig.3.5 Rockwell hardness tester

Correct hardness measurement requires a thorough understanding of the revolution of the indicator dial gauge on a Rockwell machine when the testing load is applied to the specimen .The force applied by the loading weights through the leverage system , the sharpness of the penetrator and the resistance to penetration exerted by the materiel are the variables that have a combined effect on the amount of the revolution of the large pointer .The amount may be more or less than one revolution of the dial. Consequently, it is not sufficient to read the hardness value by observing the final position of the pointer when the test is completed .The entire movement of the pointer from the moment the

additional major load is applied until the pointer comes to a rest with the additional load removed at the conclusion of the testing procedure must be recorded.

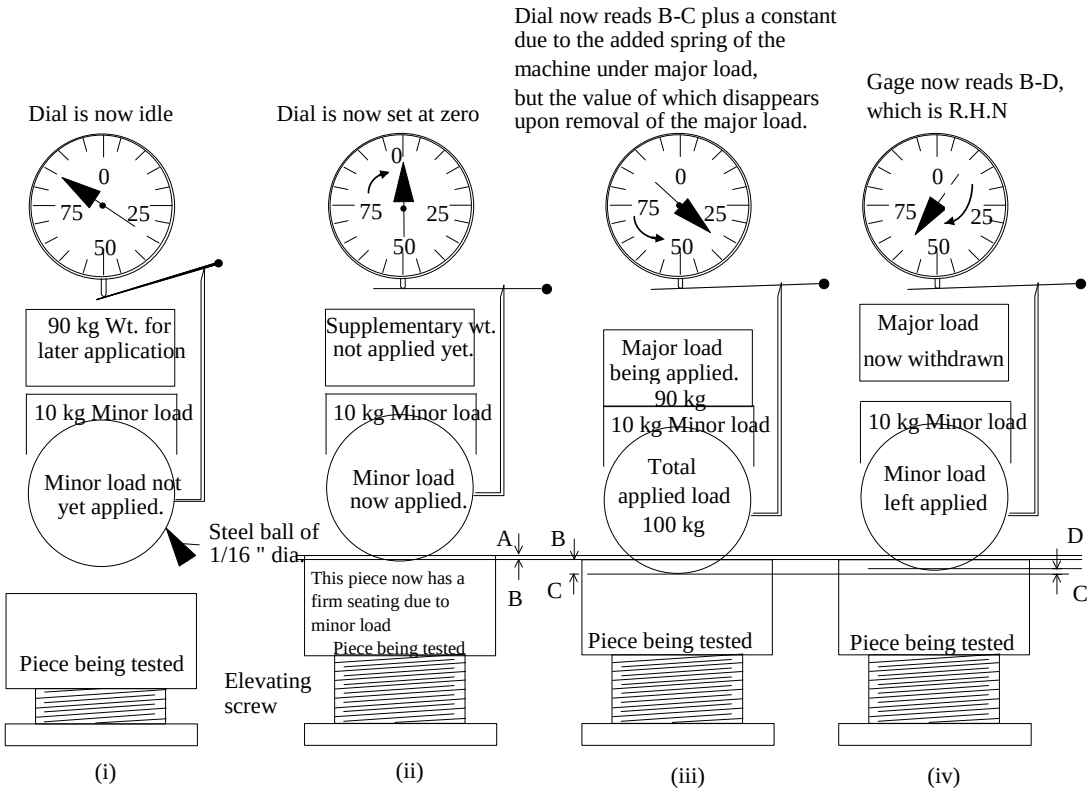
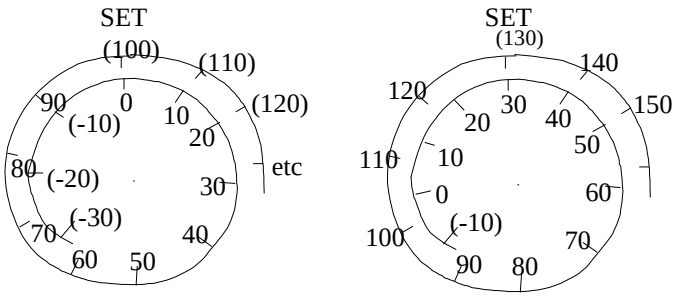


Fig.3.6 Illustrating the principle of operation of the Rockwell hardness tester

For correct determination of hardness values one has to understand the circular arrangement of the dial scale which is capable of indicating not only numbers from 0 to 100 which the dial shows , but also numbers less than zero and over 100 , even though such numbers do not appear on the dial. The dial scale should be thought of as representing a scale curled into a circle with negative numbers and numbers over 100 overlapping the 0 to 100 portion. This is illustrated in Fig. 3.7. Figure 3.7 (a) represents the black numbered scale and Fig. 3.7 (b) the red numbered scale. These two scales are out of phase with each other by 30 Rockwell units.

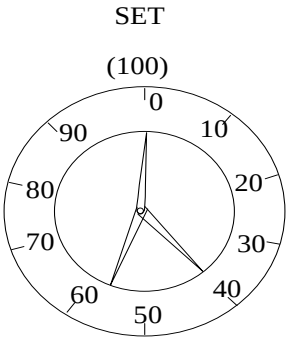


(a) Black numbered scale (b) Red numbered scale

Fig3.7 Illustration of dial reading techniques.

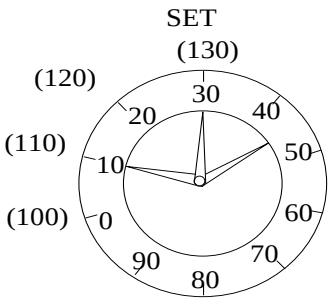
As the major load is applied , the pointer moves counter clockwise from the set position of 100 to 90, 80, 70, etc. If it continues down beyond 0, its position will then be negative with the 90 actually being (-10), 80 being (-20) etc. Subsequently when the additional load is removed the pointer returns partway upscale to its final reading position. Similar movement occurs on the red-scale. Thus merely reading the dial does not necessarily assure valid hardness reading. A negative reading is invalid because the penetrator has

sunk into the metal tested, beyond the extent of its calibrated surface zone. Pointer movement diagrams are useful in understanding the final reading and are shown in Fig. 3.8 for the RB and RC scales.



(a) Reading on C scale.

Pointer starts at SET position of 100 for C scale. Pointer position at say 40 after the major load is applied. Final reading at RC 58 after the removal of the major load.



(b) Reading on B scale.

Pointer starts at SET positin of 130 for B scale. Pointer position, say 10 after the major load is applied. Final pointer position at RB44, after the removal of the major load.

Fig. 3.8 Pointer movement for Rockwell B and C scales.

3.3 Test Specimens:

Four types of specimens are used in Hardness test

i. Brass
ii. Mild Steel
iii. High Carbon Steel
iv. Cast Iron

3.3.1 Location and Spacing of Rockwell Test Impression

In order to ensure an accurate test, the centre to centre distance of adjacent indentations must be at least 3 diameters of impression, closer spacing will give invalidly high results. Similarly, the minimum permissible distance from the edge of a test specimen to the centre of an impression must be at least 2.5 times the diameter of the impression.

3.4 Test Procedure:

3.4.1 Determination of Rockwell Hardness Number

i. Examine the machine and get it ready for testing (note that the weight marked 100 kg is in position).
ii. Place the specimen upon the anvil of the machine.
iii. Raise the anvil and the test piece by elevating screw until the specimen came in contact with the ball.
iv. Apply 10 kg minor load on the specimen by moving the pointer of the dial three times.

v. Apply the additional load (140 kg for harder specimen and 90 kg for softer material) on the specimen by pressing the appropriate handle.
vi. After few seconds of the application of the additional load, return the handle to its original position (i.e. the additional load is withdrawn now).
vii. Read the position of the pointer on the scale of the dial as the Rockwell hardness No. (C-scale is used for harder specimen and B-scale for softer material)
viii. Take three readings for each specimen by changing the location of indentation.
ix. Repeat the above steps for each of the different specimen supplied.

3.4.2 Determination of Brinell Hardness Number

- Use the chart (Sec.3.5) to obtain Brinell Hardness No, from the Rockwell Numbers determined above (note the scale used in each case when the Rockwell hardness number was determined).
- If the values are not available in the chart use the approximate equations (Sec.3.5).

3.4.3 Determination of Tensile Strength

i. Use the empirical relationships (Table4.6) to obtain tensile strength from the known Brinell number (determined in Sec.3.4.2 above).
ii. Another set of tensile strength should be obtained using the chart (Sec. 3.5). Use the already obtained Brinell No for this purpose.

3.5 Calculation

3.5.1 Relationship between Hardness Numbers

Truly speaking there is no precise relationship exists between the several types of hardness number. Approximate relationships have been developed by carrying out tests on the same material using various devices. It should be borne in mind that these relationships are affected by many factors (materials, heat treatments etc.) and for this reason too much reliance on them must be avoided. However, the relationship provided Tables 3.3 to 3.6 can be used to obtain Brinell hardness number from the known Rockwell hardness number.

Brinell (3,000 kg load) and Rockwell hardness numbers may also be converted interchangeably with an accuracy of about 10 per cent according to the following relationships:

For RB 35 to RB 100

$$BHN = \frac{7300}{130 - RB} \quad . \quad . \quad 3.4$$

For RC 20 to RC 40

$$BHN = \frac{20{,}000}{100 - RC} \quad . \quad . \quad 3.5$$

For RC 41 or greater

$$BHN = \frac{25{,}000}{100 - RC} \quad . \quad . \quad 3.6$$

where RB and RC denote the Rockwell B and C.

Table 3.3 Approximate hardness conversion numbers for nonaustenitic steels (ASTM A370) (Rockwell C to Brinell hardness)

Rockwell C scale 150 kgf load and Diamond penetrator	Brinell hardness no. 3000 kgf load and 10 mm ball	Approximate tensile strength (ksi)
68	—	—
67	—	—
66	—	—
65	739	—
64	722	—
63	706	—
62	688	—
61	670	—
60	654	—
59	634	351
58	615	338
57	595	325
56	577	313
55	560	301
54	543	292
53	525	283
52	512	273
51	496	264
50	482	255
49	468	246
48	455	238
47	442	229
46	432	221
45	421	215
44	409	208
43	400	201
42	390	194
41	381	188
40	371	182
39	362	177
38	353	171
37	344	166
36	336	161
35	327	156
34	319	152
33	311	149
32	301	146
31	294	141

Table 3.3 Approximate hardness conversion numbers for nonaustenitic steels (ASTM A370) (Rockwell C to Brinell hardness) (Continued..)

Rockwell C scale 150 kgf load and Diamond penetrator	Brinell hardness no. 3000 kgf load and 10 mm ball	Approximate tensile strength (ksi)
30	286	138
29	279	135
28	271	131
27	264	128
26	258	125
25	253	123
24	247	119
23	243	117
22	237	115
21	231	112
20	226	110

Table 3.4 Approximate hardness conversion numbers for nonaustenitic steels (ASTM A370) (Rockwell B to Brinell hardness)

Rockwell B scale 100 kgf load and 1/16 " steel ball penetrator	Brinell hardness no. 3000 kgf load and 10 mm ball	Approximate tensile strength (ksi)
100	240	116
99	234	114
98	228	109
97	222	104
96	216	102
95	210	100
94	205	98
93	200	94
92	195	92
91	190	90
90	185	89
89	180	88
88	176	86
87	172	84
86	169	83
85	165	82
84	162	81

Table 3.4: Approximate hardness conversion numbers for nonaustenitic steels (ASTM A370) (Rockwell B to Brinell hardness) (Continued..)

Rockwell B scale 100 kgf load and 1/16" steel ball penetrator	Brinell hardness no. 3000 kgf load and 10 mm ball	Approximate tensile strength (ksi)
83	159	80
82	156	77
81	153	73
80	150	72
79	147	70
78	144	69
77	141	68
76	139	67
75	137	66
74	135	65
73	132	64
72	130	63
71	127	62
70	125	61
69	123	60
68	121	59
67	119	58
66	117	57
65	116	56
64	114	–
63	112	–
62	110	–
61	108	–
60	107	–
59	106	–
58	104	–
57	103	–
56	101	–
55	100	–

Note: Tables 3.3 and 3.4 give the approximate relationships of hardness values and approximate tensile strength of steels. It is possible that steels of various compositions and processing histories will deviate in hardness-tensile strength relationship from the data presented in these Tables.

Table 3.5 Approximate hardness conversion numbers for austenitic steels (ASTM A370) (Rockwell B to Brinell hardness)

Rockwell B scale 100 kgf load and 1/16" steel ball penetrator	Brinell hardness no. 3000 kgf load and 10 mm ball
100	256
99	248
98	240
97	233
96	226
95	219
94	213
93	207
92	202
91	197
90	192
89	187
88	183
87	178
86	174
85	170
84	167
83	163
82	160
81	156
80	153

3.5.2 Relation Between the Hardness Number and Other Properties

In general, no correlation exists between any indentation hardness and the yield strength determined in a tension test since the amount of inelastic strain involved in the hardness test is much greater than in the test for yield strength. However, because of greater similarity in inelastic strain involved in the test for ultimate tensile strength and indentation hardness, empirical relations have been developed between these two properties. The approximate tensile strength of steel for several types of material is indicated in Tables 3.3 and 3.4. The empirical relationships of Table 3.6 also give approximate tensile strength from Brinell hardness number.

Table 4.6 Tensile strength from Brinell number.

Material	Tensile Strength (ksi)
For heat treated alloy steels with Brinell No. of 250 to 400	Brinell No X 0.42
For heat treated carbon steels as rolled normalised or annealed	Brinell No X 0.43
For Medium Carbon Steels as rolled normalised or annealed	Brinell No X 0.44
For Mild Steels normalised or annealed	Brinell No X 0.46
For non-ferrous rough alloy such as duralumin	$\left(\frac{Brinell.Hardness}{4}-1\right)*2.0$

Experiment No. 4

IMPACT TEST OF METAL SPECIMENS

4.1 Introduction

The behaviour of materials under dynamic loading may sometimes differ markedly from their behaviour under static or slowly applied loads. Impact loading is an important type of dynamic loading in which the load is applied suddenly, as from the impact of a moving mass. The velocity of a striking body is changed, there must occur a transfer of energy, work is done on the parts receiving the blow. The mechanics of impact involves not only the question of stresses induced but also a consideration of energy transfer and energy absorption and dissipation.

The effect of an impact load in producing stress depends on the extent to which the energy is expended in causing deformation. In the design of many types of structures and machines that must take impact loading, the aim is to provide for the absorption of as much energy as possible through elastic action and then to rely upon some kind of damping to dissipate it. In such structures the resilience (i.e. the elastic energy capacity) of the material is the significant property. In most cases the resilience data derived from static loading may be adequate. Examples of impact loading include rapidly moving loads such as those caused by a train passing over a bridge, or direct impact caused by the drop of a hammer. In machine service, impact loads are due to gradually increasing clearances which develop between parts with progressive wear.

2.2 Apparatus

Impact Testing Machine:

The standard notched bar impact testing machine is of the pendulum type (Fig. 4.1). The pendulum consists of an I-section with heavy disc at its end. It is suspended from a shaft that rotates in ball bearings and swings midway between two upright stands, at the base of which is located the specimen support. The impact testing machine generally has arrangement for two different initial position of the hammer block. The one in the higher position is for specimens which are likely to withstand higher energy.



Fig. 4.1. Impact Testing Machine

The energy-scale for this case is graduated over arrange of 0-240 ft-lb, whereas for the specimens which are likely to absorb less energy, are tested with the hammer block

positioned at a lower initial height. This second position of the hammer block is to be used with a corresponding energy scale over a range of 0-100 ft-lb.

Impact tests are performed by applying a sudden load or impulse to a standardised test piece held in a vise in specially designed testing machine. Before performing the experiment, intial error must be determined if any. The specimen is held in an anvil and is broken by a single blow of the pendulum or hammer, which falls from a fixed starting point (Fig. 4.2). In this condition it has a potential energy equal to the "WH" where W is the weight of the pendulum and H is the height of the centre of gravity above its lowest point. Upon release, and during its downward swing the energy of the pendulum is transformed from potential to kinetic energy is equal to WH. A certain portion of this kinetic energy goes into breaking the specimen. The remainder carries the pendulum through the lowest point and is then transformed back into potential energy WH' by the time the pendulum comes to rest where H' is the height in position B.

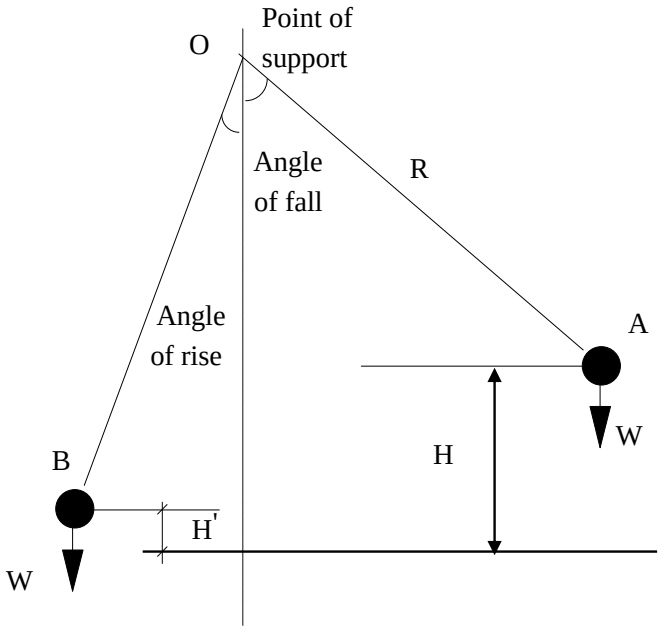


Fig.4.2 Space relation of pendulum machine.

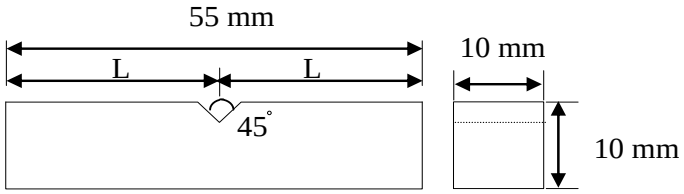
4.3 Specimens for Impact Testing

Notched bar test specimens of Mild Steel and Cast Iron having different designs are used for impact test. Two types of specimens are standardised for notched impact testing and the impact tests for metals and alloys are generally classified as the Charpy test (popular in U.S.A.) and the Izod test (commonly used in U. K.). Usually the same impact machine is designed to conduct both the Charpy and the Izod tests. The essential difference between these tests are in the positioning of the specimen (Fig.4.3 and Fig.4.4). Following three types of specimen are used for impact testing of metals:

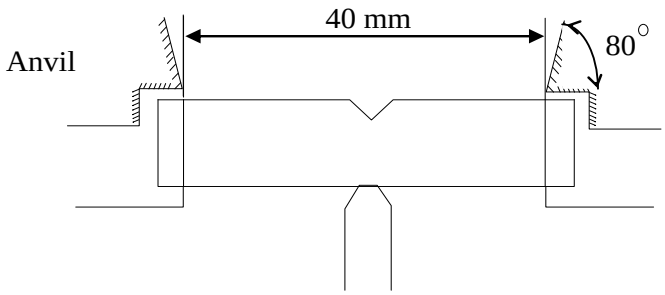
a) Charpy simple beam
b) Izod cantilever beam
c) Charpy tension rod

Charpy simple beam:

The standard flexure test specimen is a piece 10 by 10 by 55 mm notched as shown in Fig.4.3 (a) (ASTM A370). The specimen which is loaded as a simple beam, is placed horizontally between two anvils as shown in Fig. 4.3(b), so that the knife strikes opposite the notch at the mid-span.



(a) Charpy simple beam



(b) Arrangement of the specimen in machine (top view).

Fig. 4.3. Details of the charpy simple beam

Charpy tension rod:

For impact-tension tests a specimen is secured to the back edge of the pendulum. As the pendulum falls, a hammer block secured to the outstanding end of the specimen strikes against two extended anvils, the specimen being ruptured as the pendulum passes between the two anvils. Tension specimens may be plain or with circumferential notch. One type of plain specimen has a diameter of 6 mm; a corresponding notched specimen has a diameter of 6 mm as for the first type. The tension test has not been standardised and is not used to any great extent in commercial practice.

Izod cantilever beam:

The cantilever specimen is a 10 by 10 mm in section and 75 mm long having a standard 45 notch 2 mm deep. The specimen is clamped to act as a vertical cantilever. The mounting of the specimen and the relative position of the striking edge are shown in Fig. 4.4.

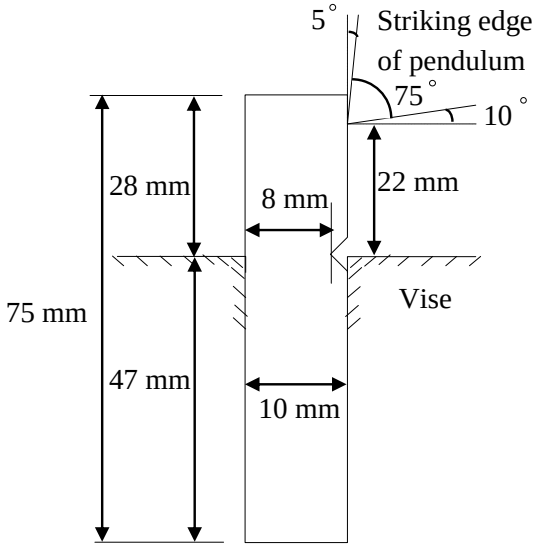


Fig. 4.4 Cantilever beam specimen and mounting for the Izod test.

8.4 Testing Procedure

i. Measure the lateral dimensions of the specimen at a full section and at the notch.
ii. Set the pointer to read minimum on the graduated disc and note down the initial error as explained in (iii).
iii. Set the hammer block in the position ‘A’ and the pointer along with the carrier, in the position ‘a’ (see figure below) and then release it. When the hammer block stops swinging, the pointer should be in position ‘b’, if not read the initial error bb'=i (this is to be used for high scale).

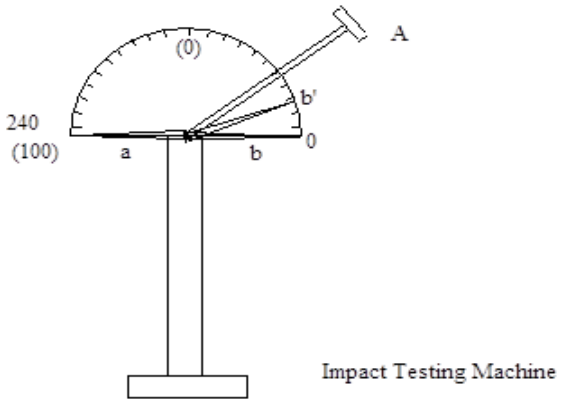


Figure 4.5

iv. In the same way as described in `iii' determine the initial error for the low scale.
v. Place and position the sample appropriately in the vise.
vi. Raise the pendulum and fix it in proper position. Release the pendulum and record the energy absorbed.
vii. The corrected energy absorbed by the specimen is then found taking into consideration of the initial error determined earlier. Note the condition of the failed specimen (whether broken or not).
viii. Repeat steps (v) to (vii) for each of the specimen supplied.

4.5 Calculation

The energy delivered to the specimen is (WH-WH'), the impact value (Fig. 8.5). The values of H and H' are indicated by a pointer moving on a scale. The scale is usually calibrated to read directly in feet-pound. Calculate the impact value for the specimen from the differences between the initial and final dial reading. Adjust the initial error prior to the experiment if any.

4.6 Usefulness of Impact Tests

The results obtained from notched bar tests are not readily expressed in terms of design requirements. Furthermore, there are no general agreement on the interpretation or significance of results obtained with this type of test. The impact test measures the energy absorbed in fracturing the specimen.

The sharpness of the notch significantly affects this value, but geometrically similar notches do not produce the same results on large parts as they do on small test pieces. Consequently true behaviour of a metal in service can only be obtained by testing full-size components, in a manner as they will be used in service. The figures, therefore, have no design value. A material of 40 ft. lb. is not twice as strong as one of 20 ft.lb.

Experiment No. 5

TENSION AND BEND TEST OF REBAR AND STEEL COUPON TEST

5.1 Introduction

Tension tests provide information on the strength and ductility of materials under uniaxial tensile stresses. This information may be useful in comparisons of materials, alloy development, quality control, and design under certain circumstances. The results of tension tests of specimens machined to standardized dimensions from selected portions of a part or material may not totally represent the strength and ductility properties of the entire end product or its in-service behavior in different environments. These test methods are considered satisfactory for acceptance testing of commercial shipments. The test methods have been used extensively in the trade for this purpose.

Bars are generally produced in strands 6 to 12 meter in length so that bending for transportation and handling purposes becomes necessary. At the site bars are straightened, and then sometimes re-bent for assembling purposes. This process will result in a loading and re-loading of steel. Bending test of rebars is essential for primary evaluation of their ductility. Certain structures, especially domes and shells will require bar bending so that the basic form of the structure can be achieved. Another example of typical field bending is the adjustment of column reinforcing steel at the beam joints. To enable assembling, bars are bent in between the beam reinforcement, this also happens for bar connections when no mechanical fasteners or connectors are used. While tests result will give a figure of the material's ductility, it does not reflect its influence to material strength. The severity of the bend test is primarily a function of the angel of bend and inside diameter to which the specimen is bent, and of the cross section of the specimen. These conditions are varied according to location and orientation of the test specimen and the chemical composition, tensile properties, hardness, type and quality of the steel specified.

5.2 Apparatus Used

Testing Machines

Reinforcing bars are bend tested using the Universal Testing Machine (UTM). Machines used for tension testing shall conform to the requirements of Practices E 4. The forces used in determining tensile strength and yield strength shall be within the verified force application range of the testing machine as defined in Practices E 4.

Gripping Devices

Various types of gripping devices may be used to transmit the measured force applied by the testing machine to the test specimens. To ensure axial tensile stress within the gage length, the axis of the test specimen should coincide with the center line of the heads of the testing machine. Any departure from this requirement may introduce bending stresses that are not included in the usual stress computation (force divided by cross-sectional area).

Dimension-Measuring Devices

Micrometers and other devices used for measuring linear dimensions shall be accurate and precise to at least one half the smallest unit to which the individual dimension is required to be measured.

Extensometers
Extensometers used in tension testing shall conform to the requirements of Practice E 83 for the classifications specified by the procedure section of this test method. Extensometers shall be used and verified to include the strains corresponding to the yield strength and elongation at fracture (if determined).

5.3 Test Procedures

5.3.1 Procedure for Tension Test of Rebar

i. Measure the diameter of the specimen by slide callipers.
ii. Punch a gage length of 8 inch on the deformed bar by using punch gage.
iii. Fix the specimen in position.
iv. Apply load at a convenient interval and increase load gradually till a waist is formed in between the marked points and the specimen breaks.
v. Record the maximum and the breaking load.
vi. Remove the broken specimen and measure smallest cross-sectional area and the final
vii. length (L_f) between the gage marks by fitting the two ends of the broken test piece together.
viii. Note the characteristics of the fractured surfaces and draw a sketch of the failed
ix. specimen.

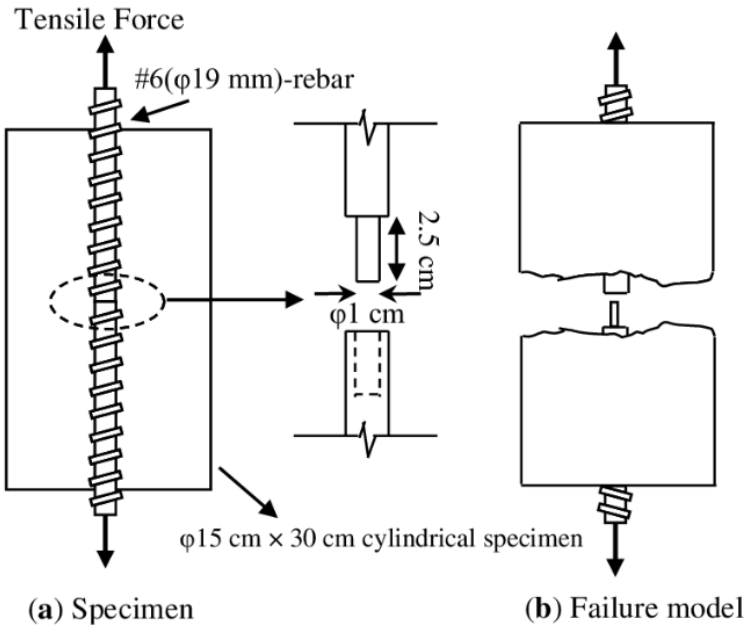


Figure 5.1 Tension test of rebar

5.3.2 Procedure for Bend Test

1. Bend test is performed according to the specifications of ASTM E 290.
2. Reinforcing bars are bend tested using the Universal Testing Machine (UTM).
3. Bars are placed horizontally on the supports that are positioned in accordance to the code (Fig. 2.3). The plunger "r" in diameter is defined by the equation:

$$r = 4 \times d_{bar} \; or \; t$$

Where: r = diameter of the plunger in mm

d_{bar} = diameter of bar being tested in mm

t = thickness of tested specimen other than bars in mm

(c is the distance between lower supports)

$$c = 2r + 3t \pm t/2$$

4. The force required to bend the bar 180˚ is a function of bar diameter. To avoid instability at the supports, the base-blocks are fixed using anchorages.
5. A loading rate is set to be 0.5kN per graduation and the deformation process is observed during testing. When a full bend is achieved, the load is removed and the bar detached from the apparatus (Fig. 5.2).

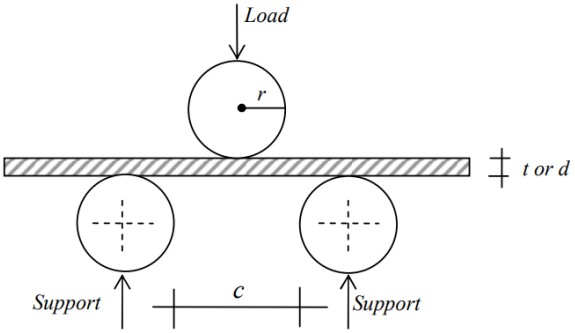


Figure 5.2 (a) Set Up of Bend Test

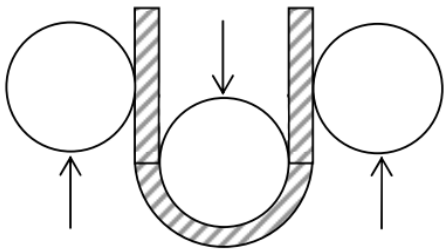


Figure 5.2 (b) Bar After Testing

6. In accordance to the ASTM code E 290 the bend is observed without any equipment and inspected for cracks or chipping.

5.3.3 Procedure for Rebend Test

1. Rebend test is performed according to the specifications of IS 1786:2008.
2. The test piece is bent to an included angle of 135˚ (see Fig. 2.5) using a mandrel of appropriate diameter.
3. The bent piece is aged by keeping in boiling water (100°C) for 30 minutes and then allowed to cool.
4. The piece shall then be bent back to have an included angle of 157.5˚. The specimen shall be considered to have passed the test if there is no rupture or cracks visible to a person of normal or corrected vision on the rebent portion.

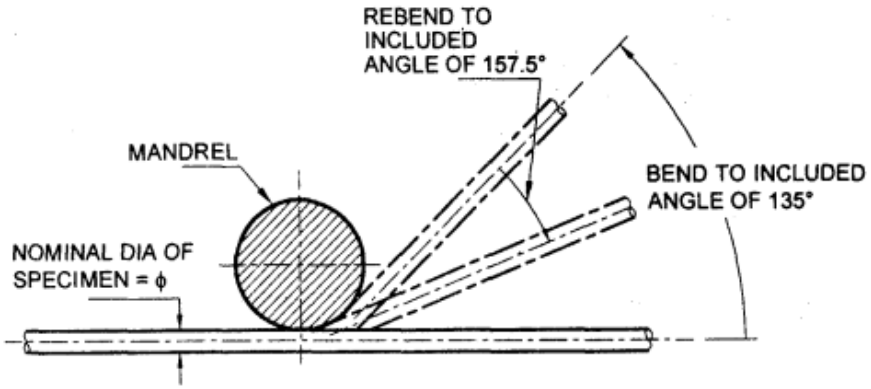


Fig.5.3 Rebend test

5.4 Calculations and Reports

Tension test of rebar

i. Determine the following parameters - proportional limit, yield stress, ultimate strength, breaking stress, modulus of elasticity, and modulus of resilience.
ii. Determine the percentage elongation, percentage reduction in area and comment on the ductility of the specimen.

Tension Test of Steel Coupon

i. Determine the following parameters – yield stress, ultimate strength.
ii. Determine the percentage elongation, percentage reduction in area and comment on the ductility of the specimen.

Bend and Rebend Test

i. Comment on the quality of rebar.
ii. Compare and contrast the Bend and Rebend test

Experiment No. 6

TEST OF CLOSELY COILED HELICAL SPRING

6.1 Introduction

A spring is defined as an elastic machine element that deflects under the action of the load and returns to its original shape when the load is removed. It can take any shape and form depending upon the application. A spring formed by winding wire into a helix along the surface of a cylinder is called helical spring. The cross-section of wire from which the spring is made may be circular, square or rectangular. The two forms of helical spring are compression helical spring and tension helical spring. The most popular type of spring is helical compression spring. In helical compression spring, the external force tends to shorten the spring. The external force acts along the axis of the spring and induces torsion shear stress in the spring wire. These types of springs are typically used in the transportation industry for suspension systems and can also be seen in certain types of industrial machinery. The test of helical spring is performed according to ASTM A125 which specifies a deflection loading of up to 85% of the original height.

6.2 Terms used in helical spring

Solid length (L_s)

When the compression spring is compressed until the coils come in contact with each other, then the spring is said to be solid. The solid length of a spring is the product of total number of coils and the diameter of the wire.

Free length (L_o)

The free length of a compression spring is the length of the spring in the free or unloaded condition.

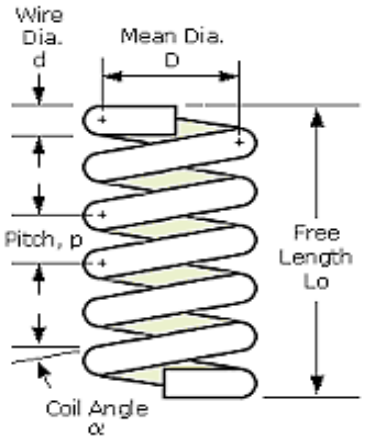


Figure: 6.1: Closely coiled helical spring

Active coils (N_a)

The number of coils which actually deform when the spring is loaded, as opposed to the inactive turns at each end which are in contact with the spring seat or base.

Coil diameter (D)

The mean diameter of the helix, i.e., $(D_{outer} + D_{inner})/2$.

Pitch (p)

The distance from center to center of the wire in adjacent active coils.

Pitch angle (a)

The angle between the coils and the base of the spring.

6.3 Behavior of Closely Coiled Helical Springs

Helical springs made of wires of circular cross section may be analysed in the elastic range by superposition of the shearing stresses. One important assumption needs to be made here is that any one coil of such a spring will be assumed to lie in a plane which is nearly perpendicular to the axis of the spring. This assumption can be made if the adjoining coils are close enough. With this assumption, a section taken perpendicular to the spring's rod may be taken to be vertical. Therefore, the forces acting on any section of the spring are (Figure 6.2)

i. The shearing force V=P

ii. Torque T=PR

where P=axial force applied on the spring and R= distance of the axis of the spring to the centroid of the rod's cross section.

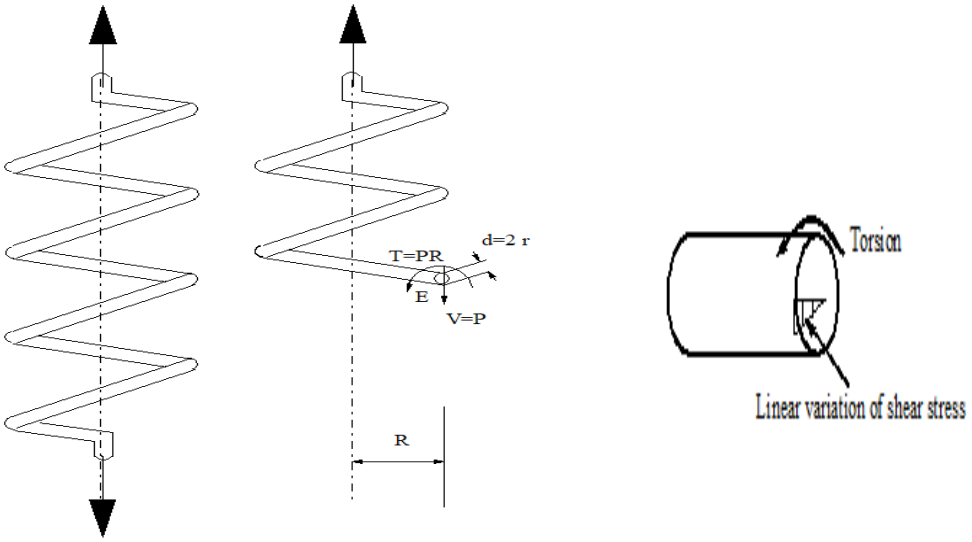


Figure 6.2: Forces acting on a closely coiled helical spring.

The maximum shearing stress at an arbitrary section of the spring can be found by superposing the direct and torsional shear stresses. Direct shearing stress in spring is customarily taken as the average shearing stress uniformly distributed over the cross section. Torsional shearing stress having a linear stress distribution will produce the maximum shear stress in the same direction as that of the direct shear stress at the inner edge of the coil at point E (Figure 6.2)

Therefore, by superposing one obtains,

$$\tau_{max} = \tau_{direct} + \tau_{torsion}$$

$$\tau_{\max} = \frac{P}{A} + \frac{Tr}{J} = \frac{P}{A} + \frac{PRr}{\frac{\pi r^4}{2}} = \frac{P}{A}\left(1 + \frac{2R}{r}\right) \qquad (6.1)$$

where $A = \pi r^2$=area of the spring's rod.

The deflection of a helical spring can be obtained (neglecting the effect of direct shearing stress, which is normally small) by using the following relationship:

$$\Delta = \frac{PR^2 L}{GJ} \qquad (6.2)$$

where L= length of the spring's rod, and
G=shearing modulus of elasticity (also known as modulus of rigidity).

For a rigorous derivation of the above relationship reference can be made to any text of Strength of Material, e.g. E.P.Popov's `Introduction to Mechanics of Solids'; Chapter 8.
For a closely coiled spring the length L of the wire may be taken with sufficient accuracy as $2\pi RN$, where N is the number of live or active coils of the spring.

Therefore, $$\Delta = \frac{2\pi PR^3 N}{JG} = \frac{64PR^3 N}{Gd^4} \qquad (6.3)$$

This equation can be used to obtain the deflection of a closely coiled helical spring along its axis when such a spring is subjected to either tensile or compressive force P.
The stiffness of a spring, commonly referred to as spring constant, is frequently used to define the spring's behaviour. The spring constant is defined as the force required to produce unit deflection. Thus, spring constant, k, defined as

$$k = \frac{P}{\Delta} = \frac{Gd^4}{64R^3 N} \qquad (6.4)$$

6.4 Testing Apparatus

Universal testing machine, Slide callipers, Vernier scale.

6.5 Test Procedure

i. Measure the diameter of the spring wire at several locations to find the mean diameter. Record the number of turns of the spring as N.
ii. Measure the outer and inner diameter of the helical spring and hence find the mean radius of the spring.
iii. Place the spring between the table and the compression block of the testing machine.
iv. Before applying any load record the vernier scale reading. Apply load at an interval of 50 kg and record the vernier reading for deflection.
v. Repeat the same operation up to 500 kg.
vi. Repeat the whole process for decreasing load at the same interval.
vii. Plot load-deflection curve in a graph paper.



6.6 Calculations and Reports

i. Calculate the stiffness of the spring from the graph of load vs deflection.
ii. Calculate the theoretical stiffness value from equation 5.4 and compare with the observed value. Also report the value of modulus of rigidity.

Experiment No. 7

BUCKLING OF SLENDER COLUMNS

7.1 Introduction

It has been discussed in the earlier chapters that the ultimate (axial) load carried by a structural member is

$$P_u=\sigma_u A \qquad (7.1)$$

where σ_u is the appropriate ultimate strength (tensile or compressive as the case may be) of the material, and A is the cross-sectional area of the member. While the above equation for determining the ultimate capacity of an axially loaded member is always true in the case of tension member, for the compression member (i.e. column), however, this is true only in the certain range of slenderness of the member concerned. For example, in the case of stocky column (short column) the above equation will hold good and the ultimate load will be obtained through complete plastification of the cross-section of the member. On the other hand for relatively slender column (long column), the column will fail at a load lower than that given by equation 6.1. The cross-section of the column may be entirely or at least partly elastic, when this type of failure takes place. This is known as the buckling effect, often an important consideration in the design of compression members. Hence, there are usually two primary concerns when analyzing and designing structures:

(1) the ability of the structure to support a specified load without experiencing excessive stress (σ_u) and

(2) the ability of the structure to support a given load without undergoing unacceptable deformation.

In some cases, however, stability considerations are important especially when the potential exists for the structure to experience a sudden radical change in its configuration. These considerations are typically made when dealing with vertical prismatic members supporting axial loads. Such structures are called columns. A column will buckle when it is subjected to a load greater than the critical load denoted by P_{cr}. That is, instead of remaining straight, it will suddenly become sharply curved as illustrated in Figure 6.1.

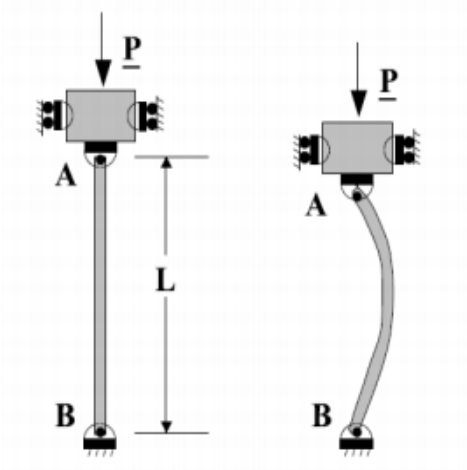


Figure 7.1: A column will buckle when a critical load is reached

7.2 The Buckling Phenomenon

Let us consider three simple examples with long, slender steel sections.

In the first, we will use two pieces of identical length and cross-sectional area, but of different shape: one piece is round, ¼ in diameter, and the other is thin 1 in by 0.05 in (Fig.7.2). The thin piece carries $\frac{1}{18}$th of the load of the round one, even though it has the same weight and cross-sectional area.

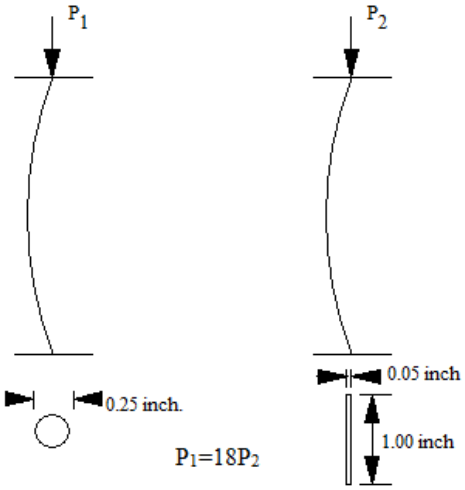


Figure 7.2: A thin strut has a lower buckling load. The cross sectional area, the material, the length and the support conditions are the same for both struts

In the next example, we will take two pieces of identical cross-section, but one twice as long as the other (Fig.7.3). The long piece carries only a quarter of the load of the shorter piece.

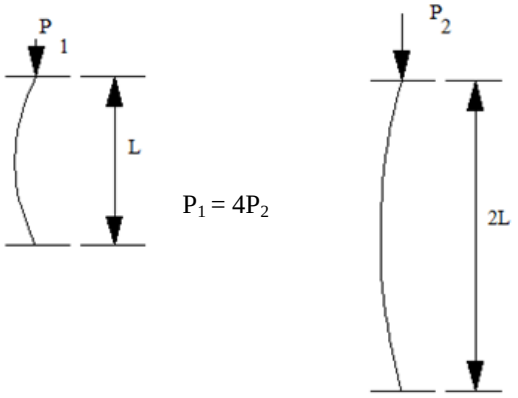


Figure 7.3: A long strut has a lower buckling load. The cross sectional dimension, the material, and the support conditions are the same for both struts.

In the third example we will take three pieces of steel of identical length and cross-section. We will load one as a cantilever; i.e., one end is firmly fixed and the other is allowed to move freely. The second one is loaded as a pin-ended column; i.e., the ends are allowed to rotate freely, but they are restrained to remain in line with the load. Another is built-in; i.e., its ends are not allowed to rotate, and it can move only in the direction of the load (Fig. 7.4).

The built-in column carries four times as much as the pin-ended column, and sixteen times as much as much as the cantilever column. Buckling evidently depends on the end restraint, the stiffness, and the length and the cross-sectional geometry (which determine the slenderness) of the column. It is an elastic phenomenon, and failure occurs whenever the energy required to recover the original shape is greater than the energy required to continue the buckling deformation.

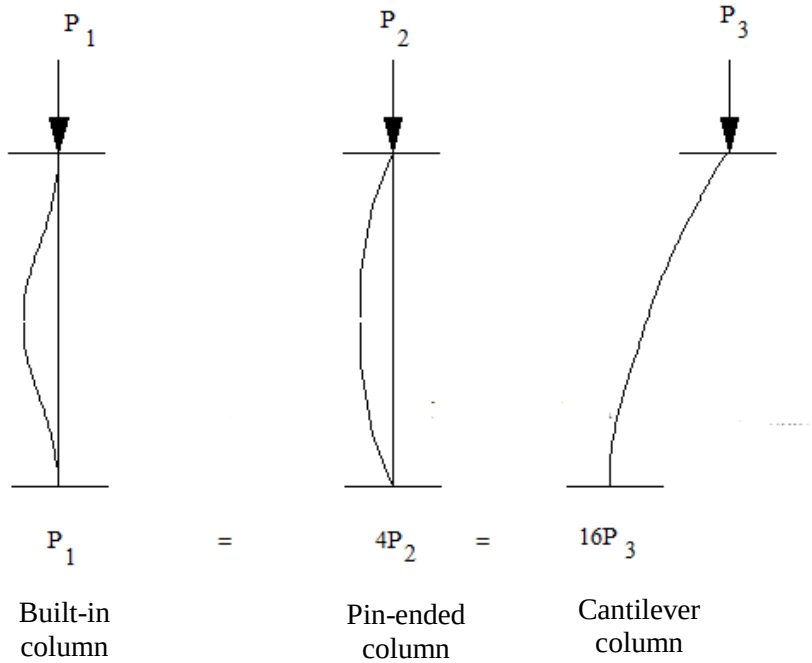


Figure 7.4: Effect of end restraints on the buckling load. The cross- sectional dimensions, the material and the length are the same for all three columns

7.3 Euler's Theory for Slender Columns

Leonard Euler derived the formula for the strength of a slender pin-ended column in 1757. It is an important part of the theory of structures and is the oldest structural formula still in use.

Consider an initially straight elastic strut under compressive end-loads (Fig.7.5). Suppose that this strut can have equilibrium positions not only when it is straight, but also when flexed elastically (Fig.7.6).

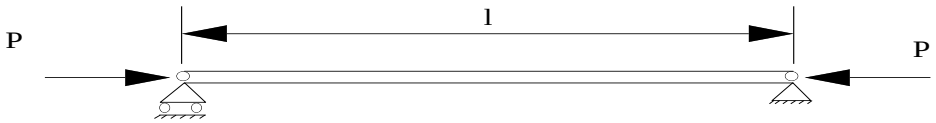


Figure 7.5: Pin ended column under compressive end loads

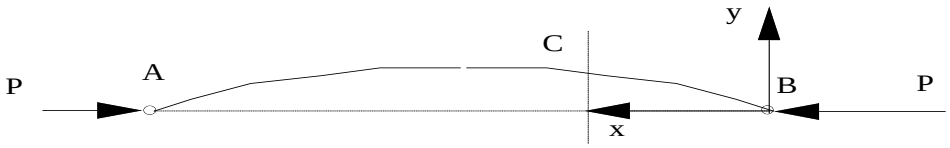


Figure 7.6: Pin ended column buckled elastically under compressive loads ls.

If we use the co-ordinates marked on Fig.7.6, x to give the distance from the rigidly pinned end and y to give the deflection corresponding to x, and if the strut's bending stiffness in the y direction is EI, we can use the usual beam bending formula (see Equation 7.6),

$$\frac{M}{I} = \frac{E}{R} \qquad . \qquad . \qquad 7.2$$

where, M is the moment at a given section,

I is the moment of inertia of the section,

E is Young's modulus and

R is the local radius of curvature at the section considered.

It is easily shown that the radius of curvature at any section is given to a first approximation by

$$\frac{1}{R} = -\frac{d^2y}{dx^2} \quad . \quad . \quad 7.3$$

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

The bending moment M is in this case given by M=Py, so that

$$Py = -EI\frac{d^2y}{dx^2} \quad . \quad . \quad 7.4$$

which is the differential equation for equilibrium configurations of the strut. The general solution to this equation is standard and is

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

we know that at x=0, y=0 and at x= ℓ, y=0.

Applying these boundary conditions one obtains:
(i) B=0, and

(ii) $A\sin \ell\sqrt{\frac{P}{EI}} = 0$

Hence, for equilibrium to exist we have either A=0 (i.e. the strut does not deflect from its straight configuration)

or $\sin \ell\sqrt{\frac{P}{EI}} = 0;$

the later case implies that

$\ell\sqrt{\frac{P}{EI}} = 0, \pi, 2\pi, ...$

we can eliminate $\ell\sqrt{\frac{P}{EI}} = 0$, for it merely considers the unloaded case. The next solution is $\ell\sqrt{\frac{P}{EI}} = \pi$, which leads to the critical value of P (i.e. the buckling load):

$$P = P_{cr} = \frac{\pi^2 EI}{\ell^2} \quad . \quad . \quad 7.5$$

Since we know now that $y = A\sin x\sqrt{\frac{P}{EI}}$ then:

either i) A=0

or ii) A is indeterminate if $P = \frac{\pi^2 EI}{\ell^2}, \frac{4\pi^2 EI}{\ell^2}, etc.$

Thus, there is no deflected equilibrium position of the strut until a critical load given by $P_{cr} = \frac{\pi^2 EI}{\ell^2}$ is reached, when the magnitude of the possible deflection becomes indeterminate. This is seen as an abrupt buckling of the strut when the critical (Euler) load is reached. No further information is given by the present analysis, but a more exact analysis would show that the undeflected equilibrium position loses its stability (though it

still exists) above the critical load, and that the deflected equilibrium positions are not indeterminate but have very large amplitudes compared with the range of accuracy of the initial assumption $\frac{1}{R} = -\frac{d^2y}{dx^2}$

In practice all struts will have very small shape imperfections which mean that small deflections do in fact occur before the critical load (see Fig. 7.7). However, these are of a much lower order of magnitude than the buckling deflections.

The formula $P_{cr} = \frac{\pi^2 EI}{\ell^2}$ can be rewritten if we write I as Ar^2 (i.e. the area of cross-section *times* the square of the radius of gyration) as in Fig- 7.8

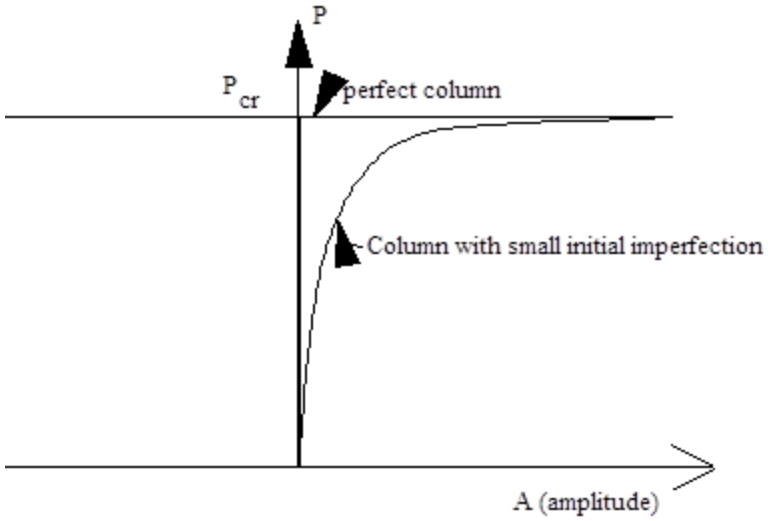


Figure 7.7: Buckling of a perfect and imperfect column

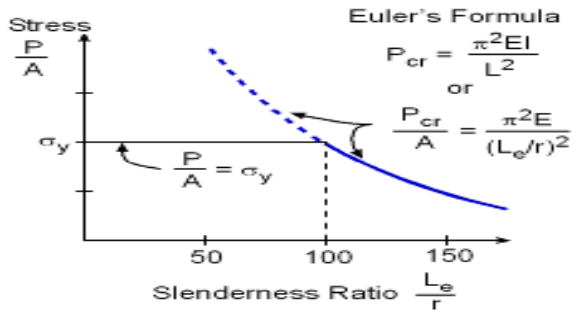


Figure 7.8: Buckling of a perfect and imperfect column

We can then divide through by A and obtain

$$\frac{P_{cr}}{A} = \sigma_{cr} = \frac{\pi^2 Er^2}{l^2}, \text{ or}$$

$$\sigma_{cr} = \frac{\pi^2 E}{\left(\frac{l}{r}\right)^2} \quad . \quad . \quad 7.6$$

where σ_{cr} is the *critical stress* and $\frac{l}{r}$ is defined as the *slenderness ratio*. The equation 7.6

is plotted as the graph of σ_{cr} against $\frac{l}{r}$ and this is known as the Euler column curve of a given material (Fig. 7.8).

If the material is elasto-plastic with a yield stress, σ_y, it is obvious that if the elastic σ_{cr} is greater than σ_y, plastic squashing rather than elastic buckling takes place. This gives the sharp cut-out to column strength curve at the lower slenderness ratios (Fig.6.8). In practice the cut-off is not sharp as indicated but curves gradually, due to inelastic buckling.

7.4 End Restrained Column: The Effective Length Concept

The preceding section describes the derivation of the critical load for a pin-ended column. But in real situation columns may have a range of support condition giving rise to the concept of end restrained column. The presence of end restraint affect the column strength and it is desirable to make proper allowance for this in both the analysis and the design of column. Use of the Euler type of approach to study the elastic buckling of end restrained columns enables the elastic critical load to be related directly to the stiffness of the restraint at either end, through the concept of effective length. This requires that the critical load formula (eq.6.5) be modified as:

$$P_{cr} = \frac{\pi^2 EI}{(k\ell)^2}$$

where k is the effective length factor and $k\ell$ is the effective length, which is defined as the length of the equivalent pin-ended column that would have the same elastic critical load as the actual end-restrained column.

Table 7.1 Effective length for various end conditions

End condition of the column	Effective Length
Both ends hinged	1.0 ℓ
One end hinged and one end fixed	0.707 ℓ
Both ends fixed	0.50 ℓ
One end fixed and one end free (i.e. cantilever)	2.0 ℓ

The effective length factor (k) for several standard cases of rigid end restraint are shown in Table 7.1. The effective length depends upon the constraints imposed on the ends of the column and Figure 6.9 shows how the effective length is related to the actual length of the column for various end conditions.

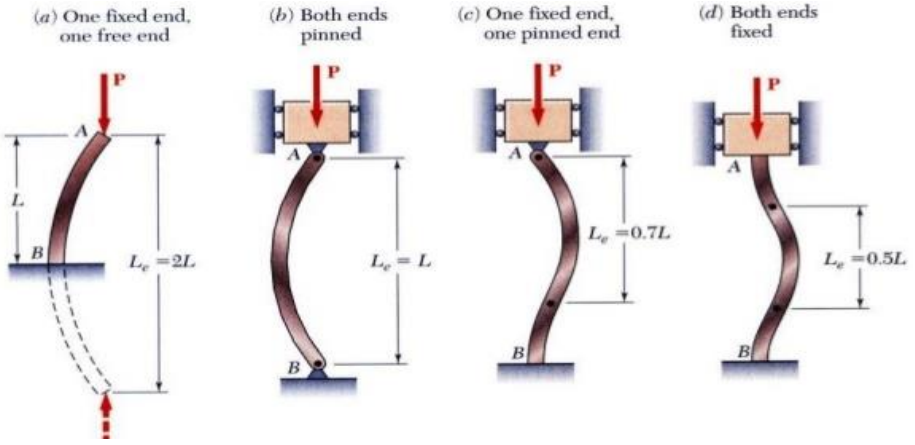


Figure 7.9: Relation between effective length and actual length of the column for various end conditions.

7.5 Test Procedure:

i. Measure the length and the mean diameter of the column to be tested.
ii. Place the column in the column testing apparatus with the both end hinged condition so that it (column's end) can rotate easily but held in position.
iii. Apply load by placing equal weights on both pans. Give a small side force to deflect (laterally) the column. Increase the load if the column straightens back upon removal of the side force.
iv. Continue the process until the applied load is just sufficient to hold the column in a bend condition. Record this load as the critical load.
v. Perform the experiment for four such columns with different lengths.
vi. Repeat the above steps (i) to(v) for two more end conditions:
(a) One end hinged and one end fixed (b) Both end fixed.

7.6 Calculations:

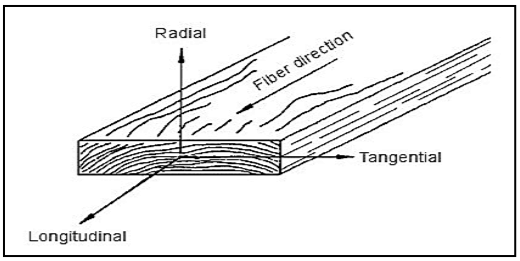
i. Calculate critical stress for each end condition – i. using actual critical load and –ii. using critical load formula
ii. Plot Stress versus slenderness ratio graph and show critical stress in it.

Experiment No. 8
COMPRESSION TEST OF TIMBER

8.1 Introduction

Timber is a product of nature and therefore is liable to a wide variation in strength and stiffness from one variety to the other. For structural purposes timber finds its use as beams, columns, bracing elements and piles. The biggest advantage of timber as a structural member is its light weight compared to the load it can sustain. Teak, Gurjan, Jarul, Gamari, Sal etc. are among the more commonly used timbers available in Bangladesh.

Timber is an anisotropic material, i.e. it has unique and independent mechanical properties in the directions of three mutually perpendicular directions- longitudinal, radial, and tangential.



Wood is primarily composed of hollow, elongate, spindle-shaped cells. Moisture in wood is stored in the hollow lumen space - which can be removed by proper seasoning and in cell wall – which cannot be removed completely. Therefore density of wood is greatly dependent on its moisture content. In addition to density, angle in between direction of loading and grain/fiber arrangement, angle of the micro-fibrils within the cell wall etc. are also highly variable. Due to this timber does not behave in truly elastic mode and make the stress – strain relationship for timber is complex. However, contrary to gray cast Iron or concrete, it does not show brittle characteristics under tensile loading and surprisingly, it is considerably stronger in tension than compression.

Timber has its greatest usable strength in tension and in bending. In compression parallel to the grain, as in columns, its estimated strength is about 75% of that in bending, while for load applied perpendicular to the grain and in shear its strength is only about 20% and 5% respectively of its strength in bending. As timbers are often used in such structural part which may often subject to compression and as timber is weak in compression, determination of ultimate compressive strength is essential before using it as structural material.

As the arrangement of wood cells produces a tubular structure, in case of applying compressive load perpendicular to the grain, the load that causes lateral collapse of the tubes or fibers. For load parallel to grain, not only the elastic strength important but also the strength at rupture. Rupture often occurs because of collapse of the tubular fibers as column. Compression load parallel to grain is carried by the strongest fibers and failure involves complete crushing of the wood fibers, whereas compression loads perpendicular to the grain are carried by both weak and strong fibers and failure involves the bending or buckling of the wood fibers.

Table 8.1: Typical Mechanical Properties of Local Timbers

Species and Seasoning	Static Bending				Compressive Strength		
					Parallel		Perpendicular
	σ_p (ksi)	σ_{ult} (ksi)	Modulus of Resilience (psi)	E (ksi)	σ_p (ksi)	σ_{ult} (ksi)	σ_p (ksi)
Burma Teak							
(i) Green	7.1	11.4	1.7	1670	4.1	5.9	1.1
(ii) Air-dry	9.2	13.9	2.6	1820	5.4	7.9	1.4
Gurjan							
(i) Green	5.3	8.6	1.0	1660	3.4	5.3	0.6
(ii) Air-dry	9.3	13.0	2.2	2250	5.7	7.5	1.0
Jarul							
(i) Green	5.8	9.4	1.3	1470	3.8	4.8	1.2
(ii) Air-dry	8.8	12.6	2.9	1510	4.7	6.6	1.4
Gamari							
(i) Green	4.0	7.3	0.9	1060	3.8	4.8	1.2
(ii) Air-dry	5.1	7.9	1.3	1080	4.7	6.6	1.4
Chittagong teak (CHT):							
i) Green	7.1	11.0	1.77	1.6	3.2	4.6	0.9
ii) Air-dry	8.9	13.2	2.54	1.7	4.4	7.2	1.3

Determination of compressive strength of timber will be conducted according to ASTM standard specification D143-2000 using specimen of 2 by 2-inch (50 by 50-mm) cross-section. The 2 by 2-in. (50 by 50-mm) size has the advantage in that it embraces a number of growth rings, is less influenced by earlywood and latewood differences than smaller size specimens, and is large enough to represent a considerable portion of the sampled material.

8.2 Determination of Yield Strength

Most materials, unlike mild steel do not have a very well defined yield point. As discussed earlier, timber does not behave in truly elastic mode and stress –strain relationship is complex, measurement of exact point of yielding is not possible. For such materials it is necessary to specify a certain measurable amount of yielding as the beginning of yielding. The actual value of the yield strength, then, will depend upon this arbitrarily selected amount of yielding. In other words, for such materials the yield point stress is defined at some particular value of the permanent set.

In order to indicate the stress where the material is strained within the range of typical yield strains or undergoes permanent deformation typical of yield points, two commonly used methods are:

i. Offset method
ii. Proof strength method

i. Offset method

Yielding is the transition of material from elastic behavior to permanent deformation. So if a material is loaded slightly higher than its proportional limit and unloaded, the unloading path will follow the same slope of elastic curve, It is the strength at which the material experiences a specific amount of permanent deformation - showing a deviation or offset

from Hook's law at the stress (YS) as shown in figure 8.2. The offset thus approximates the inelastic deformation at a given stress. This concept is the basis for the determination of yield strength by the offset method, in accordance with the definition of yield strength given in the specification ASTM E6.

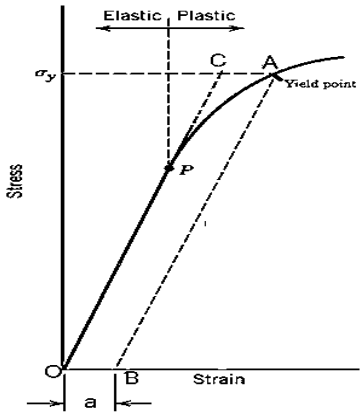


Fig-8.2: Determination of yield strength by offset method

Table 8.2: Recommended values of offset for yield strength

Materials	Offset Strain %
Cast Iron	0.02 to 0.05
Wood (parallel to the grain)	0.05
Concrete	0.01 to 0.02

The magnitude of the offset 'a' is chosen as some measurable value that is considered from experience to be of practical significance in defining a limit to the elastic range. Values of 'a' in common use are shown in Table 8.2. Though wood does not show truly elastic range, but up to a strain of about 0.05% to 0.10% there is sufficient linearity. An increase in non-linearity occurs beyond the elastic limit.

In reporting values of yield strength obtained by the offset method, the specified value of set used should be stated. For example, yield strength (offsets 0.1%) = 52,000 psi indicates that at a stress of 52,000 psi the permanent set of the material tested was 0.1% strain.

ii. Proof Strength method

An proof strain is equal to some permissible plastic strain. The stress corresponding to some specific allowable permanent set is the proof strength. Determination of proof strength differs from that of offset method in a way that for the latter case a fixed value of permanent set is specified while for the former the total strain amount is specified.



Fig- 8.3: Determination of Proof Strength

From Fig- 8.3, it is quite clear that one does not need to draw the complete stress-strain diagram for obtaining the proof strength. Generally, standard codes of practice specify the amount of total strain to be used for different materials. For example, the specification for

cold twisted ribbed bar requires the tensile proof strength to be measured at the stress corresponding to a 0.5% strain in 200 mm gage length. Reporting of proof strength should be accompanied by the amount of total strain on which it is based. For example, 0.5% (total strain) proof strength = 50,000 psi.

8.3 Failure Mechanism and Failure Surface of Timber

In addition to the σ - ε diagram and determination of the mechanical properties, another significant feature of the compression test of timber is its failure surface. As shown in Fig. 8.4, while the specimen is loaded axially (i.e., perpendicular to its end surfaces), the failure surface is observed to be almost 45^0 inclined to the end surfaces.

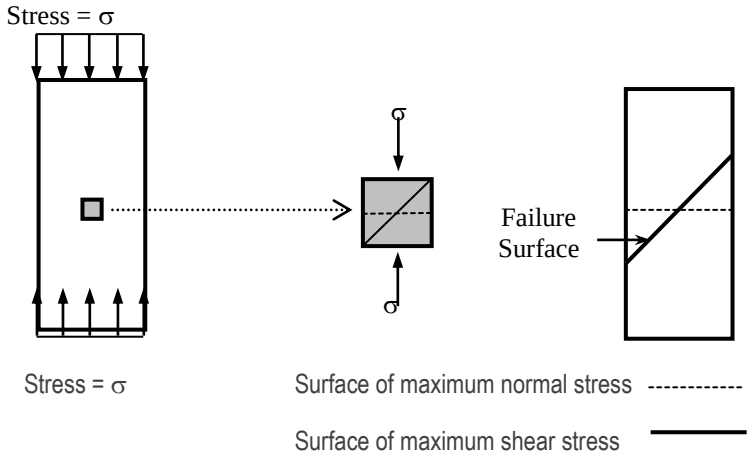


Fig- 8.4: Loading arrangement and surfaces of maximum stress

Fig-8.4 shows the loading arrangement and surfaces of maximum normal stress and shearing stress. Using the principles of stress transformation, it can be shown that the maximum normal stress for such loadings is equal to the applied load (σ), at a surface perpendicular to the loading direction while the maximum shearing stress is half that value ($\sigma/2$), at an angle 45^0 inclined. Even then, the timber specimen fails along the latter surface because of its relative weakness in shear compared to axial stress, as discussed in the previous section.

8.4 Compression Failure Patterns of Timber

Compression failures are deformations of the fibers due to excessive end compression, or to compression resulting from bending. The deformations range from well-defined buckling of the fibers visible with the unaided eye as wrinkles across the face of the piece of the fiber walls visible only with a microscope.

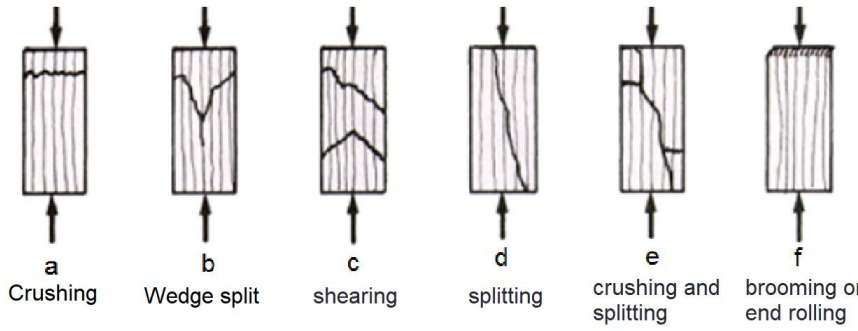


Fig-8.5: Fracture types under compression in timber

8.5 Apparatus

Compressometer

The Compressometer is used for evaluating deformation and strain characteristics of material while undergoing compression testing.

Steel scale

Slide Calliper

The universal testing machine.

8.6 Procedure

i. Measure the size of the specimen with a slide callipers.
ii. Record gage length and multiplication factor of the compressometer.
iii. Attach compressometer with the specimen and set the specimen in proper position of the testing machine.
iv. Adjust the compressometer dial to read zero
v. Apply load continuously at an uniform speed until failure and read the compressometer at 1000 lbs intervals.
vi. Take off the compressormeter when breaking starts.
vii. Record the maximum load and the final length between the gage marks.
viii. Note the characteristics of the fractured surfaces.

8.7 Calculations

i. Calculate compressive stress and corresponding strain for each load using appropriate equations.
ii. Draw the complete stress-strain diagram and determine the parameters as mentioned in the lab data sheet.
iii. Draw a neat sketch of the fractured surface of the timber and write name of the fracture type.

Experiment No. 9
STATIC BENDING TEST OF TIMBER BEAM

9.1 introduction

When beams are subjected to loads, bending stresses are set. The computation of this stress at a given section of the beam is facilitated by means of bending theory due to M. H. Navier. He postulated that under a uniform bending moment, initially plane and parallel cross-sections remain plane during bending and converge to a common center of curvature. This can be visually demonstrated by drawing a square grid on a flexible beam and then bending the beam (Fig. 9.1).

When subjected to a so-called positive moment (i.e., 'sagging' shape), the beam is strained in compression at the top and in tension at the bottom, and somewhere between there is a line at which the strain is neither tensile nor compressive. This line of zero strain is called the neutral axis.

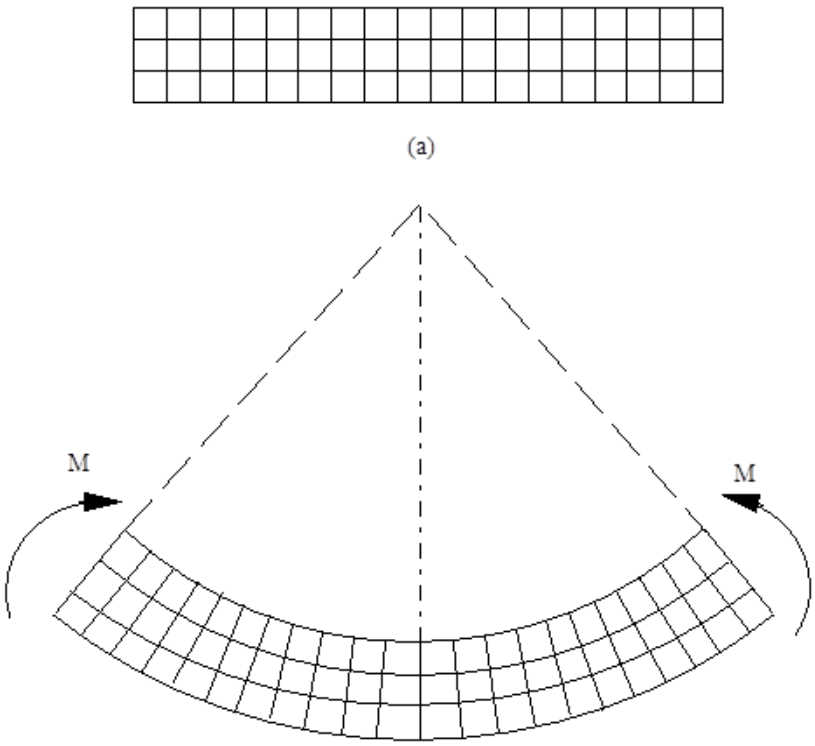


Fig. 9.1: Navier's hypothesis: Originally plane and parallel sections remain plane after bending but converge onto a common center of curvature

If R is the radius of curvature, then the normal strain of a point located at a distance y (positive downward) from the neutral axis is given by

$$\varepsilon = y/R \qquad (9.1)$$

If E is the modulus of elasticity of the material, then the corresponding normal stress is determined by Hooke's law as

$$\sigma = \varepsilon E = Ey/R \qquad (9.2)$$

If M is the bending moment at the section and I is its moment of inertia about the neutral axis, then the normal stress is also given by

$$\sigma = My/I \qquad (9.3)$$

Comparison of Eqs. (9.2) and (9.3) gives

$$\sigma = \varepsilon E = My/I$$

$$\Rightarrow E = My/I\varepsilon \qquad (9.4)$$

9.2 Experimental Verification of Navier's Hypothesis:

Navier's assumption has been proved correct for all structural materials by strain measurements on test beams under load (Fig. 8.2); strain gages are fixed along the depth of the beam, and the variation of strain throughout the section is plotted as the beam is loaded. So long as the beam is elastic, the neutral axis remains in the same position, and the strains vary proportionately with the distance from the neutral axis.

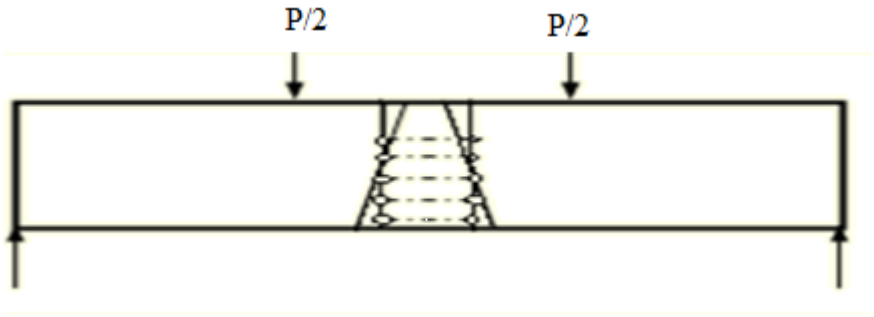


Fig. 9.2: Experimental verification of Navier's hypothesis with strain gages

In general, only the maximum stress (which must be kept within a permissible range) is of interest. This occurs at the greatest distance y form the neutral axis; in an unsymmetrical section there are two different values, one for the bottom and another from the top.

9.3 Two-Point Loading:

In two-point loading a simply supported beam is loaded at distances 'a' from either support, where L is the span of the beam as shown in Fig. 8.3, the portion of the beam between the loads (P/2 each) is free from any shear and is subjected to purely flexural stress.

The maximum deflection (in the elastic range) at the center of the beam for such a loading is given by

$$\delta_{max} = Pa\,(3L^2 - 4a^2)/48\,EI \qquad (9.5)$$

If a = L/3, the loading case is known as 'third point loading' and the maximum midspan deflection is

$$\delta_{max} = 23\,PL^3/1296\,EI \qquad (9.6)$$

where P is the total applied load on the beam and EI is the flexural rigidity of the section.

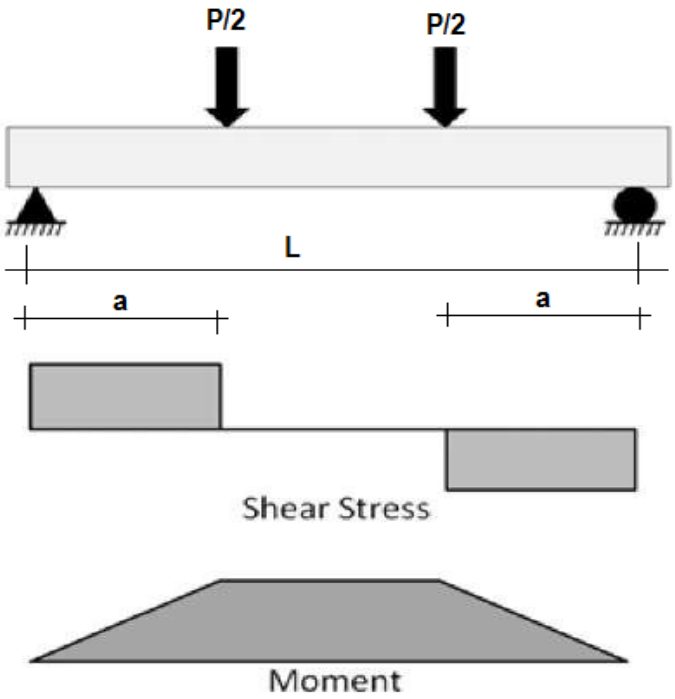


Fig. 9.3: Shear Force and Bending Moment diagrams for two-point loading

Under a known value of load P, the deflection at the center span can be measured experimentally and the above relationships [Eqs. (9.5) or (9.6)] can be used to compute the value of 'E', the modulus of elasticity of the material of the beam. For the purpose of examining Navier's hypothesis a two point loading scheme is adopted in the laboratory ensuring a region of pure bending between the point loads. Strain measurements are made at various distances from the neutral axis in the central portion of the beam. The value of 'E' is determined from the equation of the best fit straight line for P vs. δ_{max}

9.4 Apparatus:

Beam testing machine

A flexural testing machine with setup as shown in fig- 9.4 is used for conducting the experiment.

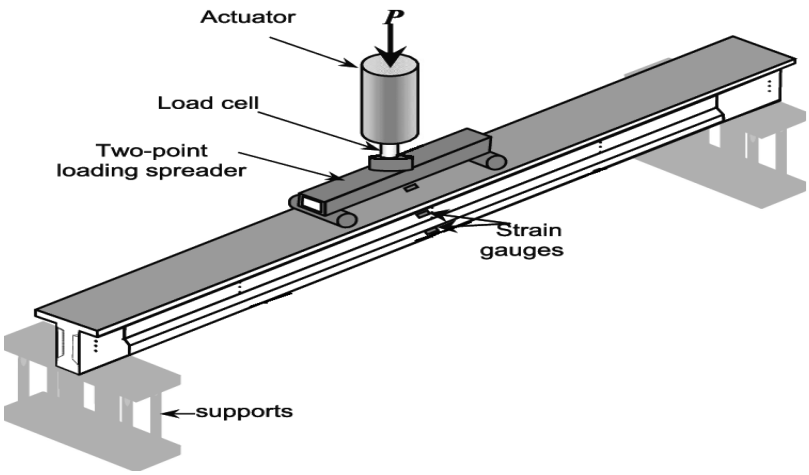
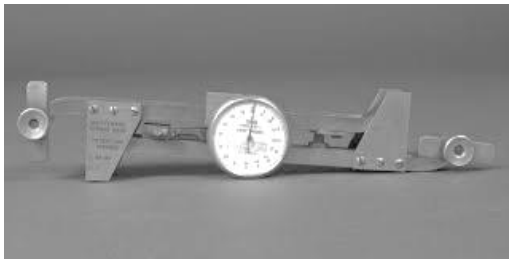


Fig -9.4: Two-point loading test machine

Steel scale or tape

Whittmore strain gage

This strain gage is used to measure strain at various points along the beam depth.



Deflectometer

The deflectometer is placed at bottom face at midpoint of the bean span.



9.5 Procedure:

i. Place the beam over the platform of beam testing machine with supports at two ends.
ii. Measure distance of each of the gage lines from the bottom of the beam.
iii. Set the deflectometer at the bottom centre of the beam.
iv. Prior to the application of the load (self-weight of the beam may be ignored) take initial reading of the strain gage at different holes.
v. Arrange two point loading and increase the load at regular intervals and record strain gage and deflectometer readings. (Loading should be kept within such limit so that the beam stresses remain elastic. This is important because Nevier's theorem as well as the deflection formula we are using here holds good for elastic cases only)

9.6 Calculation & Results

i. Calculate theoretical stresses along the gage lines by the Nevier's theorem:

$$f = \frac{My}{I}$$

ii. Draw the load-deflection curve (average straight line of the experimental points) from which obtain the value of 'E' using the relationship

$$\delta = \frac{23PL^3}{1296EI}$$

iii. Plot stress-strain diagram for the top holes and graphically find out E.