Second Year Degree Course In
Civil Engineering (SEM. - III)

SU

STRENGTH OF MATERIALS

Dr. SR PAREKAR

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NIRALI PRAKASHAN
ADVANCEMENT OF KNOWLEDGE

A TEXT BOOK OF

STRENGTH OF MATERAILS

FOR

Semester – III

Second Year Degree Course in Civil Engineering

As Per New Revised Syllabus of Shivaji University, Kolhapur, June 2014

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PREFACE

The book titled **"Strength of Materials"** is written according to the New Revised Syllabus of Shivaji University, Kolhapur.

The subject '**Strength of Materials**' is a foundation stone for any Engineering Course. Today, Engineering applications are mostly interdisciplinary, involving basics of various fundamental subjects. One of such subject of vital importance is "**Strength of Materials**". The present text is aimed at catering the needs of students appearing for Second Year Degree Course in Civil Engineering.

The text gives fundamental and simple treatment to the subject with a clear and distinct presentation of theoretical concepts and well graded numerous examples.

It consists of 6 units covering all of new revised syllabus. Each Unit gives fundamental and simple treatment to the subject with a clear and distinct presentation of theoretical concepts and well-graded examples.

I will be missing if I don't thank My Wife Mrs. Smita Parekar whose moral support and wishes have gone a long way in the making of this book.

I express my sincere thanks to Shri. Dineshbhai Furia, Jignesh Furia and M. P. Munde for publishing this book.

Suggestions for improvement and constructive criticism of this book are warmly welcomed and will be incorporated in next edition.

Pune **Dr. S. R. Parekar**

SYLLABUS

SECTION - I

Unit I **[9 Hrs]**

Engineering properties of different materials, St. Venant's principle, simple stress and strain, Hooke's law, elastic behaviour of the body under external actions, composite sections under axial loading, temperature stresses, elastic constants, normal stresses and strains in three dimensions.

Unit II **[6 Hrs]**

Analysis of statically determinate beams S.F. and B.M. diagrams, virtual work approach for computation of shear force and bending moment.

Unit III **[5 Hrs]**

Analysis of circular shafts subjected to torsion, power transmitted. Analysis of thin walled cylinders.

SECTION - II

Unit IV **[6 Hrs]**

Bending Stresses in beams, simple design problems.

Unit V **[5 Hrs]**

Shear stress distribution in beams.

Unit VI **[9 Hrs]**

Strain energy due to different types of actions, impact loading. Strain energy method for deflection of determinate beams, bents and trusses.

CONTENTS

Unit... I

SIMPLE STRESSES AND STRAINS

1.1 INTRODUCTION

The group of studies known as mechanics may be divided and classified in many ways, one of which is indicated below :

$$\text{Mechanics} \begin{cases} \text{Particle and Rigid bodies} \\ \text{(Applied Mechanics)} \\ \text{Deformable bodies} \end{cases} - \begin{cases} \text{Elastic (Strength of Materials)} \\ \text{Plastic (Advanced Course in Plasticity)} \\ \text{Fluid (Hydraulics, Fluid Mechanics, Aerodynamics)} \end{cases}$$

In the usual Applied or Engineering mechanics, all the bodies studied are considered to be particles or rigid bodies - particles when the dimensions of the body are neglected, rigid bodies when the dimensions are considered but the deformations are neglected.

There are many cases in which the distortions of different dimensions of the body must be considered. Structural members, machine parts and springs are usually made of solid materials that deform considerably under the action of external loads, but regain their original shape after the load is removed. Such materials are said to be ***elastic***.

In all the studies to follow, the free body concept as used in earlier studies in mechanics, will be found indispensable, as well as equations of equilibrium, because the subject "Strength of Materials" is built upon previous knowledge of mechanics with the addition of only a few new concepts.

To illustrate the distinction between the problems of Applied Mechanics and those of Strength of Materials, consider the beam of Fig. 1.1.

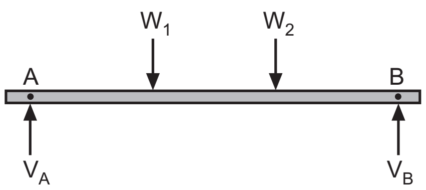


Fig. 1.1

In Applied Mechanics, we learned how to apply the equations of equilibrium to the free body in order to determine the unknown reactions V_A and V_B, having given the magnitude and spacing of loads. Although the beam does deform due to applied loads, the changes in the dimensions are so small that it has no appreciable effect on the reactions. That is, we consider the beam to be a rigid body.

In Strength of Materials, we shall continue to neglect these deformations while determining the reactions, but we shall be concerned with these deformations while doing other calculations like we may wish to determine how much the beam will deflect or we may be interested in the deformations as a step in determining the internal stresses. Magnitude of these internal stresses must be known in order to proportion a member for a given length and loading.

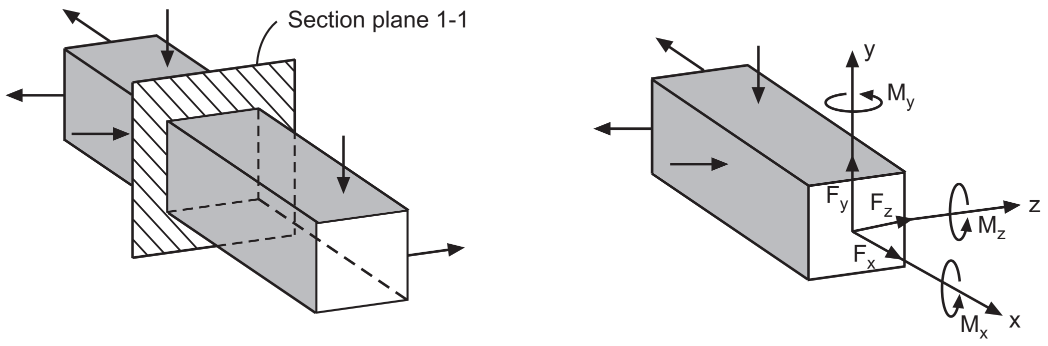
Throughout this text, we study the principles that govern two fundamental concepts, strength and rigidity. In this first chapter, we start with the simple axial loading, later we consider bending loads, twisting loads and finally we discuss simultaneous combinations of these three basic types of loadings.

1.2 LOADS AND THEIR CLASSIFICATION

Loads may be classified in two ways :

(a) According to manner to their application : As per this classification, loads may be classified as (i) Dead load, (ii) Live load, (iii) Wind load, (iv) Seismic loads, (v) Temperature loads, (vi) Impact loads, (vii) Erection loads, etc.

(b) According to effect they produce : Variety of loads acting on structural member produce different types of effect. For convenience these forces are resolved into components that are normal and tangential to the cross-section as shown in Fig. 1.2. The origin of the reference axis is always taken at the centroid of the cross-section. Each of these components have different structural effect and produces different structural deformation.



(a) General loading on member ***(b) Internal forces at cross-section 1-1***

Fig. 1.2

Various components and their structural names are as follows :

(i) F_x : Axial Force : The force acting *normal to the cross-section and passing through CG* is called as axial force. The primary effect of axial force is to change the length of member. Axial force may be tensile in nature (pull) which causes increase in the length of a member or compressive in nature (push) which causes decrease in the length of a member.

(ii) F_y ; F_z : Shear Forces : The force acting *tangential to the cross-section* is called as shear force. The primary effect of these forces is to cause sliding of one cross-section with respect to other.

(iii) M_x : Torsional Moment : Net moment vector acting *normal to the cross-section* is called as torsional moment or torque or torsion. The primary effect of torsional moment is to cause rotation of different cross-sections of member with respect to each other about polar axis. This rotation is called as twist.

(iv) M_y ; M_z : Bending Moment : Net moment vector acting *tangential to the cross-section* is called as bending moment. These moments cause bending of the member about an axis parallel to the cross-section and ultimately produce slopes and deflection.

The subject Strength of Materials is the study of all above structural actions, corresponding deformations and stresses produced by an individual action or combination thereof.

1.2.1 St. Venant's Theory

The deformation of the twisted bar consist of

(i) Rotation of the cross – sections of the bar as in the case of a circular shaft.

(ii) Warping of the cross – sections which is the same for all the cross sections.

Assumptions for Geometrical Behaviour

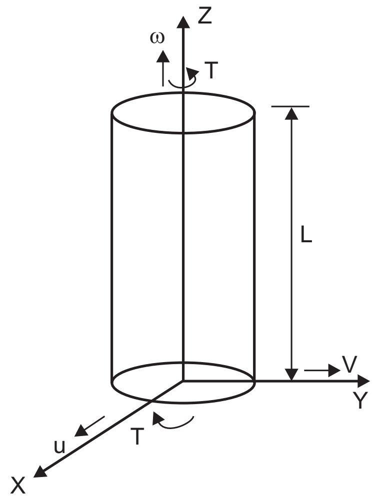


Fig. 1.3

(i) The stresses or strains at a point sufficiently far from the location of two sets of applied load do not differ significantly if these loads have the same resultant force and moment.

(ii) Each cross-section above z-axis rotates as a rigid body. (No distortion of cross-section shape in x, y direction)

(iii) Cross-sections are free to warp in the z-direction but the warping is the same for all cross-section.

(iv) Body forces due to gravitational = Weight etc. are neglected.

(v) Rate of twist i.e. $k = \left(\frac{d\alpha}{dz}\right)$ = constant.

Note :

Warping : Extensional deformation in the direction of the axis @ which the torque is applied.

1.3 STRESS

When as elastic body is subjected to loads, it undergoes deformation. While undergoing deformations, the particles of the material offer a resisting force. When this resisting force equals the applied loads, equilibrium is attained and further deformation stops. This internal resistance is called as *stress*. The resistance per unit area is called as intensity of stress. Generally, the word stress refers to *intensity of stress*. Thus, stress is *resistance per unit area.*

1.3.1 Types of Stresses

Stresses are of two types : (i) Normal Stresses and (ii) Shear Stresses.

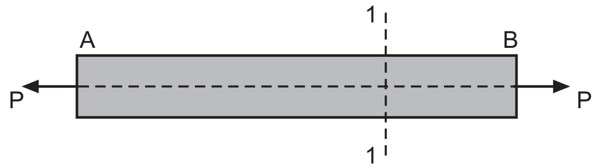
Stresses which act normal to the section are called as normal stresses while that acting tangential to the section are called shear stresses. It should be noted that *axial force* produces *uniform normal stresses* over the section while *bending moment* produces *linearly varying stresses* over the section within elastic limit, as discussed later in the text. Shear force and torsional moment produces shear stresses over the section. Thus, type of stress produced depends on the type of action the cross-section is subjected to.

Normal stresses can further be classified as tensile or compressive in nature, depending on kind of deformation the member undergoes.

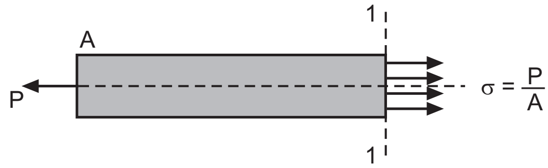
Fig. 1.4 (a) shows member subjected to axial tensile force. Consider section 1-1 and FBD of part of the member as shown in Fig. 1.4 (b). For equilibrium, cross-section must offer a resistive force = applied force = P. This resistive force per unit area is called as ***normal stress***.

Thus, for axial force, normal stress $= \boldsymbol{\sigma_n = \frac{P}{A}}$ ... (1.1)

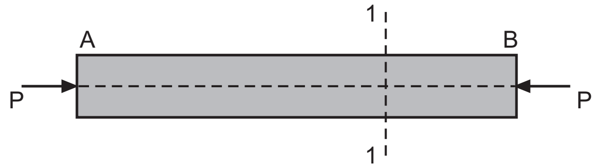
where, A = cross-sectional area of member.



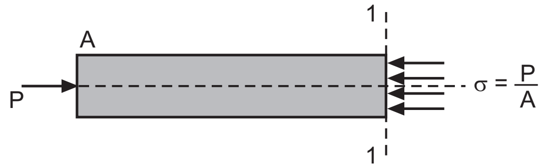
(a) Member subjected to axial tension (Pull)



(b) Uniform normal tensile stresses produced by axial pull



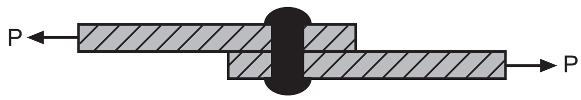
(c) Member subjected to axial compression (Push)



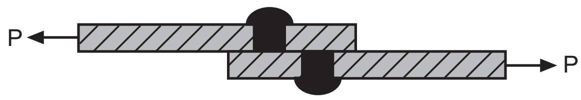
(d) Uniform normal compressive stresses produced by axial push

Fig. 1.4

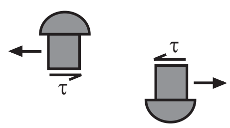
Fig. 1.4 (c) and 1.4 (d) respectively show compressive force and corresponding normal stresses.



(a) Simple lap joint



(b) Shear failure of joint



(c) FBD of part of rivets

Fig. 1.5

Fig. 1.5 shows a simple riveted lap joint and its shear failure. It should be noted that, the force which causes failure of rivet is acting tangential to its cross-section and hence produces shear stress (τ).

$$\text{Shear stress} = \tau = \frac{\text{Shear force}}{\text{Cross-sectional area}} \quad \text{... (1.2)}$$

1.3.2 Sign Convention and Unit of Stress

Normal tensile stress is considered positive while normal compressive stress is considered negative.

Shear stress 'τ' which produces clockwise couple is considered positive and that producing anticlockwise couple is considered negative as shown in Fig. 1.6.

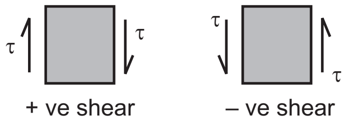


Fig. 1.6

Unit of stress is MPa or GPa (mega or gega Pascal).

Note : 1 MPa = 1 N/mm^2

1 GPa = 1 kN/mm^2

∴ 1 GPa = 10^3 MPa

1.4 STRAIN

When an elastic body is subjected to loads, it undergoes deformation. Strain is a ***measure of deformation produced by application of external forces***.

1.4.1 Types of Strains

Strains are of two types : (i) Linear strain and (ii) Shear strain.

1. Linear Strain : It is the ratio of alteration in any dimension of the body to the respective original dimension.

$$\text{Thus,} \quad \text{Linear strain} = \varepsilon = \frac{\text{Change in dimension}}{\text{Original dimension}} \quad \text{... (1.3)}$$

In case of an axial force, linear strain produced along the length is called as ***longitudinal strain*** while that produced along cross-section is called as ***lateral strain***.

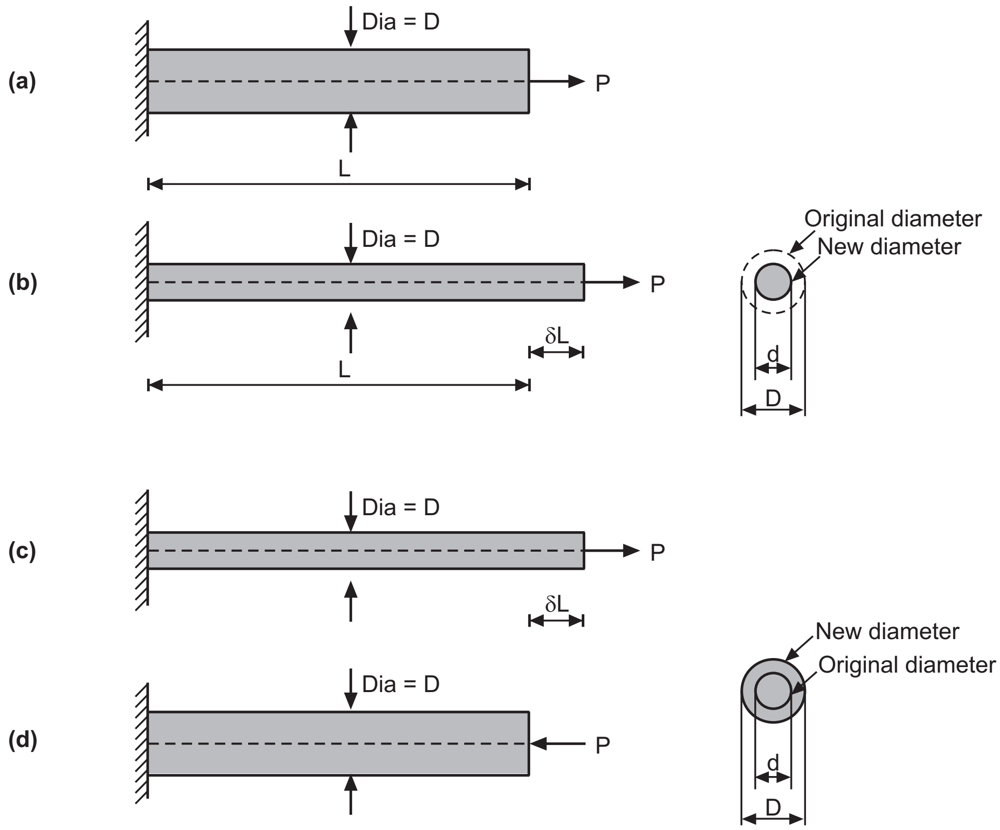


Fig. 1.7(i) : Longitudinal and Lateral strains

Linear strain may be tensile or compressive in nature. Axial pull causes increase in length while decrease in cross-sectional dimensions and axial push causes decrease in length while increase in cross-sectional dimensions as shown in Fig. 1.7(i).

Thus,

$$\text{Longitudinal strain} = \varepsilon_L = \frac{\text{Change in length}}{\text{Original length}}$$

$$\therefore \quad \varepsilon_L = \frac{\delta L}{L} \qquad \text{... (1.4)}$$

$$\text{Lateral strain} = \varepsilon_{Lt} = \frac{\text{Change in cross-sectional dimensions}}{\text{Original cross-sectional dimensions}} \qquad \text{... (1.5)}$$

For the example of circular bar considered in Fig. 1.7(i),

$$\text{Lateral strain} = \varepsilon_{Lt} = \frac{\text{Change in diameter}}{\text{Original diameter}}$$

(ii) Shear strain : If an element ABCD shown in Fig. 1.7(ii) is subjected to shear stress τ on faces AB and CD, then it undergoes angular deformation ϕ as shown.

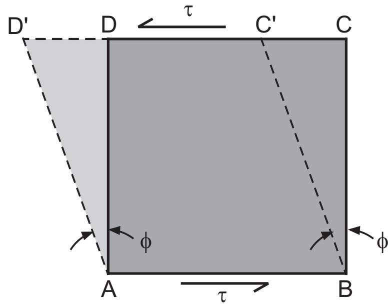


Fig. 1.7(ii)

$$\text{Shear strain} = \gamma = \tan\phi = \frac{DD'}{AD} \quad \text{... (1.6)}$$

Shear strain being very small,

$$\tan\phi \approx \phi$$

1.4.2 Sign Convention and Unit of Strain

Linear strain tensile in nature is considered positive while that compressive in nature is considered negative.

Shear strain sign convention is same as explained in article 1.3.2.

Strain does not have any unit.

1.5 POISSON'S RATIO (μ)

It is the ratio of lateral strain to linear strain.

Thus,
$$\mu = \frac{\text{Lateral strain}}{\text{Linear strain}} = \frac{\varepsilon_{Lt}}{\varepsilon_L} \quad \text{... (1.7)}$$

The value of Poisson's ratio depends on type of material and for most metals it is 0.25 to 0.35.

1.6 HOOKE'S LAW AND MODULUS OF ELASTICITY (E)

By experiment it has been established for many structural materials that, within elastic limit, the elongation of the bar is proportional to tensile force. This linear relationship between the force and the elongation produced by it was formulated by Robert Hooke and hence known as Hooke's law.

If bars of same material but different lengths and different cross-sectional areas are experimented, it is observed that its elongation is proportional to tensile force, length and inversely proportional to the cross-sectional area.

Thus,
$$\delta L \propto \frac{PL}{A}$$

OR
$$\delta L = \frac{PL}{AE} \quad \text{... (1.8)}$$

where, E = constant for any given material and is called as ***Modulus of elasticity or Young's modulus.***

From equation (1.8), we can further write,

$$E = \frac{\sigma_n}{\varepsilon_L} \quad \text{... (1.9)}$$

as $\sigma = \frac{P}{A}$ and $\varepsilon_L = \frac{\delta L}{L}$

Thus, Hooke's law states that ***stress is proportional to strain.*** It should be noted that unit of Modulus of elasticity is same as that of stress.

1.7 MODULUS OF RIGIDITY OR SHEAR MODULUS (G)

The shear stress (τ) is proportional to shear strain (γ) as long as proportional limit in shear is not exceeded.

Thus, $\tau \propto \gamma$

i.e. $\tau = G\gamma$

or $$G = \frac{\tau}{\gamma} \quad \text{... (1.10)}$$

where, G = Modulus of rigidity or Shear modulus

It should be noted that the unit of modulus of rigidity is same as that of stress.

1.8 VOLUMETRIC STRESS AND VOLUMETRIC STRAIN

When an elastic body is subjected to three mutually perpendicular equal direct stresses as shown in Fig. 1.8, it undergoes a change in volume without distortion of shape. Such a stress is called as *volumetric stress* (σ_v). Such a state of stress occurs when a cube is at a large depth in a liquid. The intensity of compressive pressure will have the same magnitude on all the faces. Such a state of stress is also called as *hydrostatic* state of stress.

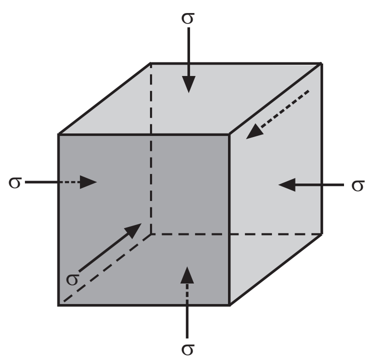


Fig. 1.8

The ratio of change in volume to original volume of a body is called as volumetric strain.

$$\varepsilon_v = \frac{\delta V}{V} \quad \text{... (1.11)}$$

where, δV = Change in volume

V = Original volume