Alfurat Alawsat Technical University
Technical Engineering College/ Najaf
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STRENGTH OF MATERIALS

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The course named " Strength of Materials" or "Mechanics of Materials" deals with, Concept of stress, Stresses and strains, Axial loading and axial deformation, Hook's law, Statically indeterminate members, Stresses due to temperature, Torsion, Internal forces in beams, pure bending or Beam theory, Transverse loading and shear stresses in beams, beam deflection, Transformation of stresses and strains,. Principal stresses and strains, in addition to Axially compressed members and buckling of columns.

Course Objectives

1. Be aware of the mathematical background for the different topics of strength of materials introduced in this course.

2. Understanding of stress concept and types of stresses.

3. Understanding of stress strain relationship and solving problems.

4. Understanding of internal forces in beams, how to draw shear force and bending moment diagrams.

5. Understanding of beam analysis, stresses in beams, beam theory and shear stresses.

6. Understanding of torsion in shafts, determination of shear stresses and twisting angle due to torsion.

7. Understanding of methods of calculation beam deflection.

8. Understanding of transformation of stresses and constructing of Mohr’s Circle.

9. Understanding of Axially compressed members and buckling of columns.

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TOPICS

1. *concept of stress*
2. *Concept of Strain*
3. *Statically indeterminate problems*
4. *Thermal stresses*
5. *Stresses in thin wall vessels, Poison's ratio*
6. *Beams, shear force and bending moment equations.*
7. *Shear force and bending moment Diagrams*
8. *Stresses in Beams, Bending stresses*
9. *Shear stresses in Beams*
10. *Deflection of Beams*
11. *Torsion*
12. *Buckling of Columns*
13. *Stress Transformation and Mohr's Circle*
14. *Problems on Mohr's Circle*

CHAPTER 1

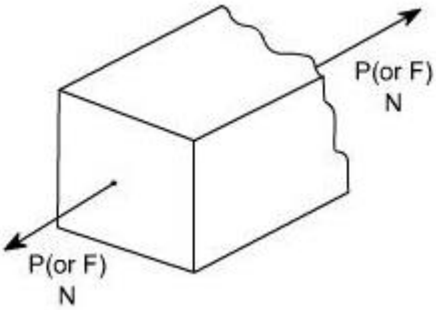
Stress

Concept of Stress : Let us introduce the concept of stress, as we know that the main problem of engineering mechanics of material is the investigation of the internal resistance of the body, i.e. the nature of forces set up within a body to balance the effect of the externally applied forces.

The externally applied forces are termed as loads. These externally applied forces may be due to any one or more of the followings:

(i) due to service conditions
(ii) due to environment in which the component works
(iii) through contact with other members
(iv) due to fluid pressures
(v) due to gravity or inertia forces (Self weight of the structure).

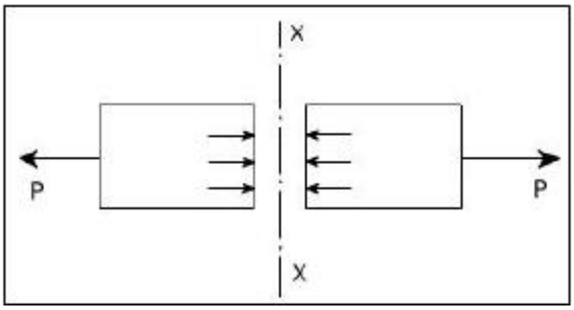
As we know that in mechanics of deformable solids, externally applied forces acts on a body and body suffers a deformation. From equilibrium point of view, this action should be opposed or reacted by internal forces which are set up within the particles of material due to cohesion. These internal forces give rise to a concept of stress. Therefore, let us define a term stress:



Stress:

Let us consider a rectangular bar of some cross–sectional area and subjected to some load or force (in Newton).

Let us imagine that the same rectangular bar is assumed to be cut into two halves at section XX. Each portion of this rectangular bar is in equilibrium under the action of load P and the internal forces acting at the section XX has been shown.



Simple Stress

Simple stress is expressed as the ratio of the applied force divided by the resisting area or :

$$\sigma = \text{Force / Area}.$$

It is the expression of force per unit area to structural members that are subjected to external forces and/or induced forces. Here we are using an assumption that the total force or total load carried by the bar is uniformly distributed over its cross_section.

Units :

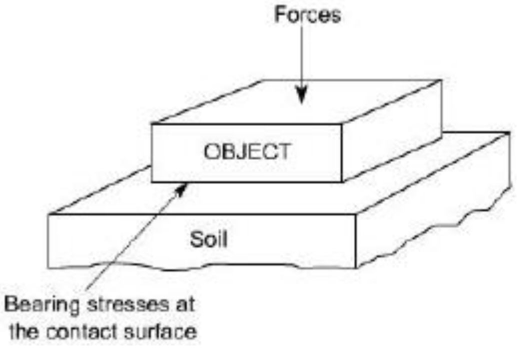
The basic units of stress in S.I units i.e. (International System) are **N / m²** (or Pa , Pascal)

MPa = 10^6 Pa , GPa = 10^9 Pa , KPa = 10^3 Pa

Sometimes **N/mm²** units are also used, because this is an equivalent to MPa , while **US** customary unit is ***pound per square*** inch , **psi**. (lb/in²).

Simple stress can be classified as **normal stress, shear stress, and bearing stress**.
Normal stress develops when a force is applied perpendicular to the cross-sectional area of the material. If the force is going to pull the material, the stress is said to be **tensile stress** and **compressive stress** develops when the material is being compressed by two opposing forces.

Shear stress is developed if the applied force is parallel to the resisting area. Example is the bolt that holds the tension rod in its anchor. Another condition of shearing is when we twist a bar along its longitudinal axis. This type of shearing is called torsion and covered in Chapter 3.



Another type of simple stress is the **bearing stress**, it is the contact pressure between two bodies. (It is in fact a compressive stress).

Suspension bridges are good examples of structures that carry these stresses. The weight of the vehicle is carried by the bridge deck and passes the force to the stringers (vertical cables), which in turn, supported by the main suspension cables. The suspension cables then transferred the forces into bridge towers.

STREMGTH OF MATERIALS

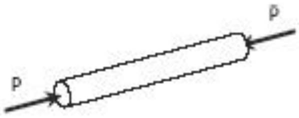
Normal Stress

The resisting area is perpendicular to the applied force, thus normal. There are two types of normal stresses; tensile stress and compressive stress. Tensile stress applied to bar tends the bar to elongate while compressive stress tend to shorten the bar.

σ = Force / Area

σ = P/ A

Bar in Tension



Bar in Compression

where P is the applied normal load in Newton and A is the area in mm^2. The maximum stress in tension or compression occurs over a section normal to the load.

EXAMPLE PROBLEMS IN NORMAL STRESS

Example 101: A hollow steel tube with an inside diameter of 100 mm must carry a tensile load of 400 kN. Determine the outside diameter of the tube if the stress is limited to 120 MN/m^2.

Solution 101:

$P = \sigma A$

where:

$P = 400\ \text{kN} = 400\ 000\ \text{N}$

$\sigma = 120\ \text{MPa}$

$A = \frac{1}{4}\pi D^2 - \frac{1}{4}\pi(100^2)$

$= \frac{1}{4}\pi(D^2 - 10\ 000)$

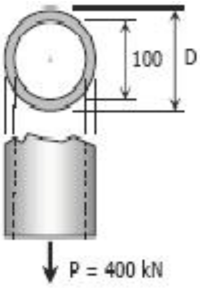
thus,

$400\ 000 = 120[\frac{1}{4}\pi(D^2 - 10\ 000)]$

$400\ 000 = 30\pi D^2 - 300\ 000\pi$

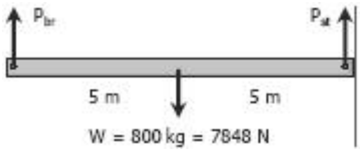
$$D^2 = \frac{400\ 000 + 300\ 000\pi}{30\pi}$$

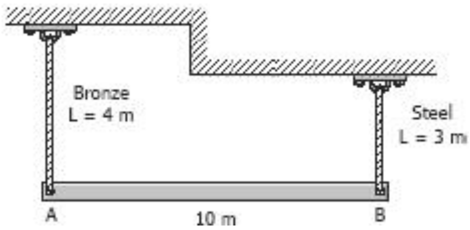
$D = 119.35\ \text{mm}$



Example 102 A homogeneous 800 kg bar AB is supported at either end by a cable as shown in Fig. P-105. Calculate the smallest area of each cable if the stress is not to exceed 90 MPa in bronze and 120 MPa in steel.

Solution:





By symmetry:

$$P_{br} = P_{st} = \tfrac{1}{2}(7848)$$
$$= 3924\text{ N}$$

For bronze cable:

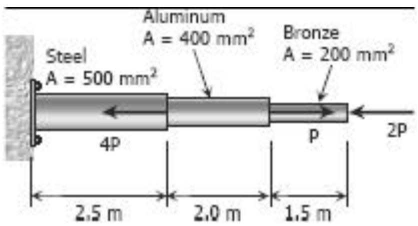
$$P_{br} = \sigma_{br} A_{br}$$
$$3924 = 90A_{br}$$
$$A_{br} = 43.6\text{ mm}^2$$

For steel cable:

$$P_{st} = \sigma_{st} A_{st}$$
$$3924 = 120A_{st}$$
$$A_{st} = 32.7\text{ mm}^2$$

Example 103 An aluminum rod is rigidly attached between a steel rod and a bronze rod as shown in Fig. P-108. Axial loads are applied at the positions indicated. Find the maximum value of P that will not exceed a stress in steel of 140 MPa, in aluminum of 90 MPa, or in bronze of 100 MPa.

Solution:



For bronze:

$\sigma_{br} A_{br} = 2P$

$100(200) = 2P$

$P = 10\ 000\text{ N}$

For aluminum:

$\sigma_{al} A_{al} = P$

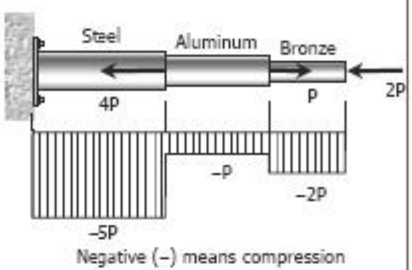
$90(400) = P$

$P = 36\ 000\text{ N}$

For Steel:

$\sigma_{st} A_{st} = 5P$

$P = 14\ 000\text{ N}$



For safe P, use $P = 10\ 000\text{ N} = \mathbf{10\ kN}$

Example 104 A 12-inches square steel bearing plate lies between an 8-inches diameter wooden post and a concrete footing as shown in Fig. P-110. Determine the maximum value of the load P if the stress in wood is limited to 1800 psi and that in concrete to 650 psi.

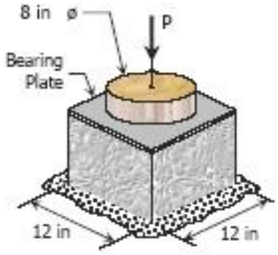


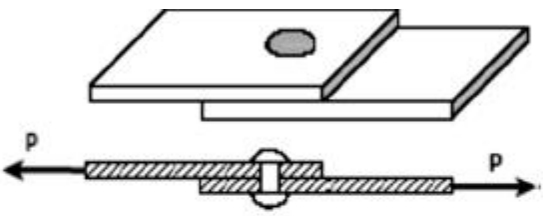
Figure P-110

Shearing Stress

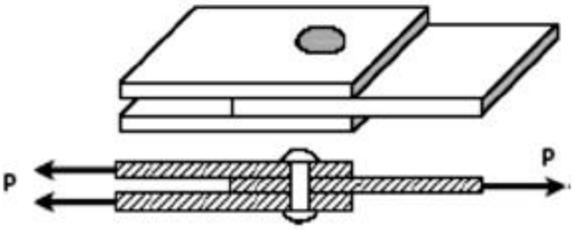
Forces parallel to the area resisting the force cause shearing stress. It differs to tensile and compressive stresses, which are caused by forces perpendicular to the area on which they act. Shearing stress is also known as tangential stress.

where V is the resultant shearing force which passes through the centroid of the area A being sheared.

$$\tau = \frac{V}{A}$$



Single Shear

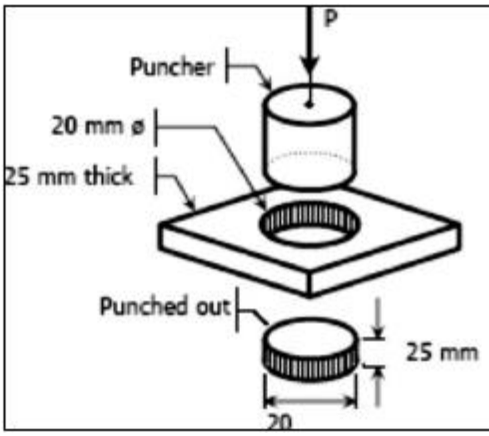


Double Shear

SOLVED EXAMPLES IN SHEARING STRESS

Example 105 : What force is required to punch a 20-mm-diameter hole in a plate that is 25 mm thick? The shear strength is 350 MN/m^2.

Solution:



The resisting area is the shaded area along the perimeter and the shear force V is equal to the punching force P.

$$V = \tau A$$
$$P = 350[\pi(20)(25)]$$
$$= 549\,778.7 \text{ N}$$
$$= \mathbf{549.8 \text{ kN}}$$

Example 106 Find the smallest diameter bolt that can be used in the clevis shown in Fig. 1-11b if P = 400 kN. The shearing strength of the bolt is 300 MPa.

Solution :

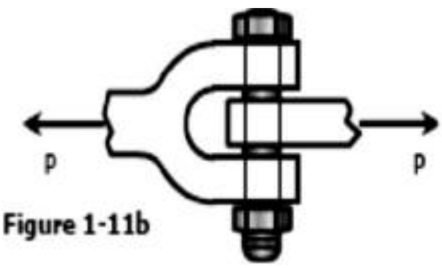


Figure 1-11b

The bolt is subject to double shear.

$$V = \tau A$$
$$400(1000) = 300[2(\tfrac{1}{4}\pi d^2)]$$
$$d = 29.13 \text{ mm}$$

Example 107 Compute the shearing stress in the pin at B for the member supported as shown in Fig. The pin diameter is 20 mm.

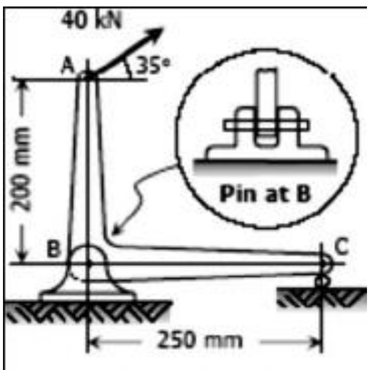
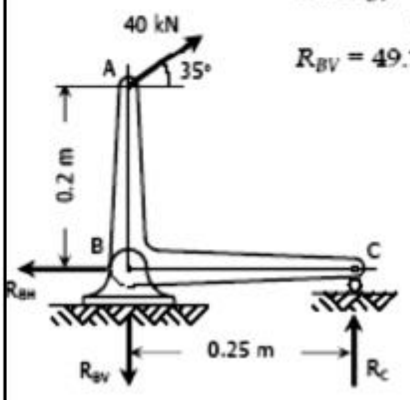


Figure P-119

Solution :



Free Body Diagram

From the FBD:

$\Sigma M_C = 0$

$0.25R_{BV} = 0.25(40 \sin 35°) + 0.2(40 \cos 35°)$

$R_{BV} = 49.156$ kN

$\Sigma F_H = 0$

$R_{BH} = 40 \cos 35° = 32.766$ kN

$R_B = \sqrt{R_{BH}^2 + R_{BV}^2} = \sqrt{32.766^2 + 49.156^2} = 59.076$ kN → shear force of pin at B

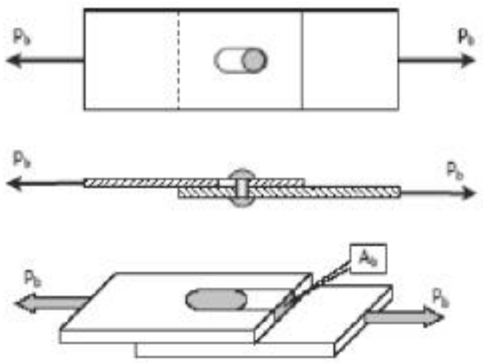
$V_B = \tau_B A$ → double shear

$59.076(1000) = \tau_B \{2[\frac{1}{4}\pi(20^2)]\}$

$\tau_B = 94.02$ **MPa**

Bearing Stress

Bearing stress is the contact pressure between the separate bodies. It differs from compressive stress, as it is an internal stress caused by compressive forces.



$$\sigma_b = \frac{P_b}{A_b}$$

SOLVED EXAMPLES IN BEARING STRESS

Example 125 In Fig. 1-12, assume that a 20-mm-diameter rivet joins the plates that are each 110 mm wide. The allowable stresses are 120 MPa for bearing in the plate material and 60 MPa for shearing of rivet. Determine (a) the minimum thickness of each plate; and (b) the largest average tensile stress in the plates.

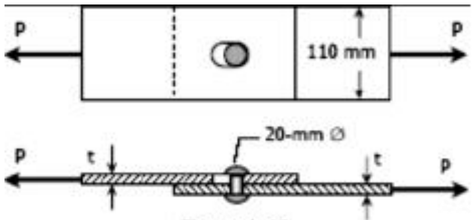


Figure 1-12

Solution

(a) From shearing of rivet:

$P = \tau A_{rivets}$

$= 60[\frac{1}{4}\pi(20^2)]$

$= 6000\pi$ N

From bearing of plate material:

$P = \sigma_b A_b$

$6000\pi = 120(20t)$

$t = 7.85$ **mm**

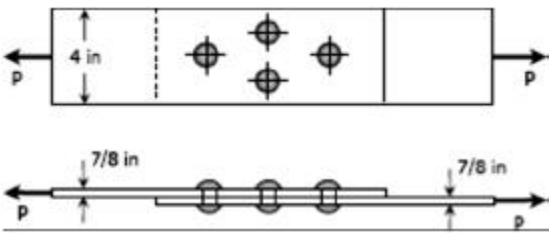
(b) Largest average tensile stress in the plate

$P = \sigma A$

$6000\pi = \sigma[7.85(110 - 20)]$

$\sigma = 26.67$ **MPa**

Example 126 The lap joint shown in Fig. P-126 is fastened by four ¾-in.-diameter rivets. Calculate the maximum safe load P that can be applied if the shearing stress in the rivets is limited to 14 ksi and the bearing stress in the plates is limited to 18 ksi. Assume the applied load is uniformly distributed among the four rivets.



Solution

Based on shearing of rivets:

$P = \tau A$

$P = 14[4\,(\frac{1}{4}\pi)(\frac{3}{4})^2\,]$

$P = 24.74$ kips

Based on bearing of plates:

$P = \sigma_b\, A_b$

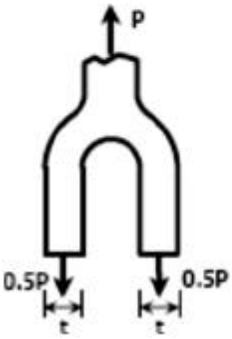
$P = 18[4\,(\frac{3}{4})(\frac{7}{8})\,]$

$P = 47.25$ kips

Safe load $P =$ **24.74 kips**

Example 127: In the clevis shown in Fig. 1-11b, find the minimum bolt diameter and the minimum thickness of each yoke that will support a load P = 14 kips without exceeding a shearing stress of 12 ksi and a bearing stress of 20 ksi.

Solution:



For shearing of rivets (double shear)

$P = \tau A$

$14 = 12[2(\frac{1}{4}\pi d^2)]$

$d = 0.8618$ **in** → diameter of bolt

For bearing of yoke:

$P = c_b A_b$

$14 = 20[2(0.8618t)]$

$t = 0.4061$ **in** → thickness of yoke

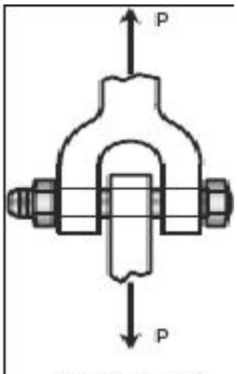


Figure 1-11b