NORMAL AND SHEAR STRESS

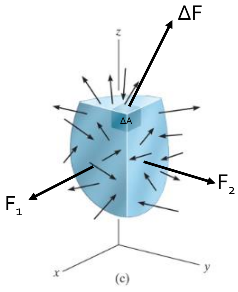
Samantha Ramirez, MSE

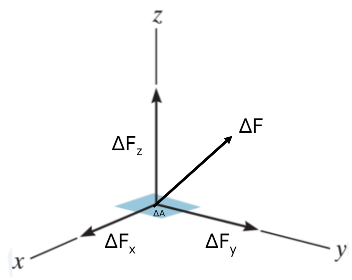
Objectives

1. Define stress, normal stress, direct shear stress, and factor of safety.
2. Design members subjected to an axial load while considering allowable stress.
3. Design members subjected to direct shear while considering allowable stress.

Stress

- The intensity of the internal force acting on a specific plane (area) passing through a point.





- ΔA is an infinitesimal size area with a uniform force acting on it.

Stress Equations

- **Normal Stress (σ)** is the intensity of force, or force per unit area, acting normal to ΔA.

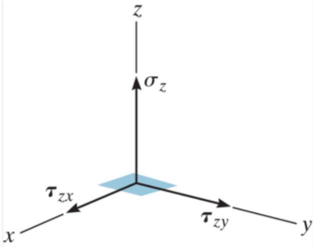
$$\sigma_z = \lim_{\Delta A \to 0} \frac{\Delta F_z}{\Delta A}$$

- **Shear Stress (τ)** is the intensity of force, or force per unit area, acting parallel to ΔA.

$$\tau_{zx} = \lim_{\Delta A \to 0} \frac{\Delta F_x}{\Delta A}$$

$$\tau_{zy} = \lim_{\Delta A \to 0} \frac{\Delta F_y}{\Delta A}$$

- Subscripts
  - First letter is the orientation of force normal to ΔA
  - Second letter is the orientation of force causing shear



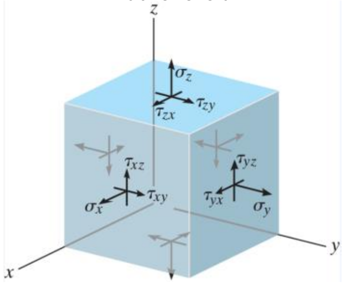
Stress States

$\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{xz}, \tau_{yx}, \tau_{yz}, \tau_{zx}, \tau_{zy}$

$\tau_{xy} = \tau_{yx}, \tau_{xz} = \tau_{zx}, \tau_{yz} = \tau_{zy}$

$\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{xz}, \tau_{yz}$

Volume Element



Units

N/m² (Pa)

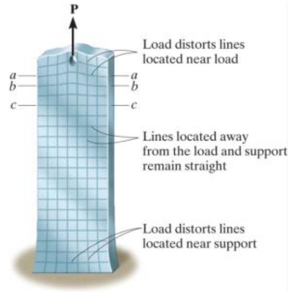
1000 N/m² (kPa)

lb_f/in^2 (psi)

1000 lb_f/in^2 (ksi)

Saint-Venant's Principle

- The stress and strain at points in a body sufficiently away from the region of load application will be the same as the stress and strain produced by any applied loadings that have the same statically equivalent resultant.

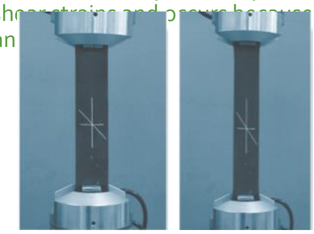


Saint-Venant's Principle

- "If the forces acting on a small portion of the surface of an elastic body are replaced by another statically equivalent system of forces acting on the same portion of the surface, this redistribution of loading produces substantial changes in the stresses locally, but has a negligible effect on the stresses at distances which are large in comparison with the linear dimensions of the surface on which the forces are changed." (B. Saint-Venant, Mém. savants étrangers, vol. 14, 1855.)

Deformation

- Deformation is defined as the changes to a body's shape and size when a load is applied.
- Deformation is specified by normal and shear strains and occurs because of loads an

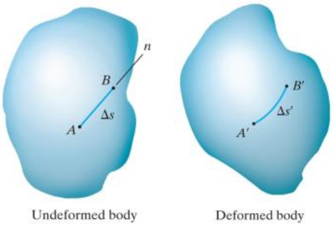


Average Normal Strain (ε)

- The elongation or contraction of a line segment per unit length

$$\varepsilon_{avg} = \frac{\Delta s' - \Delta s}{\Delta s} = \frac{\Delta L}{\Delta s}$$

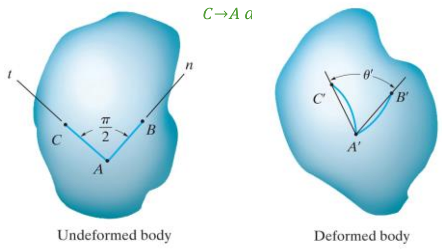
- Strain depends on geometry of formation
- Stress and strain are independent of each other



Average Shear Strain (γ)

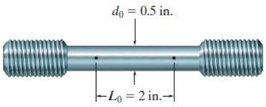
- The change in angle between two lines that were originally perpendicular

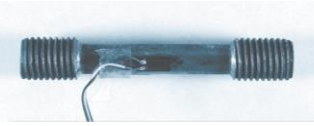
$$\gamma_{nt} = \frac{\pi}{2} - \lim_{\substack{B \to A\ a \\ C \to A\ a}} \theta'$$



Tensile Test

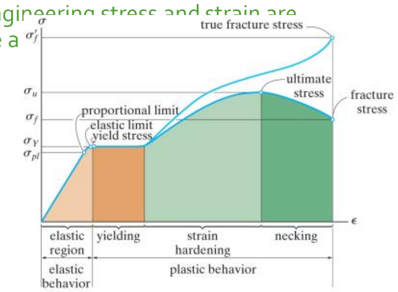
- P is measured using a load cell
  - $\sigma_{avg} = \frac{P}{A}$
- δ is elongation measured using an extensometer (optical or mechanical)
  - $\varepsilon_{avg} = \frac{\delta}{L_o}$
- A strain gauge can be used to measure strain directly





Stress-Strain Diagram

- The most important result from the tension test is the stress-strain diagram (σ-ε diagram).
- Nominal or engineering stress and strain are used to create a
  - $\sigma = \frac{F}{A}$
  - $\varepsilon = \frac{\Delta L}{L_o}$



Stress-Strain Diagram Properties

- Proportional Limit
  - The upper stress limit in the linear elastic region of a σ-ε diagram
- Elastic Limit
  - If the load is removed before reaching the elastic limit, the specimen will return to its original shape
  - If the load passes the elastic limit, the specimen will permanently deform
- Yield Strength
  - The stress that causes a material to breakdown and deform permanently
  - When yield strengths is not well defined, the offset yield strength can be calculated
    - A line parallel to the initial straight-line portion of the stress-strain curve at 0.2% strain (0.002 in/in).
- Ultimate Tensile Strength
  - The maximum stress the material will reach through testing
  - Necking occurs (visibly see permanent deformation)
- Fracture Stress
  - The stress when the material breaks

Necking

Failure of a ductile material

Hooke's Law

- The proportional limit was observed by Robert Hooke in 1676

$$E = \frac{\sigma}{\varepsilon}$$

  - E: Young's Modulus, the constant of proportionality
    - Young's Modulus or the modulus of elasticity is a mechanical property of a material that indicates stiffness.
  - $\frac{\sigma}{\varepsilon}$: Slope of the straight-line portion of the stress-strain curve

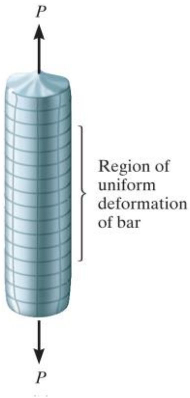
- Theoretical Moduli
  - Steel: E=29 Msi or 200 GPa
  - Aluminum: E=10 Msi or 69 Gpa

- The modulus of elasticity can only be used if a materials has linear elastic behavior and is being subjected to stresses below the proportional limit.
  - If a material has yielded, the modulus of elasticity cannot be used.

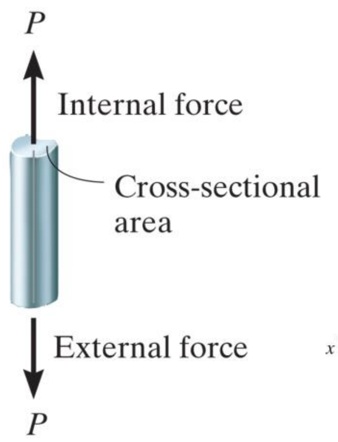
AVERAGE NORMAL STRESS

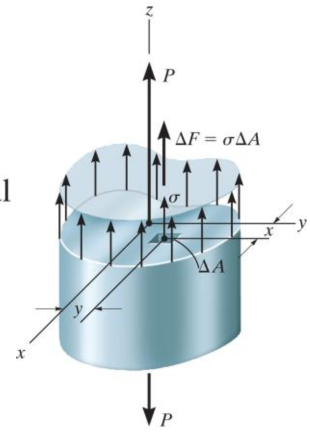
Uniaxial Tensile Test

- Axially Loaded Bar (Uniaxial Tensile Test)
  - Assumptions
    - Homogeneous material
    - Isotropic material
    - Bar remains straight and cross-section flat
    - P is applied along the centroid axis



Average Normal Stress





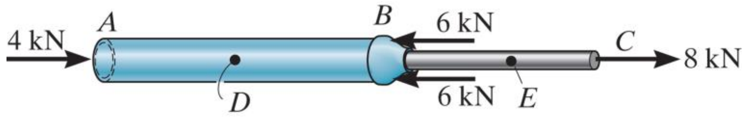
$$\int dF = \int \sigma dA$$

$$P = \sigma_{Avg} A$$

$$\boldsymbol{\sigma_{Avg} = \frac{P}{A}}$$

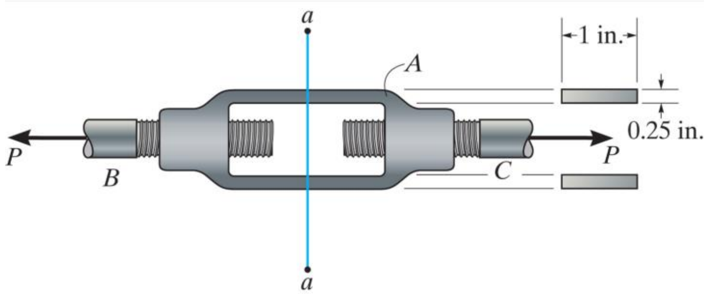
Example 1

- The built-up shaft consists of a pipe AB and solid rod BC. The pipe has an inner diameter of 20 mm and an outer diameter of 28 mm. The rod has a diameter of 12 mm. Determine the average normal stress at D and E and represent the stress on a volume element located at each of these points.



Example 2

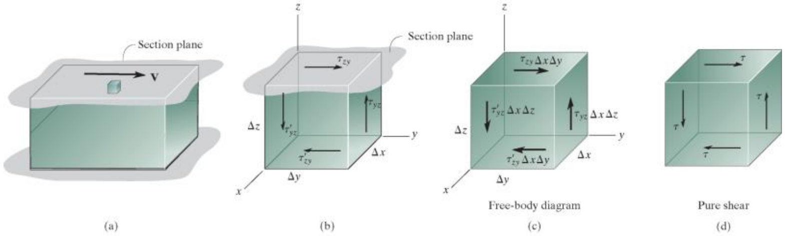
- If the turnbuckle is subjected to an axial force of P=900 lb, determine the average normal stress developed in section a-a and in each bolt shank at B and C. Each bolt shank has a diameter of 0.5 in.



SHEAR STRESS IN CONNECTIONS

Average Shear Stress **<u>in Connections</u>**

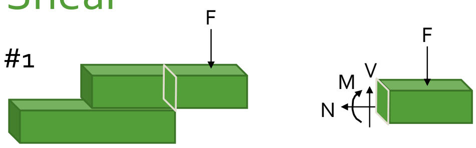
- Direct Shear
- <u>Shear Stress</u> is the force per unit area that acts in a plane of the cross-sectional area.



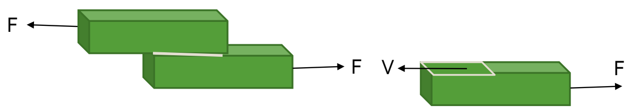
$$\tau_{Avg} = \frac{V}{A}$$

Single Shear

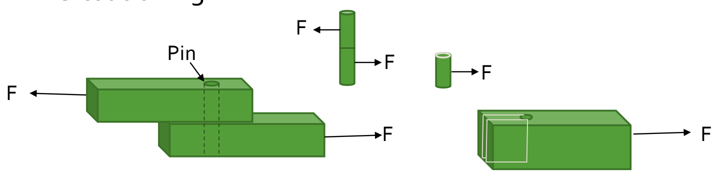
- Situation #1



- Situation #2

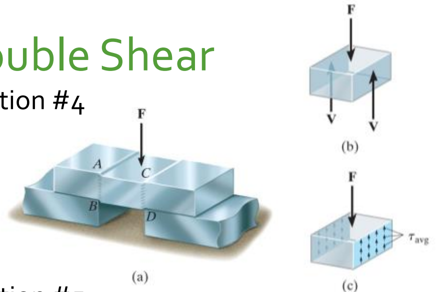


- Situation #3

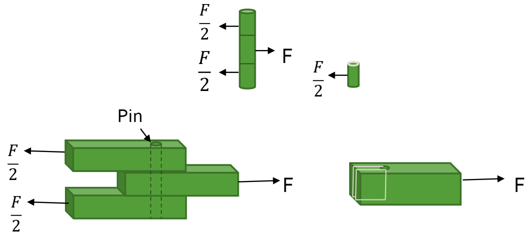


Double Shear

- Situation #4

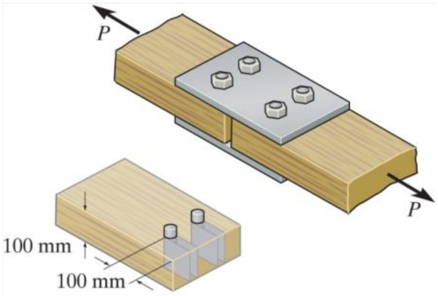


- Situation #5



Example 3

- If the joint is subjected to an axial force of P=9 kN, determine the average shear stress developed in each of the 6-mm diameter bolts between the plates and the members and along each of the four shaded shear planes.



Factor of Safety

- Factor of Safety (FS) is a ratio of the failure load, F_{fail}, divided by the allowable load, F_{allow}. (FS>1)

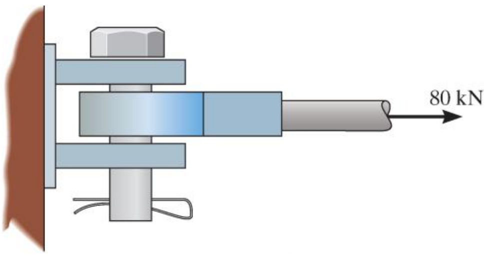
$$FS = \frac{F_{Fail}}{F_{Allow}}$$

- If the load applied to the member is linearly related to the stress developed within the member, then

$$FS = \frac{N_{Fail}}{N_{Allow}} = \frac{\sigma_{Fail}}{\sigma_{Allow}} \qquad FS = \frac{V_{Fail}}{V_{Allow}} = \frac{\tau_{Fail}}{\tau_{Allow}}$$

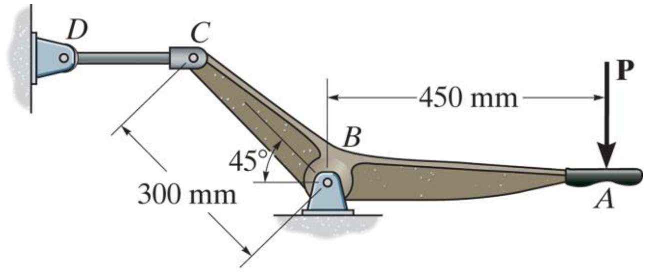
Example 4

- The pin is made of a material having a failure shear stress of 100 MPa. Determine the minimum required diameter of the pin to the nearest mm. Apply a factor of safety of 2.5 against shear failure.



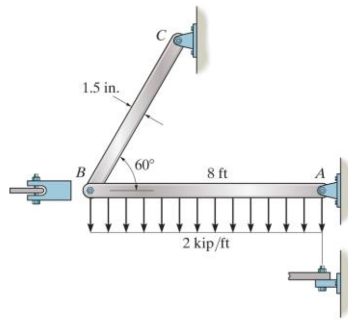
Example 5

- Determine the maximum vertical force P that can be applied to the bell crank so that the average normal stress developed in the 10 mm diameter rod, CD, and the average shear stress developed in the 6 mm diameter double sheared pin B not exceed 175 MPa and 75 MPa, respectively.



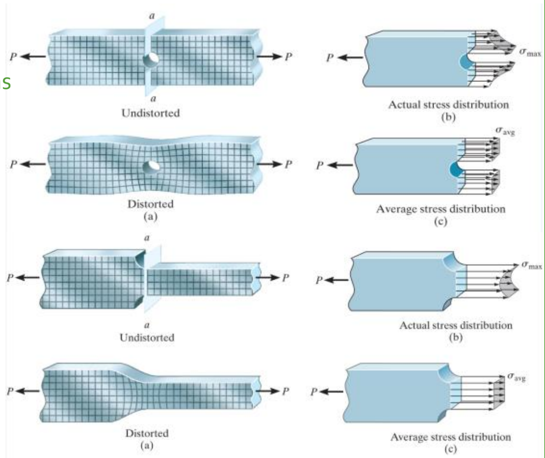
Example 6

- To the nearest 1/16", determine the required thickness of member BC and the diameter of the pins at A and B if the allowable normal stress for member BC is σ_{Allow}=29 ksi and the allowable shear stress for the pins is τ_{Allow}=10 ksi.



Normal Stress Concentrations

- Holes and sharp transitions at a cross section will create stress concentrations.
- In engineering practice, only the maximum stress at these sections must be known.
- The maximum normal stress occurs at the *smallest* cross-sectional area.



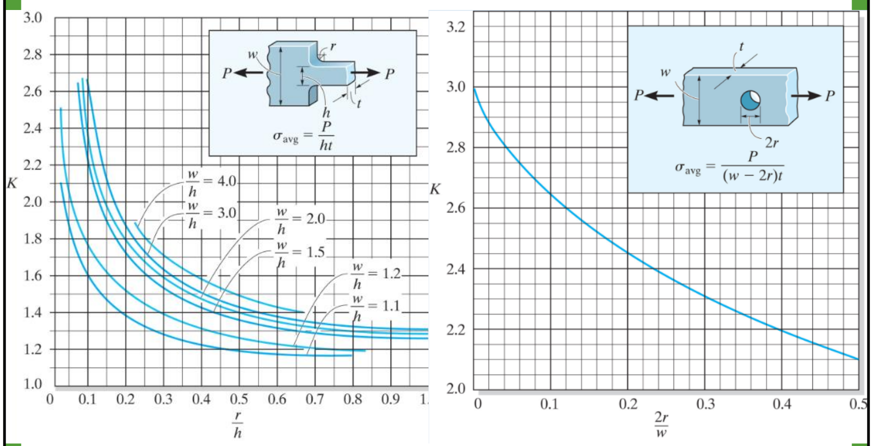
Stress Concentration Factor

- A stress concentration factor "K" is used to determine the maximum stress at sections where the cross-sectional area changes.

$$K = \frac{\sigma_{max}}{\sigma_{avg}}$$

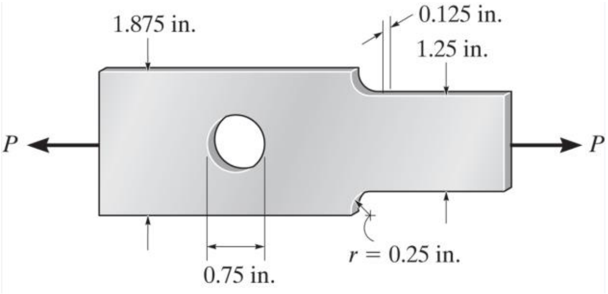
- K is found from graphs in handbooks of stress analysis
- σ_{avg} is the average normal stress at the smallest cross section

Stress Concentration Factor Tables



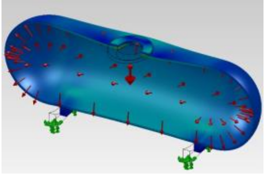
Example 7

- Determine the maximum normal stress developed in the bar when it is subjected to a tension of P=2 kip.



Thin-Walled Pressure Vessels

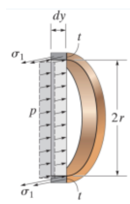
- Cylindrical or spherical vessels are commonly used in industry to serve boilers or tanks.
- A "thin wall" refers to a vessel having an inner radius to wall thickness ratio of 10 or more $\left(\frac{r}{t} \geq 10\right)$.
- We will assume a uniform or constant stress distribution throughout the thickness because it is thin.
- Pressure vessels are subjected to loadings in all directions.



Cylindrical Vessels

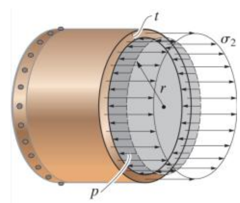
Circumferential or Hoop Stress (σ_1)

$$\sigma_1 = \frac{pr}{t}$$



Longitudinal or Axial Stress (σ_2)

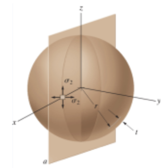
$$\sigma_2 = \frac{pr}{2t}$$

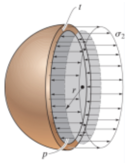


Spherical Vessels

$$\sigma_2 = \frac{pr}{2t}$$

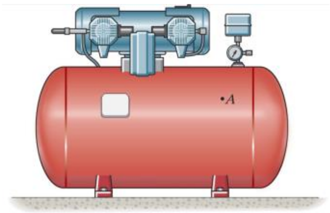
- σ_1, σ_2: the normal stress in the hoop and longitudinal directions, respectively.
  - Each is assumed to be constant throughout the wall of the cylinder, and each subjects the material to tension.
- p: the internal gauge pressure developed by the contained gas
- r: the inner radius of the cylinder
- t: the wall thickness ($r/t \geq 10$)





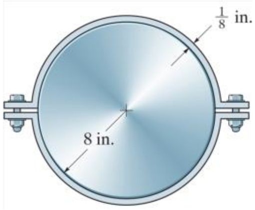
Example 8

- The tank of the air compressor is subjected to an internal pressure of 90 psi. If the internal diameter of the tank is 22 in, and the wall thickness is 0.25 in, determine the stress components acting at point A. Draw a volume element of the material at this point, and show the results on the element.



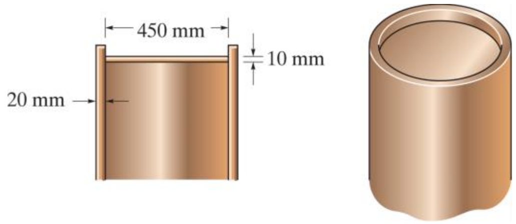
Example 9

- The A-36 steel band is 2 in wide and is secured around the smooth rigid cylinder. If the bolts are tightened so that the tension in them is 400 lb, determine the normal stress in the band, the pressure exerted on the cylinder, and the distance half the band stretches.



Example 10

- A pressure-vessel head is fabricated by gluing the circular plate to the end of the vessel as shown. If the vessel sustains an internal pressure of 450 kPa, determine the average shear stress in the glue and the state of stress in the wall of the vessel.



SHEAR STRESS DUE TO TORSION

Samantha Ramirez, MSE

Objective

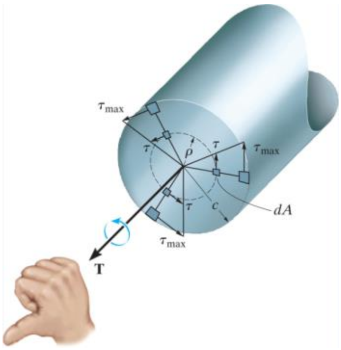
1. Define shear stress due to an internal torsional moment, polar moment of inertia, and power transmitted by a torsional shaft.
2. Design torsional-loaded members including noncircular shafts.

The Torsional Formula

$$\tau_{max} = \frac{Tc}{J}$$

- τ_{max}: maximum shear stress (occurs at the outer surface)
- T: resultant internal torque
- J: polar moment of inertia
- c: outer radius of shaft

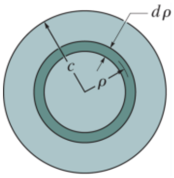
$$\tau = \frac{T\rho}{J}$$



Section Property: Polar Moment of Inertia

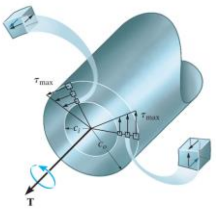
- Solid Circular Shaft

$$J = \frac{\pi}{2} c^4$$



- Tubular Shaft

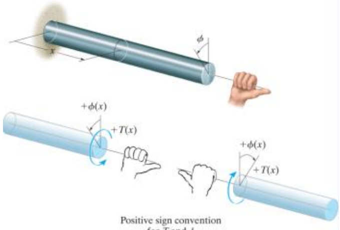
$$J = \frac{\pi}{2}\left(c_o^4 - c_i^4\right)$$



Recall:
How to Determine
Internal Resultant Torque

- If necessary, determine the reactions on the shaft
- Section (cut) the shaft perpendicular to its axis at the point where the shear stress is to be determined
- Draw a free-body diagram of the shaft on either side of the cut
- Use a static-equilibrium equation and the following sign convention to obtain the internal torque at the section

- Sign Convention
  - Using the right-hand rule, the torque and angle of twist will be positive, provided the thumb is directed outward from the shaft when the fingers curl to give the tendency for rotation.



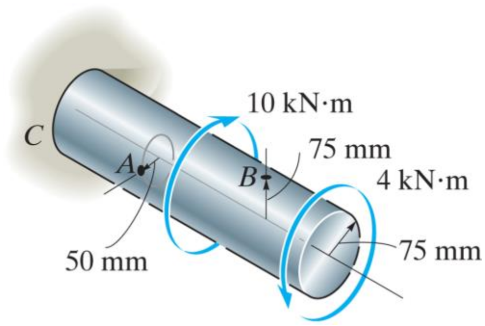
Positive sign convention for T and ϕ.

Torque Diagram

- A torsion diagram is a graphical representation of the internal resultant torque at any point along a shaft.

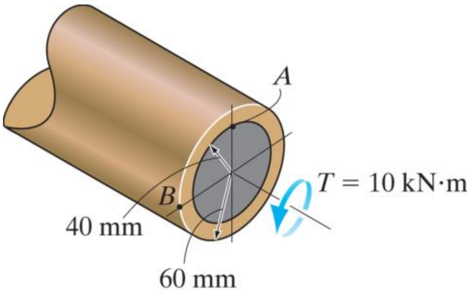
Example 1

- The solid shaft is fixed to the support at C and subjected to the torsional loadings shown. Determine the shear stress at points A and B and sketch the shear stress on the volume elements located at these points.



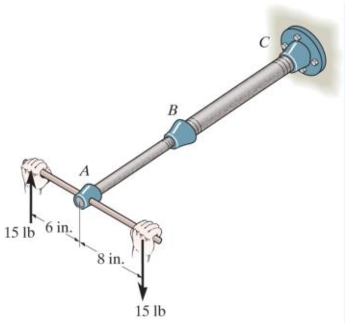
Example 2

- The hollow circular shaft is subjected to an internal torque of T=10 kNm. Determine the shear stress developed at points A and B. Represent each state of stress on a volume element.



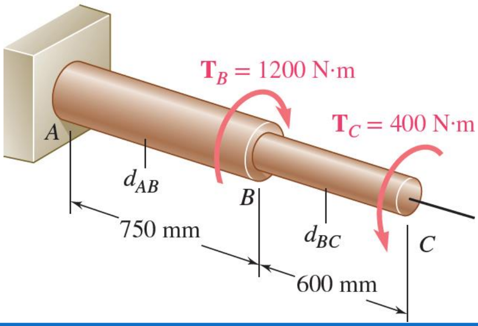
Example 3

- The assembly consists of two sections of galvanized steel pipe connected together using a reducing coupling at B. The smaller pipe has an outer diameter of 0.75 in and an inner diameter of 0.68 in, whereas the larger pipe has an outer diameter of 1 in and an inner diameter of 0.86 in. If the pipe is tightly secured into the wall at C, determine the maximum shear stress developed in each section of the pipe when the couple shown is applied to the handles of the wrench.



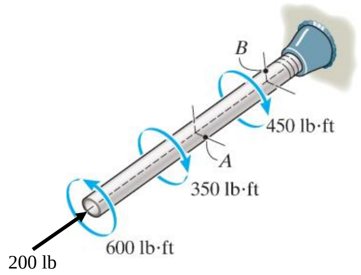
Example 4

- The solid shaft shown is formed of a brass for which the allowable shear stress is 55 Mpa. Neglecting the effect of stress concentrations, determine the smallest diameters dAB and dBC for which the allowable shearing stress is not exceeded.



Example 5

- The copper pipe has an outer diameter of 2.50 in and a wall thickness of 0.1 in. If it is tightly secured to the wall and three torques and one compressive force are applied to it, determine the stress developed at points A and B. These points lie on the pipe's outer surface. Sketch the stress on a volume element for each point.



Power Transmission

- Power
  - The work performed per unit of time
- The power transmitted by a shaft subjected to a T and angular velocity "ω" is:

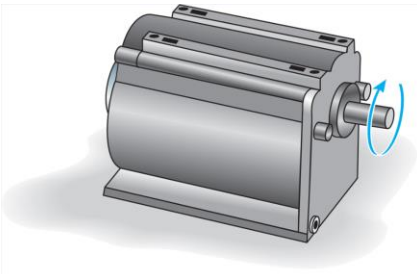
$$P = T\omega$$

- The size of the shaft can be determined using the allowable shear stress:

$$\tau_{allow} = \frac{Tc}{J}$$

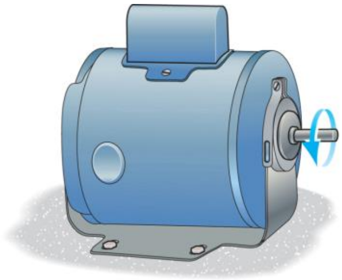
Example 6

- The gear motor can develop 3 hp when it turns at 150 rev/min. If the allowable shear stress for the shaft is τ_{allow}=12 ksi, determine the smallest diameter of the shaft to the nearest 1/8 in that can be used.



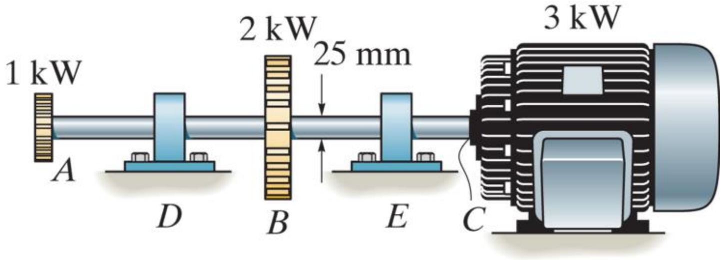
Example 7

- The 25 mm diameter shaft on the motor is made of a material having an allowable shear stress of τ_{allow}=75 MPa. If the motor is operating at its maximum power of 5 kW, determine the minimum allowable rotation of the shaft.



Example 8

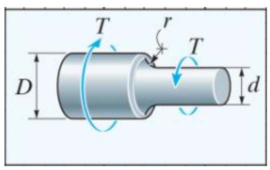
- The solid steel shaft AC has a diameter of 25 mm and is supported by smooth bearings at D and E. It is coupled to a motor at C, which delivers 3 kW of power to the shaft while it is turning at 50 rev/s. If gears A and B remove 1 kW and 2 kW, respectively, determine the maximum shear stress developed in the shaft within regions AB and BC. The shaft is free to turn in its support bearing D and E.

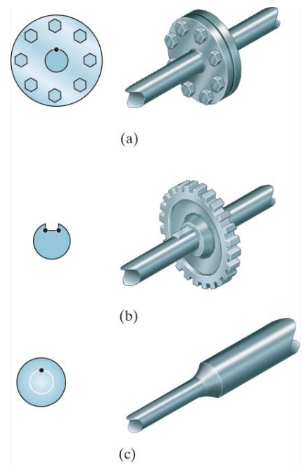


Stress Concentration

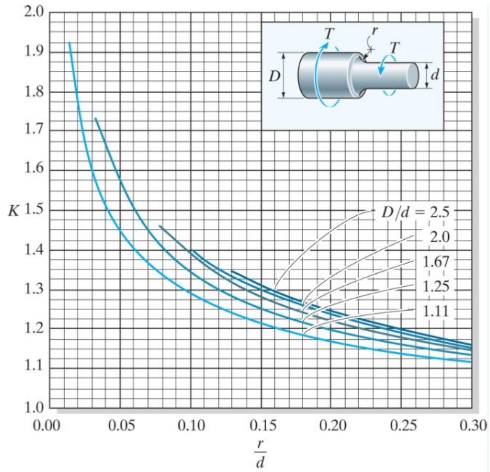
$$\tau_{max} = K\tau_{max,original} = K\frac{Tc}{J}$$

- Under torsion, the shaft will break at the smallest part of the neck.



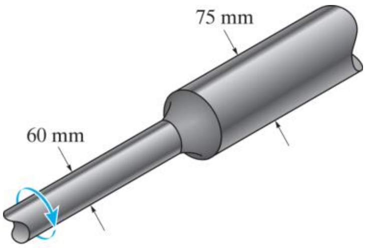


Torsional Stress-Concentration Factor Table



Example 9

- The step shaft is to be designed to rotate at 720 rpm while transmitting 30 kW of power. Is this possible? The allowable shear stress is τ_{allow}=12 MPa and the radius at the transition on the shaft is 7.5 mm.



MODULE 2C: NORMAL STRESS DUE TO BENDING MOMENT

Samantha Ramirez, MSE

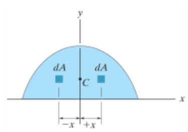
CENTROIDS & MOMENTS OF INERTIA

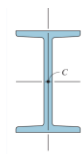
Centroids

- The centroid of an area refers to the point that defines the geometric center for the area.
- In cases where the area has an axis of symmetry, the centroid will lie along this axis.
- Composite Area: The area can be sectioned or divided into several parts having simpler shapes

$$\bar{x} = \frac{\sum \tilde{x} A}{\sum A} \qquad \bar{y} = \frac{\sum \tilde{y} A}{\sum A}$$

- $\tilde{x}, \tilde{y}$: the algebraic distances (or x & y coordinates) for the centroid of each composite part
- A: the area of each composite part



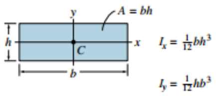


Moments of Inertia

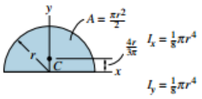
- A geometric property that is calculated about an axis.

$$I_x = \bar{I}_{x'} + Ad_y^2 \qquad I_y = \bar{I}_{y'} + Ad_x^2$$

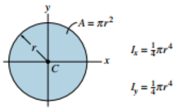
- The term Ad^2 is zero if the axis passes through the area's centroid
- Composite areas can be used to calculate the moment of inertia of complex shapes
- You can subtract the moment of inertia of an empty area from the moment of inertia of the entire area.



Rectangular area



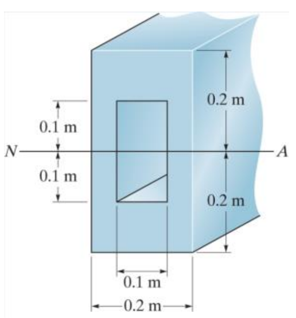
Semicircular area

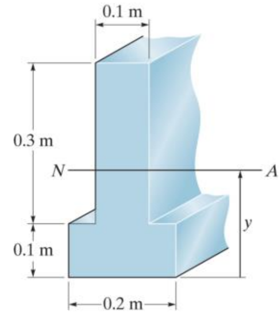


Circular area

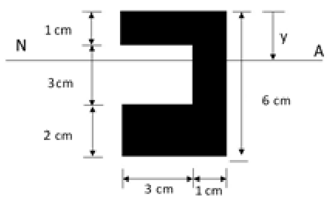
Determining Centroids & Moments of Inertia

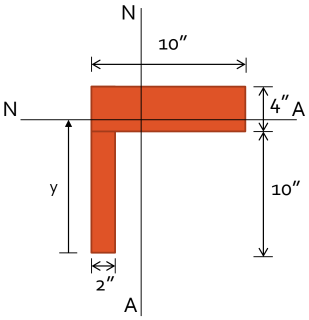
- Determine the centroid and moment of inertia for each of the following cross-sections about the neutral axis.





Determining Centroids & Moments of Inertia

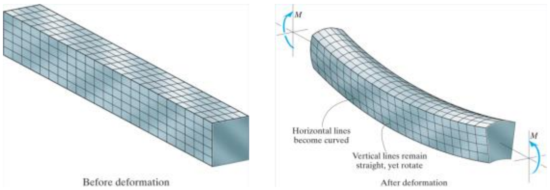




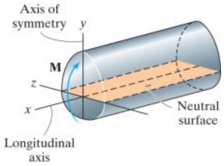
NORMAL STRESS DUE TO BENDING MOMENT

Bending Deformation of a Straight Member

- When a bending moment is applied, the longitudinal lines become curved and the vertical transverse lines remain straight and undergo a rotation.

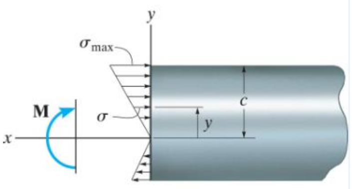


- The neutral surface is found between the stretched and compressed surfaces and does not experience any change in length.



Normal Stress Distribution in Bending

- Assuming a homogeneous material and linear elastic deformation, the stress also varies in a linear fashion over the cross-sectional area.



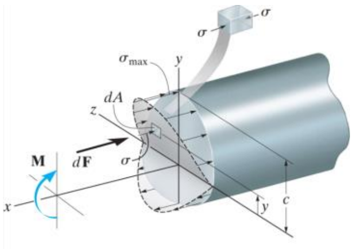
Bending stress variation (profile view)

$$\sigma = -\left(\frac{y}{c}\right)\sigma_{max}$$

Maximum Flexure Formula

$$\sigma_{max} = \frac{Mc}{I}$$

- σ_{max}: the maximum normal stress in a member which occurs at a point on the cross-sectional area farthest away from the neutral axis
- M: the resultant internal moment
- c: the perpendicular distance from the neutral axis to where σ_{max} acts (point farthest from the neutral axis)
- I: the moment of inertia of the cross-sectional area about the neutral axis



Bending stress variation

The Flexure Formula

- Similarly,

$$\sigma = -\frac{My}{I}$$

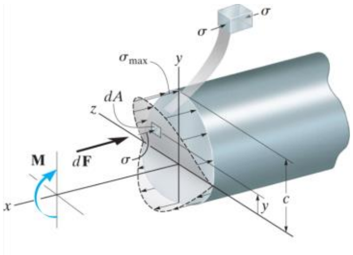
- where y is the perpendicular distance from the neutral axis to the point of interest

- This equation is valid for beams with cross-sectional areas symmetric about the y-axis.

- Note: For linear elastic materials, the neutral axis passes through the centroid

Procedure for Analysis
Flexure Formula

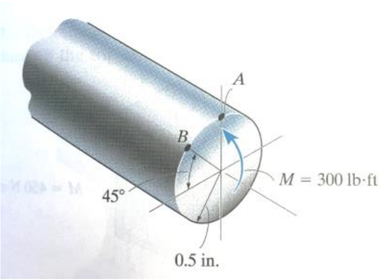
1. Internal Moment
   - FBD/Statics
   - FBD/Solids
2. Section Property
   - Moment of Inertia
3. Normal Stress
   - Specify the location y
   - Apply Flexure Formula



Bending stress variation

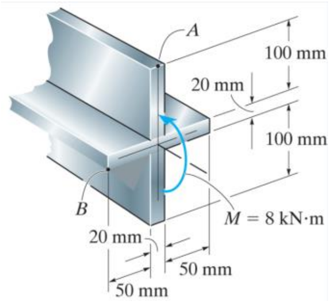
Example 1

- The steel rod having a diameter of 1 in is subjected to an internal moment of M=300 lb-ft. Determine the stress created at points A and B. Also, sketch a 3-D view of the stress distribution acting over the cross section.



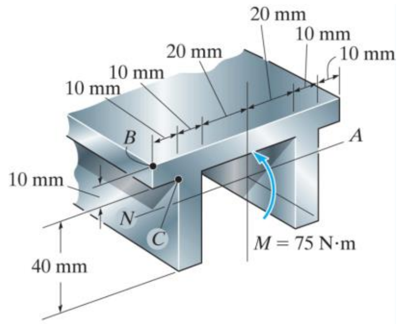
Example 2

- The aluminum strut has a cross-sectional area in the form of a cross. If it is subjected to the moment M = 8 kNm, determine the bending stress acting at points A and B, and show the results acting on volume elements located at these points.



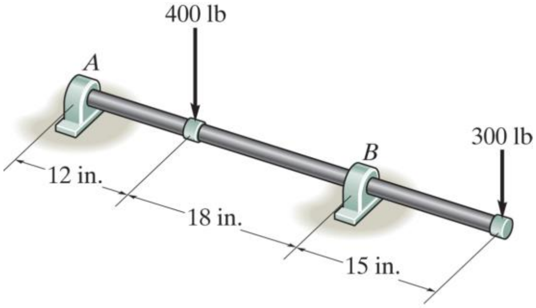
Example 3

- The aluminum machine part is subjected to a moment of M = 75 Nm. Determine the maximum tensile and compressive bending stresses in the part.



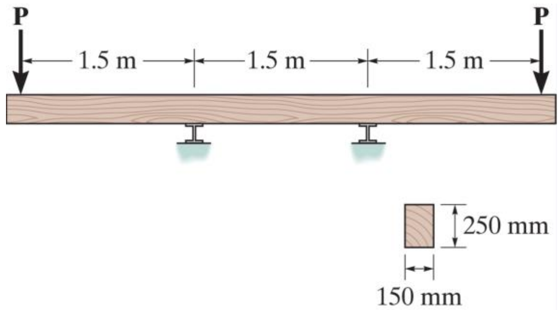
Example 4

- Determine the smallest allowable diameter of the shaft which is subjected to the concentrated forces. The sleeve bearings at A and B support only vertical forces, and the allowable bending stress is σ_{allow}=22 ksi.



Example 5

- The beam has a rectangular cross section as shown. Determine the largest load P that can be supported on its overhanging ends so that the bending stress does not exceed σ_{max}=10 MPa.

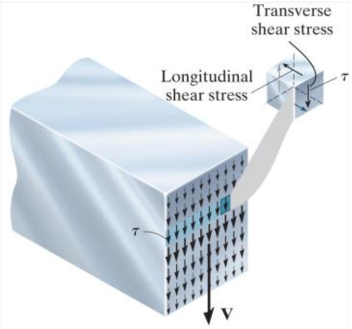


SHEAR STRESS DUE TO SHEAR FORCE

Samantha Ramirez, MSE

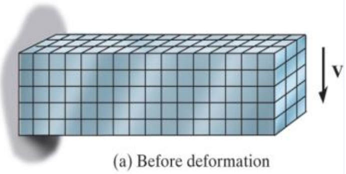
Transverse Shear Stress

- A beam will support both shear forces and bending moments. Due to the complementary property of shear, this stress will create corresponding longitudinal shear stresses which will act along longitudinal planes of the beam.

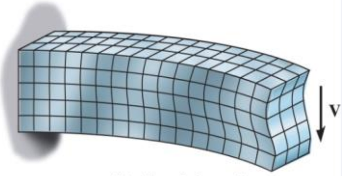


Shear in Straight Members

- Transverse loadings will generate both bending moments and shear forces along the beam.
- When a beam is subjected to both bending and shear, the cross section will not remain plane.
  - Assuming small cross-sectional warping allows it to be neglected.



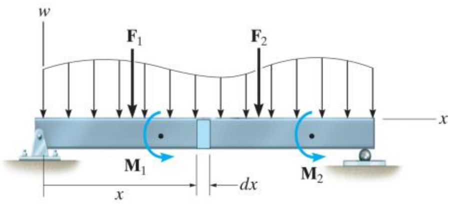
(a) Before deformation

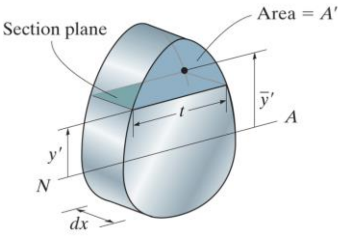


(b) After deformation

Transverse Shear Stress

- The shear formula was derived by horizontal force equilibrium of the longitudinal shear stress and bending stress distributions acting on a portion of a differential segment of a beam.
- The shear formula is valid for homogeneous materials and the internal resultant shear force is directed along an axis of symmetry.





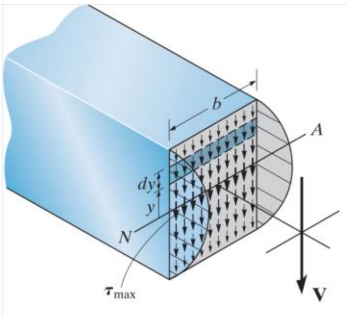
The Shear Formula

$$\tau = \frac{VQ}{It}$$

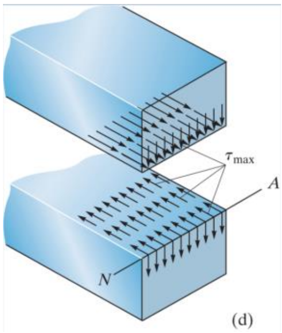
- τ: the shear stress in the member at the point located a distance y′ from the neutral axis
- V: the internal resultant shear force
- Q: $\bar{y}$′A′ , where A′ is the area of the top (or bottom) portion of the member's cross-sectional area, above (or below) the section plane where t is measured, and $\bar{y}$′ is the distance from the neutral axis to the centroid of A′
- I: the moment of inertia of the entire cross-sectional area calculated about the neutral axis
- t: the width of the member's cross-sectional area, measured at the point where τ is to be determined

Shear Stress Distribution

Shear Stress Distribution

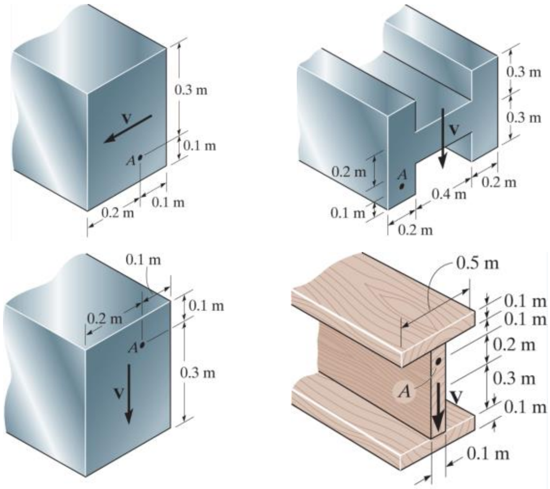


Shear Stress on a Volume Element



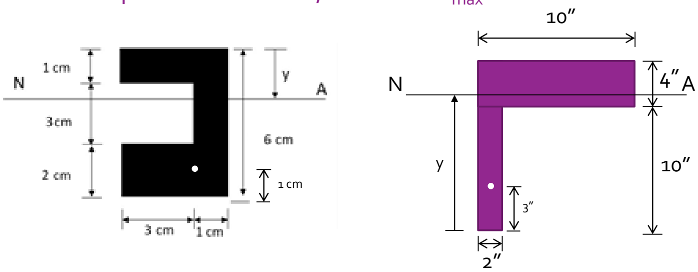
Solving for Q and t

- Calculate the value of I, Q, and t that are used in the shear formula for finding the shear stress at point A.



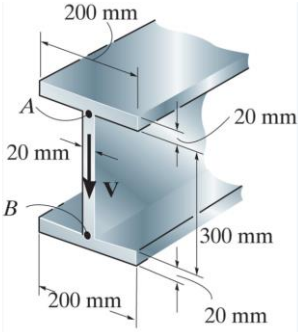
Solving for Q and t

- Calculate the value of Q and t that are used in the shear formula for finding the shear stress at the point shown. Also, calculate Q_{max}.



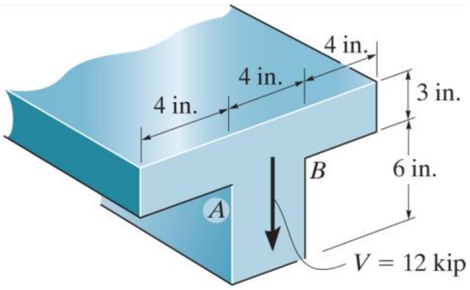
Example 1

- If the wide-flange beam is subjected to a shear of V=20 kN, determine the shear stress on the web at A. Indicate the shear-stress components on a volume element located at this point.



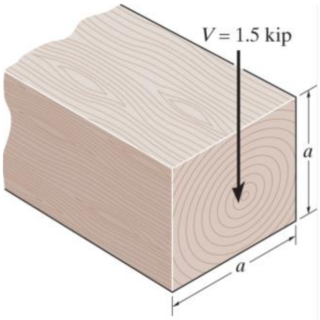
Example 2

- If the T-beam is subjected to a vertical shear of V = 12 kip, determine the maximum shear stress in the beam. Also, compute the shear-stress jump at the flange-web junction AB. Sketch the variation of the shear-stress intensity over the entire cross section.



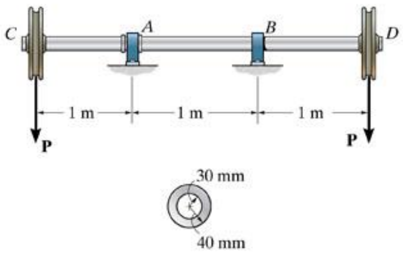
Example 3

- The beam has a square cross-section and is made of wood having an allowable shear stress of 1.4 ksi. If it is subjected to a shear force of 1.5 kip, determine the smallest dimension a of its sides.



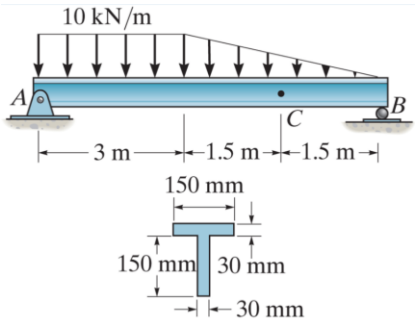
Example 4

- The shaft is supported by a smooth thrust bearing at A and a smooth journal bearing at B. If P=26 kN, determine the absolute maximum shear and bending stress in the shaft.



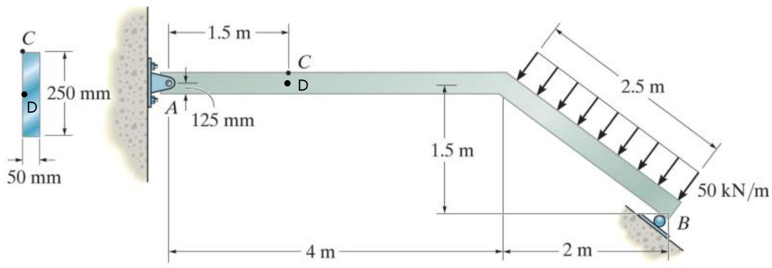
Example 5

- Determine the maximum shear stress and normal stress in the T-beam at the critical section where the internal shear force is maximum and internal bending moment is maximum.



Example 6

- The member shown has a rectangular cross section. Determine the state of stress that the loading produces at C and D.



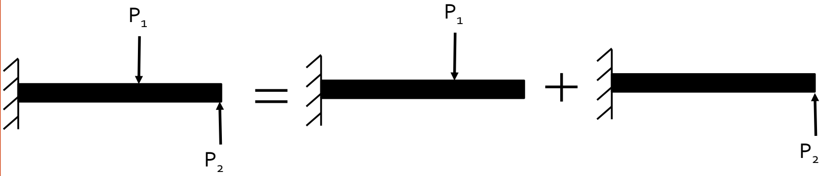
(a)

STRESS
COMBINED LOADING

Samantha Ramirez, MSE

Principle of Superposition

- The resultant stress or displacement at the point can be determined by algebraically summing the stress or displacement caused by each load component applied separately to the member.



- The principle of superposition is valid only when the relationship between stress, strain, and loads is linear and the original geometry or configuration of the member is not significantly changed.

State of Stress Caused by Combined Loading

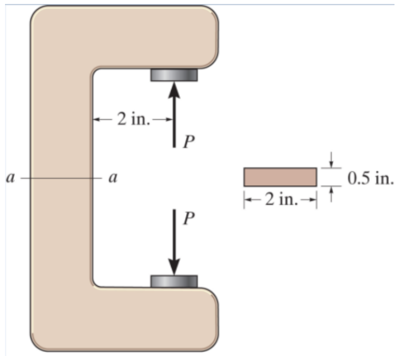
- The cross section of a member is subjected to several loadings simultaneously.
- The method of superposition can be used to determine the resultant stress distribution on the cross section as long as:
  - A linear relationship exists between the stress and the loads
  - The geometry of the member should not undergo significant changes when the loads are applied

Procedure for Analysis

1. Internal Loadings
   - Cut member perpendicular to its axis at the point where the stress is to be determined.
   - Obtain the resultant internal normal force, shear force, bending moment, and torsional moment.
     - Force components act through the centroid of the cross section
     - Moment components are computed about centroidal axes
2. Stress Components
   - Determine the stress component associated with each internal loading
     - Normal Force: $\sigma = \frac{F}{A}$
     - Shear Force: $\tau = \frac{VQ}{It}$
     - Bending Moment: $\sigma = -\frac{My}{I}$
     - Torsional Moment: $\tau = \frac{T\rho}{J}$
3. Superposition
   - Determine the resultant normal and shear stress components and represent using a volume element or stress distribution.

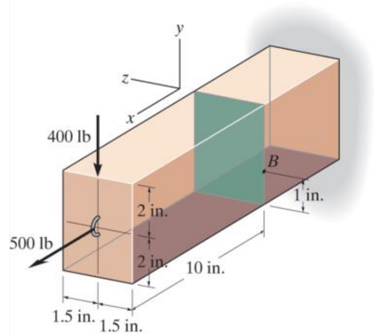
Example 1

- Determine the magnitude of the load P that will cause a maximum normal stress of 30 ksi in the link along section a-a.



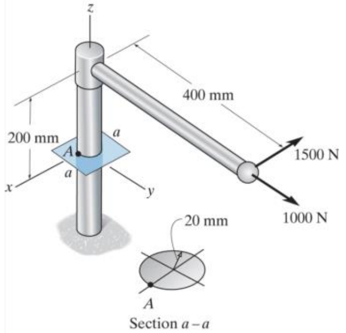
Example 2

- The beam has a rectangular cross section and is subjected to the loading shown. Determine the state of stress at point B. Show the results in a differential element at the point.



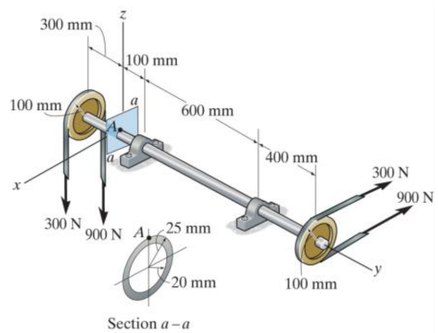
Example 3

- Determine the state of stress at point A on the cross section of the pipe assembly at section a-a. Show the results in a differential element at the point.



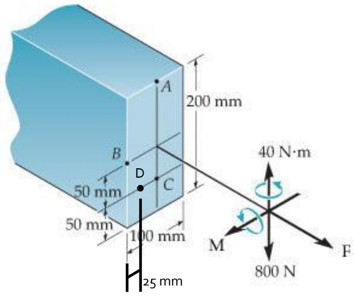
Example 4

- Determine the state of stress at point A on the cross section of the shaft at section a-a. Show the results in a differential element at the point.



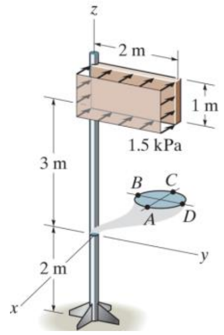
Example 5

- Determine the state of stress at point D on the cross-section shown. The internal loads are shown in the diagram. M is 30 Nm and F is 500 N.



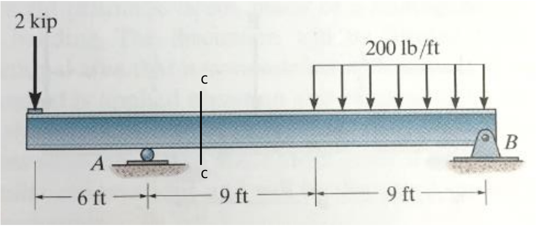
Example 6

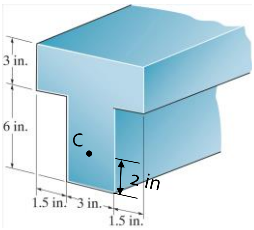
- The sign is subjected to the uniform wind loading. Determine the stress components at points A and B on the 100 mm diameter supporting post. Show the results on a volume element located at each of these points.



Example 7

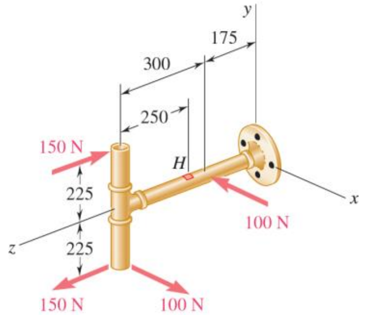
- Determine the state of stress at point C of the cross-section at section c-c. Section c-c is 3 ft from point A and point C is 2 in from the bottom of the cross section. Sketch the results on a volume element.





Example 8

- Several forces are applied to the pipe assembly. Knowing that each section of pipe has inner and outer diameters equal to 36 and 42 mm, respectively, determine the normal and shear stresses at point H located at the top of the outer surface of the pipe.



Dimensions in mm