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# Statics and Strength of Materials

## Course Code: MMEC 341

## Bachelor's Degree

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Major of Production Technology

Riyadh College of Technology

Lecture 3

Basic Concepts in Strength of Materials

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# Outline

Basic Concepts in Strength of Materials:

- Basic Unit Systems
- Relationship Among Mass, Force, and Weight
- The Concept of Stress
- Direct Normal Stress
- Stress Elements for Direct Normal Stresses
- The Concept of Strain
- Direct Shear Stress
- Stress Element for Shear Stresses
- Preferred Sizes and Standard Shapes

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# Basic Unit Systems

The basic quantities for any unit system are length, time, force, mass, temperature, and angle. Table 1–1 lists the units for these quantities in the SI unit system, and Table 1–2 lists the quantities in the U.S. Customary unit system.

- International System of Units, and is abbreviated SI
- The formal name for the U.S. Customary unit system is the English Gravitational Unit System (EGU).

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# Basic Unit Systems

**TABLE 1–1** Basic quantities in the SI metric unit system.

| Quantity | SI unit | Other metric units |
|---|---|---|
| Length | Meter (m) | Millimeter (mm) |
| Time | Second (s) | Minute (min), hour (h) |
| Force | Newton (N) | $kg \cdot m/s^2$ |
| Mass | Kilogram (kg) | $N \cdot s^2/m$ |
| Temperature | Kelvin (K) | Degrees Celsius (°C) |
| Angle | Radian (rad) | Degree (°) |

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# Basic Unit Systems

**TABLE 1–2** Basic quantities in the U.S. Customary unit system.

| Quantity | U.S. Customary unit | Other U.S. units |
|---|---|---|
| Length | Foot (ft) | Inch (in.) |
| Time | Second (s) | Minute (min), hour (h) |
| Force | Pound (lb) | kip[a] |
| Mass | Slug | $lb \cdot s^2/ft$ |
| Temperature | Degrees Fahrenheit (°F) | |
| Angle | Degree (°) | Radian (rad) |

[a] 1.0 kip = 1000 lb. The name is derived from the term "kilopound."

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# Basic Unit Systems

**Prefixes for SI Units.** In the SI system, prefixes should be used to indicate orders of magnitude, thus eliminating digits and providing a convenient substitute for writing powers of 10, as generally preferred for computation. Prefixes representing steps of 1000 are recommended. Those usually encountered in strength of materials are listed in Table 1–3. Table 1–4 shows how computed results should be converted to the use of the standard prefixes for units.

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# Basic Unit Systems

**TABLE 1–3** Prefixes for SI units.

| Prefix | SI symbol | Factor |
|---|---|---|
| Giga | G | $10^9 = 1\ 000\ 000\ 000$ |
| Mega | M | $10^6 = 1\ 000\ 000$ |
| Kilo | k | $10^3 = 1000$ |
| Milli | m | $10^{-3} = 0.001$ |
| Micro | μ | $10^{-6} = 0.000\ 001$ |

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# Basic Unit Systems

**TABLE 1–4** Proper method of reporting computed quantities.

| Computed result | Reported result |
|---|---|
| 0.005 48 m | $5.48 \times 10^{-3}$ m or 5.48 mm |
| 12 750 N | $12.75 \times 10^{3}$ N or 12.75 kN |
| 34 500 kg | $34.5 \times 10^{3}$ kg or 34.5 Mg (megagrams) |

Appendix A–22 gives conversion factors for use in performing conversions, which it is in the end of this lecture pages.

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# Relationship Among Mass, Force, and Weight

Force and mass are separate and distinct quantities. Weight is a special kind of force.

- Mass refers to the amount of the substance in a body.
- Force is a push or pull effort exerted on a body either by an external source or by gravity.
- Weight is the force of gravitational pull on a body.

Mass, force, and weight are related by Newton's law:

Force = Mass ´ Acceleration

We often use the symbols F for force, m for mass, and a for acceleration. Then,

$$F = m \times a \quad or \quad m = \frac{F}{a}$$

# Relationship Among Mass, Force, and Weight

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When the pull of gravity is involved in the calculation of the weight of a mass, a takes the value of g, the acceleration due to gravity. Then, using W for weight,

$$W = m \times \mathrm{g} \quad or \quad m = \frac{W}{\mathrm{g}} \qquad (1\text{-}1)$$

The value for g in the SI system is 9.81 $m/s^2$.

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# Units for Mass, Force, and Weight

Table 1–1 shows the preferred units and some other convenient units for mass and force in the SI unit system. Table 1–2 shows the same for the U.S. unit system and is for reference only in this text. The units for force are also used as the units for weight.

The newton (N) in the SI unit system is named in honor of Sir Isaac Newton, and it represents the amount of force required to give a mass of 1.0 kg an acceleration of 1.0 $m/s^2$. Equivalent units for the newton can be derived as follows using Newton's law with units only:

$$F = m \times a = kg.m/s^2 = \text{Newton}$$

The conversion of weight and mass is illustrated in the following example problems.

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# Example Problem 1

A hoist lifts 425 kg of concrete. Compute the weight of the concrete, that is, the force exerted on the hoist by the concrete.

## Solution

| | |
|---|---|
| Objective | Compute the weight of a mass of concrete. |
| Given | $m = 425$ kg |
| Analysis | $W = m \times g; \quad g = 9.81\ \text{m/s}^2$ |
| Results | $W = 425\ \text{kg} \times 9.81\ \text{m/s}^2 = 4170\ \text{kg} \cdot \text{m/s}^2 = 4170\ \text{N}$ |
| Comment | Thus, 425 kg of concrete weighs 4170 N. |

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# Example Problem 2

A hopper contains 35 kN of coal. Determine its mass.

**Solution**

| | |
|---|---|
| Objective | Compute the mass of a hopper of coal. |
| Given | $W = 35\ \text{kN}$ |
| Analysis | $m = W/g; \quad g = 9.81\ \text{m/s}^2$ |
| Results | $m = 35\,000\ \text{N}/9.81\ \text{m/s}^2 = 3568\ \text{N}\cdot\text{s}^2/\text{m} = 3568\ \text{kg}$ |
| Comment | Thus, 35 kN of coal has a mass of 3568 kg. |

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# Density and Specific Weight

To characterize the mass or weight of a material relative to its volume, we use the terms "density" and "specific weight," defined as follows:

- Density is the amount of mass per unit volume of a material.
- Specific weight is the amount of weight per unit volume of a material.

We will use the Greek letter ρ (rho) as the symbol for density. For specific weight, we will use γ (gamma). The units for density and specific weight are summarized in Table 1–5.

**TABLE 1–5** Density and specific weight units.

| | U.S. customary | SI metric |
|---|---|---|
| Density | $slugs/ft^3$ | $kg/m^3$ |
| Specific weight | $lb/ft^3$ | $N/m^3$ |

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# The Concept of Stress

Understanding the meaning of stress in a load-carrying member, as given in the following definition, is of utmost importance in studying strength of materials.

Stress is the internal resistance offered by a unit area of the material from which a member is made to an externally applied load.

We are concerned with what happens inside a load-carrying member. We must determine the magnitude of force exerted on each unit area of the material. The concept of stress can be expressed mathematically as

$$\text{Stress} = \frac{\text{Force}}{\text{Area}} = \frac{F}{A} \qquad (1\text{-}2)$$

# The Concept of Stress

- In the SI unit system, the standard unit for force is the newton (N) and area is in square meters.
- Thus, the standard unit for stress is the $N/m^2$, given the name pascal and abbreviated as Pa.
- Typical levels of stress in mechanical and structural analysis are several million pascals, so the most convenient unit for stress is the megapascal or MPa.
- In calculating the cross-sectional area of load-carrying members, measurements of dimensions in mm are usually used.
- Then, the stress would be in $N/mm^2$, and it can be shown that this is numerically equal to the unit of MPa.

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# Example Problem 3

Assume that a force of 15 000 N is exerted over a square area 50 mm on a side. The resisting area would be 2500 $mm^2$ and the resulting stress would be

**Solution**

$$\text{Stress} = \frac{\text{Force}}{\text{Area}} = \frac{15\,000\ \text{N}}{2500\ \text{mm}^2} = \frac{6.0\ \text{N}}{\text{mm}^2}$$

Converting this to pascals would produce

$$\text{Stress} = \frac{6.0\ \text{N}}{\text{mm}^2} \times \frac{(1000)^2\ \text{mm}^2}{\text{m}^2} = 6.0 \times 10^6\ \text{N/m}^2 = 6.0\ \text{MPa}$$

In summary, *the unit of N/mm² is identical to the MPa*. Stress in SI units can be reported as

N/$m^2$ or Pascal or Pa

N/$mm^2$ or megapascal or MPa

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# Direct Normal Stress

One of the most fundamental types of stress that exists is the normal stress, indicated by the lowercase Greek letter σ (sigma), in which the stress acts perpendicular, or normal, to the cross section of the load-carrying member. If the stress is also uniform across the resisting area, the stress is called a “direct normal stress.” Normal stresses can be either compressive or tensile, defined as follows:

- A compressive stress is one that tends to crush the material of the load-carrying member and to shorten the member itself.
- A tensile stress is one that tends to stretch the member and pull the material apart.

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# Direct Normal Stress

The equation for direct normal stress follows from the basic definition of stress because the applied force is shared equally across the entire cross section of the member carrying the force. That is,

$$\text{Direct normal stress} = \sigma = \frac{\text{Applied force}}{\text{Area of cross section}} = \frac{F}{A} \qquad (1\text{-}3)$$

The area of the cross section of the load-carrying member is taken perpendicular to the line of action of the force.

An example of a member subjected to compressive stress is shown in Figure 1–9.

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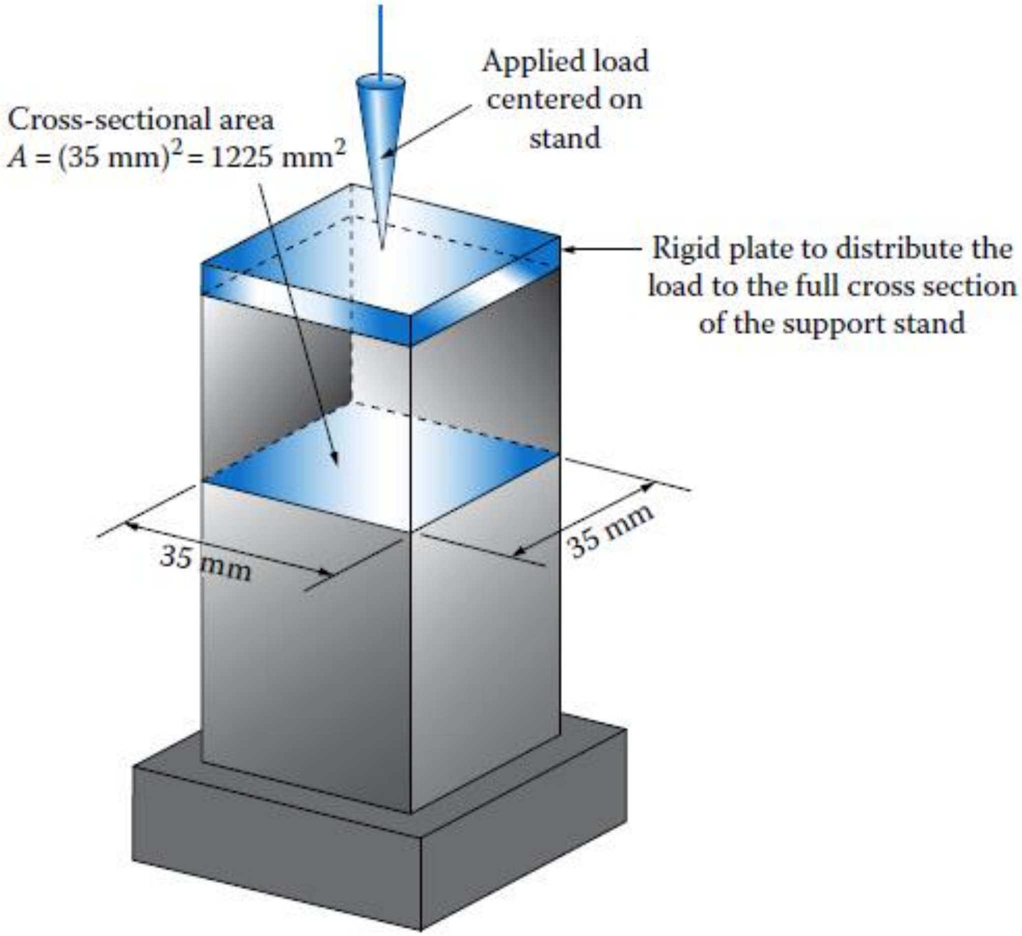
# Direct Normal Stress

**FIGURE 1–9** Example of direct compressive stress.



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# Example Problem 4

Figure 1–9 shows a support stand designed to carry downward loads. Compute the stress in the square shaft at the upper part of the stand for a load of 120 kN. The line of action of the applied load is centered on the axis on the shaft, and the load is applied through a thick plate that distributes the force to the entire cross section of the stand.

## Solution

**Objective** Compute the stress in the upper part of the stand.

**Given** Load = $F$ = 120 kN; load is centered on the stand.
The cross section is square; the dimension of each side is 35 mm.

# Example Problem 4

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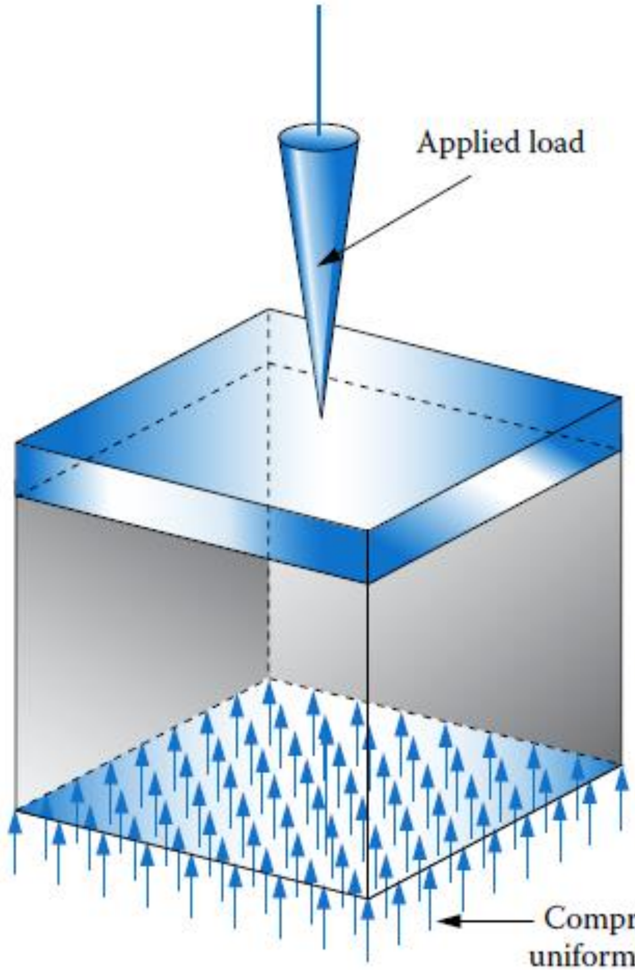
**FIGURE 1–10** Compressive stress on an arbitrary cross section of support stand shaft.




On any cross section of the stand, there must be an internal resisting force that acts upward to balance the downward applied load. The internal force is distributed over the cross sectional area, as shown in Figure 1–10.

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# Solution 4

Results Stress = $\sigma$ = Force/Area = $F/A$ (compressive)

$$F = 120 \text{ kN}$$

$$A = (35 \text{ mm})^2 = 1225 \text{ mm}^2$$

$$\sigma = F/A = 120\,000 \text{ N}/1225 \text{ mm}^2 = 98.0 \text{ N/mm}^2 = 98.0 \text{ MPa}$$

Comment This level of stress would be present at any part of any cross section of the square shaft between its ends.

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# Example Problem 5

Figure 1–3 shows two circular rods carrying a casting weighing 11.2 kN. If each rod is 12.0 mm in diameter and the two rods share the load equally, compute the stress in the rods.

## Solution

| | |
|---|---|
| Objective | Compute the stress in the support rods. |
| Given | Casting weighs 11.2 kN. Each rod carries half the load. |
| | Rod diameter = $D$ = 12.0 mm |
| Analysis | Direct tensile stress is produced in each rod. Use Equation (1–3). |

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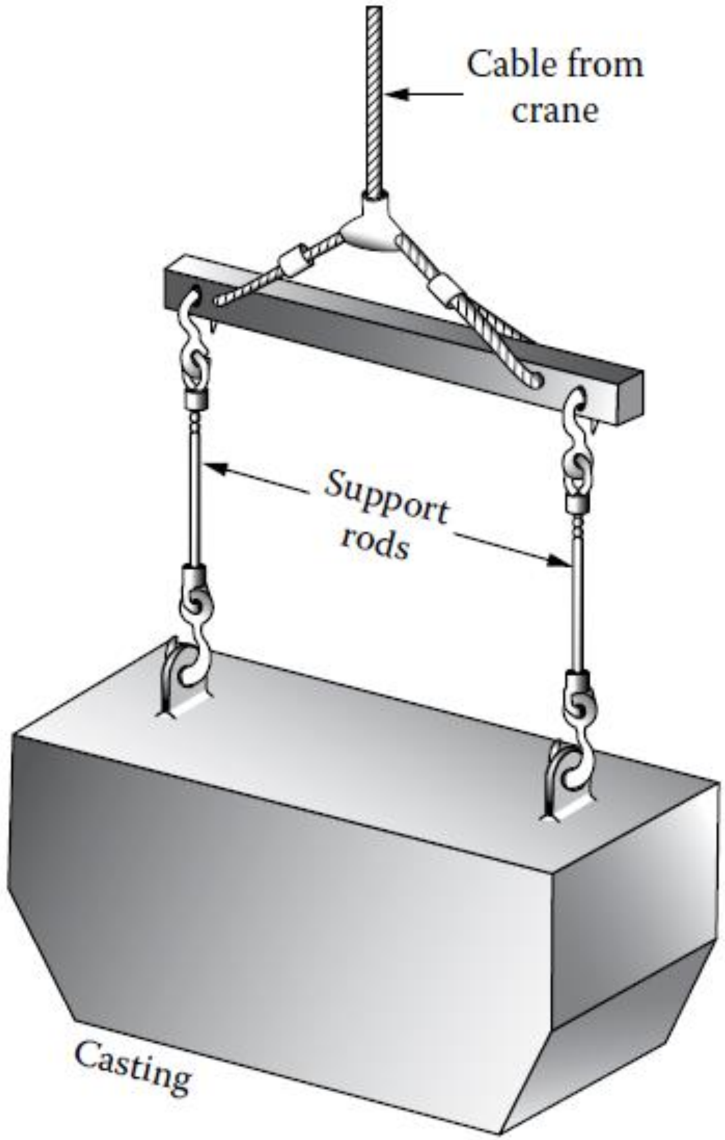
# Example Problem 5

**FIGURE 1–3** Two rods supporting a heavy casting.



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# Example Problem 5

FIGURE 1–11 Tensile stress on an arbitrary cross section of a circular rod.

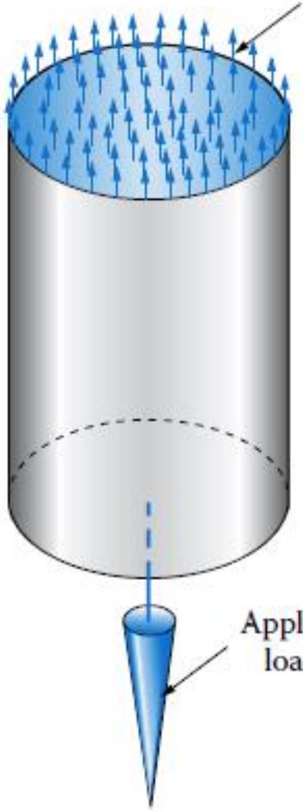


Figure 1–11 shows an arbitrarily selected part of the rod with the applied load on the bottom and the internal tensile stress distributed uniformly over the cut section.

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# Solution 5

Results $F = 11.2\ \text{kN}/2 = 5.60\ \text{kN}$ or $5600\ \text{N}$ on each rod

$$\text{Area} = A = \pi D^2/4 = \pi(12.0\ \text{mm})^2/4 = 113\ \text{mm}^2$$

$$\sigma = F/A = 5600\ \text{N}/113\ \text{mm}^2 = 49.5\ \text{N/mm}^2 = 49.5\ \text{MPa}$$

Comment Figure 1–11 shows an arbitrarily selected part of the rod with the applied load on the bottom and the internal tensile stress distributed uniformly over the cut section.

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# Stress Elements for Direct Normal Stresses

The illustrations of stresses in Figures 1–10 and 1–11 are useful for visualizing the nature of the internal resistance to the externally applied force, particularly for these cases in which the stresses are uniform across the entire cross section.

Consider a small cube of material anywhere inside the square shaft of the support stand shown in Figure 1–9. There must be a net compressive force acting on the top and bottom faces of the cube, tending to crush it, as shown in Figure 1–12(a). If the faces are considered to be unit areas, these forces can be considered to be the stresses acting on the faces of the cube. Such a cube is called a “stress element.” A simple stress element like this one is often shown as a two-dimensional square element rather than the three-dimensional cube, as shown in Figure 1–12(b).

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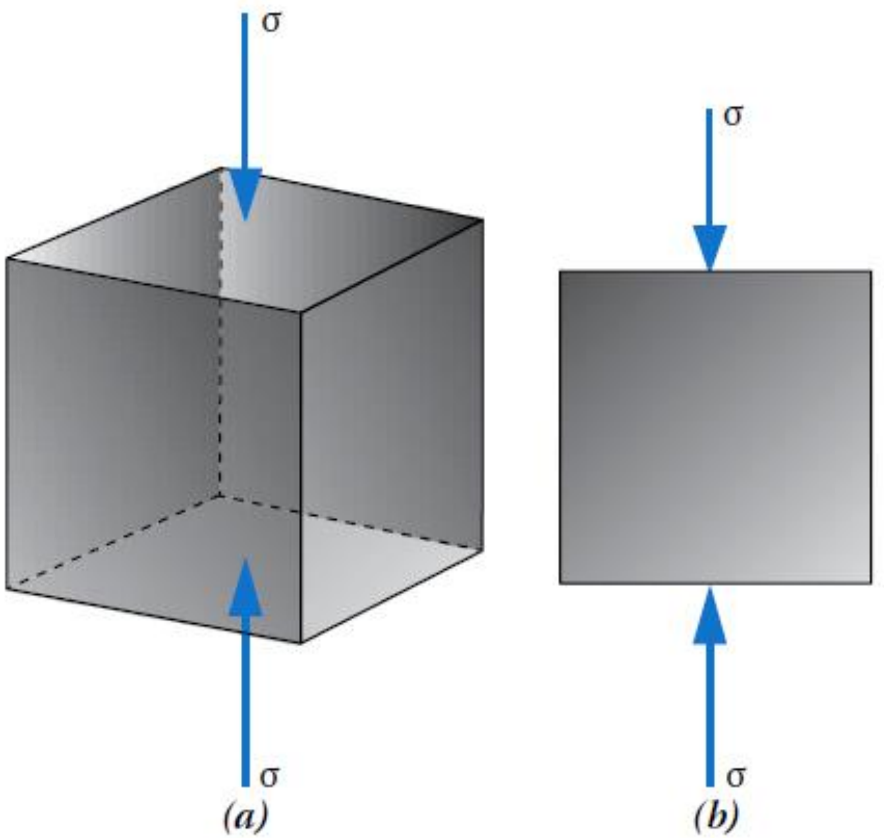
# Stress Elements for Direct Normal Stresses

**FIGURE 1–12** Stress element for compressive stresses: ***(a)*** three-dimensional stress element and ***(b)*** two-dimensional stress element.




Because the element is taken from a body in equilibrium, the element itself is also in equilibrium and the stresses on the top and bottom faces are the same.

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# Stress Elements for Direct Normal Stresses

Similarly, the tensile stress on any element of the rod in Figures 1–3 and 1–11 can be shown as in Figure 1–13 with the stress vector acting outward from the element, tending to pull it apart. Note that either compressive or tensile stresses are shown acting perpendicular (normal) to the surface of the element.

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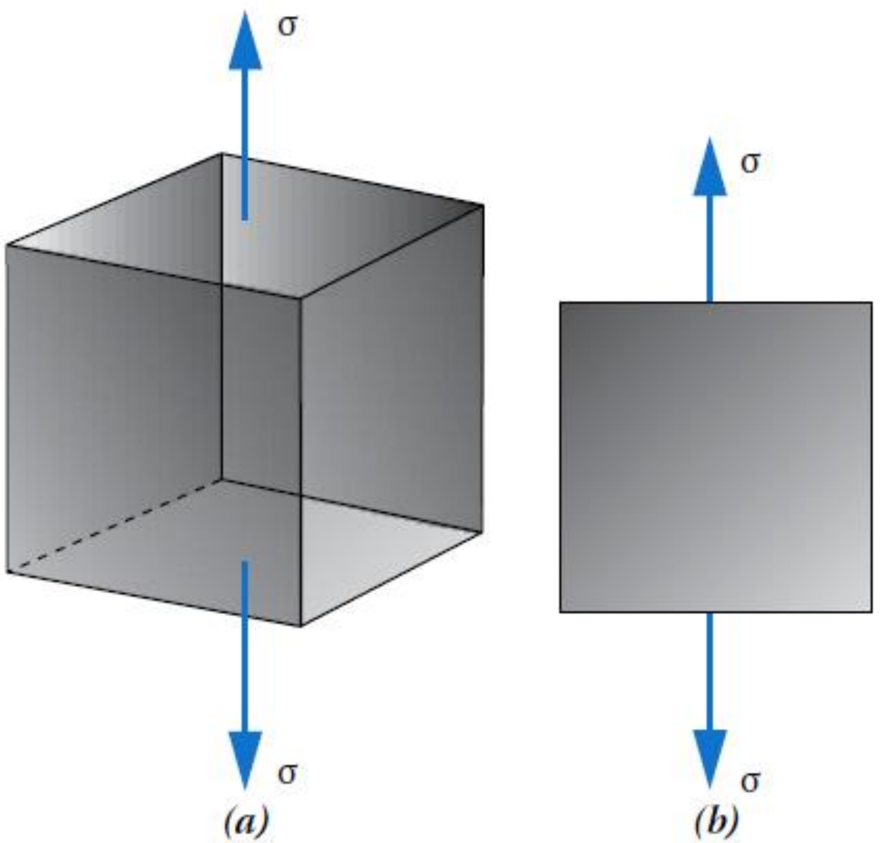
# Stress Elements for Direct Normal Stresses

**FIGURE 1–13** Stress element for tensile stresses: ***(a)*** three-dimensional stress element and ***(b)*** two-dimensional stress element.



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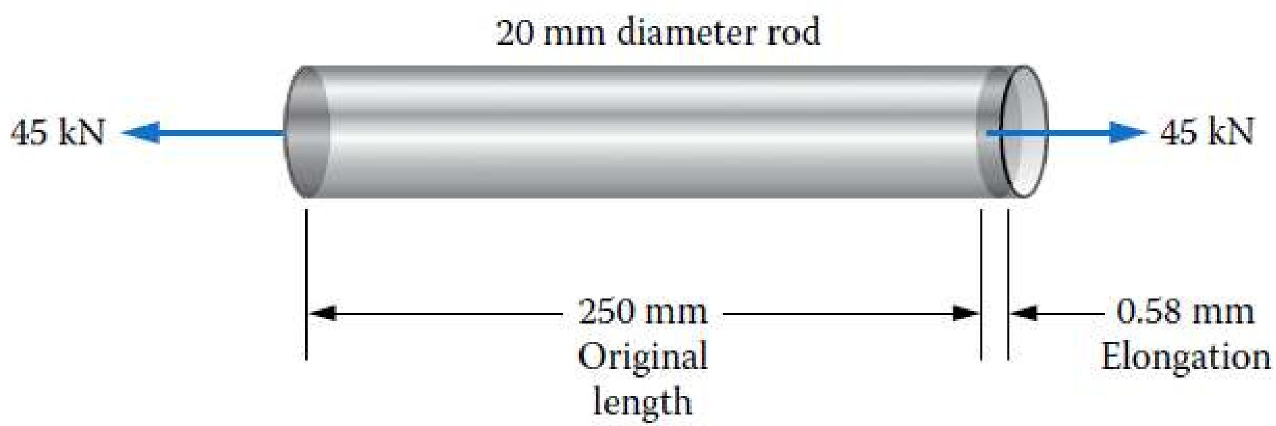
# Concept of Strain

Any load-carrying member deforms under the influence of the load applied. The square shaft of the support stand in Figure 1–9 gets shorter as the heavy equipment is placed on the stand. The rods supporting the casting in Figure 1–3 get longer as the casting is hung onto them.

The total deformation of a load-carrying member can, of course, be measured.

**FIGURE 1–14** Elongation of a bar in tension.



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# Concept of Strain

Figure 1–14 shows an axial tensile force of 45 kN applied to an aluminum bar that has a diameter of 20 mm. Before the load was applied, the length of the bar was 250.00 mm. After the load is applied, the length is 250.58 mm. Thus, the total deformation is 0.58 mm. Strain, also called "unit deformation," is found by dividing the total deformation by the original length of the bar. The lowercase Greek letter epsilon (ε) is used to denote strain:

**Definition of Strain**

$$\text{Strain} = \varepsilon = \frac{\text{Total deformation}}{\text{Original length}} \qquad (1\text{-}4)$$

For the case shown in Figure 1–14,

$$\varepsilon = \frac{0.58\ \text{mm}}{250.00\ \text{mm}} = 0.0023\ \text{mm/mm}$$

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# Concept of Strain

Strain could be said to be dimensionless because the units in the numerator and denominator could be canceled. However, it is better to report the units as mm/mm to maintain the definition of deformation per unit length of the member.

$$\frac{\text{Numerator}}{\text{Denominator}} = \frac{\text{mm}}{\text{mm}}$$

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# Direct Shear Stress

Shear refers to a cutting-like action. When you use common household scissors, often called “shears,” you cause one blade of the pair to slide over the other to cut (shear) paper, cloth, or other material. A sheet metal fabricator uses a similar shearing action when cutting metal for ductwork.

The examples described in this section along with their accompanying figures illustrate several cases where direct shear is produced. That is, the applied shearing force is resisted uniformly by the area of the part in shear, producing a uniform level of shearing force across the entire area being sheared, called As.

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# Direct Shear Stress

The symbol used for shear stress is $\tau$, the lowercase Greek letter tau. Then, the direct shear stress can be computed as

**Direct Shear Stress**

$$\text{Direct shear stress} = \tau = \frac{\text{Applied force}}{\text{Shear area}} = \frac{F}{A_s} \qquad (1\text{-}5)$$

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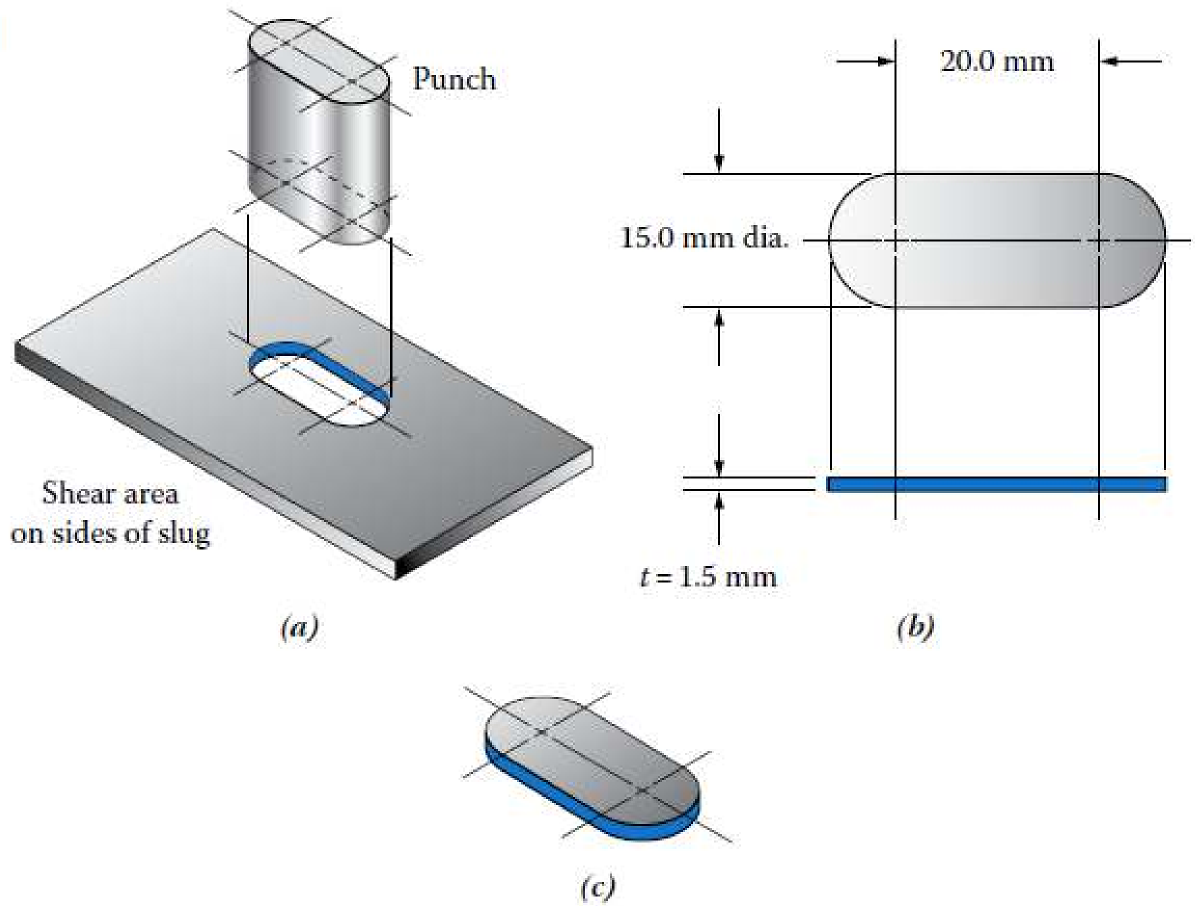
# Direct Shear Stress

**FIGURE 1–15** Illustration of direct shear stress in a punching operation: *(a)* punching operation, *(b)* geometry of slug, and *(c)* slug.



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# Direct Shear Stress

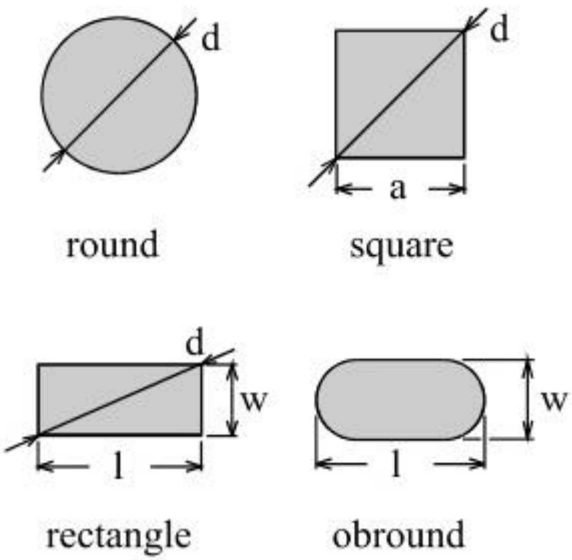
Figure 1–15 shows a punching operation where the objective is to actually cut one part of the material from the other. The punching action produces a slot in the flat sheet metal. The part removed in the operation is sometimes called a "slug." Therefore, the shearing action occurs along the sides of the slug, shown in blue in Figure 1–15. The area in shear for this case is computed by multiplying the length of the perimeter of the cut shape by the thickness of the sheet. That is, for a punching operation,

**Shear Area for Punching**

$$A_s = \text{Perimeter} \times \text{Thickness} = p \times t \qquad (1\text{-}6)$$

# Example Problem 6

For the punching operation shown in Figure 1–15, compute the shear stress in the material if a force of 5500 N is applied through the punch. The thickness of the material is 1.5 mm.




Calculation of the circumference :

Round : $C = \pi * d$

Square : $C = 4 * a$

Rectangle : $C = 2 * l + 2 * w$

Obround : $C = \pi * w + 2 * (l - w)$

# Solution 6

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Objective Compute the shear stress in the material.

Given $F = 5500$ N; shape to be punched shown in Figure 1–15; $t = 1.5$ mm.

Analysis The sides of slug are placed in direct shear resisting the applied force. Use Equations (1–5) and (1–6).

Results The perimeter, $p$, is

$$p = 2(20.0\ \text{mm}) + \pi(15.0\ \text{mm}) = 87.1\ \text{mm}$$

The shear area is

$$A_s = p \times t = (87.1\ \text{mm})(1.5\ \text{mm}) = 130.7\ \text{mm}^2$$

Then, the shear stress is

$$\tau = F/A_s = 5500\ \text{N}/130.7\ \text{mm}^2 = 42.1\ \text{MPa}$$

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# Direct Shear Stress

**Single Shear**. A pin or a rivet is often inserted into a cylindrical hole through mating parts to connect them, as shown in Figure 1–16. When forces are applied perpendicular to the axis of the pin, there is the tendency to cut the pin across its cross section, producing a shear stress. This action is often called “single shear” because a single cross section of the pin resists the applied shearing force. In other words, in this arrangement, a single area of failure would separate the components. The pin is usually designed so the shear stress is below the level that would cause the pin to fail.

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# Direct Shear Stress

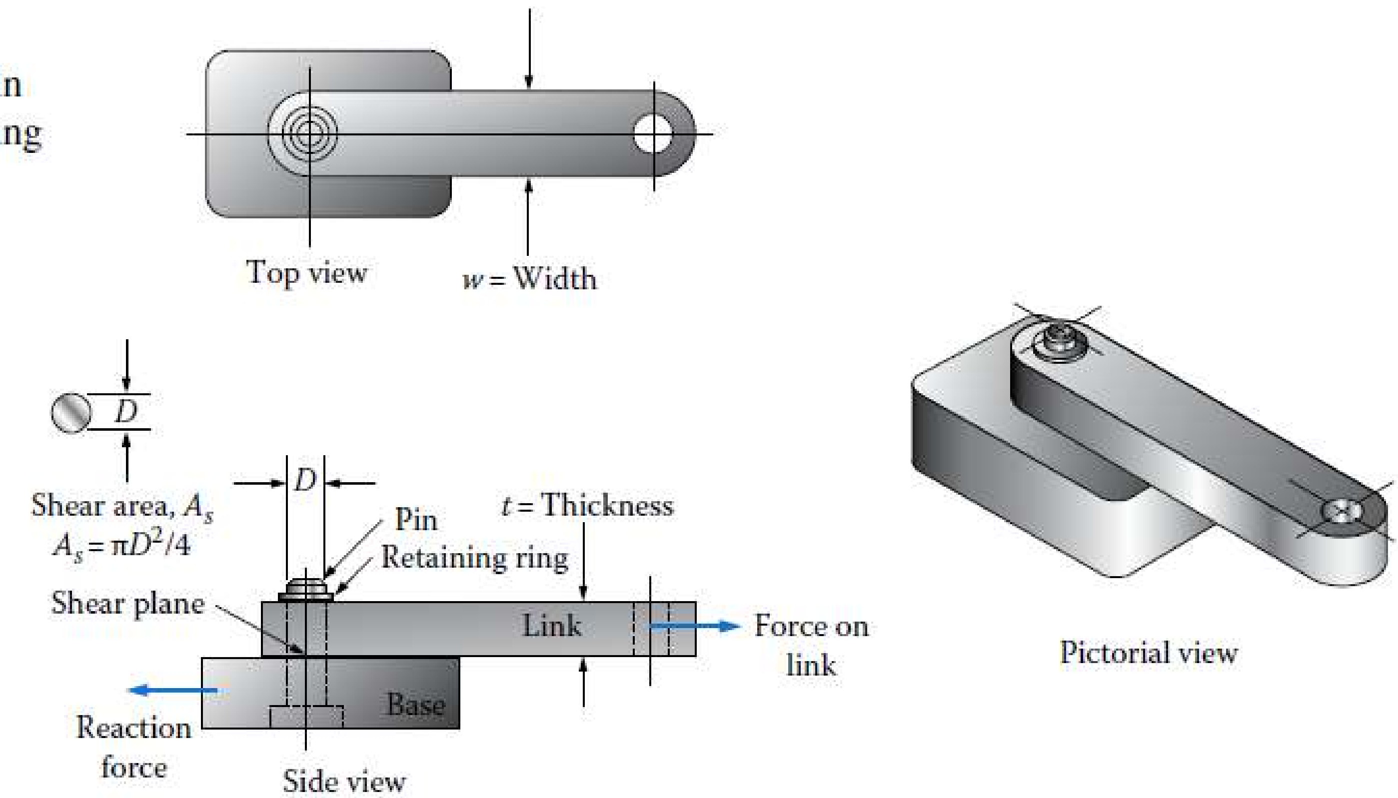


**FIGURE 1–16** Pin connection illustrating single shear.

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# Direct Shear Stress

**Double Shear.** When a pin connection is designed as shown in Figure 1–17, there are two cross sections to resist the applied force. In this arrangement, the pin is in double shear. In this arrangement, there must be two areas of failure to separate the components.

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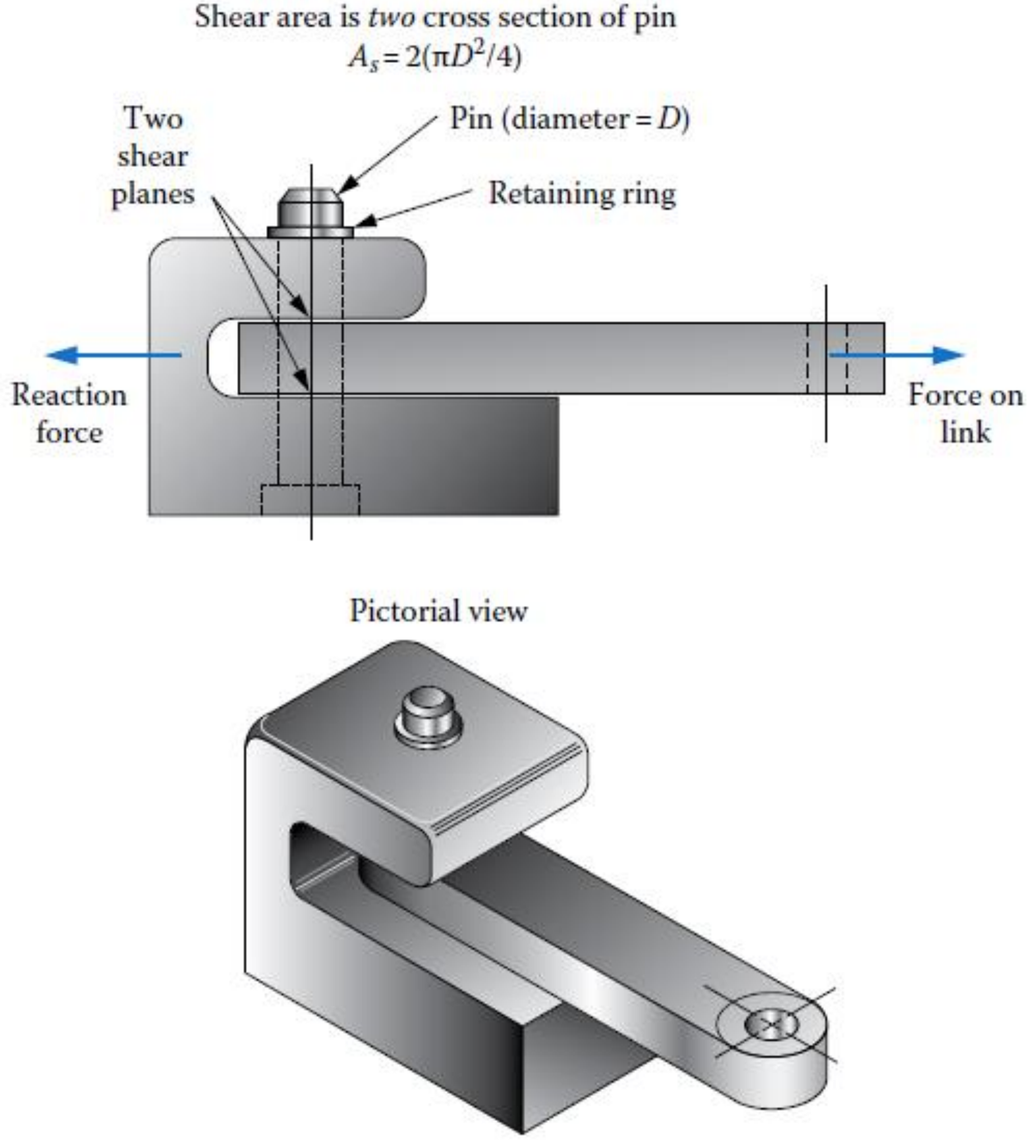
# Direct Shear Stress

**FIGURE 1–17** Pin connection illustrating double shear.

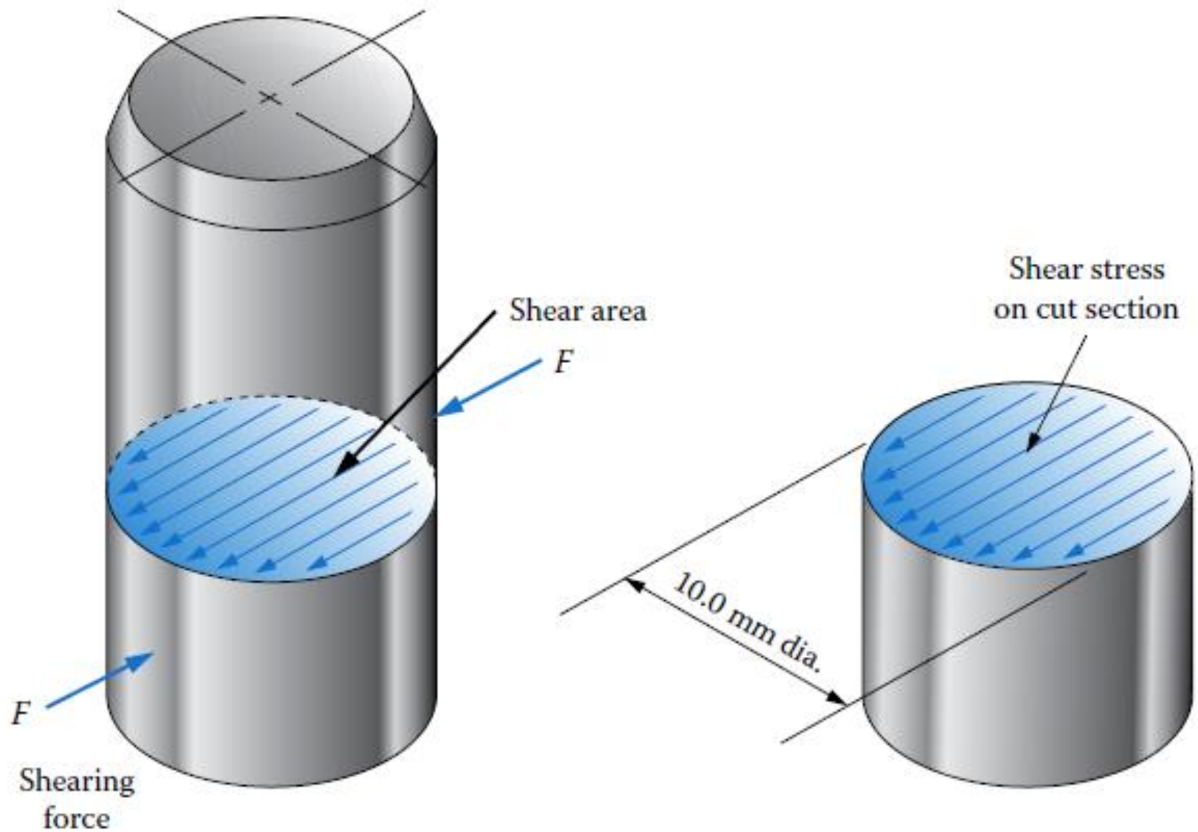


# Example Problem 7

The force on the link in the simple pin joint shown in Figure 1–16 is 3550 N.

If the pin has a diameter of 10.0 mm, compute the shear stress in the pin.

**FIGURE 1–18** Direct shear stress in a pin in single shear.



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# Solution 7

Objective Compute the shear stress in the pin.

Given $F = 3550$ N; $D = 10.0$ mm

Analysis The pin is in direct shear with one cross section of the pin resisting all of the applied force (single shear). Use Equation (1–4).

Results The shear area, $A_s$, is

$$A_s = \frac{\pi D^2}{4} = \frac{\pi(10.0\ \text{mm})^2}{4} = 78.5\ \text{mm}^2$$

Then, the shear stress is

$$\tau = \frac{F}{A_s} = \frac{3550\ \text{N}}{78.5\ \text{mm}^2} = 45.2\ \text{N/mm}^2 = 45.2\ \text{MPa}$$

# Example Problem 8

If the pin joint just analyzed was designed as shown in Figure 1–17, compute the shear stress in the pin.

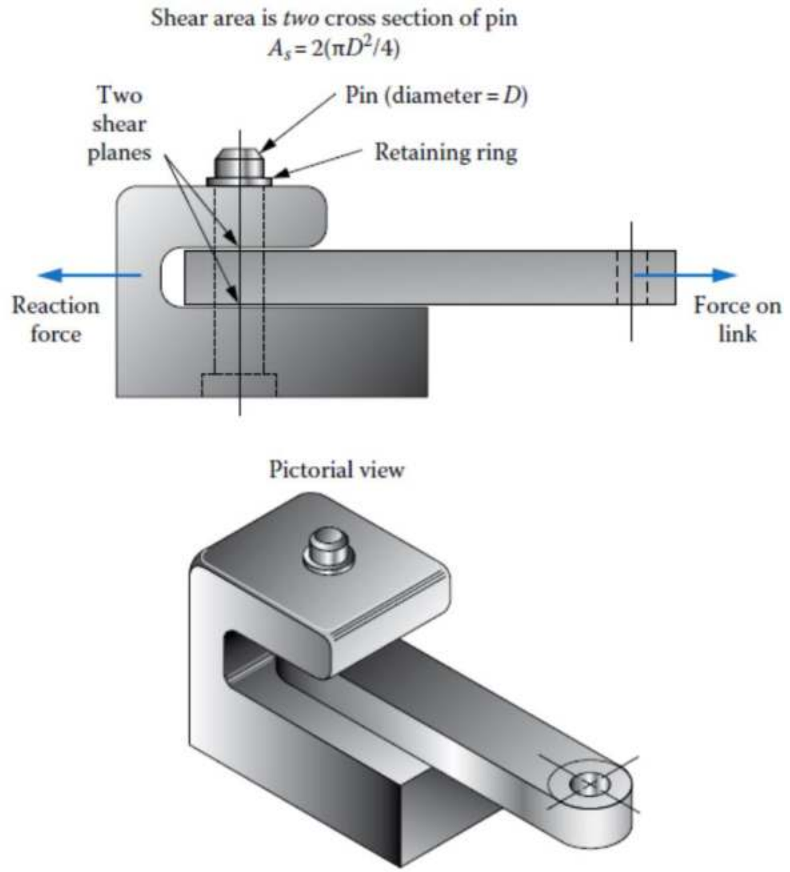


**FIGURE 1–17** Pin connection illustrating double shear.

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# Solution 8

Objective Compute the shear stress in the pin.

Given $F = 3550$ N; $D = 10.0$ mm (same as in Example Problem 1–6)

Analysis The pin is in direct shear with two cross sections of the pin resisting the applied force (double shear). Use Equation (1–4).

Results The shear area, $A_s$, is

$$A_s = 2\left(\frac{\pi D^2}{4}\right) = 2\left[\frac{\pi(10.0\text{ mm})^2}{4}\right] = 157\text{ mm}^2$$

The shear stress in the pin is

$$\tau = \frac{F}{A_s} = \frac{3550\text{ N}}{157\text{ mm}^2} = 22.6\text{ N/mm}^2 = 22.6\text{ MPa}$$

Comment The resulting shear stress is $\frac{1}{2}$ of the value found for single shear.

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# Direct Shear Stress

**Keys.** Figure 1–19 shows an important application of shear in mechanical drives. When a power transmitting element, such as a gear, chain sprocket, or belt pulley, is placed on a shaft, a key is often used to connect the two and permit the transmission of torque from one to the other. The torque produces a tangential force at the interface between the shaft and the inside of the hub of the mating element. The torque is reacted by the moment of the force on the key times the radius of the shaft. That is, $T = F(D/2)$. Then, the force is $F = 2T/D$.

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# Direct Shear Stress

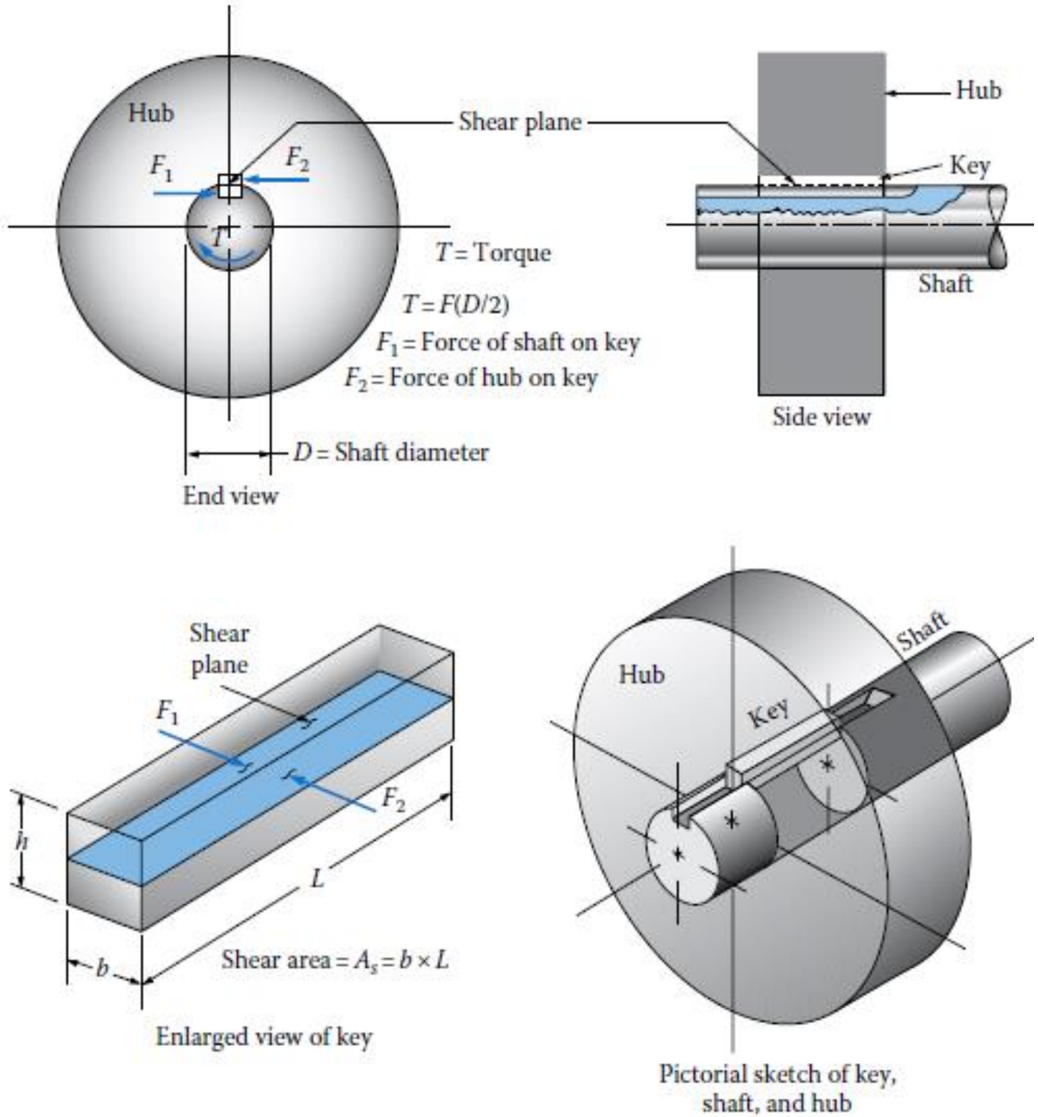


**FIGURE 1–19** Direct shearing action on a key between a shaft and the hub of a gear, pulley, or sprocket in a mechanical drive system.

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# Direct Shear Stress

In Figure 1–19, the force $F_1$ is shown exerted by the shaft on the left side of the key. On the right side, an equal force $F_2$ is the reaction exerted by the hub on the key. This pair of forces tends to cut the key, producing a shear stress. Note that the shear area, $A_s$, is a rectangle with dimensions b × L.

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# Example Problem 9

Figure 1–19 shows a key inserted between a shaft and the mating hub of a gear. If a torque of 170 N·m is transmitted from the shaft to the hub, compute the shear stress in the key. For the dimensions of the key, use L = 20.0 mm; h = b = 6.0 mm. The diameter of the shaft is 30 mm.

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# Solution 9

**Objective** Compute the shear stress in the key.

**Given** $T = 170\ \text{N}\cdot\text{m}$; $D = 30.0$ mm; $L = 20.0$ mm; $h = b = 6.0$ mm.

**Analysis** The key is in direct shear. Use Equation (1–5).

Shear area: $A_s = b \times L = (6.0\ \text{mm})(20.0\ \text{mm}) = 120\ \text{mm}^2$. The force on the key is produced by the action of the applied torque. The torque is reacted by the moment of the force on the key times the radius of the shaft. That is, $T = F(D/2)$. Then, the force is

$$F = 2T/D = (2)(170\ \text{N}\cdot\text{m})/(0.030\ \text{m}) = 11\,333\ \text{N} = 11.333\ \text{kN}$$

Then, the shear stress is

$$\tau = F/A_s = 11\,333\ \text{N}/120\ \text{mm}^2 = 94.4\ \text{MPa}$$

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# Stress Element for Shear Stresses

An infinitesimally small cubic element of the material from the shear plane of any of the examples shown in previous slides would appear as shown in Figure 1–20 with the shear stresses acting parallel to the surfaces of the cube. For example, an element taken from the shear plane of the key in Figure 1–19 would have a shear stress acting toward the left on its top surface. For equilibrium of the element with regard to horizontal forces, there must be an equal stress acting toward the right on the bottom surface. This is the cutting action characteristic of shear.

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# Stress Element for Shear Stresses

But the two stress vectors on the top and bottom surfaces cannot exist alone because the element would tend to rotate under the influence of the couple formed by the two shearing forces acting in opposite directions. To balance that couple, a pair of equal shear stresses is developed on the vertical sides of the stress element, as shown in Figure 1–20(a).

The stress element is often drawn in the two-dimensional form shown in Figure 1–20(b). Note how the stress vectors on adjacent faces tend to meet at the corners. Such stress elements are useful in the visualization of stresses acting at a point within a material subjected to shear.

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# Stress Element for Shear Stresses

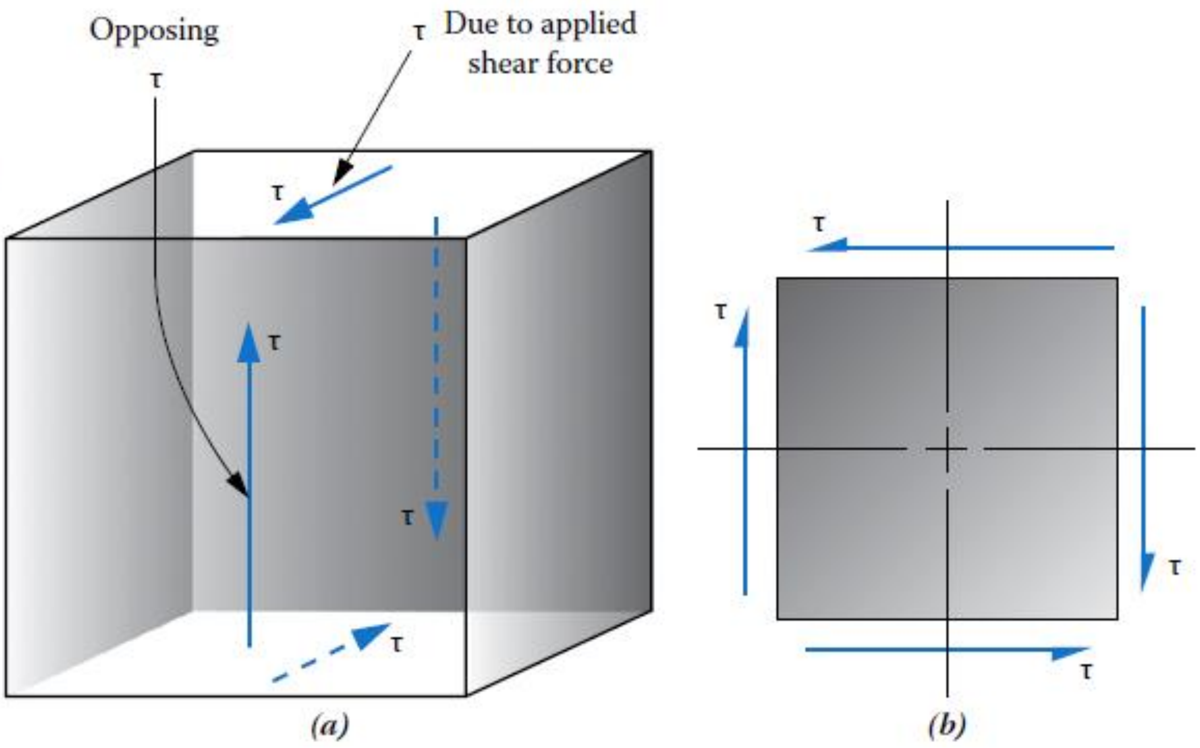


**FIGURE 1–20** Stress element showing shear stress: *(a)* three-dimensional stress element and *(b)* two-dimensional stress element.

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# Preferred Sizes and Standard Shapes

One responsibility of a designer is to specify the final dimensions for load-carrying members. After completing the analyses for stress and deformation (strain), minimum acceptable values for dimensions are known that will ensure that the member will meet performance requirements. The designer then typically specifies the final dimensions to be standard or convenient values that will facilitate the purchase of materials and the manufacture of the parts. This section presents some guides to aid in these decisions.

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# Preferred Sizes and Standard Shapes

**Preferred Basic Sizes.** When the component being designed will be made to the designer's specifications, it is recommended that final dimensions be specified from a set of preferred basic sizes. Appendix A–2 lists such data for metric dimensions and includes U.S. customary standards for reference. Note that dimensions are shown in two colors. The sizes shown in blue are the first choices and should be used if they satisfy the strength and deflection requirements and if they are not unsatisfactorily large. If the smallest acceptable size is in black, it can be selected provided it is available at reasonable cost and delivery time.

# Preferred Sizes and Standard Shapes

**Standard Screw Threads.** Threaded fasteners and machine elements having threaded connections are manufactured according to standard dimensions to ensure interchangeability of parts and to permit convenient manufacture with standard machines and tooling. Appendix A–3 gives dimensions for metric threads. Again, U.S. Customary data are also available for reference. Standard metric thread designations are of the form

$$M10 \times 1.5$$

where M stands for metric
10 is the basic major diameter in mm
1.5 is the pitch between adjacent threads in mm

Thus, the designation shown would denote a metric thread with a basic major diameter of 10.0 mm and a pitch of 1.5 mm.

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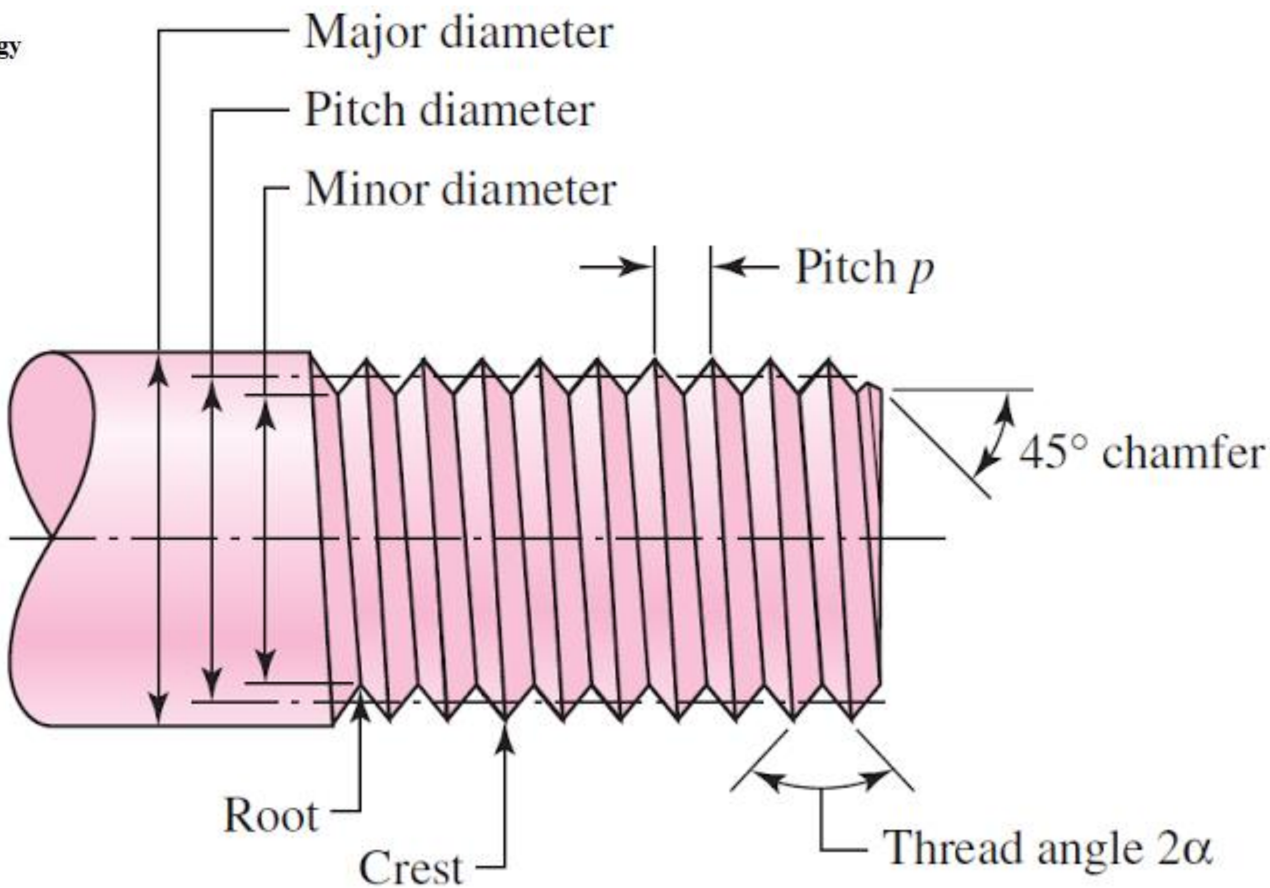
# Preferred Sizes and Standard Shapes




**Terminology of Screw Threads**

## A–2 Preferred basic sizes.

| Fractional (in.) | | | | Decimal (in.) | | | SI metric (mm) | |
|---|---|---|---|---|---|---|---|---|
| $\frac{1}{64}$ | 0.015 625 | 5 | 5.000 | 0.010 | 2.00 | 8.50 | **1.0** | **40** |
| $\frac{1}{32}$ | 0.031 25 | $5\frac{1}{4}$ | 5.250 | 0.012 | 2.20 | 9.00 | 1.1 | 45 |
| $\frac{1}{16}$ | 0.0625 | $5\frac{1}{2}$ | 5.500 | 0.016 | 2.40 | 9.50 | **1.2** | **50** |
| $\frac{3}{32}$ | 0.093 75 | $5\frac{3}{4}$ | 5.750 | 0.020 | 2.60 | 10.00 | 1.4 | 55 |
| $\frac{1}{8}$ | 0.1250 | 6 | 6.000 | 0.025 | 2.80 | 10.50 | **1.6** | **60** |
| $\frac{5}{32}$ | 0.156 25 | $6\frac{1}{2}$ | 6.500 | 0.032 | 3.00 | 11.00 | 1.8 | 70 |
| $\frac{3}{16}$ | 0.1875 | 7 | 7.000 | 0.040 | 3.20 | 11.50 | **2.0** | **80** |
| $\frac{1}{4}$ | 0.2500 | $7\frac{1}{2}$ | 7.500 | 0.05 | 3.40 | 12.00 | 2.2 | 90 |
| $\frac{5}{16}$ | 0.3125 | 8 | 8.000 | 0.06 | 3.60 | 12.50 | **2.5** | **100** |
| $\frac{3}{8}$ | 0.3750 | $8\frac{1}{2}$ | 8.500 | 0.08 | 3.80 | 13.00 | 2.8 | 110 |
| $\frac{7}{16}$ | 0.4375 | 9 | 9.000 | 0.10 | 4.00 | 13.50 | **3.0** | **120** |
| $\frac{1}{2}$ | 0.5000 | $9\frac{1}{2}$ | 9.500 | 0.12 | 4.20 | 14.00 | 3.5 | 140 |
| $\frac{9}{16}$ | 0.5625 | 10 | 10.000 | 0.16 | 4.40 | 14.50 | **4.0** | **160** |
| $\frac{5}{8}$ | 0.6250 | $10\frac{1}{2}$ | 10.500 | 0.20 | 4.60 | 15.00 | 4.5 | 180 |
| $\frac{11}{16}$ | 0.6875 | 11 | 11.000 | 0.24 | 4.80 | 15.50 | **5.0** | **200** |
| $\frac{3}{4}$ | 0.7500 | $11\frac{1}{2}$ | 11.500 | 0.30 | 5.00 | 16.00 | 5.5 | 220 |
| $\frac{7}{8}$ | 0.8750 | 12 | 12.000 | 0.40 | 5.20 | 16.50 | **6** | **250** |
| 1 | 1.000 | $12\frac{1}{2}$ | 12.500 | 0.50 | 5.40 | 17.00 | 7 | 280 |
| $1\frac{1}{4}$ | 1.250 | 13 | 13.000 | 0.60 | 5.60 | 17.50 | **8** | **300** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $1\frac{1}{2}$ | 1.500 | $13\frac{1}{2}$ | 13.500 | 0.80 | 5.80 | 18.00 | 9 | 350 |
| $1\frac{3}{4}$ | 1.750 | 14 | 14.000 | 1.00 | 6.00 | 18.50 | **10** | **400** |
| 2 | 2.000 | $14\frac{1}{2}$ | 14.500 | 1.20 | 6.50 | 19.00 | 11 | 450 |
| $2\frac{1}{4}$ | 2.250 | 15 | 15.000 | 1.40 | 7.00 | 19.50 | **12** | **500** |
| $2\frac{1}{2}$ | 2.500 | $15\frac{1}{2}$ | 15.500 | 1.60 | 7.50 | 20.00 | 14 | 550 |
| $2\frac{3}{4}$ | 2.750 | 16 | 16.000 | 1.80 | 8.00 | | **16** | **600** |
| 3 | 3.000 | $16\frac{1}{2}$ | 16.500 | | | | 18 | 700 |
| $3\frac{1}{4}$ | 3.250 | 17 | 17.000 | | | | **20** | **800** |
| $3\frac{1}{2}$ | 3.500 | $17\frac{1}{2}$ | 17.500 | | | | 22 | 900 |
| $3\frac{3}{4}$ | 3.750 | 18 | 18.000 | | | | **25** | **1000** |
| 4 | 4.000 | $18\frac{1}{2}$ | 18.500 | | | | 28 | |
| $4\frac{1}{4}$ | 4.250 | 19 | 19.000 | | | | **30** | |
| $4\frac{1}{2}$ | 4.500 | $19\frac{1}{2}$ | 19.500 | | | | 35 | |
| $4\frac{3}{4}$ | 4.750 | 20 | 20.000 | | | | | |

*Note:* The sizes highlighted in *blue* are the first choices. Use the sizes in *black* when a smaller increment is needed.

## A–3 Screw threads.

(a) American Standard thread dimensions, numbered sizes

| Size | Basic major diameter, $D$ (in.) | Coarse threads: UNC | | Fine threads: UNF | |
|---|---|---|---|---|---|
| | | Threads per inch, $n$ | Tensile stress area (in.$^2$) | Threads per inch, $n$ | Tensile stress area (in.$^2$) |
| 0 | 0.0600 | — | — | 80 | 0.001 80 |
| 1 | 0.0730 | 64 | 0.002 63 | 72 | 0.002 78 |
| 2 | 0.0860 | 56 | 0.003 70 | 64 | 0.003 94 |
| 3 | 0.0990 | 48 | 0.004 87 | 56 | 0.005 23 |
| 4 | 0.1120 | 40 | 0.006 04 | 48 | 0.006 61 |
| 5 | 0.1250 | 40 | 0.007 96 | 44 | 0.008 30 |
| 6 | 0.1380 | 32 | 0.009 09 | 40 | 0.010 15 |
| 8 | 0.1640 | 32 | 0.0140 | 36 | 0.014 74 |
| 10 | 0.1900 | 24 | 0.0175 | 32 | 0.0200 |
| 12 | 0.2160 | 24 | 0.0242 | 28 | 0.0258 |

(b) American Standard thread dimensions, fractional sizes

| Size | Basic major diameter, $D$ (in.) | Coarse threads: UNC<br>Threads per inch, $n$ | Coarse threads: UNC<br>Tensile stress area (in.$^2$) | Fine threads: UNF<br>Threads per inch, $n$ | Fine threads: UNF<br>Tensile stress area (in.$^2$) |
|---|---|---|---|---|---|
| $\frac{1}{4}$ | 0.2500 | 20 | 0.0318 | 28 | 0.0364 |
| $\frac{5}{16}$ | 0.3125 | 18 | 0.0524 | 24 | 0.0580 |
| $\frac{3}{8}$ | 0.3750 | 16 | 0.0775 | 24 | 0.0878 |
| $\frac{7}{16}$ | 0.4375 | 14 | 0.1063 | 20 | 0.1187 |
| $\frac{1}{2}$ | 0.5000 | 13 | 0.1419 | 20 | 0.1599 |
| $\frac{9}{16}$ | 0.5625 | 12 | 0.182 | 18 | 0.203 |
| $\frac{5}{8}$ | 0.6250 | 11 | 0.226 | 18 | 0.256 |
| $\frac{3}{4}$ | 0.7500 | 10 | 0.334 | 16 | 0.373 |
| $\frac{7}{8}$ | 0.8750 | 9 | 0.462 | 14 | 0.509 |
| 1 | 1.000 | 8 | 0.606 | 12 | 0.663 |
| $1\frac{1}{8}$ | 1.125 | 7 | 0.763 | 12 | 0.856 |
| $1\frac{1}{4}$ | 1.250 | 7 | 0.969 | 12 | 1.073 |
| $1\frac{3}{8}$ | 1.375 | 6 | 1.155 | 12 | 1.315 |
| $1\frac{1}{2}$ | 1.500 | 6 | 1.405 | 12 | 1.581 |
| $1\frac{3}{4}$ | 1.750 | 5 | 1.90 | — | — |
| 2 | 2.000 | | | — | — |

*(Continued)*

## A–3 Screw threads.

(c) Metric thread dimensions

| | Coarse threads: UNC | | Fine threads: UNF | |
|---|---|---|---|---|
| Basic major diameter, $D$ (in.) | Pitch (mm) | Tensile stress area ($mm^2$) | Pitch (mm) | Tensile stress area ($mm^2$) |
| 1.0 | 0.25 | 0.460 | — | — |
| 1.6 | 0.35 | 1.27 | 0.20 | 1.57 |
| 2.0 | 0.40 | 2.07 | 0.25 | 2.45 |
| 2.5 | 0.45 | 3.39 | 0.35 | 3.70 |
| 3 | 0.5 | 5.03 | 0.35 | 5.61 |
| 4 | 0.7 | 8.78 | 0.50 | 9.79 |
| 5 | 0.8 | 14.2 | 0.50 | 16.1 |
| 6 | 1.0 | 20.1 | 0.75 | 22.0 |
| 8 | 1.25 | 36.6 | 1.00 | 39.2 |
| 10 | 1.50 | 58.0 | 1.25 | 61.2 |
| 12 | 1.75 | 84.3 | 1.25 | 92.1 |
| 16 | 2.00 | 157 | 1.5.0 | 167 |
| 20 | 2.5 | 245 | 1.5 | 272 |
| 24 | 3.0 | 353 | 2.0 | 384 |
| 30 | 3.5 | 561 | 2.0 | 621 |
| 36 | 4.0 | 817 | 3.0 | 865 |
| 42 | 4.5 | 1121 | — | — |
| 48 | 5.0 | 1473 | — | — |

Designations for American Standard Unified Screw Threads: UNC, unified coarse threads: UNF, unified fine threads.

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# Appendix A–22

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# Appendix A–22

**A–22** Conversion factors.

**General approach to the application of conversion factors:** Arrange the conversion factor from the table in such a manner that, when multiplied by the given quantity, the original units cancel out, leaving the desired units. Examples follow:

***Example A–22–1.*** Convert a stress of 36 ksi to MPa:

$$\sigma = 36\ \text{ksi} \times \frac{6.895\ \text{MPa}}{\text{ksi}} = 248\ \text{MPa}$$

***Example A–22–2.*** Convert a stress of 1272 MPa to ksi:

$$\sigma = 1272\ \text{MPa} \times \frac{1.0\ \text{ksi}}{6.895\ \text{MPa}} = 184\ \text{ksi}$$

**Mass** Standard SI unit, kilogram (kg); equivalent unit, N · s²/m

$\frac{14.59\ \text{kg}}{\text{slug}}$ $\frac{32.174\ \text{lb}_m}{\text{slug}}$ $\frac{2.205\ \text{lb}_m}{\text{kg}}$ $\frac{453.6\ \text{g}}{\text{lb}_m}$ $\frac{2000\ \text{lb}_m}{\text{ton}_m}$ $\frac{1000\ \text{kg}}{\text{metric ton}_m}$

**Force** Standard SI unit, newton (N); equivalent unit, kg · m/s²

$\frac{4.448\ \text{N}}{\text{lb}_f}$ $\frac{10^5\ \text{dynes}}{\text{N}}$ $\frac{4.448 \times 10^5\ \text{dynes}}{\text{lb}_f}$ $\frac{224.8\ \text{lb}_f}{\text{kN}}$ $\frac{1000\ \text{lb}}{\text{K}}$

**Length**

$\frac{3.281\ \text{ft}}{\text{m}}$ $\frac{39.37\ \text{in.}}{\text{m}}$ $\frac{12\ \text{in.}}{\text{ft}}$ $\frac{25.4\ \text{mm}}{\text{in.}}$ $\frac{1.609\ \text{km}}{\text{mi}}$ $\frac{5280\ \text{ft}}{\text{mi}}$

**Area**

$\frac{144\ \text{in.}^2}{\text{ft}^2}$ $\frac{10.76\ \text{ft}^2}{\text{m}^2}$ $\frac{645.2\ \text{mm}^2}{\text{in.}^2}$ $\frac{10^6\ \text{mm}^2}{\text{m}^2}$ $\frac{43\,560\ \text{ft}^2}{\text{acre}}$ $\frac{10^4\ \text{m}^2}{\text{ha}}$

**Volume**

$\frac{1728\ \text{in.}^3}{\text{ft}^3}$ $\frac{231\ \text{in.}^3}{\text{gal}}$ $\frac{7.48\ \text{gal}}{\text{ft}^3}$ $\frac{264\ \text{gal}}{\text{m}^3}$ $\frac{3.785\ \text{L}}{\text{gal}}$ $\frac{35.3\ \text{ft}^3}{\text{m}^3}$

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# Appendix A–22

**Section modulus**

$\frac{1.639\times10^4\ \text{mm}^3}{\text{in.}^3}$ $\frac{10^9\ \text{mm}^3}{\text{m}^3}$

**Moment of inertia or second moment of an area**

$\frac{4.162\times10^5\ \text{mm}^4}{\text{in.}^4}$ $\frac{10^{12}\ \text{mm}^4}{\text{m}^4}$

**Density (mass/unit volume)**

$\frac{515.4\ \text{kg/m}^3}{\text{slug/ft}^3}$ $\frac{1000\ \text{kg/m}^3}{\text{g/cm}^3}$ $\frac{32.17\ \text{lb}_m/\text{ft}^3}{\text{slug/ft}^3}$ $\frac{16.018\ \text{kg/m}^3}{\text{lb}_m/\text{ft}^3}$

**Specific weight (weight/unit volume)**

$\frac{157.1\ \text{N/m}^3}{\text{lb}_f/\text{ft}^3}$ $\frac{1728\ \text{lb/ft}^3}{\text{lb/in.}^3}$

**Bending moment or torque**

$\frac{8.851\ \text{lb}\cdot\text{in.}}{\text{N}\cdot\text{m}}$ $\frac{1.356\ \text{N}\cdot\text{m}}{\text{lb}\cdot\text{ft}}$

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# Appendix A–22

**A–22** Conversion factors.

| | | | | | |
|---|---|---|---|---|---|
| **Pressure, stress, or loading** Standard SI unit, pascal (Pa); equivalent units, $N/m^2$ or $kg/m \cdot s^2$ | | | | | |
| $\frac{144\ lb/ft^2}{lb/in.^2}$ | $\frac{47.88\ Pa}{lb/ft^2}$ | $\frac{6895\ Pa}{lb/in.^2}$ | $\frac{1\ Pa}{N/m^2}$ | $\frac{6.895\ MPa}{ksi}$ | |
| **Energy** Standard SI unit, joule (J); equivalent units, $N \cdot m$ or $kg \cdot m^2/s^2$ | | | | | |
| $\frac{1.356\ J}{lb \cdot ft}$ | $\frac{1.0\ J}{N \cdot m}$ | $\frac{8.85\ lb \cdot in.}{J}$ | $\frac{1.055\ kJ}{Btu}$ | $\frac{3.600\ kJ}{W \cdot h}$ | $\frac{778\ ft \cdot lb}{Btu}$ |
| **Power** Standard SI unit, watt (W); equivalent unit, J/s or $N \cdot m/s$ | | | | | |
| $\frac{745.7\ W}{hp}$ | $\frac{1.0\ W}{N \cdot m/s}$ | $\frac{550\ lb \cdot ft/s}{hp}$ | $\frac{1.356\ W}{lb \cdot ft/s}$ | $\frac{3.412\ Btu/h}{W}$ | $\frac{1.341\ hp}{kW}$ |