Engineering Structures and Materials

- Mechanics of materials is a branch of applied mechanics that deals with the behavior of solid bodies subjected to various types of loading.
- A thorough understanding of mechanical behavior is essential for the safe design of all structures.
- Mechanics of materials is a basic subject in many engineering fields.

Mechanics of Material
Earthquakes

The 2017 Central Mexico earthquake struck at 13:14 on September 19, 2017 with a magnitude estimated to be Mw 7.1 and strong shaking for about 20 seconds.

Mechanics of Material
Space Shuttle Columbia

The Space Shuttle Columbia disaster occurred on February 1, 2003, when the Space Shuttle Columbia disintegrated over Texas during re-entry into the Earth's atmosphere.

Mechanics of Material
Space Shuttle Columbia

The loss of Columbia was a result of damage sustained during launch when a piece of foam insulation the size of a small briefcase broke off the Space Shuttle external. The debris struck the leading edge of the left wing, damaging the Shuttle's thermal protection system.

Mechanics of Material
I-35W Mississippi River Bridge

The I-35W Mississippi River bridge catastrophically failed during the evening rush hour on August 1, 2007, collapsing to the river and riverbanks beneath.
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Mechanics of Material

Collapse of Can Tho Bridge

On September 26, 2007 a 90 meter section of an approach ramp, which was over 30 meters above the ground, collapsed – possible due to rains weaken the foundation.

Engineering Structures and Materials

Leonardo da Vinci (1452–1519)

Galileo Galilei (1564–1642)

performed experiments to determine the strength of wires, bars, and beams.

Leonhard Euler (1707–1783)

Developed the mathematical theory of columns and calculated the theoretical critical load of a column in 1744, long before any experimental evidence existed to show the significance of his results.

Engineering Structures and Materials

Numerical problems require that you work with specific units of measurements.

The two accepted standards of measurement are the International System of Units (SI) and the U.S. Customary System (USCS).

As you know significant digits are very important in engineering.

In our work in this section, three significant digits provides enough accuracy.
Stress and Strain

- The fundamental concepts of **stress** and **strain** can be illustrated by considering a prismatic bar that is loaded by axial forces $P$ at the ends.

- A *prismatic bar* is a straight structural member having constant cross section throughout its length.

- In this illustration, the axial forces produce a uniform stretching of the bar; hence, the bar is said to be in **tension**.

Stress

- The tensile load $P$ acts at the bottom end of the bar.

- At the top of the bar are forces representing the action of the removed part of the bar.

- The intensity of force (that is, the force per unit area) is called the **stress** (commonly denoted by the Greek letter $\sigma$).

\[ \sigma = \frac{P}{A} \]

- The stress acting perpendicular to the cut surface, it is referred to as a **normal stress**.

- The equation $\sigma = P/A$ will give the average normal stress.

Stress

- **Sign convention** for normal stresses is:
  - $+$ for tensile stresses and
  - $-$ for compressive stresses.

- Because the normal stress $\sigma$ is obtained by dividing the axial force by the cross-sectional area, it has **units of force per unit of area**.
Stress

- **In SI units:**
  Force is expressed in newtons (N) and area in square meters (m²). A N/m² is a pascals (Pa).

- **In USCS units:**
  Stress is customarily expressed in pounds per square inch (psi) or kips per square inch (ksi).
  
  7,000 Pa to make 1 psi

Normal Strain

- The change in length is denoted by the Greek letter \( \delta \) (delta).

- An axially loaded bar undergoes a change in length, becoming longer when in tension and shorter when in compression.

- The concept of elongation per unit length, or strain, denoted by the Greek letter \( \varepsilon \) (epsilon) and given by the equation
  
  \[ \varepsilon = \frac{\delta}{L} \]

Normal Strain

- If the bar is in tension, the strain is called a **tensile strain**
- If the bar is in compression, the strain is called a **compressive strain**
- Tensile strain is taken as positive (+), and compressive strain as negative (-).

Normal Strain

- The strain \( \varepsilon \) is called a **normal strain** because it is associated with normal stresses.
- Because normal strain \( \varepsilon \) is the ratio of two lengths, it is a **dimensionless quantity**; that is, it has no units.

Example

Consider a steel bar having length \( L \) of 2.0 m. When loaded in tension, the bar might elongate by an amount \( \delta \) equal to 1.4 mm.

\[
\varepsilon = \frac{\delta}{L} = \frac{1.4 \times 10^{-3} \text{ m}}{2.0 \text{ m}} = \frac{0.00070}{1} = 0.00070 = 7.0 \times 10^{-4}
\]

The resulting state of stress and strain is called **uniaxial stress and strain**.
Example

A prismatic bar with a circular cross section is subjected to an axial tensile force. The measured elongation is $\delta = 1.5$ mm. Calculate the tensile stress and strain in the bar.

The resulting state of stress and strain is called **uniaxial stress and strain**.
Group Problem 3
A bar has 2 in.\(^2\) cross-sectional area; if the allowable stress at failure for the material is 25,000 psi, what is the maximum forced the bar would support?

Group Problem 4
If a bar elongates 2.5 in. and the original length is 10.0 ft., what is the strain?

Group Problem 5
If the bar fails at strains greater than 0.15 and the original length of the bar is \(L = 10\) ft., what is the maximum allowable deformation before failure?

Stress–Strain Diagrams
- The mechanical properties of materials are determined by tests performed on small specimens of the material.
- In order that test results may be compared easily, the dimensions of test specimens and the methods of applying loads have been standardized.

Tension Test
- The axial stress \(\sigma\) in the test specimen is calculated by dividing the load \(P\) by the cross-sectional area \(A\).
- Strain in the bar is found from the measured elongation \(\delta\) between the gage marks by dividing \(\delta\) by the gage length \(L\).

Developing a Stress–Strain Diagram
- After performing a tension or compression test and determining the stress and strain at various magnitudes of the load, we can plot a diagram of stress versus strain.
- Stress–strain diagrams were originated by: Jacob Bernoulli (1654–1705) and J. V. Poncelet (1788–1867).
Developing a Stress–Strain Diagram

Stress–Strain for Steel

- The first material we will discuss is: **structural steel**
- A stress–strain diagram for a typical structural steel in tension is shown:

Stress–Strain for Steel

![Stress–Strain for Steel](image)

Stress–Strain for Aluminum

![Stress–Strain for Aluminum](image)

Stress–Strain for Rubber

![Stress–Strain for Rubber](image)

Linear Elasticity

- When a material returns to its original dimensions after unloading, it is called **elastic**
- When a material behaves elastically and also exhibits a linear relationship between stress and strain, it is said to be **linearly elastic**.
### Linear Elasticity

The linear relationship between stress and strain for a bar in simple tension or compression can be expressed by the equation:

$$\sigma = E \varepsilon$$

where $E$ is a constant known as the **modulus of elasticity** (units are either psi or Pa).

### Hooke’s Law

The equation $\sigma = E \varepsilon$ commonly known as **Hooke's law**

- For the famous English scientist Robert Hooke (1635–1703).
- Hooke was the first person to investigate the elastic properties of materials, and he tested such diverse materials as metal, wood, stone, bones, and sinews.
- He measured the stretching of long wires supporting weights and observed that the elongations “always bear the same proportions one to the other that the weights do that make them”

### Linear Elasticity

If the material in the bar is considered linear-elastic and the tensile stress is 25,000 psi and the tensile strain is 0.005, what is the modulus of elasticity of the material?

$$E = \frac{\sigma}{\varepsilon} = \frac{25,000}{0.005} = 5,000,000 \text{ psi} = 5 \times 10^6 \text{ psi}$$

### Group Problem 6

- Determine the cross-sectional area of a 100-ft. steel cable supporting a 20,000 lb. tensile force while not exceeding an allowable tensile stress of 50,000 psi or a maximum elongation of 0.050 ft. Assume the modulus of elasticity of steel is $E = 29,000,000$ psi (assume all values are “exact” measurements).
Materials that undergo large strains before failure are classified as **ductile**.

Ductile materials include mild steel, aluminum and some of its alloys, copper, magnesium, lead, molybdenum, nickel, brass, bronze, nylon, teflon, and many others.

Materials that fail in tension at relatively low values of strain are classified as **brittle** materials.

Examples are concrete, stone, cast iron, glass, ceramic materials, and many common metallic alloys.

Ordinary **glass** is a nearly ideal brittle material.

Compression tests of metals are customarily made on small specimens in the shape of cubes or circular cylinders.

Concrete is tested in compression on every important construction project to ensure that the required strengths have been obtained.

The standard ASTM concrete test specimen is 6 in. in diameter, 12 in. long, and 28 days old (the age of concrete is important because concrete gains strength as it cures).

However, when yielding begins, the behavior is quite different. Consider compression of copper.

The stress–strain diagrams described in the preceding section illustrate the behavior of various materials as they are **loaded** statically in tension or compression.

Now let us consider what happens when the load is slowly removed, and the material is **unloaded**.
Plasticity

- Now let us suppose that we load this same material to a much higher level
- If the loading is too great a residual strain, or permanent strain, remains in the material
- The corresponding residual elongation of the bar is called the permanent set. The material is said to be partially elastic

Creep

- Development of additional strains over long periods of time and are said to creep

Relaxation

End of Mechanics of Materials

Any Questions?