Optional Extra Credit (Dec 6)

Group Project: 1-4 people (can do alone if you want but graded by the same rubric, incentive to have to work on your groupwork skills)

Graded based upon in-class presentation You are to pick some movie scene where you question whether the scene could physically happen. You should do calculations based on what we learned in class to analyze if the movie did it correctly.

Section 9.10





What does it take to change the shape or volume of a solid? **An external force**

Solid

Holds Shape

Fixed Volume

Like a spring, the shape of an object will return if a small force is applied.

Large forces might break/deform object



Cat head

Solids

Like a spring, the shape of an object will return if a small force is applied.

Stress is force per unit area causing a deformation (change in length/shape/volume).

Stress = Force / Contact Area

Strain is a measure of the <u>amount</u> it's deformed when a force is applied.

Why We Care About Strain



Ex: roads, airplane wings, medical inserts, building materials, etc.









Performance for the controversial metal-on-metal (MoM) hip replacement devices continues to create cause for concern, particularly in women, according to this year's National Joint Registry (NJR) Annual Report, UK.

Revision rates (how likely it is that a patient will need an operation to remove and usually replace a prosthesis) for the



Vital applications in understanding how biological tissues and materials respond to forces.

Bone Mechanics and Fracture Healing: Bone is a living material that constantly remodels in response to mechanical stresses and strains. The concept of stress and strain helps explain how bones adapt to forces over time (Wolff's law) and why they break when subjected to excessive force (just like springs). This knowledge aids in designing effective treatments for fractures and in creating orthopedic implants. **Tissue Engineering and Scaffold Design**: Engineering scaffolds for growing tissues requires understanding the stress and strain responses of both the scaffold material and the cells it supports. Biomedical engineers design scaffolds with specific mechanical properties to mimic natural tissue, ensuring that cells experience stresses similar to those in a natural environment, which promotes proper growth.

Cardiovascular Health and Aneurysm Risk: Blood vessels are constantly under stress from blood pressure, and understanding strain in the vessel walls is crucial for predicting conditions like aneurysms. The relationship between stress, strain, and elasticity in blood vessel walls helps in the development of treatments and monitoring tools for hypertension, arteriosclerosis, and other cardiovascular issues. **Design of Prosthetics and Implants**: For joint replacements, dental implants, and prosthetics, engineers must select materials and shapes that withstand the stress and strain of regular body

movements. For example, the design of knee replacements considers the distribution of stress and strain to minimize wear and mimic the natural movement.

Soft Tissue Biomechanics: Ligaments, tendons, and muscles experience different types of strain depending on movement and load. Understanding these properties is critical for injury prevention, physical rehabilitation, and sports medicine. It also guides the design of artificial replacements, such as synthetic ligaments.

Skin Mechanics and Wound Healing: Skin elasticity and strain distribution influence how it responds to wounds, sutures, and grafts. Stress and strain analysis can help in designing better wound closures and in developing synthetic skin or skin graft materials that integrate well with natural tissue.

Orthodontics and Dental Mechanics: In orthodontics, applying controlled stress to teeth over time allows for gradual movement within the jaw bone (orthodontic remodeling). Stress and strain also guide the design of dental implants, which must handle the forces exerted during chewing.

What can happen to the dimensions of an object when you put stress on it?



Elasticity in Length **Fixed wall** Pushing atoms closer together $TensileStress = \frac{F}{A} = Y \frac{\Delta L}{L_o}$ $TensileStrain = \frac{\Delta L}{L_o}$ $1Pa = 1N / m^2$ Y = Young's Modulus $\Delta L = L_f - L_o$ A material with a large Y is difficult to stretch or compress. What must be the units of Y?



Example Problem

The total cross-sectional area of the calcified portion of the two forearm bones is approximately 2.4 cm². During a car crash, the forearm is slammed against the dashboard. The arm comes to rest from an initial speed of 80 km/h in 5.0 ms. If the arm has an effective mass of 3.0 kg, what is the compressional stress that the arm withstands during the crash?

$$a = \frac{\Delta v}{\Delta t}$$
 $Stress = \frac{F}{A} = \frac{ma}{A}$





Elasticity in Shape Bending or breaking bonds The volume stays the same in this type of stress. (e.g., punching out a hole in paper or wall)

In shear stress, the applied force is parallel to the cross-sectional area. (In tensile stress, the force is \perp to **CS** area.)

What is the **shear** cross-sectional area of the missing paper? A. πr^2 B. $\pi r^2 t$ ShearStress = $\frac{F}{A_{CS}} = S \frac{\Delta x}{h}$ Q117 C. $2\pi r$ D. $2\pi r t$ A_{CS} A_{CS} h Q117 ShearStrain = $\frac{\Delta x}{h}$

A material with a large shear modulus *S* is difficult to bend. ickness



Volume Elasticity

The shape stays the same.

The bulk modulus characterizes how easy it is to uniformly squeeze a material in all directions. (For example, if you put the material deep in the ocean.)

VolumeStress =
$$\Delta P = -B \frac{\Delta V}{V_o}$$

 $B = BulkModulus$

Notice the negative sign. Makes sense: Increasing the pressure on an object, decreases it volume and vice versa.





Industry found that it could improve electron travel in transistors by straining (essentially squeezing) silicon.

Strain can allow quicker, more efficient transfer of electrons.



This is just a quick taste of Materials Science, the field where scientists learn how to make stronger armor, faster computers, more energy-efficient batteries, flexible solar cells, crash-safe vehicles, space stations that can withstand cosmic rays, and much more!





Superhero Punching

(Tricky. I won't be this mean on a quiz.)



Cross section ~ 100 cm²

Superheroes sometimes punch holes through steel walls. If the ultimate shear strength of steel is 2.50 x 10⁸ Pa, what force is required to punch through a steel plate 2.0 cm thick (t)? Assume the superhero's fist has a cross-sectional area of 100 cm² and is approximately circular.

What is the **shear** cross-sectional area of the missing steel? A. πr^2 B. $2\pi r^2$

C. 2πr D. $2\pi rt$ Q129





Superhero Punching



Superheroes sometimes punch holes through steel walls. If the ultimate shear strength of steel is 2.50 x 10^8 Pa, what force is required to punch through a steel plate 2.0 cm thick (t)? Assume the superhero's fist has a cross-sectional area of 100 cm^2 and is approximately circular.

Qualitatively, what would happen to the superhero on delivery of the punch? What physical law applies?



Limits of the Human Body

Bone has a Young's modulus of 1.8 x 10¹⁰ Pa. Under compression, it can withstand a stress of about 1.6×10^8 Pa before breaking. Assume that a femur (thigh bone) is 0.5 m long and calculate the amount of compression this bone can withstand before breaking.

Two rods are made of the same kind of steel and have the same diameter.



A force of magnitude *F* is applied to the end of each rod. Compared to the rod of length *L*, the rod of length 2*L* has

- A. more stress and more strain.
- B. the same stress and more strain.
- C. the same stress and less strain.
- D. less stress and less strain.
- E. the same stress and the same strain.



Two rods are made of the same kind of steel. The longer rod has a greater diameter.



A force of magnitude *F* is applied to the end of each rod. Compared to the rod of length *L*, the rod of length 2*L* has

- A. more stress and more strain.
- B. the same stress and more strain.
- C. the same stress and less strain.
- D. less stress and less strain.
- E. the same stress and the same strain.



Main Ideas in Class Today

After today, you should be able to:

- Determine the Stress and Strain a material can withstand
- Understand how to apply to breaking things

Extra Practice: 9.65, 9.67, 9.69, 9.71