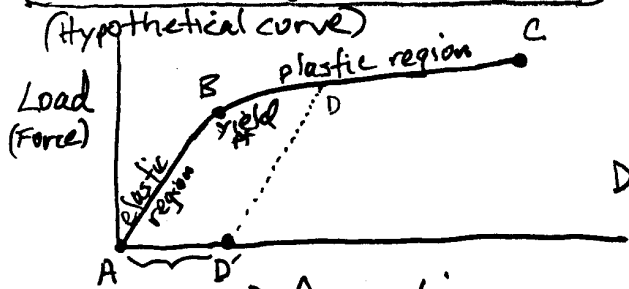


Biomechanics of Bone



A = Unloaded
 B = Yield point
 C = Failure
 D → D' = permanent deformation

Deformation
 (change in original length)

In elastic region - bone returns to _____ when unloaded

In plastic region - _____ deformation occurs ()

Curve tells us:

1. _____ before failure
2. _____ before "
3. _____ (slope of curve)
4. " " to failure
 (work done to failure) = area under curve



Stress = _____

(same as pressure)

stress is measured on a plane surface within a structure in response to applied loads

units: $N/m^2 = Pa$



$\frac{\text{newtons}}{(\text{meter})^2} = (\text{pascal})$

one Pa is very small stress

1,000 Pa = 1 kPa kilopascal

1,000,000 Pa = 1 MPa megapascal

1,000,000,000 Pa = 1 GPa gigapascal

Example: It takes 250N force to fracture a certain bone with a cross sectional area of 2 mm^2 . What is the stress on the bone at this point?

$F = 250 \text{ N}$ $A = 2 \text{ mm}^2 =$

$1 \text{ m} = 1000 \text{ mm}$

$(1 \text{ m})^2 = ()^2 = \frac{\quad}{\quad} = 10^6 \text{ mm}^2$

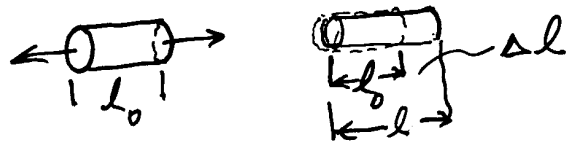
$\therefore 1 \text{ mm}^2 = \frac{1}{10^6} \text{ m}^2 = 10^{-6} \text{ m}^2$

$\sigma = \frac{250 \text{ N}}{2 \times 10^{-6} \text{ m}^2} = 125 \times 10^6 \text{ Pa}$

=

Stress is a _____ property

= deformation that occurs at a point in the structure under load as a proportion of the original length of the structure



$$\epsilon = \text{strain} = \frac{l - l_0}{l_0} = \frac{\Delta l}{l_0}$$

Example $l_0 = 100 \text{ mm}$
 $l = 101 \text{ mm}$
 $\Delta l = 101 - 100 = 1 \text{ mm}$

$$\epsilon = \frac{1 \text{ mm}}{100 \text{ mm}} = 0.01$$

or " " "

Strain is a _____ property

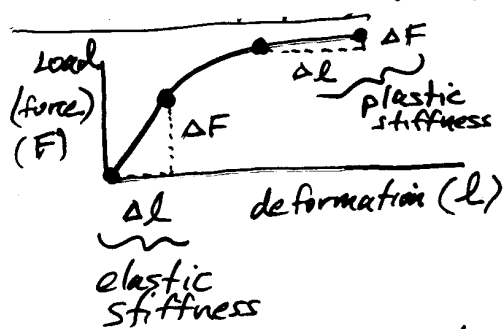
_____ are tissue properties

_____ are mechanical

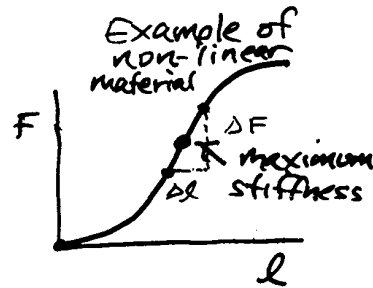
_____ properties of the entire structure being loaded

stiffness ; modulus of elasticity (Young's modulus) ④

: stiffness (K)

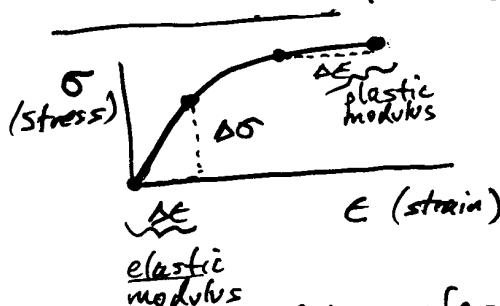


$$K = \frac{\Delta F}{\Delta l} = \frac{\text{change in } F}{\text{change in } l}$$



SI unit: $\frac{\Delta F}{\Delta l} = \frac{N}{m} = \frac{\text{newtons}}{\text{meter}}$

: Young's modulus (E)



$$E = \frac{\Delta \sigma}{\Delta \epsilon} = \frac{\text{change in } \sigma}{\text{change in } \epsilon}$$

SI unit: $\frac{\Delta \sigma}{\Delta \epsilon} = \frac{\text{Pa}}{1?x}$

= Pa or MPa

*strain is dimensionless

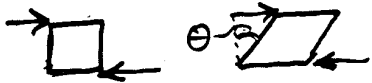
Young's modulus refers specifically to elastic region.

Note: stiffness is the slope of the _____ curve. Modulus is the slope of the _____ curve.

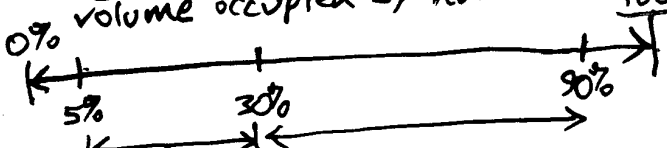
Normal strain vs shear strain

1. Normal strain = $\frac{\text{change in length}}{\text{original length}}$

2. Shear strain = θ (rad)
 = change in angle
 SI unit: dimensionless quantity



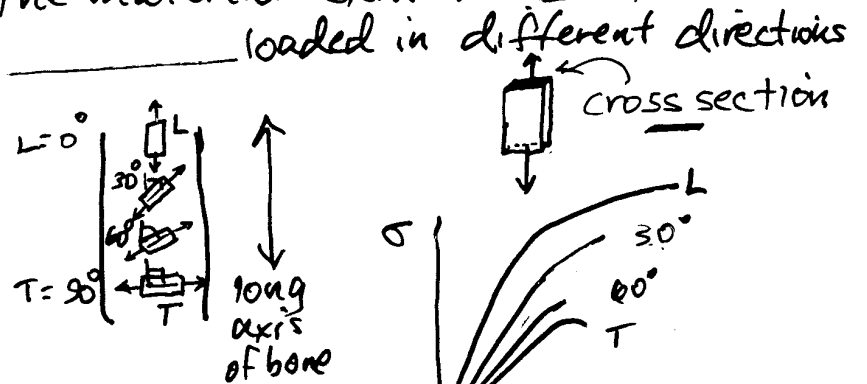
Bone types: _____
 = classifications along a _____
 Porosity = proportion of a bone's volume occupied by non-mineralized tissue.



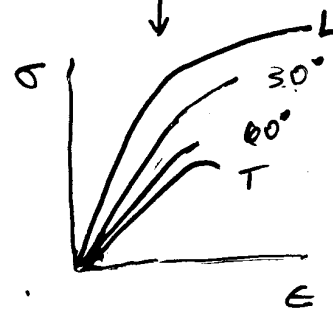
Cortical bone tends to be _____ than cancellous bone. Cortical bone can sustain greater stress (ie. _____), but less strain before failure.
 _____ = inverse of stiffness, so cancellous bone is _____ than cortical

"in vitro" tests: strain at failure:
 Cortical $\sim \epsilon_{max} \approx 2\%$ cancellous $\epsilon = 7.5\%$
 (not 75% in book)

Biological tissues (including both types of bone) are _____ - that is the material exhibits _____



Data from femoral shaft measured in tension



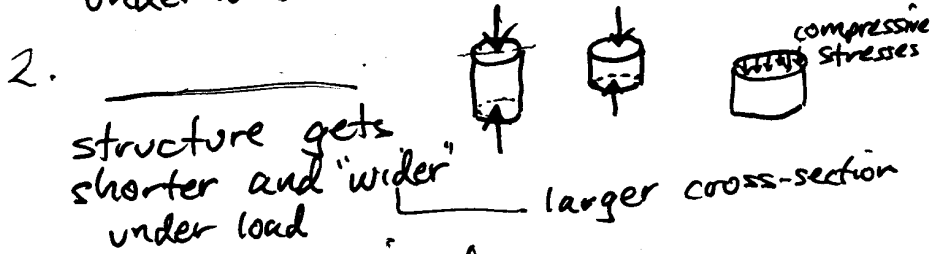
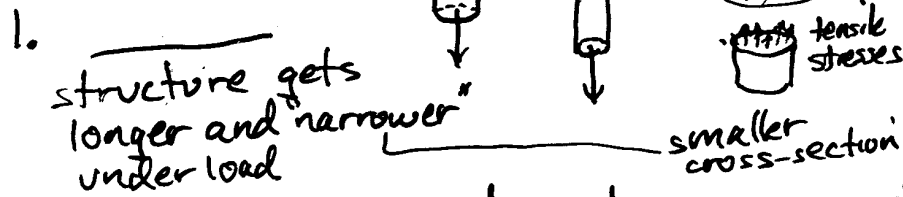
_____ materials behave equally in all directions. "Material" & "tissue" can be used interchangeably in this class. Thus "material properties" are the same as "tissue properties" (e.g. stress, strain, modulus)

_____ vs _____ materials is one that, when fractured, the pieces can be put back together to conform approx. to the original shape

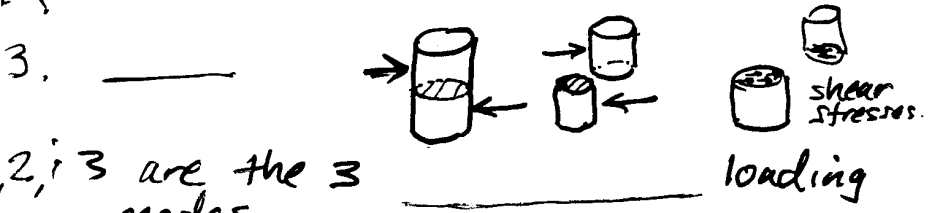
(7)

_____ cannot do this.
 Classification depends on the amount of plastic deformation before failure
 Older bones are _____ than younger bones.
 Cancellous bone is _____ than cortical bone

Bone behavior under various loading modes



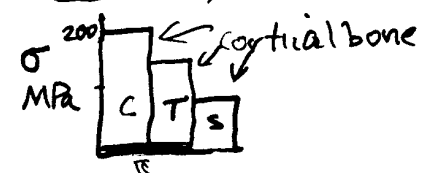
1 & 2 are considered _____



1, 2, & 3 are the 3 modes

(8)

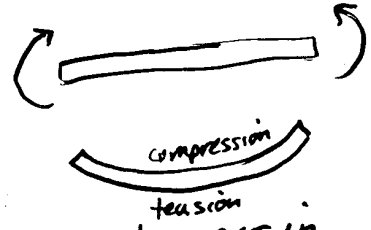
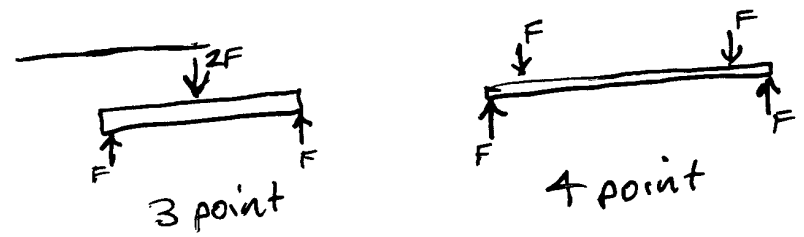
Cortical bone is strongest in _____, then _____, then _____.



units

$$= \frac{\text{change in shear stress}}{\text{change in shear strain}} = \frac{\text{Pa}}{\text{rad}}$$
 = Pa
 or kPa, MPa etc
 dimensionless

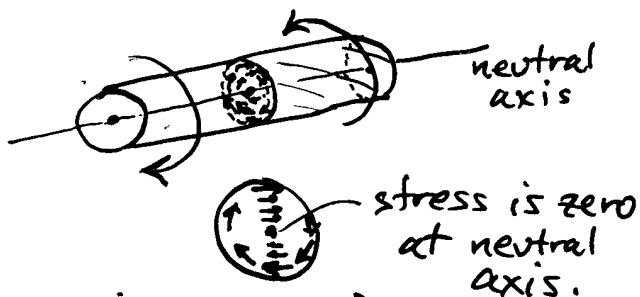
Combined loading modes



Adult bones are stronger in _____ than _____ - so failure under bending loads tends to occur on the _____ (convex)

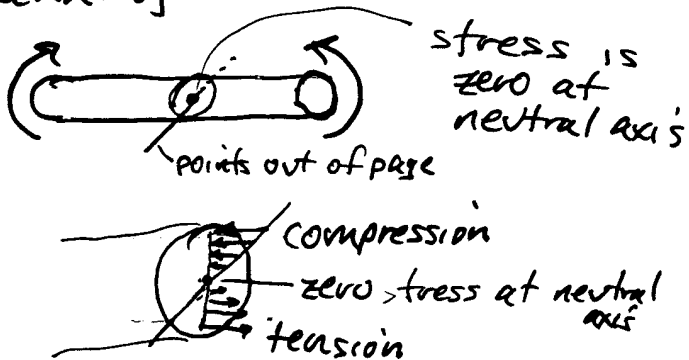
9

However young children tend to get fractures on the inner side because of the differences in material properties of young vs old bone.



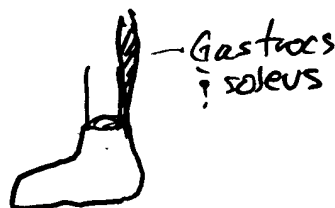
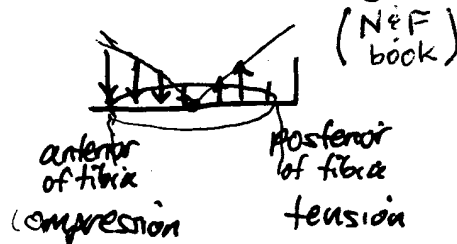
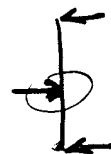
stress increases with distance away from neutral axis

Note: a similar phenomenon occurs in bending



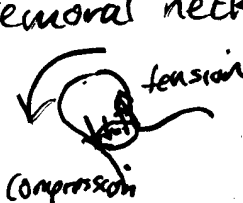
10

How do muscles affect stresses in bones? Boot top example (Fig 1-31)



muscle adds compressive stresses so overall pattern looks like zero tensile stress up to a somewhat higher compressive stress anteriorly

Femoral neck example



Gluteus medius muscle (N&F book) (Fig 1-32)

Compression w/o tension

Presence of muscle allows a sharing of the energy being absorbed between bone & muscle.