Guest Lecture - Terry Neimeyer
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and
Concepts in Strength of Materials

CIEG 125 Introduction to Civil Engineering
Fall 2006

Lecture 5

Today's class

- Guest Lecture
- Group 7, 8 and 9 ethics presentations
- Strength of Materials

Outline - Materials

- From Rigid to Deformable Bodies
- Stress
- Strain
- Modulus of Elasticity
- Deformation Examples
- Design Stress

Rigid and Deformable Bodies

- To use only static analysis:
  - structural members are assumed to be rigid bodies
  - the number of support reactions matches the number of equilibrium equations
- However:
  - Structures are not completely rigid
  - They deform to resist the loads they carry
  - They often are statically indeterminate

Deformation of Bodies

- To determine how a structure deforms:
  - we must know what the forces are in the various members of the structure
  - we must know how those forces are distributed over each member

    (called stress)
  - we must know how the member responds or deflects under these forces

    (called strain)

Stress

- Stress is defined as the internal force per unit area in a structural member.

σ = stress

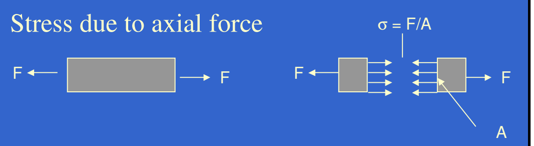
= F/A = Force / Area

Dimensions: $M\,L/T^2 / (L^2) = M/(L\,T^2)$

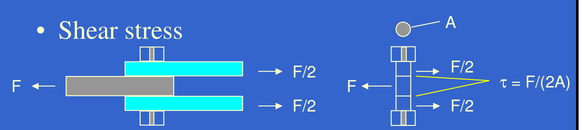
Units: N/m^2 or lb/in^2 (psi)

Stress, con't.

- Stress due to axial force

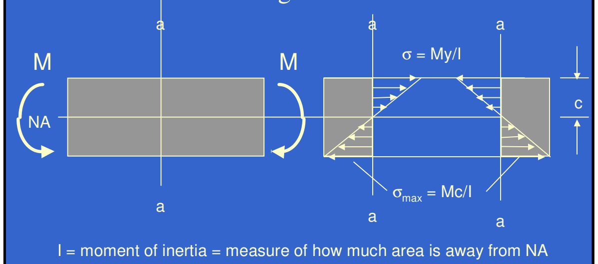


- Shear stress

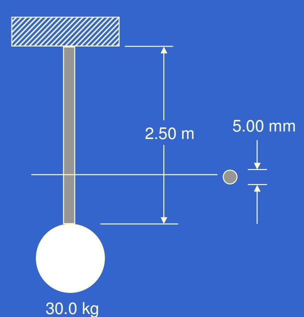


Stress, con't.

- Stress due to bending moments



Stress Example



F = 30.0 kg * 9.81 m/s^2
= 294 N
A = (π /4)*(5.00mm)^2
= 19.6 mm^2

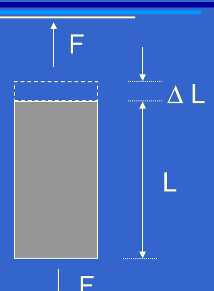
σ = F/A
= 294 N / 19.6 mm^2
= 15.0 N/mm^2
= 1.5 x 10^7 Pa
= 15 MPa

Strain

- Materials change shape (deform) under load.
- For an axial load, the elongation or compression per unit length is the strain.
  strain = $\Delta L/L$
- Strain has no units and is dimensionless

Strain, con't.

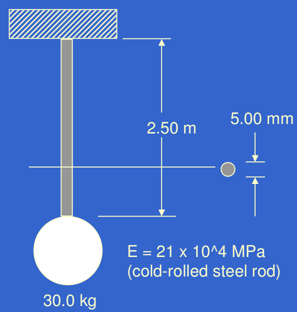
$\varepsilon = \Delta L / L$



Modulus of Elasticity

- The modulus of elasticity, E, relates stress to strain for different materials
- $\sigma = E\,\varepsilon$
- Linear relation first discovered by Hooke
- Relationship between σ and ε is also known as Hooke's law
- Dimensions: Dimensions: $M\,L/T^2 / (L^2) = M/(L\,T^2)$
- Units: N/m^2 (Pa), N/mm^2 (MPa),
  lb/in^2 (psi), kips/ in^2 (ksi)

Strain Example



σ = 15.0 MPa

ε = σ/E
= 15.0 MPa/210000 MPa
= 7.14 x 10^-5 mm/mm
= 0.0000714 mm/mm
= 0.0000714 m/m

ΔL = εL
= (0.0000714 m/m) * 2.50 m
= 0.000178 m
= 0.178 mm

Modulus of Elasticity, con't.

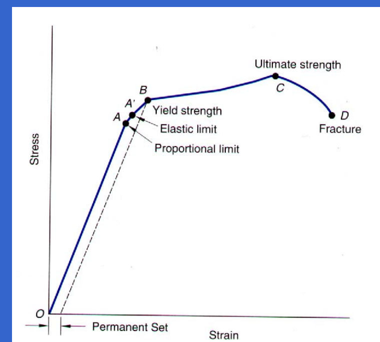


Image is Figure 9.24 on pp. 268 in Engineering Fundamental and Problem Solving, Eide et al.

Modulus of Elasticity, con't.

- Elastic limit
  - upper limit of stress range over which material will return to its original shape.
- Proportional limit
  - upper limit of stress range over which E is constant
  - defines range over which a constant linear relationship between stress and strain exists.

Modulus of Elasticity, con't.

- Yield Strength
  - stress at which material undergoes a permanent strain of somewhere from 0.05 to 0.3
  - material is said to "yield" or start to "go plastic"
- Ultimate Strength
  - highest stress carried by the material
  - usually occurs after a lot of strain
  - notice the strain hardening behavior of material

Moduli of Elasticity

Material	E, psi	E, Gpa
Cold-rolled steel	30 x 10^6	210
Cast iron	16 x 10^6	110
Copper	16 x 10^6	110
Aluminum	10 x 10^6	70
Stainless steel	27 x 10^6	190
Nickel	30 x 10^6	210

Table 9.1 on pp. 269 in Engineering Fundamental and Problem Solving, Eide et al.

Ultimate and Yield Strengths

Material	Ultimate Strength Mpa	psi	Yield Strength Mpa	psi
Cast iron	310	45 x 10^3	210	30 x 10^3
Wrought Iron	345	50 x 10^3	210	30 x 10^3
Structural Steel (A36)	415	60 x 10^3	240	35 x 10^3
Stainless Steel	620	90 x 10^3	210	30 x 10^3
Aluminum	125	18 x 10^3	85	12 x 10^3
Copper	455	66 x 10^3	415	60 x 10^3

Table 9.2 on pp. 270 in Engineering Fundamental and Problem Solving, Eide et al.

Example

- Cast Iron:
  Ultimate tensile strength ~ 310 MPa
- Iron +5% carbon:
  Ultimate tensile strength ~ 415 MPa
- Other elements improve properties (ductility, tensile strength, resistance to corrosion.)

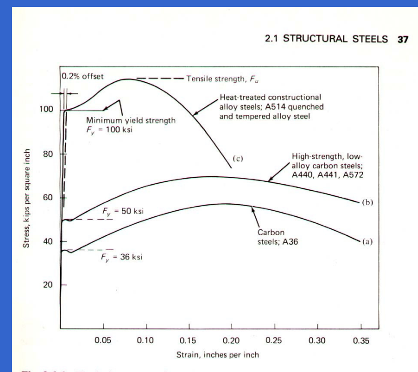
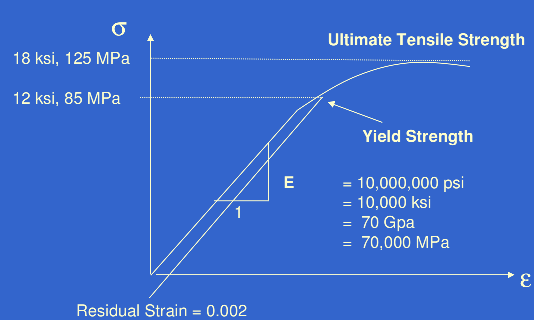


Fig. 2.1.1 Typical stress-strain curves.

Fig. 2.1.1 on pp. 37 in Steel Structures: Design and Behavior, by Salmon and Johnson, 1980

Example - Aluminium



How do the behaviors differ?

- How do steel and aluminum behave when the stress is below their respective proportional limits?
- Describe the difference between the way the two materials may fail under load.

Design Stress

- The term design stress is the maximum stress an engineer expects to see in the structure under all loading conditions
- However, uncertainty exists in:
  - loads expected
  - material resistence
  - workmanship
- Engineers usually never have design stress due to actual loads = yield stress

Design Stress and Safety Factors

- To address this uncertainty, engineers typically do one of the following:
  - allowable stress design
    make the allowable design stress be less than the yield stress by a factor of safety
  - load and resistance factor design
    multiply the loads by a factor of safety and ensure the design stress < yield stress

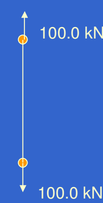
Example

Design a tension member/rod made out of aluminum to carry a load of 100kN given σ_y = 85 Mpa. Use two different methods:

(1) allowable stress design with a safety factor of 0.66

(2) determine the equivalent load factor for LRFD design

Free Body of Member



Example

1) allowable stress design with a safety factor of 0.66

σ_y = 85 MPa

σ_{all} = Allowable Stress = 0.66 * σ_y = 56 MPa

A_{req} = F/ σ_{all} = 50.0 kN / 56 x 10^3 kN/m^2
= 0.00089 m^2
= 890 mm^2

d_{req} = $(4 * A / \pi)^{0.5}$ = 34 mm

Example, con't.

(2) load factor design with a load factor of 1.5

σ_y = 85 MPa

F_{fact} = factored load = 1.5 * F_{CD} = 1.5 * 50.0 kN = 75 kN

A_{req} = F_{fact} / σ_y = 75 kN / 85 x 10^3 kN/m^2
= 0.00088 m^2
= 880 mm^2

d_{req} = $(4 * A / \pi)^{0.5}$ = 33 mm

Summary

- Statics identifies forces on statically determinate structures
- Stress, Strain, and Young's Modulus (E) are needed to determine the deformations of structural members
- Once you have member deformations, you can compute structure deflections from these member deformations.

Next Week

- Report 1 is due at the **beginning** of class
- Bridges
- Gunn and Vesilind: Chapter 5, Groups 10, 11 and 12.