Activity 2.3b – Engineering Problem Solving Answer Key

1. A force of 200 lbs pushes against a rectangular plate that is 1 ft. by 2 ft. Determine the pressure in $\frac{lb}{ft^2}$ and $\frac{lb}{in^2}$ that the plate exerts on the ground due to this force.

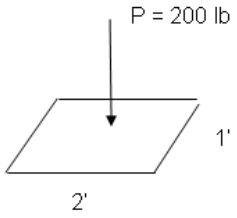
1. SOLUTION

Press = P/A

Area = A = 2' x 1' = 2 ft^2

convert to in^2

$$A = 2\,ft^2 x \frac{12in}{1\,ft} x \frac{12in}{1\,ft} = 288in^2$$



$$\text{Press} = \frac{P}{A} = \frac{200lb}{2\,ft^2} = 100\frac{lb}{ft^2}$$

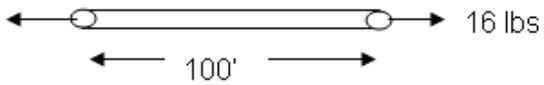
Or

$$\text{Press} = \frac{200lb}{288in^2} = 0.674\,psi$$

2. A piece of steel wire 100 feet long, with a cross-sectional area of 0.004 sq. in., must be stretched with a pull of 16 pounds when in use. If the modulus of elasticity of steel is 30,000,000 psi:

2. SOLUTIONS

a) What is the total elongation δ in the entire length of the wire?



Knowns: A = .004 in^2 L = 100 ft = 1200 in E = 30 x 10^6 psi

$$\delta = \frac{PL}{AE} = \frac{(16lbs)(1200in)}{(.004in^2)(30x10^6\,psi)} = 0.160in$$

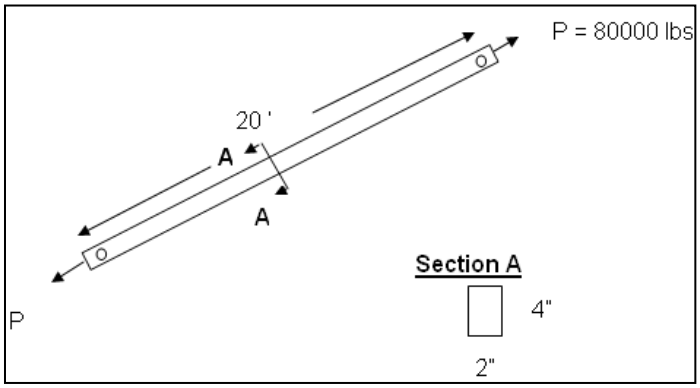
b) What tensile stress is produced by the pull?

$$\sigma = \frac{P}{A} = \frac{16lbs}{.004in^2} = 4000\,psi$$

3. A 2” by 4” rectangular piece of steel, that is 20 feet long between centers of the pins at its ends, is used as the diagonal member in a bridge. If the total tensile load in the steel is 80, 000 pounds and the modulus of elasticity is 30, 000,000 psi, calculate:

3. SOLUTIONS

a) The tensile stress-



Knowns: P = 80,000 lbs

E = 30 x 10^6 psi

A = 2 “x 4 “= 8 in^2

σ = $\frac{P}{A} = \frac{80000lbs}{8in^2} = 10000\,psi$

b) The total elongation caused by the load-

L = 20’ x 12” = 240 “

δ = $\frac{PL}{AE} = \frac{(80000lbs)(240in)}{(8in^2)(30x10^6\,psi)} = 0.080in$

c) The unit elongation-

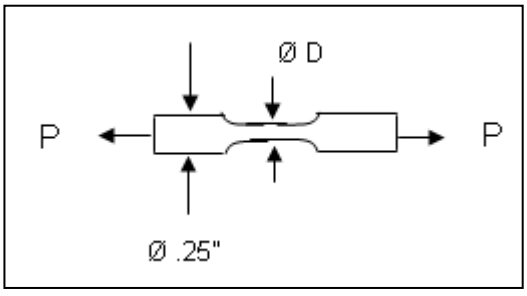
ε = $\frac{\delta}{L} = \frac{0.080in}{240in} = 0.00033$ in.

4. A sample of material is ¼ “diameter and must be turned to a smaller diameter to be able to be used in a tensile machine. The target breaking point for the material is 925 pounds. The tensile strength of the material is 63,750 psi. What diameter would the sample have to be turned to in order to meet the specified requirements?

4. SOLUTION

Knowns: P = 925 lbs

δ = 63,700 psi (at pt of failure)



Equations:

1) A = $\frac{\Pi D^2}{4} = .7854D^2$

2) σ = $\frac{P}{A}$

Combine Equation 1 and 2:

σ = $\frac{P}{.7854D^2}$

(continued next page)

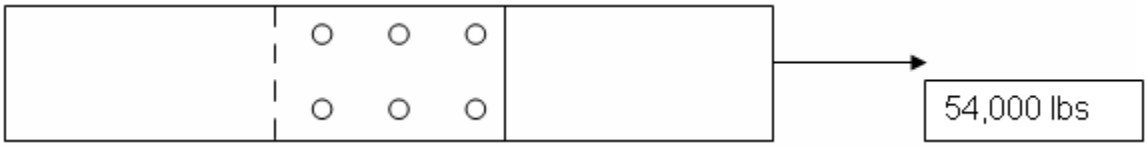
Substitute knowns and solve for D that would just barely hold 925 lbs:

$$63750 \text{ psi} = \frac{925lbs}{.7854D^2}$$

$$D^2 = \frac{925lbs}{(.7854in)(63750\,psi)} \approx .018454413in^2$$

$$D \approx \sqrt{0.18454413in^2} \approx \textbf{0.136" Therefore, part must be slightly less than 0.136"}$$

5. Two pieces of steel are held together with six bolts. One end of the first piece of steel is welded to a beam and the second piece of steel is bolted to the first. There is a load of 54,000 pounds applied to the end of the second piece of steel. The tensile strength of steel is 74,000 psi, the shear strength is 48,000 psi.



5. SOLUTIONS

a) Calculate the diameter of the bolts needed to support the load.

Assume that the 6 bolts share the load evenly:

$$P = \frac{54000lbs}{6} = 9000 \text{ lbs}$$

Knowns: P = 9000 lbs Shear Strength = τ = 48000 psi (at failure)

Equations:

1) $\tau = \frac{P}{A}$ 2) $A = .7854D^2$

Combine Equation 1 and 2:

$$\tau = \frac{P}{.7854D^2}$$

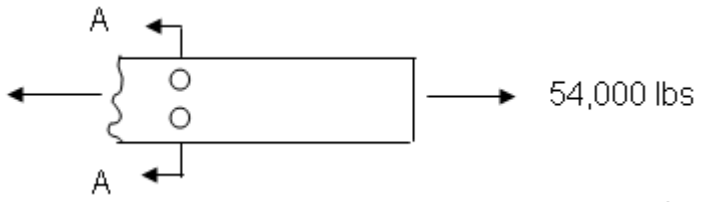
Substitute Values and solve for D

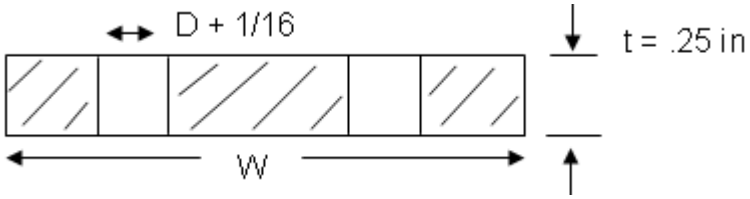
$$48000 \text{ psi} = \frac{9000lbs}{.7854D^2}$$

$$D^2 = \frac{9000lbs}{(.7854in)(48000\,psi)} \approx .23873185 \text{ in}^2$$

D ≈ .489 inch **Closest standard bolt size = 0.500 inch**

b) Find the width of the steel if the thickness of the steel is ¼". The bolt holes are 1/16" larger than the bolt.





Section A

Knowns: P = 54,000 lbs t = .25 in D = .500 in
Tensile Stress = σ = 74,000 psi at failure

Unknowns: W and Total Area shown by Section A (the area of the rectangle with the bolt hole areas removed)

Equations: 1) $A = [W - 2(D+1/16)]t$

2) $\sigma = \frac{P}{A}$

Combine Equations and solve for W:

$$\sigma = \frac{P}{(W - 2D - .125)t}$$

$$74000\ psi = \frac{54000lb}{(W - 2(.5in) - .125)(.25in)}$$

$$74000\ psi = \frac{54000lb}{(W - 1in - .125)(.25in)}$$

$$74000\ psi = \frac{54000lb}{.25W - .28125}$$

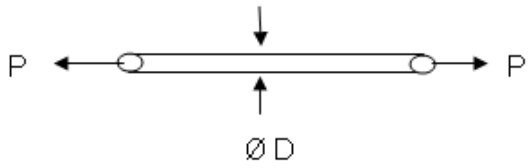
$$.25W - .28125 = \frac{54000lb}{74000\,psi}$$

.25W ≈ 1.01097973 in so **W ≈ 4.0444 in**

NOTE: If the solution to Part B shown above doesn't make sense then leave some space and go to the next problem, Mr. Bayer can show you an easier way to do it in class.

6. Determine the required nominal diameter of a threaded steel rod to carry an axial load of 16,000 pounds in tension if the tensile stress of 20,000 psi is permitted.

6. SOLUTION



Knowns: P = 16,000 lbs σ = 20,000 psi

Unknowns: the Diameter of the steel rod: D

Equations:

1) A = $\frac{\Pi D^2}{4} = .7854D^2$ 2) $\sigma_{max} = \frac{P}{A}$

Combine Equations and Solve for D:

20000 psi = $\frac{16000\,psi}{.7854D^2}$

$D^2 = \frac{16000}{.7854(20000)}$

D ≈ 1.009”

7. A piece of wire 1200 feet long, with a cross-sectional area of 2.25 sq. in., must be stretched with a pull of 1600 pounds when in use. If the modulus of elasticity of this steel is 30,000,000 psi:

7. SOLUTIONS

a) What is the total elongation δ in the entire length of the wire?

Knowns: P = 1600 lbs A = 2.25 in^2 E = 30 x 10^6 psi

L = 1200’ x 12 = 14,400”

Unknowns: δ

Equation: $\delta = \frac{PL}{AE}$

Substitute and solve:

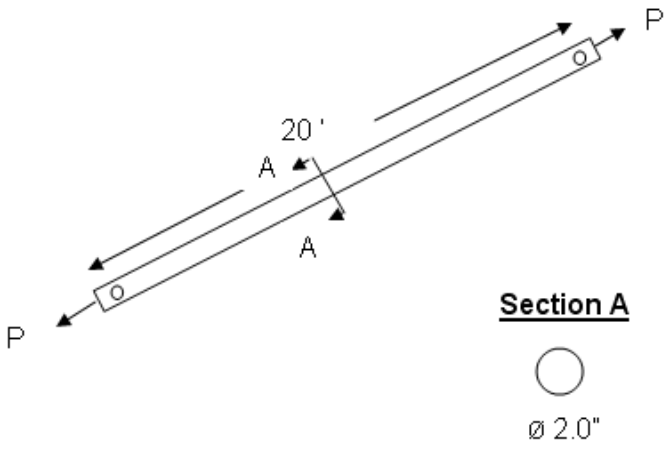
$$\delta = \frac{PL}{AE} = \frac{(1600lbs)(14400in)}{(2.25in^2)(30x10^6\ psi)} \approx \mathbf{0.341"}$$

b) What tensile stress is produced by the pull?

$$\sigma = \frac{P}{A} = \frac{1600lbs}{2.25in^2} \approx \mathbf{711.1\ psi}$$

8. A 2" circular piece of steel, that is 20 feet long between centers of the pins at its ends, is used as the diagonal member in a bridge. If the total tensile load in the steel is 180,000 pounds and the modulus of elasticity is 30,000,000 psi, calculate:

8. SOLUTIONS



a) The tensile stress-

Knowns: P = 180,000 lbs D = 2" L = 20' x 12 = 240"

Cross sectional Area = $\frac{\Pi D^2}{4} = .7854D^2 \approx 3.142\ in^2$

Unknowns: σ

Equations:

$$\sigma = \frac{P}{A} = \frac{180000lbs}{3.142in^2} \approx \textbf{57,288 psi}$$

b) The total elongation caused by the load-

$E = 30 \times 10^2$ psi

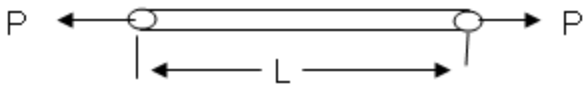
$$\delta = \frac{PL}{AE} = \frac{(180000lbs)(240in)}{(3.142in^2)(30x10^6\ psi)} \approx \textbf{0.458”}$$

c) The unit elongation-

$$\varepsilon = \frac{\delta}{L} = \frac{.458in}{240in} \approx \textbf{0.0019}$$

9. A round, steel 1-1/8” diameter rod, is 85 feet 6 inches in length, and supports an axial load (P) in tension. Calculate:

9. SOLUTIONS



a) The maximum unit tensile stress in the rod, if the axial load (P) is 12,000 lb.

Knowns: P = 12000 lbs D = 1.125” L = 85.5’ x 12 = 1026”

Cross sectional Area = $\frac{\Pi D^2}{4} = .7854D^2 \approx 0.994$ in^2

Unknowns: σ

Equation:

$$\sigma = \frac{P}{A} = \frac{12000lbs}{0.994in^2} \approx \textbf{12072 psi}$$

b) The maximum allowed load (P) on this rod, if the unit tensile stress must not exceed 25,000 psi.

Knowns: σ_{max} = 25000 psi

Unknowns: P

Equation:

$$\sigma = \frac{P}{A}$$

Substitute and solve for P:

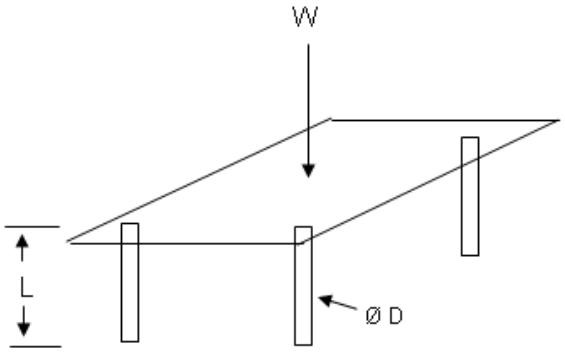
P = (25000 psi)(.994 in^2) ≈ **24850 lbs**

c) The total elongation of the rod, if E= 30,000,000 psi using the maximum allowed load from part B.

$$\delta = \frac{PL}{AE} = \frac{(24850lbs)(1026in)}{(.994in^2)(30x10^6\ psi)} \approx \textbf{0.855”}$$

10. A sleigh is supported and held off the ground with four vertical ½” diameter rods. If the modulus of Elasticity is 10,000,000 psi and the length of each rod is 1 ft., how much weight in toys can be put into this sleigh without compressing the rods more than .01” and ultimately destroying the sleigh?

10. SOLUTION



Knowns: D = .5” L = 1’ = 12” E = 10x10^6 psi

δ_{max} = .01”

Cross sectional Area of each leg= $\frac{\Pi D^2}{4} = .7854D^2$ ≈ 0.1963 in^2

Unknowns: W, P

Equations:

Assume that each leg supports the load equally and that the load on each leg is P:
W = 4P

$\delta = \frac{PL}{AE}$

Substitute values and solve for P:

.01 in = $\frac{P(12in)}{(.1963in^2)(10x10^6\ psi)}$

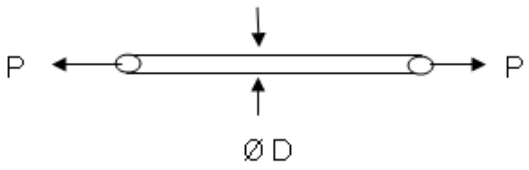
P ≈ 1636 lb

Solve for W:

W = 4P ≈ **6544 lbs**

11. A piece of wire is subjected to a load of 8000 lb. and is 60 ft. in length. The wire deforms a total of 1” in length due to this weight. If the Modulus of Elasticity is 30,000,000 psi, what is the diameter of the wire?

11. SOLUTION



Knowns: P = 8000 lbs L = 60’ = 720” δ = 1”

E = 30x10^6 psi

Unknowns: D

Equations:

1) A = $\frac{\Pi D^2}{4} = .7854D^2$ 2) $\delta = \frac{PL}{AE}$

Combine Equations and Solve for D:

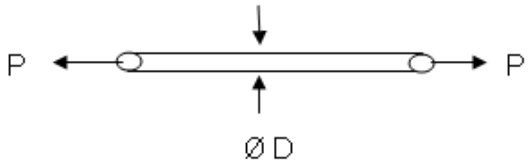
$$1 \text{ in} = \frac{(8000lbs)(720in)}{(.7854D^2)(30x10^6\ psi)}$$

$$D^2 = \frac{(8000lbs)(720in)}{(.7854)(30x10^6\ psi)}$$

D ≈ 0.494 in

12. A piece of circular aluminum with a diameter of ¼ ft. and 13 ft. in length is used as a structural component of a robot. If the tensile load applied to the component is equivalent to 84 tons and the Modulus of Elasticity is 10,000,000 psi, what is the total elongation in the entire length of the rod?

12. SOLUTION



Knowns: D = .25' = 3" L = 13' = 156"

P = 84 tons = 168000 lbs E = 10 x 10^6 psi

Cross sectional Area A = $\frac{\Pi D^2}{4} = .7854D^2$ ≈ 7.069 in^2

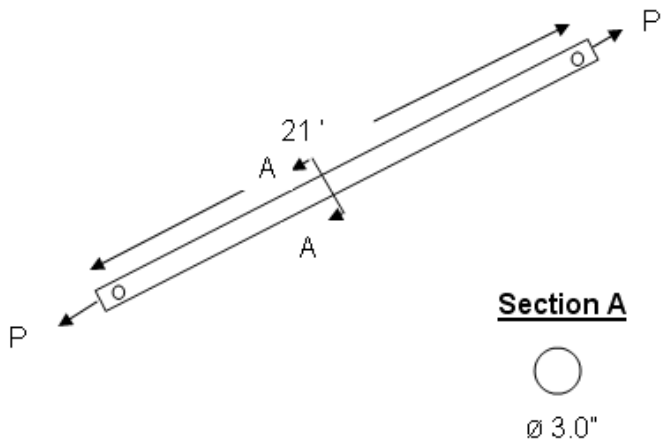
Unknowns: δ

Equation:

$$\delta = \frac{PL}{AE} = \frac{(168000lbs)(156in)}{(7.069in^2)(10x10^6\ psi)} \approx \mathbf{0.371\ in}$$

13. Calculate the stress created in a 3” diameter piece of steel that is 21 feet long between the centers of pins at its ends, and is used as a diagonal member in a bridge. The load applied to this member is 181,000 pounds and the modulus of Elasticity is 30,000,000 psi.

13. SOLUTION



Knowns: P = 181000 lbs D = 3” L = 21’ = 252”

Cross sectional Area A = $\frac{\Pi D^2}{4} = .7854D^2$ ≈ 7.069 in^2

E = 30 x 10^6 psi

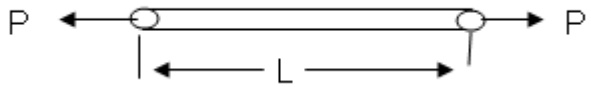
Unknowns: σ

Equation:

$$\sigma = \frac{P}{A} = \frac{181000lbs}{7.069in^2} \approx \mathbf{25605\ psi}$$

14. A strand of wire 1,000 ft. long with a cross-sectional area of 3.5 sq. inches must be stretched with a load of 2000 lb. The modulus of Elasticity of this metal is 29,000,000 psi. What is the unit deformation of this material?

14. SOLUTION



Knowns: L = 1000' = 12000" A = 3.5 in^2 P = 2000 lb

E = 29 x 10^6 psi

Unknowns: ε

Equations:

1) $\delta = \frac{PL}{AE}$ 2) $\varepsilon = \frac{\delta}{L}$

Solve Equation 1 for δ, then use in equation 2:

$$\delta = \frac{PL}{AE} = \frac{(2000lb)(12000in)}{(3.5in^2)(29x10^6\ psi)} \approx 0.236 \text{ in}$$

$$\varepsilon = \frac{\delta}{L} = \frac{.236in}{12000in} \approx \mathbf{0.0000197in.}$$

Conclusion

1. You have been asked to design a machine to punch circular holes into a sheet of metal. Create a sketch of the problem and set up the equations to calculate shear stress in the metal sheet. Make sure to include applied force, hole diameter, modulus of elasticity and sheet thickness.

   Students should demonstrate an understanding of the problem solving process by creating a clear sketch, with all parts labeled, and by using the correct terminology. The formulas specified should be correct for their diagram.

2. A community in a mountainous area has developed a playground in a park by a stream. The time it takes for children who live on the other side of the stream to walk to the playground is an hour. The stream is 60 feet across. You have been asked to come up with a design for a cable bridge for foot traffic only. What size cables will need to be obtained so 10 average-sized children can walk on the bridge at once?

   Some discussion should precede this problem in order to establish what an "average" child weighs. The answer will depend on this information and on how complicated each student wants to make the bridge design. Computer software can, and should, be used in the design process.