This product has been updated to incorporate all changes shown in the comments on the webpage and email comments as of October, 30 2017. If you have purchased this product prior to this date and wish for the latest version then please email Justin Kauwale at contact@engproguides.com.

The following changes have not been incorporated into the product as of the date above and should be noted.

None.

Step 2: Find radius of gyration

The radius of gyration compares the moment of inertia and the cross sectional area. The larger cross sectional area will cause the radius of gyration to increase, which means the object is less slender. You will need to compute the radius of gyration for both the x and y axis and use the minimum radius of gyration for the next step.

$$\text{Radius of Gyration} \rightarrow r_{min} = \sqrt{\frac{I}{A}}$$

Step 3: Find the slenderness ratio

Once you have the minimum radius of gyration and the effective length, then you can find the slenderness ratio with the following equation.

$$\text{Slenderness Ratio} \rightarrow R = \frac{L_e}{r_{min}};$$

Step 4: Find column constant

The column constant takes into account the modulus of elasticity and the yield stress of the material. A material with a larger yield stress will mean the column is much stronger and thus the column can be longer before it will be considered slender and therefore subject to buckling.

$$\text{Column Constant} \rightarrow C = \sqrt{\frac{2\pi^2 E}{\sigma_{yield}}}$$

$$E = \text{Young's Modulus}$$

Step 5: Compare slenderness ratio and column constant

Finally, compare the slenderness ratio and column constant. If the slenderness ratio is less than the column constant then the object is considered to be slender and long. Thus the column will be subject to buckling

$R > C$	$R < C$
Column is considered slender	*Column is not slender*
Column is subject to buckling	*Column might not be subject to buckling before yield stress.*
Use Euler formula to determine critical buckling load	*Use Johnson formula to determine critical buckling load*

5.1 Critical Buckling Load

The force at which a skinny column will fail under compression (buckling) is directly related to the material's Young's Modulus and moment of inertia. The force is inversely related to the square of the length and a constant which describes the degrees of freedom of the column. The

6.4 PARALLEL AXIS THEOREM

The polar second moment of area is still the second moment of area. The polar term just refers to the fact that these equations focus on circular cross sections. Similar to the second moment of area section, the parallel axis theorem also applies. When a shaft is off-center and the axis needs to be adjusted to account for this difference, then you can use the parallel axis theorem. This theorem states that the second moment of area about an axis can be adjusted to another axis by adding the cross sectional area multiplied by the distance between the two axes squared.

$$J_{new} = J_{old} + A * d^2$$

$$d = perpendicular\ distance\ between\ the\ old\ axis\ and\ the\ new\ axis$$

6.5 TORSION FAILURE

The failure of a shaft during torsion will depend on whether the material is ductile versus brittle. If the material is ductile, then the material will most likely fail due to a maximum shear stress. If the material is brittle then the material will most likely fail due to a maximum tensile stress. This concept is a little difficult to grasp, but you can try to imagine a brittle material twisting and at the same time the material is twisting, the material is elongating and creating tension in a direction that is 45 degrees from the longitudinal direction.

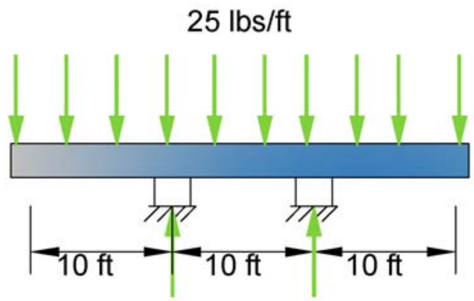
Figure 12: Ductile materials (left) will flex in torsion, until the maximum shear stress is met and the material will fail at a near 90 degree angle. Brittle materials (right) will not flex in torsion and will fail in tension at an angle near 45 degrees to the longitudinal direction.

When you are completing a torsion problem and you are finding the shear stress due to torsion, you can compare this shear stress value to either the shear or tensile strength of the material based on the type of material. On the PE exam and in practice, you will most likely not encounter a ductile material loaded in torsion. Ductile materials like copper and aluminum are rarely loaded in torsion. It is most common that all the various types of steel will be loaded in torsion, such that you can use the shear strength when comparing the design shear stress.

9.0 Practice Problems

9.1 Problem 1 - Bending

A wood beam is situated as shown in the figure below. The material has strength of 900 psi. The beam shall be designed to have a safety factor of 1.0. What should be the dimension of the height of the beam? Assume the height of the beam is 2 times the width of the beam.



(a) 0.89 in

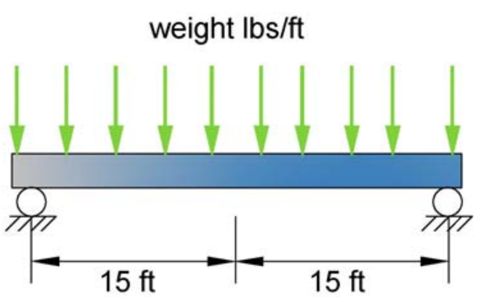
(b) 2.03 in

(c) 2.55 in

(d) 5.84 in

9.2 Problem 2 - Bending

A W 8 x 10 beam has an allowable stress of 50 ksi and dimensions as shown below. What is the maximum weight per foot that the beam can support?



(a) 12,000 lb/ft

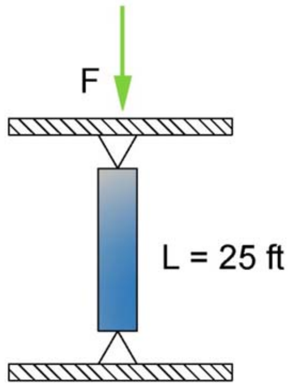
(b) 21,000 lb/ft

(c) 36,000 lb/ft

(d) 42,000 lb/ft

9.3 PROBLEM 3 - BUCKLING

A W 6 X 9 steel column with yield strength of 40 ksi and a modulus of elasticity of 29,000 ksi will be used to support an unknown load. What is the critical buckling load of this column? Assume the column is slender.



(a) 9 kips

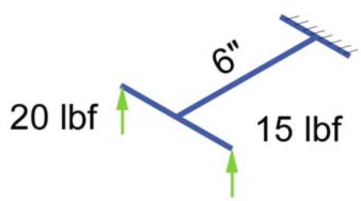
(b) 19 kips

(c) 26 kips

(d) 52 kips

9.4 PROBLEM 4 - TORSION

A handle is torqued to close a valve against the point shown in the figure below. What is the maximum shear stress developed at the outer wall of the solid stem? The length of the stem is 6" and the handle has a diameter of 4". The stem has a radius of 2". The forces are applied at the end of the handle at equal distances from the center.



(a) 1.6 psi

(b) 3.2 psi

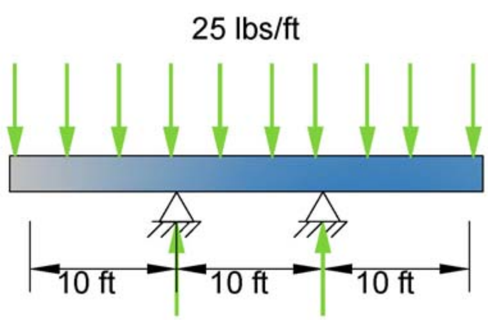
(c) 5.0 psi

(d) 10.1 psi

10.0 Solutions

10.1 Solution 1 - Bending

A wood beam is situated as shown in the figure below. The material has strength of 900 psi. The beam shall be designed to have a safety factor of 1.0. What should be the dimension of the height of the beam? Assume the height of the beam is 2 times the width of the beam.



First, use your beam diagrams from either your Machinery's Handbook or the link that was previously discussed and solve for the reactionary forces.

$$R_1 = \frac{25 * 30 * (30 - 2(10))}{2 * 10} = 375\ lbs$$

$$R_2 = \frac{25 * 30 * (30 - 2(10))}{2 * 10} = 375\ lbs$$

Next use these reaction forces to solve for the max moment of inertia.

$$M_{max} = -\frac{25 * 10^2}{2} = 1{,}250\ lb - ft$$

Finally, use the section modulus equation to solve for the dimensions of the beam.

$$S = \frac{I}{c} = \frac{\mathrm{M}}{\sigma_{\mathrm{allow}}}; \text{where } \mathrm{I} = \frac{\mathrm{bh}^3}{12} \text{ and } \mathrm{c} = \frac{\mathrm{h}}{2} \text{ and } \mathrm{b} = \frac{1}{2}\mathrm{h}$$

$$\sigma_{\mathrm{allow}} = 900\mathrm{psi}$$

$$\frac{1}{12} * \frac{\frac{1}{2}h(h^3)}{h/2} = \frac{1{,}250\ lb - ft}{900\ \mathrm{psi}};$$

$$h^3 = \frac{1{,}250\ lb - ft * \left(12\frac{in}{ft}\right) * 12}{900\ \mathrm{psi}};$$

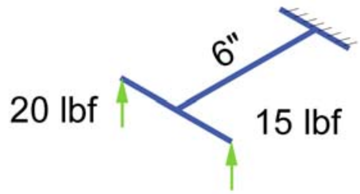
$$h^3 = 200;$$

$$h = 5.84\ in$$

The correct answer is most nearly, **(d) 5.84 in.**

10.4 Solution 4 - Torsion

A handle is torqued to close a valve against the point shown in the figure below. What is the maximum shear stress developed at the outer wall of the solid stem? The length of the stem is 6" and the handle has a diameter of 4". The stem has a radius of 2". The forces are applied at the end of the handle at equal distances from the center.



First, you need to calculate the torque on the stem. So you need to balance the moments upon the center of the stem at the handle.

$$M = 0 = 20lbf * 2\text{"-15lbf*2"} + T$$

$$T = 10\ lbf - in$$

Then use the maximum shear stress equation.

$$\tau = \frac{TR}{J};\ \ Solid\ shafts \rightarrow J = \frac{\pi}{2}R^4$$

$$\tau = \frac{(20\ lbf - in) * (2\ in)}{\frac{\pi}{2}(2in)^4};$$

$$\tau = 1.59\ psi$$

The correct answer is most nearly, **(a) 1.6 psi**.

The first number designation, “209” is the number assigned to the standard. The following number after the dash, “14” stands for the year it was issued. In this case, the standard was issued in 2014.

The important standards for the exam to be aware of are ASTM “A” and “B”. Do not purchase these standards, just be aware that they exist and what these standards cover.

4.2 AWS

The American Welding Society’s standards covers all aspects of welding, like safety, materials, corrosion, different types of welding, different welding conditions and different welding applications. You should go through the website, to get a feel of the available standards and the type of material that is covered by AWS.

https://pubs.aws.org/

4.3 ANSI

American National Standards Institute or ANSI includes information on quality management, medical devices, IT security, fall protection and a lot more topics, including topics within Machine Design. The standard that would be most applicable to Machine design would be the one shown below on threads. However, there are similar standard specifications for items like roller chains, bearings, shafts and many other machine design elements that require specifications to ensure that manufacturer’s products are compatible with one another.

ASME B1.1/ANSI/ASME B1.2/ ANSI/ASME B1.20.1 – Unified Screw and Pipe Threads Package

4.4 UL

UL is an independent safety science company. It tests equipment, materials and products to confirm if they meet the UL safety standards. You will often find the following seal on a product, which indicates that the product has been tested and certified to meet a certain standard.

UL LISTING