8.10 Problem 10 - Project Management

Which of the following is TRUE about critical path in project management?

(a) The critical path has the greatest amount of slack.

(b) The critical path shows the earliest that a project can be finished.

(c) The critical path is constant throughout the life of a project.

(d) The critical path is the shortest path in a project.

8.11 Problem 11 – Project Management

Calculate the critical path length, given the following activity table.

Activity	Time (days)	Predecessor
A	4	N/A
B	3	N/A
C	5	B
D	2	A
E	10	D
F	4	C,D,E
G	3	D
H	4	G

(a) 12 days

(b) 14 days

(c) 16 days

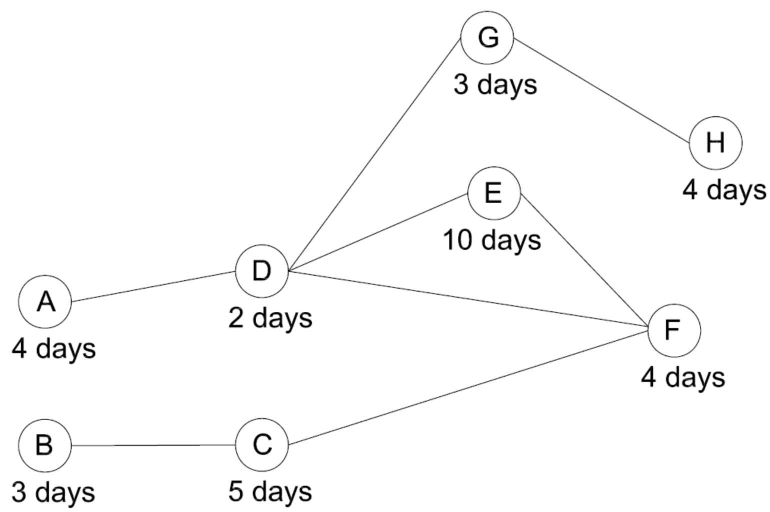
(d) 20 days

9.11 Solution 11 – Project Management

Calculate the critical path length, given the following activity table.

Activity	Time (days)	Predecessor
A	4	N/A
B	3	N/A
C	5	B
D	2	A
E	10	D
F	4	C,D,E
G	3	D
H	4	G

Go through and calculate all the possible paths by drawing the diagram.



Next, calculate the length of all the paths.

A – D – G – H = 13 days

A – D – E – F = 20 days

B – C – F = 12 days

The correct answer is most nearly, (d) 20 days.

(a) 12 days

(b) 14 days

(c) 16 days

(d) 20 days

in the following equation, α is the ratio of change in length (ΔL) to the total starting length (L_0) and change in temperature (ΔT).

When a pipe is heated or cooled, the length of the pipe will change based on the temperature and a coefficient of thermal expansion which is dependent on the material.

$$\Delta L = L_0 * \alpha * (T_1 - T_0)$$

$$where\ \Delta L = change\ in\ length\ of\ pipe\ (ft);\ L_0 = Initial\ Length$$

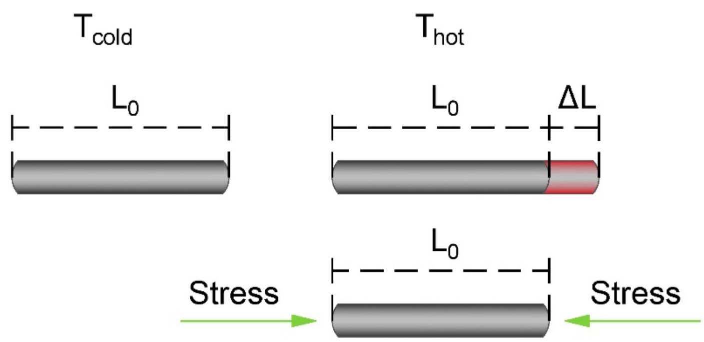


Figure 19: Increasing the temperature causes thermal expansion.

Bending stress: The bending stress of a pipe due to external forces or the weight of a pipe can be found using simple free body diagrams as shown in the following section.

4.5 THERMAL CONDUCTIVITY

Thermal conductivity is the ability of a material to conduct heat with a given temperature difference. Thermal conductivity is the material property that measures the rate of change in heat per unit distance per unit temperature difference.

$$q = k * \frac{dt}{dx}$$

$$q = heat\ flow\ per\ unit\ time\ per\ unit\ area\ (\frac{W}{m^2}\ or\ \frac{Btu}{h - ft^2})$$

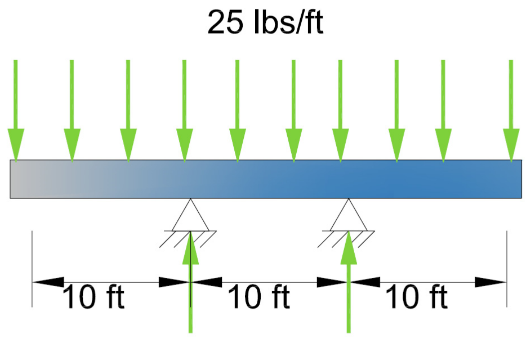
$$k = thermal\ conductivity\ (\frac{W}{m - °K}\ or\ \frac{Btu}{h - ft - °F})$$

More commonly on the PE exam you will use the following equation to conduct an energy balance as energy is transferred from one material to another material. The first step is to find the heat flow rate through an area of the subject material, as shown below.

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

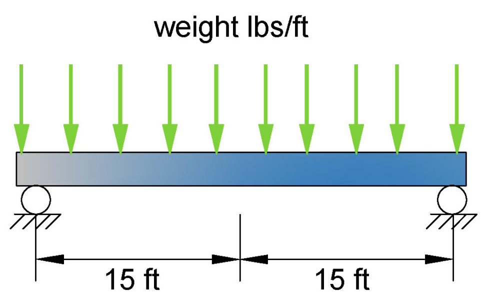
(c) 2.55 in

(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?

$$I_x = 30.8\ in^4, h = 7.89 in$$



(a) 120 lb/ft

(b) 210 lb/ft

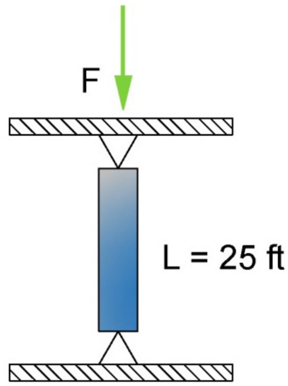
(c) 289 lb/ft

(d) 420 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.

$$W\ 6\ x\ 9\ Properties \rightarrow A = 2.68\ in^2; I_{xx} = 16.4\ in^4; I_{yy} = 2.2\ in^4; S = 5.56\ in^3$$



(a) 9 kips

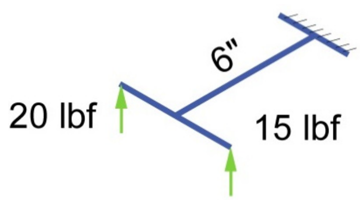
(b) 19 kips

(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 length 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) 0.8 psi

(b) 3.2 psi

(c) 5.0 psi

(d) 10.1 psi

The typical questions asked with actuators are to calculate the output force, the required pressure to output a force, the speed of the cylinder, the flow needed for a cylinder speed and the cylinder area required.

13.3.1 Cylinder force

The force that a cylinder can produce is a result of the pressure of the fluid within the cylinder and the area that the cylinder acts upon.

$$Force\ (lbf) = Pressre\ (psi) * Area\ (in^2)$$

In the equation above, the pressure describes the pressure of the hydraulic or pneumatic fluid. The area is the area that is conducting the mechanical power.

13.3.2 Fluid pressure

If the force required and the cylinder area is given, then you can use the reverse of the previous equation to find the required pressure to achieve the mechanical work.

$$Pressure\ (psi) = Force \frac{(lbf)}{Area(in^2)}$$

13.3.3 Cylinder speed

The next type of question is determining the cylinder speed, which is based upon the volume of the cylinder and the flow rate of the pressurized fluid. As the fluid fills the cylinder, it moves the cylinder. The rate at which the cylinder is moved can be found with the below equation.

$$Cylinder\ speed\ \left(\frac{ft}{\min}\right) = \frac{Volumetric\ flow\ rate\ (\frac{ft^3}{\min})}{Area_{cylinder}(ft^2)}$$

13.3.4 Fluid flow

The next type of question is the opposite of the cylinder speed type question. If you are given the required cylinder speed and the area of the cylinder, then you must determine the required fluid flow. The below equation can be used for this type of problem.

$$Volumetric\ flow\ rate\ \left(\frac{ft^3}{\min}\right) = Area_{cylinder}(ft^2) * Cylinder\ speed\ \left(\frac{ft}{\min}\right)$$

13.3.5 Bulk modulus

15.0 Practice Problems

15.1 Problem 1 – Pressure Vessel

A pipe is carrying compressed air at a pressure of 500 psi. The pipe has an internal diameter of 19.5" and the pipe has a thickness of 0.5". The ends of the 10' long pipe is capped at both ends and sealed airtight. What is the hoop stress developed in the pipe?

$$\sigma = \frac{PR}{t}$$

(a) 3,910 psi

(b) 4,875 psi

(c) 7,820 psi

(d) 9,750 psi

15.2 Problem 2 – Pressure Vessel

A cylindrical pressure vessel has an internal pressure of 1,000 psi. The pressure vessel has an internal diameter of 15.5" and a thickness of 0.25". One end of the pressure vessel will be capped with a bolt-nut system. What force should the cap be capable of withstanding?

(a) $2.0\ x\ 10^5\ lbf$

(b) $3.5\ x\ 10^5\ lbf$

(c) $5.0\ x\ 10^5\ lbf$

(d) $7.5\ x\ 10^5\ lbf$

16.0 Solutions

16.1 Solution 1 – Pressure Vessels

A pipe is carrying compressed air at a pressure of 500 psi. The pipe has an internal diameter of 19.5" and the pipe has a thickness of 0.5". The ends of the 10' long pipe is capped at both ends and sealed airtight. What is the hoop stress developed in the pipe?

The pipe can be treated as a thin walled vessel because the ratio of the radius to the thickness is greater than 10.

$$\frac{9.75''}{0.5''} > 10 \rightarrow thin\ walled\ pressure\ vessel\ assumption$$

So you can use the thin walled pressure vessel equation to find the hoop stress.

$$\sigma = \frac{PR}{t}$$

$$\sigma = \frac{500\ psi * (9.75'')}{0.5''}$$

$$\sigma = 9{,}750\ psi$$

The correct answer is most nearly, **(d) 9,750 psi**.

16.2 Solution 2 – Pressure Vessel

A cylindrical pressure vessel has an internal pressure of 1,000 psi. The pressure vessel has an internal diameter of 15.5" and a thickness of 0.25". One end of the pressure vessel will be capped with a bolt-nut system. What force should the cap be capable of withstanding?

In this question you must find the force acting upon the capped end. This is equal to the internal pressure multiplied by the area of the capped end.

$$Force = \sigma(psi) * area(in^2)$$

$$Force = 1{,}000\ psi * \pi * \frac{15.5^2}{4} = 188{,}691\ lbf$$

The correct answer is most nearly, **(a)** $\mathbf{2.0\ x\ 10^5\ lbf}$

3.1 BOLTS

A bolt is a type of fastener that passes through a hole in two or more components and is then tightened by a nut on its threaded end. A screw has similar construction, with a head and a threaded end. The difference between a screw and a bolt is in their intended use. Bolts are used to fasten together two unthreaded components with a nut. Screws are used to join components, where at least one of the components is threaded. For example, a screw that is drilled into two pieces of wood joins two threaded components. The screw creates the threads within the wood. A bolt that connects two pieces of wood would require a non-threaded hole. The bolt would be set into the hole, connecting the two pieces of wood. A nut would then be used to tighten the two pieces together.

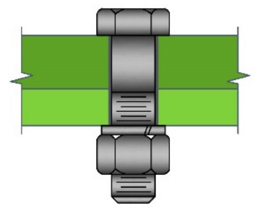


Figure 7: A bolt connects two non-threaded components. A nut is placed at the threaded end of the bolt to secure and tighten the two components together.

The nut is threaded and matched to the bolt. The lifting and lowering torque required to tighten or loosen the nut is similar to the equation shown for power screws. If you encounter a question with a threaded bolt or screw, you may either have to check this section or the power screw section.

The last aspect of bolts is that bolts are removable, similar to screws. Rivets on the other hand are permanent fasteners.

3.1.1 Tension or Clamping Force

The main PE questions will revolve around the purpose of the bolt, which is to clamp two components together. The clamping force causes the bolt to stretch, which means the bolt is undergoing tension. The bolt can also undergo more tension as the joined components undergo more loading. The bolt must be strong enough to resist this tension. The bolt will experience other external loads like moment and shear loads, which will be discussed later.

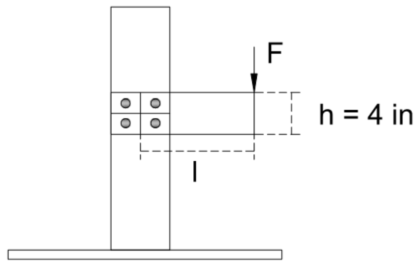
When a bolt is secured to two components, it produces an initial tension also known as pretension or bolt preload. This is the first force that acts upon the bolt.

The next force is the force due to an external tension load. When a tension load acts upon the two components that are joined together, the amount of external load applied will be divided between the two components and the bolt(s). The equation that determines how much of the load acts upon the bolt and how much of the load acts upon the two components is shown below. In this equation, the initial tension load is added to a fraction of the external tension load

5.0 PRACTICE PROBLEMS

5.1 PROBLEM 1 – BOLTS

In the diagram below, there is a force (F) of 5,000 lbs acting upon a bolt pattern at a linear distance (l) of 12” from the centroid of the bolt pattern. What is the moment imparted upon the bolt pattern?



(a) 5,000 lb-ft

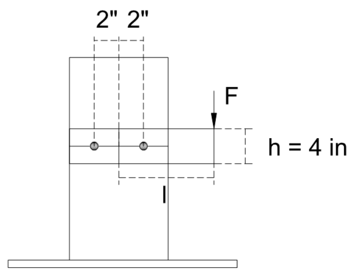
(b) 5,300 lb-ft

(c) 5,900 lb-ft

(d) 6,100 lb-ft

5.2 PROBLEM 2 – BOLTS

In the diagram below, there is a force (F) of 6,000 lbs acting upon a bolt pattern at a linear distance (l) of 6” from the centroid of the bolt pattern. What is the total shear force acting upon the right bolt? Assume the bolts are identical.



(a) 3,000 lbs

(b) 7,500 lbs

(c) 12,000 lbs

(d) 24,600 lbs

5.7 PROBLEM 7 – WELDING

The figure shows a weld under torsion. The fillet welds each have a throat of 1/8". The horizontal distance from "A" to the external load is 7". What is the secondary shear stress that acts upon point, "A", solely in the vertical direction? The centroid is located at point (0.8 in, -1.8 in), where the origin is at the intersection of the vertical and horizontal welds in green.

(a) 33,860 psi

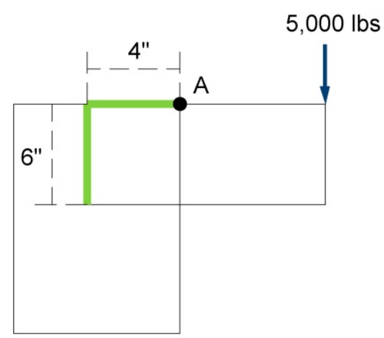
(b) 43,950 psi

(c) 83,910 psi

(d) 93,570 psi

5.8 PROBLEM 8 – WELDING

The figure shows a weld under torsion. The fillet welds each have a throat of 1/8". The horizontal distance from "A" to the external load is 7". What is the primary shear stress that acts upon point, "A"? The centroid is located at point (0.8 in, -1.8 in), where the origin, (0,0) is located at the intersection of the horizontal and vertical welds in green.



(a) 4,120 psi

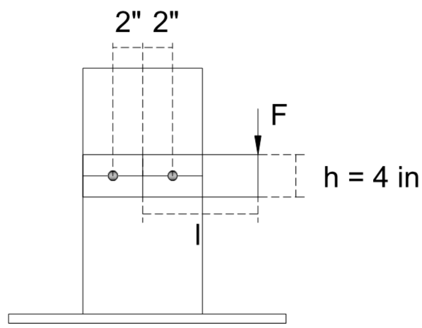
(b) 5,000 psi

(c) 5,660 psi

(d) 6,990 psi

6.2 Solution 2 – Bolts

In the diagram below, there is a force (F) of 6,000 lbs acting upon a bolt pattern at a linear distance (l) of 6" from the centroid of the bolt pattern. What is the total shear force acting upon the right bolt? Assume the bolts are identical.



First, find the primary shear force due to the downward force.

$$External\ Force = 6{,}000\ lbs \rightarrow Each\ bolt\ takes \frac{1}{2}\ 6{,}000\ lbs = 3{,}000\ lbs$$

Next find the secondary shear force due to the moment created at the centroid of the fastener group. The centroid is in the middle of the two bolts. The radial distance between the centroid and the force is found with the equation below.

$$D = 6\ in$$

$$Moment = 6{,}000\ lbs * 6.0\ in$$

$$Moment = 36{,}000\ lb - in$$

The shear force acting upon the right bolt due to moment is found by using the NCEES Mechanical PE Reference Handbook equation.

$$F_i = \frac{M}{\sum r_i^2}$$

$$r_i = radius\ from\ centroid\ to\ fastener\ "i"$$

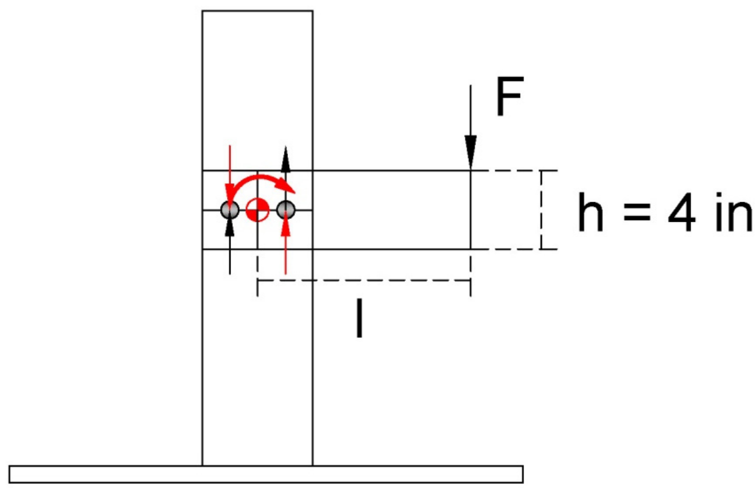
$$F_i = force\ on\ fastener\ "i"$$

$$F_i = \frac{(36{,}000\ lb - in) * 2\ in}{2^2 + 2^2\ in^2}$$

$$F_i = 9{,}000\ lb$$

$$Secondary\ Shear\ Force \rightarrow F_{bolt2} = F_{bolt\ right} = 9{,}000\ lb$$

Finally, add the primary and secondary shear forces, since the vectors are in the same direction.



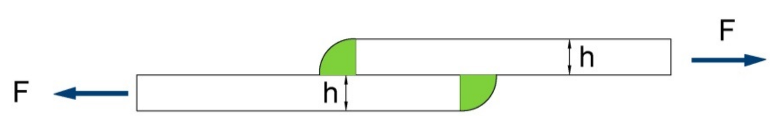
This figure shows how the moment in red imparts a reactive force in red that opposes the direction of the moment. The primary shear force that reacts to the external force "F", will be in the opposite direction of the external force. The primary and secondary shear forces on the left bolt oppose each other and the forces on the right bolt are cumulative.

$$F = 3{,}000 + 9{,}000\ lbs = 12{,}000\ lbs$$

The correct answer is most nearly, **(c) 12,000 lbs.**

6.3 SOLUTION 3 – WELDING

Two steel plates are joined by a double-fillet lap weld. The expected tensile load is 500 kN. The steel plates are 5 cm thick (h) and the welds have sides equal to the thickness of the steel plates. What is the tensile stress in the weld, if the length of the weld is equal to 100 cm?



The first step is to find the area of the weld that the tensile force acts upon.

$$Area\ of\ single\ weld = throat * length$$

$$throat = \frac{5\ cm}{\sqrt{2}} = 3.54\ cm$$

$$M = 5{,}000\ lbs * 10.2\ in = 51{,}000\ lb - in$$

The shear stress due to the vertical component of the red force will be equal to the Moment times the horizontal distance between the centroid and point "A" divided by the second polar moment of area. You do not use the radial distance, because this will give you the total force as opposed to solely the vertical component.

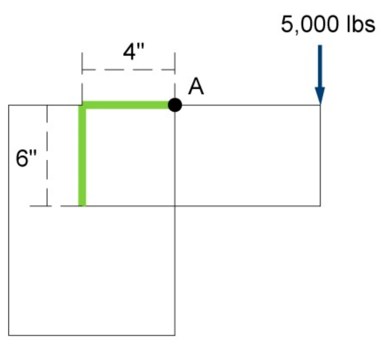
$$J = 0.707 * (0.125)\frac{[(b+d)^4 - 6 * b^2 * d^2]}{[12(b+d)]} = \frac{[(4+6)^4 - 6 * 4^2 * 6^2]}{[12(4+6)]} = 4.82\ in^4$$

$$\sigma'' = \frac{M * r_{horiz}}{J} = \frac{51{,}000\ lb - in * (3.2\ in)}{4.82\ in^4} = 33{,}858\ psi$$

The correct answer is most nearly, (a) 33,860 psi

6.8 Solution 8 – Welding

The figure shows a weld under torsion. The fillet welds each have a throat of 1/8". The horizontal distance from "A" to the external load is 7". What is the primary shear stress that acts upon point, "A"? The centroid is located at point (0.8 in, -1.8 in), where the origin, (0,0) is located at the intersection of the horizontal and vertical welds in green.



First, you need the throat area for the given weld pattern.

$$Area = 0.707 * h * (b+d) = 0.707 * (0.125\ in) * (4\ in + 6\ in) = 0.884\ in^2$$

The primary shear stress that opposes the downward external shear force can be calculated by dividing the external shear force by the total weld area.

$$\sigma' = \frac{5{,}000\ lbs}{0.884\ in^2} = 5{,}658\ psi$$

The correct answer is most nearly, **(c) 5,660 psi**.