SPINOFFS

Spinoffs are relatively short learning modules inspired by the LTAs. They can be easily implemented to support student learning in courses ranging from prealgebra through calculus. The Spinoffs typically give students an opportunity to use mathematics in a real world context.

LTA - SPINOFF 13A	Don't Tread On Me
LTA - SPINOFF 13B	Wait a Moment for the Shear fun of it all

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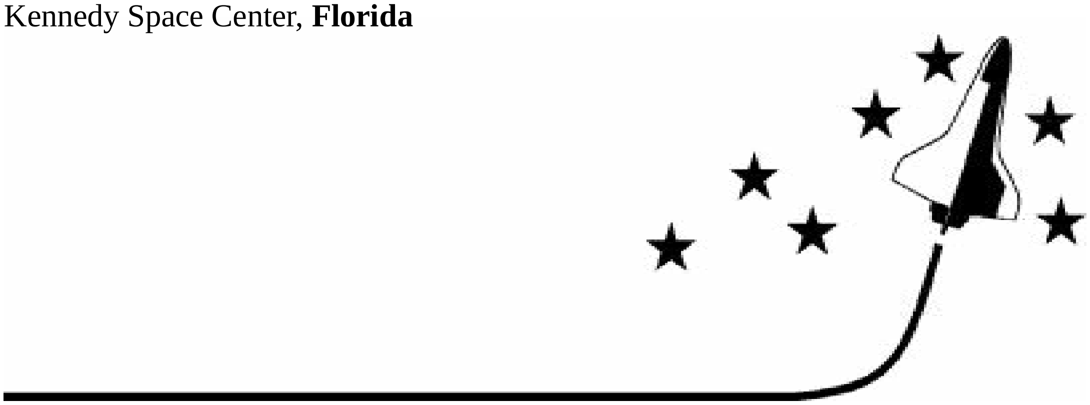

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SPINOFF 13B

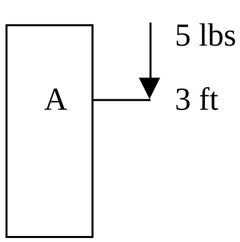
Wait a Moment for the Shear Fun of It All

You may have seen the Space Shuttle out on the launch pad ready to take off. It is an impressive sight, a vehicle weighing more than 4 million pounds (mostly from the fuel needed to lift off) ready to be blasted into space. What you may not know is how it got there. A special vehicle called a Crawler takes the Shuttle to the launch pad at the whopping speed of 1 mile per hour. NASA had to build a special road to get the Space Shuttle from the Vehicle Assembly Building, where fuel tanks are attached to the Orbiter, to the launch pad. Why? The weight of the Shuttle, the Crawler, and the mobile launch platform (MLP), all together over 17 million pounds, would crush a normal road. This special road called the Crawlerway consists of two lanes that are each 40 feet wide. The lanes are separated by a 50-foot median. The Crawlerway has four layers that support the huge weight. The top layer is from 4 to 8 inches of gravel. Below that is 3 feet of graded and crushed stone, then 2.5 feet of hydraulic fill, and finally 1 foot of selected fill. If you would like to see pictures of the Crawler and Crawlerway, go to the following web sites:
http://www.ksc.nasa.gov/facilities/crawler.html or
http://www.ksc.nasa.gov/facilities/crawlerway.html.

Krista Shaffer is an engineer at NASA's Kennedy Space Center in Florida. She has worked in the Construction Management office and currently works in the Joint Project Management office. You have been hired as her summer intern and are going to help her solve a critical problem that has been discovered by workers in the Maintenance and Operations office. There is a tunnel containing utility lines (gas, electric, etc.) that cuts underneath the Crawlerway at one point. This tunnel is used to get the necessary utilities to the launch pads. While inspecting the gas lines, workers from the Maintenance and Operations office noticed cracks in the concrete walls of the tunnel. As you might imagine, if this tunnel were to collapse there could be serious repercussions. The Space Shuttle is made up of numerous delicate instruments. If the tunnel were to collapse while the Shuttle was going over it, the Crawler and the Space Shuttle could be significantly damaged. The cost could easily run into millions of dollars. As reported by the engineering firm that was hired to look into the problem, "Since the failure of the existing tunnel … could produce unacceptable damages to the crawler-transporter, the MLP and/or the Space Shuttle, the structural safety of the tunnel is of vital importance." [Project Documentation, March 1994, RS&H]

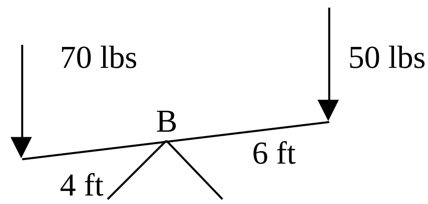
To tackle the tunnel problem, Krista Shaffer viewed the tunnel as if it were a beam supporting the road and anything on it. This worksheet will lead you through some of the ideas that Krista considered when solving this problem.

The torque of a system around some point is a measure of its tendency to turn around that point. Torque is found by multiplying force times distance. In this Spinoff, the force is the object's weight. (The concept of moment is closely related to torque. Moment is found by multiplying mass times distance rather than weight times distance. If both torque and moment are calculated for a situation on Earth, the results will only vary by the gravitational constant g.) For example, consider a beam with one end fixed to a wall and the other end holding a flowerpot weighing 5 lbs.



The torque about point A would be 3 ft * 5 lbs which equals 15 ft-lbs. (If you use the International System (SI) of measurement kg-m-s, the unit of torque would be a Newton-meter, N-m.) The greater the torque, the more the beam will tend to turn. Of course, we would not want to allow the torque to be so great that the beam breaks off.

For a more complicated example, let's consider a seesaw. A child is sitting on each end as shown in the diagram:

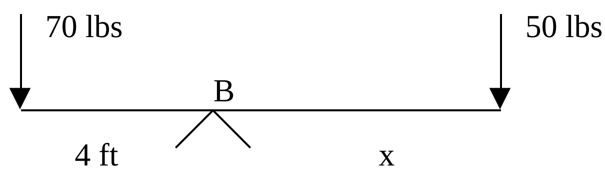


In this example, one child's weight tends to turn the seesaw clockwise and one tends to turn it counterclockwise. Since the forces are acting in opposite directions, the torques will be assigned opposite signs. Let's consider clockwise to be positive torque and counterclockwise to be negative torque.

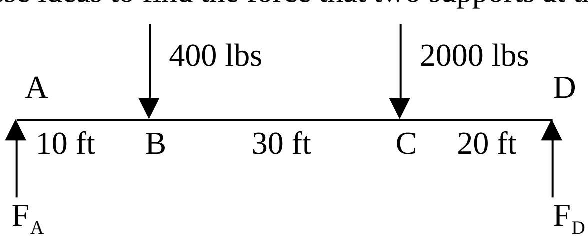
The torque about the point B is 50 lbs*6 ft + (-70 lbs)*(4 ft) which equals 20 ft-lbs.

1) Which way is the seesaw going to turn? Why?

2) Consider the seesaw below. At what distance x from point B should the fifty pound force be applied so that the seesaw balances? (That is, what value of x will make the torque zero.)



Let's use these ideas to find the force that two supports at the end of a beam exert on the beam.



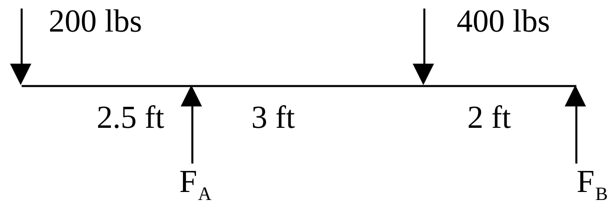
We have a 400-lb force located 10 ft from point A and a 2000-lb force located 40 feet from point A.

Let F_A represent the force the left support exerts upward on the beam, and F_D represent the force the right support exerts upward on the beam.

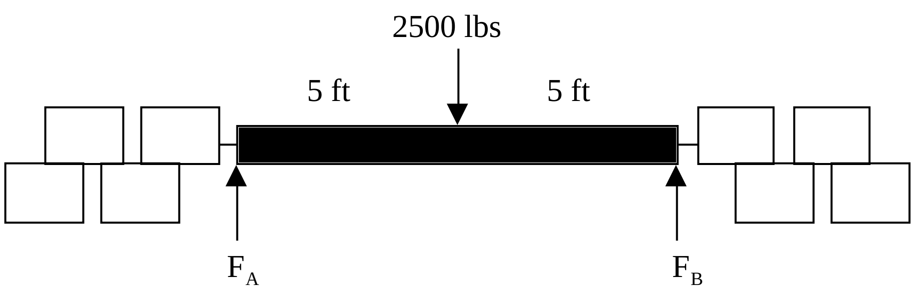
First, if the beam is not moving, then $F_A + F_D$ must equal 2400 lbs. (If these forces were not equal, the beam would start moving either up or down). Second, we know that the torque about point A must equal zero or the beam would be turning. So,
400 lbs*10 ft + 2000 lbs*40 ft + ($-F_D$ lbs)*60 ft = 0.

3) Use these two facts to determine the forces F_A and F_D.

4) Find the forces F_A and F_B being exerted by the two supports under the beam below:

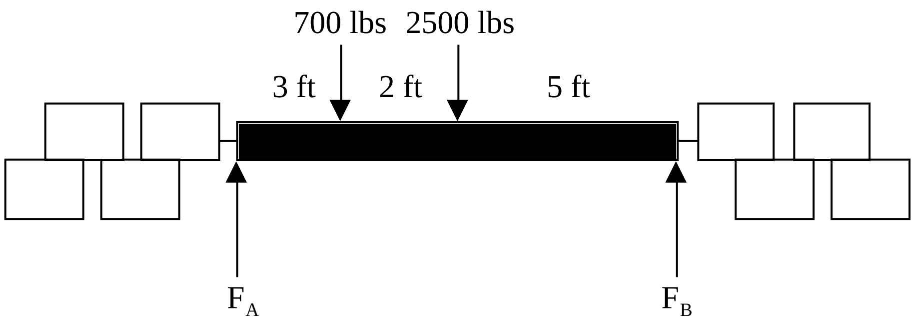


For a given beam that is supporting a load, we need to make sure the forces will not be so great as to break the beam. There are numerous factors to consider such as length of the beam, the material of which it is made, and the number of beams supporting the load. The tunnel problem mentioned at the beginning of this exercise is a complicated example of these ideas. Krista Shaffer, the engineer who worked on this problem, also worked on a simpler problem. A beam is placed across the top of an opening for an elevator. On each side of the beam and above it are cement blocks. Each end of the beam has a steel rod that goes from a block to the beam. The beam supports a uniform load (spread evenly across the beam) of approximately 2500 lbs, including the weight of the beam. In this case, we can treat the load as though it is concentrated at the center.



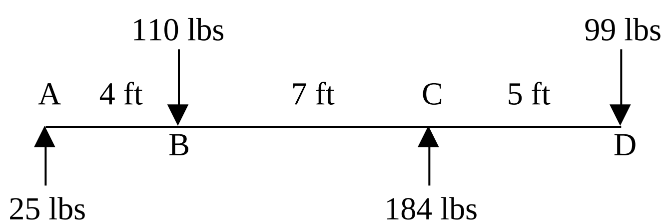
5) Use the diagram to determine forces F_A and F_B.

6) Suppose an engineer comes to you and asks if the structure could support an object weighing 700 lbs if its center was placed 3 feet from the left end of the beam. After looking through your resource manuals, you find that the steel rods on either end will be safe as long as neither F_A or F_B are more than 1600 lbs. Krista and her colleagues generally use a safety factor to make sure that they never get close to the actual limit of a material's abilities. With this in mind, figure in a 92% safety factor to assure that neither F_A or F_B exceed 92% of their maximum abilities. Can the engineer safely place her load on our beam?

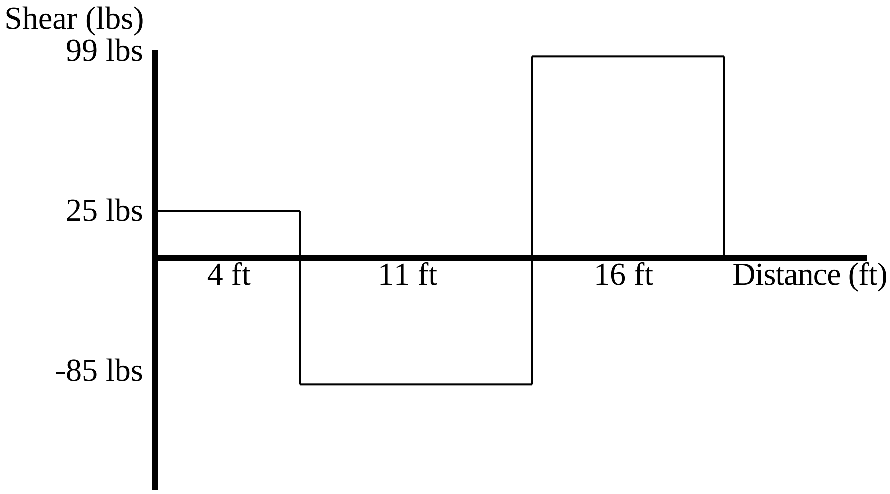


Extensions for Calculus

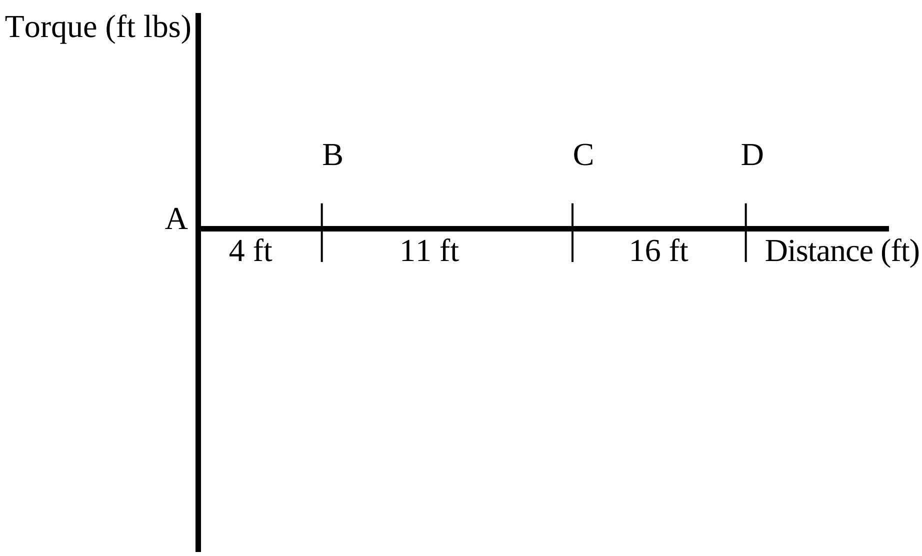
The shear on a beam is a measure of its tendency to want to tear apart. We can look at a graph of the shear at each point on a beam by simply showing the forces accumulated moving from left to right. For example, consider



This shear can be graphed as follows:



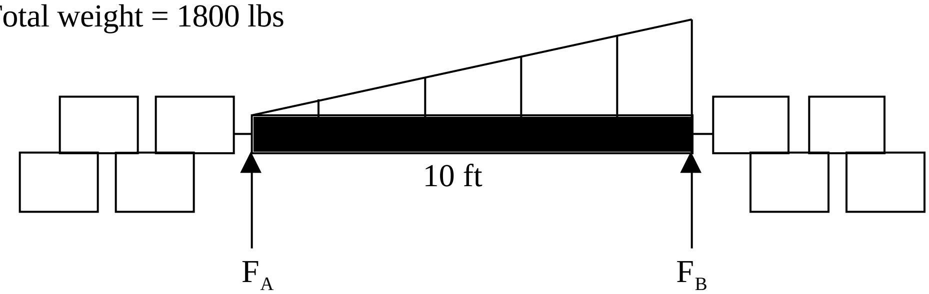
7) Consider the torque of the beam about each of the points A, B, C and D taking into account only the part of the beam to the left of the point. For example, the torque about A would be zero because there is no beam to the left of A. The torque about B would be (25*4) = 100 ft-lbs. Because there is one force of 25 pounds to the left of B, and it is pushing clockwise, we count it as positive. Now, find the torque to the left of C and to the left of D. Next, plot these points on the graph below. It turns out that the torque graph in this case will be piecewise linear, so the points can be connected with lines to create a piecewise linear graph.



8) Look at the shear and the torque graphs very carefully. What is the relationship between shear and torque?

9) What if the load on the beam is not uniform? Suppose the load on the beam is distributed as shown below:

Total weight = 1800 lbs



There is a total weight on the beam of 1800 lbs. As you can see, more of the weight is concentrated at the right end than the left. Suppose that the density of the load is uniform and that the load rises to a height of 2 feet at the right end of the beam. Use calculus to find F_A and F_B. Are we within safety limits?