Calculating Cable Tension

Subject(s): Science/Math

Grade Level: 9th – 12th

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Objectives: To demonstrate the effect of cable geometry on cable tension and to show the trigonometric relationship between cable geometry and cable tension.

Materials Needed: Known weight, tape measure, small diameter rope or cable, pulley and spring scale.

Background:

The most efficient way to lift and support a load is to lift if vertically. This might be possible in logging with a helicopter or balloon, but does not work with cable yarding systems. In these systems, the cable is fixed at both ends and suspended over the operating area and some of the lifting capacity of the cable is lost to forces acting in the horizontal, rather than the vertical direction.

The lifting capacity of the cable, often called wire rope in logging, is a function of its size … primarily its diameter. Lifting capacity is directly proportional to the square of the diameter or the end area of the cable. Depending on the type of steel used to construct the cable and the strength of the material used in its middle section (core), cable of a given size will have a measured capacity of a certain number of pounds of breaking strength. A ¾ inch wire rope used as a skyline in logging, for example, would have a breaking strength of 58,800 pounds. You would not operate a cable up to its breaking strength, however. A wire rope acts like a spring that stretches under load and returns to its original shape when the load is released. Just like a spring that is overloaded, however, if the cable is loaded past what is called its elastic limit, it will not return to its original shape. This occurs at a load of about half of the breaking strength and will severely weaken the cable for future applications. Cables are usually operated with a factor of safety to prevent the cable from being stretched beyond its elastic limit and to guard against sudden dynamic loads that may occur in logging. With a factor of safety of 3, the effective safe working load of the inch cable would be 58,800/3 or 19,600 pounds. This would be the value used to plan the number of logs a cable could carry each logging cycle.

Procedure:

1. Use a single cable or rope to lift the known weight vertically. Measure the tension in the cable with the spring scale. What should the scale read?
2. Now loop the cable or rope through a pulley. Attach the pulley to the load and lift the load vertically with both ends of the cable. Measure the tension in each of the cable segments

   What is the tension in the two halves of the cable? If it is lower, why?

   Will the tension be the same throughout the cable?
3. Tie one end with a spring scale to a fixed object. Measure the height of the scale above the floor. With the weight still tied to the pulley, move a distance of 10 feet from the fixed end of the cable. Keeping the height of the end of the cable the same as at the fixed end, pull on the cable until the weight is completely suspended by the cable. Measure the tension in each end of the cable, the horizontal distance from the weight to the person holding the free end of the cable. Measure the length of the cable from the fixed end to the weight and the distance of the load above the floor.

   Why is the cable tension higher than when the load was lifted vertically?

   How much of the load weight is being supported by each end of the cable?

   Without direct measurement, determine the amount of vertical deflection of the cable (the distance from a chord line connecting the end points and the load).
4. Move the free end of the cable back another 10 feet. Repeat the experiment and measurements of part 3 and calculate the vertical deflection.

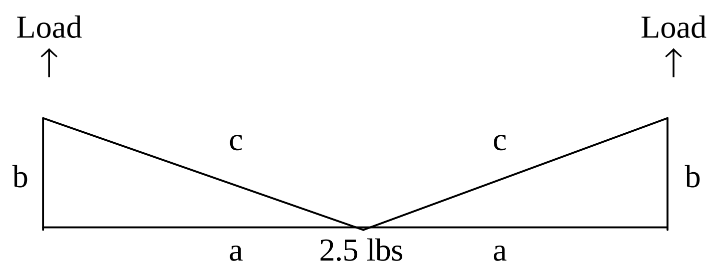
   What is happening to the tension cable? Why?

5. Now lower the fixed end of the cable by 1 foot and repeat the experiment at the same distances as used in part 3. Keep the free end of the cable the same height as the fixed end. Repeat the measurements and calculations of part 3. How does cable tension compare to that of part 3? Why is it higher?

The theoretical distribution of load in the cable can be calculated from the dimension of the triangle formed by the cable, and the floor. The amount of tension in each cable segment will be proportional to the length arm of the triangle as follows:

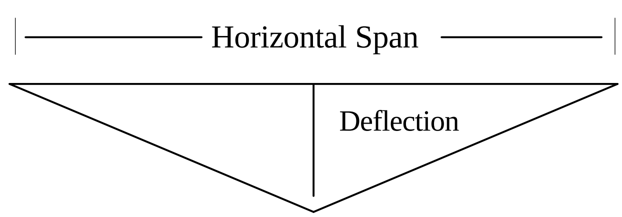
$$\frac{\text{Length a}}{\text{Tension a}} = \frac{\text{Length b}}{\text{Tension b}} = \frac{\text{Length c}}{\text{Tension c}}$$

Where the triangle has the dimensions shown below:



a. How much of the load will be carried vertically by each end of the cable?

2. Calculate the theoretical tension in the cable and compare it with the observed values for parts 3, 4 and 5.
   a. Knowing the length of the triangle arms, how else could you calculate tension?



$$\text{\% Deflection} = \left[\frac{\text{Deflection}}{\text{Horizontal Spar}}\right] 100\%$$

3. Calculate the percent deflection for the setting you developed in parts 3, 4 and 5.
   a. What happened to percent deflection as the horizontal span increased?
   b. What happened to percent deflection when the vertical distance decreased
   c. What is the relationship between percent deflection and the tension in the cable?
   d. How does tension in the span relate to the load it can carry?
   e. What would limit the percent deflection in a real cable setting?

CALCULATION OF CABLE TENSION – EXAMPLE

Assume the load is located 4 feet from the chord line with a horizontal span of 20 feet. The load is 2.5 pounds.

The hypotenuse of the right triangle (length of arm "c") is

$$\text{Length c} = \sqrt{\text{Length a}^2 + \text{Length b}^2} = \sqrt{(4^2 + 10^2)} = 10.77$$

Use this length and the ratio of length to tension to calculate the tension in arm "c" of the triangle.

$$\frac{\text{Length a}}{\text{Tension a}} = \frac{\text{Length c}}{\text{Tension c}} \qquad \frac{4}{1.25} = \frac{10.77}{\text{Tension c}}$$

$$\text{Tension c} = \frac{(10.77)\,(1.25)}{4} = 3.37$$

You can also calculate percent deflection from the amount of deflection (4 feet) and the horizontal span (10 + 10 = 20 feet).

$$\text{Percent Deflection} = \frac{4\text{ ft}}{20\text{ ft}}\,(100\%) = 20\%$$