The Case of the OVERLOADED SLING

By Mitch Ricketts

Math Toolbox is designed to help readers apply STEM principles to everyday safety issues. Many readers may feel apprehensive about math and science. This series employs various communication strategies to make the learning process easier and more accessible.

Workers use slings (in conjunction with cranes and other lifting machines) to move heavy loads that would be difficult to handle by other means. Slings may be constructed of chain, wire rope, metal mesh, synthetic fibers, webbing and other materials. As Figure 1 illustrates, loaded slings can sometimes fail, with potentially devastating effects for anyone working nearby.

Slings fail for many reasons, including overloading, improper rigging or components that have been damaged by prior use. No specific cause was reported for the case illustrated in Figure 1 in which a falling steel beam seriously injured a young worker; however, one common reason for sling failure in general is hitching at angles that create too much tension in the sling legs, causing the sling to pull apart.

One fact that is known about the case in Figure 1 is that the load was rigged using a two-leg bridle hitch: Each sling leg was attached separately to the beam at bottom, and both legs were attached to a single fitting at top. This arrangement gives the bridle-hitch sling its characteristic shape of an inverted V.

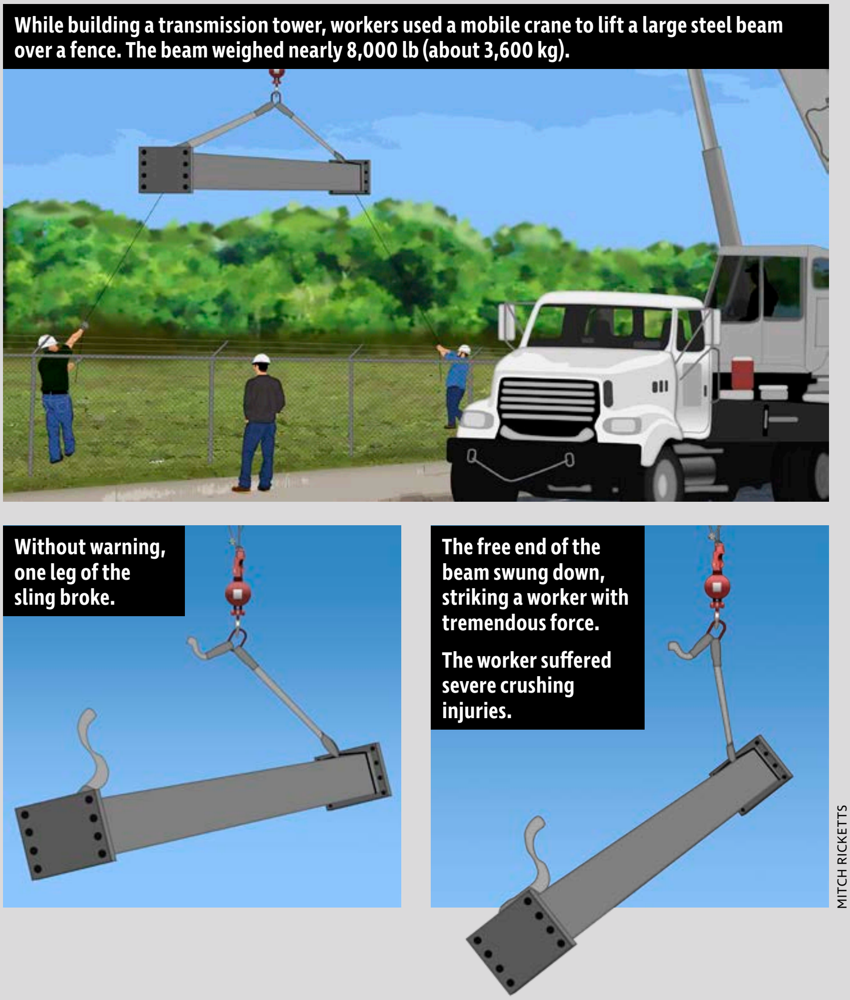
Slings with bridle hitches are used in many workplaces, mainly because they are versatile and provide adequate stability for an assortment of loads. Unfortunately, bridle hitches are subject to substantial internal stresses, especially when the legs are rigged at improper angles.

This article focuses on the stresses created in slings with two-leg bridle hitches. For comparison, the article also examines stresses in slings with vertical hitches. We can use this knowledge to help operators understand why manufacturers' angle-dependent load ratings should never be exceeded. As will be demonstrated in a future article, we can also use this knowledge to calculate acceptable loads at sling angles that may not be listed in manufacturers' labels and charts.

The calculations presented here assume that slings are used in accordance with guidance published by manufacturers, American Society of Mechanical Engineers (ASME, 2018) and OSHA (2020).

FIGURE 1

SLING FAILS TRAGICALLY AT CONSTRUCTION SITE



Note. Adapted from "Young Worker Seriously Injured by Falling Steel Beam (Hazard Alert: Injury 2010-10)," by WorkSafe BC, 2010.

Sling & Rigging Concepts

This discussion applies to slings that have no more than two evenly loaded legs rigged with vertical or bridle hitches. Vertical hitches are rigged perpendicularly to the load. Bridle hitches are rigged at acute angles, with legs attached to a single fitting at top. Figure 2 illustrates examples of slings with bridle and vertical hitches within the scope of this article.

FIGURE 2

BRIDLE & VERTICAL SLING HITCHES

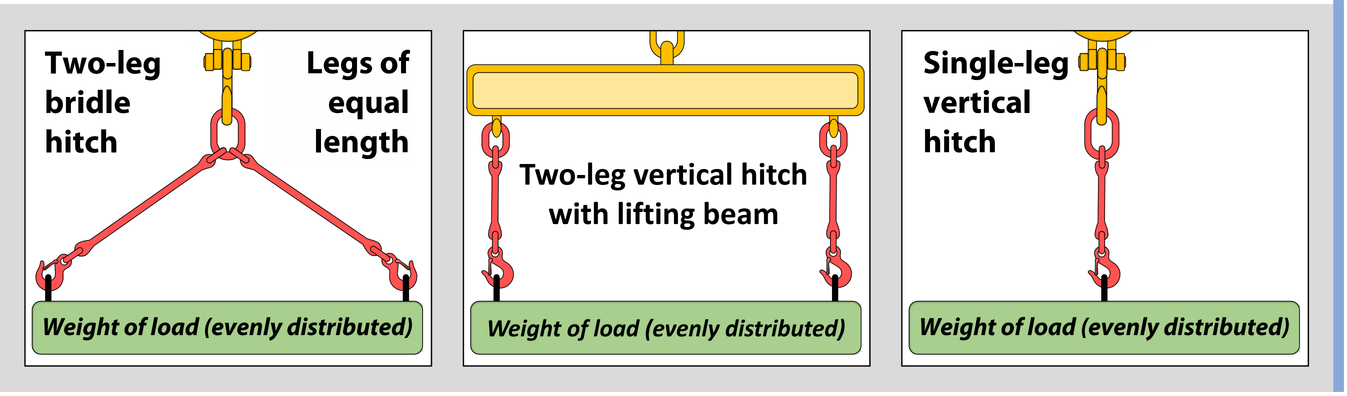
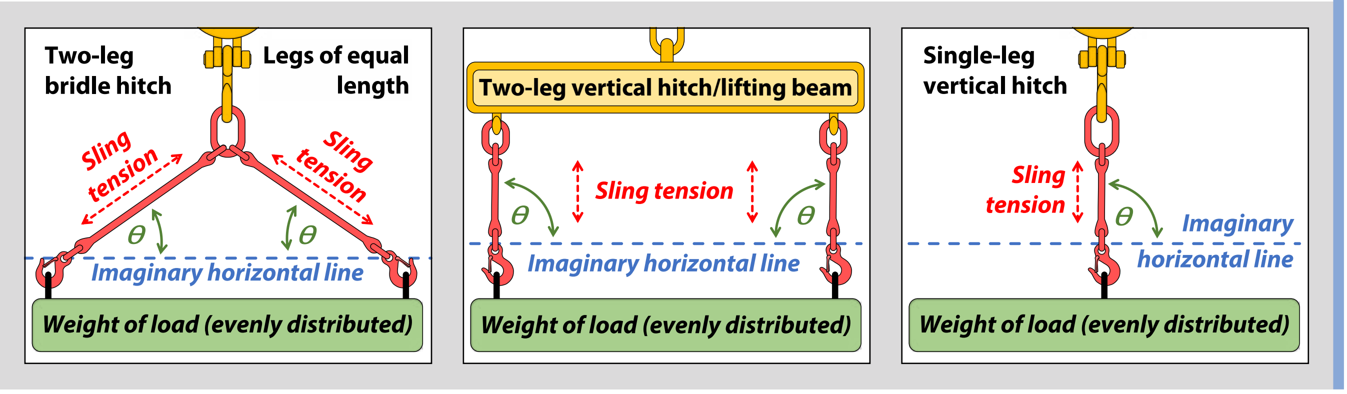


FIGURE 3

TENSION IN BRIDLE- & VERTICAL-HITCH SLING LEGS



An important concept for any sling hitch is the angle of loading (sometimes called the horizontal angle). This angle is important because it affects the internal stresses within each sling leg. Figure 3 illustrates the angle of loading (θ). For loads being lifted upward, as examined in this article, the angle of loading is the acute angle between the sling leg and the horizontal plane. (For nonvertical load handling, the angle of loading is more generally defined as the acute angle between the sling leg and the plane perpendicular to the direction of pull.)

All else being equal, angles of loading near 90° create the least stress within slings, while angles near 0° are more likely to cause sling failure. Most standards and regulations prohibit loading angles of less than 30° (unless approved by a qualified person) due to the extreme stresses involved.

Other concepts related to the safe loading of slings include the designed breaking load, rated load and design factor.

•The **designed breaking load** is the minimum load that will cause a new sling to break due to internal stresses. In practice, we should never load a sling to its designed breaking load. Instead, we must incorporate an appropriate margin to account for uncertainties that may cause the sling to break unexpectedly. The appropriate margin is generally provided when we observe the sling's rated load, which is also known as the rated capacity or working load limit (WLL).

•The **rated load** is the maximum allowable load printed on the manufacturer's label that is attached to the sling. The rated load is calculated as the designed breaking load divided by the design factor. For example, if a sling has a designed breaking load of 12,000 lb and a design factor of 4, the rated load is 3,000 lb (12,000 lb ÷ 4 = 3,000 lb).

•The **design factor** is a number that accounts for uncertainties in sling performance during actual load handling. Readers may have already deduced that the design factor equals the designed breaking load divided by the rated load. For example, if a sling has a designed breaking load of 5,000 lb and a rated load of 1,000 lb, the design factor is 5 (5,000 lb ÷ 1,000 lb = 5). Design factors of at least 4 or 5 are commonly required by standards such as ASME B30.9-2018.

To prevent sling failure, we must rig loads stably and handle them smoothly so that slings are not subject to shock loading. Shock load is a brief increase in force caused by the sudden movement, shifting or stopping of a load. Other factors that may cause premature failure of slings include exposure to extreme temperatures, incompatible chemicals and ultraviolet light (for some materials).

A major objective of safe rigging is to avoid excessive tension within sling legs and other sling components. Tension can be defined simply as a pulling force within a material. Extreme tension can stretch a sling or pull it apart. Slings are at increased risk of breaking any time the internal tension exceeds the rated load. For slings that have no more than two evenly loaded legs rigged with vertical or bridle hitches, tension in each sling leg is calculated as the weight of the load divided by the product of the number of sling legs and the sine of the loading angle, as follows:

$$T_{per\ sling\ leg} = \frac{W}{N \cdot sin\,\theta}$$

where:

T = tension (pull) in each sling leg due to the force of the load and the angle of loading in vertical- and bridle-hitch slings with no more than two legs

W = weight of the load (including the weight of any hardware added between the sling and the load)

N = number of sling legs

θ = angle of loading (angle from horizontal)

sin = sine of the angle

Note: Additional factors (which are not explored in this article) must be considered to determine the sling tension for other types of hitches (such as choker and basket hitches) as well as for slings with more than two legs and slings with legs that are not evenly loaded.

Figure 3 (p. 49) illustrates the components of the equation for bridle- and vertical-hitch sling legs.

FIGURE 4
CALCULATING SLING TENSION

At loading angles less than 90°, the tension in the left sling leg plus the tension in the right sling leg exceeds the weight of the entire load (6,974 lb left + 6,974 lb right = 13,948 lb, in this example).

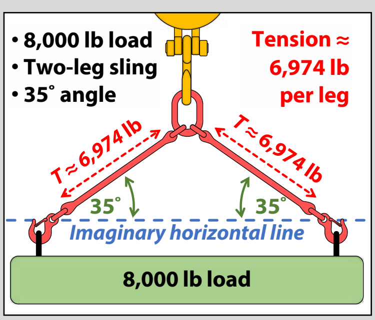


FIGURE 5
CALCULATING SLING TENSION

At a 90° angle of loading, tension is simply the weight of the load divided by the number of sling legs. This is because the sine of 90° is 1, within the denominator.

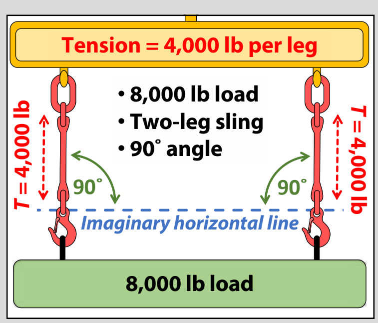


FIGURE 6
CALCULATING SLING TENSION

For a single-leg sling at a 90° angle of loading, tension equals the weight of the load. This is because the sine of 90° is 1 and the number of sling legs is also 1, resulting in a value of 1 for the denominator.

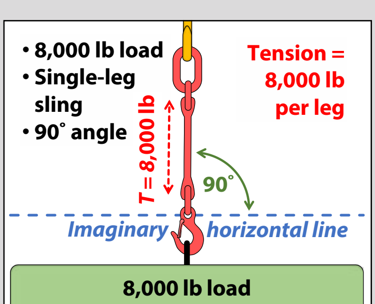
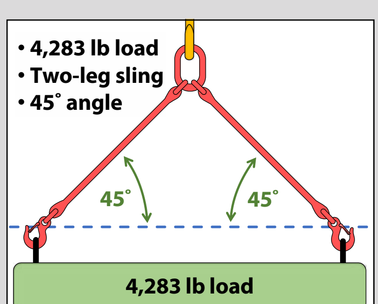


FIGURE 7
YOU DO THE MATH, QUESTION 1



Calculating Sling Tension

The angle of loading was not recorded in the case that introduced this topic, so we will calculate sling tension using hypothetical values. With that in mind, imagine that a two-leg sling supports a load of 8,000 lb (including the weight of any hardware attached between the sling and the load). The acute angle of each sling leg is 35° from horizontal. Assuming that the sling's own weight is insignificant, what is the tension within each sling leg in pounds (lb)? This problem is illustrated in Figure 4, and the data can be summarized as follows:

- The load weighs 8,000 lb. This is the value of W in the formula.
- The sling has two legs. This is the value of N in the formula.
- The angle of loading is 35°. This is the value of θ in the formula.

Based on these data, we can calculate the tension per sling leg, $T_{per\ sling\ leg}$, as follows:

Step 1: Start with the equation for tension per sling leg:

$$T_{per\ sling\ leg} = \frac{W}{N \cdot sin\,\theta}$$

Step 2: Insert the known values for weight of the load (W = 8,000 lb), number of sling legs (N = 2) and angle of loading (θ = 35°). Then solve for $T_{per\ sling\ leg}$:

$$T_{per\ sling\ leg} = \frac{8{,}000}{2 \cdot sin\,35} = 6{,}973.79\ lb$$

Note 1: Most calculators have a *SIN* button that will provide the correct answer with keystrokes similar to the following in this case: *8000÷(2XSIN35)=*.

Note 2: If your calculation results in -9,341.81 lb per sling leg, it is likely that your calculator is set to interpret angles in units of radians instead of degrees. The calculator manual will explain how to select the degree function (for example, many calculators have a dedicated button that toggles between *DEG*, for degrees, and *RAD*, for radians). The procedure is a bit different in an Excel spreadsheet because the program actually requires converting the angle to radians before applying the sine function. You can calculate the answer in Excel for this example with the following cell formula: *=8000/(2*SIN(RADIANS(35)))*.

Step 3: Our calculation indicates the tension within the left sling leg is 6,973.79 lb and the tension in the right sling leg is also 6,973.79 lb. Even with the load divided between two sling legs, the angle of 35° creates so much stress that the tension within just one leg is equal to 87% of the entire load. The tension becomes even more extreme as angles get smaller. For example, a loading angle of 30° in a two-leg sling will create tension in a single leg that equals the full weight of the load. For angles less than 30° in a two-leg sling, the tension within a single leg will actually exceed the weight of the complete load. We will see an example of this in Problem 3 of "You Do the Math."

Alternate example: Let's calculate the tension per sling leg using a different example. Once again, suppose the sling has two legs and supports a load of 8,000 lb. This time, however, imagine that the rigging employs vertical hitches. To keep both sling legs vertical, we attach them to a lifting beam at top. Since the sling legs are vertical, the angle of loading is 90°. The data are summarized as follows (illustrated in Figure 5):

•The load weighs 8,000 lb. This is the value of W in the formula.

•The sling has two legs. This is the value of N in the formula.

•The angle of loading is 90°. This is the value of θ in the formula.

To calculate the new value for tension per sling leg, we use the original equation:

$$T_{per\ sling\ leg} = \frac{W}{N \cdot sin\,\theta}$$

Next, insert the current values for weight of the load (W = 8,000 lb), number of sling legs (N = 2) and angle of loading (θ = 90°) to obtain the following result:

$$T_{per\ sling\ leg} = \frac{8{,}000}{2 \cdot sin\,90} = 4{,}000\ lb$$

The calculated value of 4,000 lb per sling leg indicates tension was reduced dramatically when we changed the angle of loading from 35° to 90°. This is because the sine of 35° in the denominator of the first example is about 0.57, while the sine of 90° in the denominator of the second example is 1.0. Since the sine of 90° is 1, the equation for two-leg vertical-hitch slings can be reduced to $T_{per\ sling\ leg} = W \div N$. In other words, for two-leg slings with vertical hitches, the tension per sling leg is simply one-half the weight of the entire load. *Note:* If your calculation resulted in 4,474.29 lb per sling leg, see Note 2 in the first example. In Excel, you can calculate this example with the following cell formula: *=8000/(2*SIN(RADIANS(90)))*.

A final example: Once again, imagine that a sling supports a load of 8,000 lb. This time, however, the sling consists of only one vertical leg, with an angle of loading equal to 90°. The data are summarized as follows (illustrated in Figure 6):

•The load weighs 8,000 lb. This is the value of W in the formula.

•The sling has one leg. This is the value of N in the formula.

•The angle of loading is 90°. This is the value of θ in the formula.

To calculate tension in the single sling leg, we use the original equation:

$$T_{per\ sling\ leg} = \frac{W}{N \cdot sin\,\theta}$$

Next, we insert the current values for weight of the load (W = 8,000 lb), number of sling legs (N = 1) and angle of loading (θ = 90°):

$$T_{per\ sling\ leg} = \frac{8{,}000}{1 \cdot sin\,90} = 8{,}000\ lb$$

The result of 8,000 lb per sling leg is not unexpected, given that a single vertical sling leg is supporting the entire load. In fact, since the sine of 90° is 1 and the number of legs is also 1, the equation for single-leg vertical slings can be reduced to $T_{per\ sling\ leg} = W$, or simply, tension equals the weight of the load. *Note:* If your calculation resulted in 8,948.58 lb per sling leg, see Note 2 in the first example. In Excel, you can calculate this example with

FIGURE 8
YOU DO THE MATH, QUESTION 2

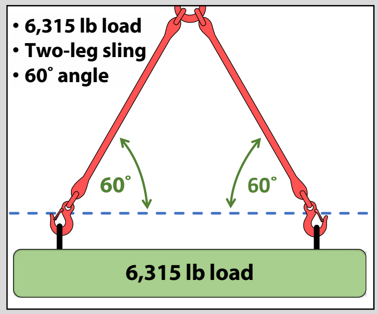


FIGURE 10
HOW MUCH HAVE I LEARNED, QUESTION 4

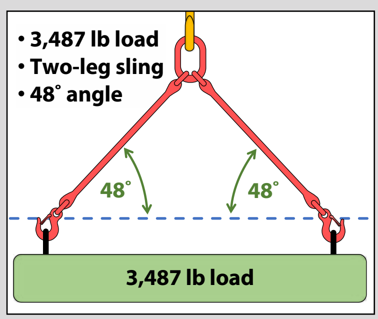


FIGURE 9
YOU DO THE MATH, QUESTION 3

This is a potentially hazardous angle of loading.

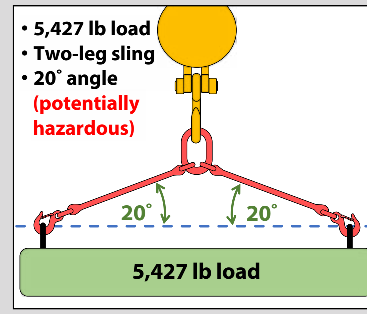
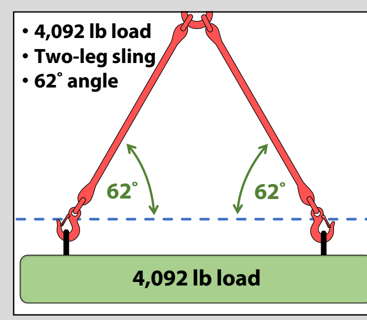


FIGURE 11
HOW MUCH HAVE I LEARNED, QUESTION 5



the following cell formula: *=8000/(1*SIN(RADIANS(90)))*.

You Do the Math

Apply your knowledge to the following questions. Answers are on p. 55.

1) A two-leg bridle-hitch sling supports a load of 4,283 lb (including the weight of any hardware attached between the sling and the load). The angle of each sling leg is 45° from horizontal. Assuming that the weight of the sling is insignificant, what is the tension within each sling leg in pounds (lb)? Use the equation for $T_{per\ sling\ leg}$. This problem is illustrated in Figure 7 (p. 50).

2) A two-leg bridle-hitch sling supports a load of 6,315 lb (including the weight of any hardware attached between the sling and the load). The angle of each sling leg is 60° from horizontal. Assuming that the weight of the sling is insignificant, what is the tension within each sling leg in pounds (lb)? Use the equation for $T_{per\ sling\ leg}$. This problem is illustrated in Figure 8 (p. 51).

3) A two-leg bridle-hitch sling supports a load of 5,427 lb (including the weight of any hardware attached between the sling and the load). The angle of each sling leg is 20° from horizontal. This problem is illustrated in Figure 9 (p. 51).

a) Assuming that the weight of the sling is insignificant, what is the tension within each sling leg in pounds (lb)? Use the equation for $T_{per\ sling\ leg}$.

b) Explain why this angle of loading is potentially hazardous.

Relating Our Knowledge to Sling Labels & Charts

Our discussion so far has illustrated that forces created in sling legs depend not only on the weight of the load and number of sling legs, but also on the angle of loading. Rated loads described in manufacturers' labels and charts are based in part on the calculations explored in this article. For example, a manufacturer may list a 2,300-lb-per-leg rated load for a vertical hitch, but only a 1,626-lb-per-leg rated load for a bridle hitch at a 45° angle of loading. This is because both loads create the same tension per sling leg, as follows:

$$T_{per\ leg\ at\ 2{,}300\ lb\ and\ 90°} = \frac{2{,}300\ lb}{1 \cdot sin\ 90} = 2{,}300\ lb$$

$$T_{per\ leg\ at\ 1{,}626\ lb\ and\ 45°} = \frac{1{,}626\ lb}{1 \cdot sin\ 45} = 2{,}300\ lb$$

Workers use slings (in conjunction with cranes and other lifting machines) to move heavy loads that would be difficult to handle by other means. Slings fail for many reasons, including overloading, improper rigging or components that have been damaged by prior use.

In a future article, we will calculate rated loads for bridle hitches at sling angles that may not be listed in manufacturers' labels and charts.

How Much Have I Learned?

Try these problems on your own. Answers are on p. 55.

4) A two-leg bridle-hitch sling supports a load of 3,487 lb (including the weight of any hardware attached between the sling and the load). The angle of each sling leg is 48° from horizontal. Assuming that the weight of the sling is insignificant, what is the tension within each sling leg in pounds (lb)? Use the equation for $T_{per\ sling\ leg}$. This problem is illustrated in Figure 10 (p. 51).

5) A two-leg bridle-hitch sling supports a load of 4,092 lb (including the weight of any hardware attached between the sling and the load). The angle of each sling leg is 62° from horizontal. Assuming that the weight of the sling is insignificant, what is the tension within each sling leg in pounds (lb)? Use the equation for $T_{per\ sling\ leg}$. This problem is illustrated in Figure 11 (p. 51).

The Language of Sling Leg Tension

Readers will encounter the following concepts in codes, certification exams, and conversations with other professionals. Match the numbered concepts with their paraphrased definitions (lettered). All concepts have been defined in the text, formulas and illustrations. Answers are on p. 55.

Concepts

6) angle of loading (θ)
7) bridle hitch
8) design factor
9) designed breaking load
10) rated load (rated capacity, working load, WLL)
11) shock load
12) tension (T)
13) vertical hitch

Definitions (in random order)

a) A number calculated as the designed breaking load divided by the rated load.
b) Acute angle between the sling leg and the horizontal plane (for loads being lifted upward).
c) A brief increase in force caused by the sudden movement, shifting or stopping of a load.
d) A hitch with the sling leg(s) attached perpendicularly to the load.
e) A hitch with two or more sling legs at acute angles, attached to a single fitting at the top.
f) The maximum allowable load printed on the manufacturer's sling label (calculated as the designed breaking load divided by the design factor).
g) The minimum load that will cause a new sling to break due to internal stresses.
h) A pulling force within a material.

For Further Study

Learn more from the following source: *ASSP's ASP Examination Prep: Program Review and Exam Preparation*, edited by Joel M. Haight, 2016. **PSJ**

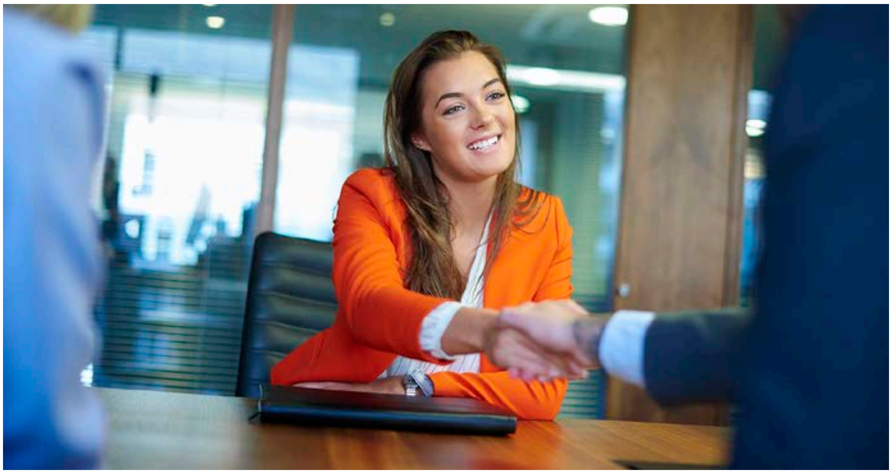
References

American Society of Mechanical Engineers (ASME). (2018). Slings (ASME B30.9-2018). New York, NY: Author.

OSHA. (2020). Guidance on safe sling use. Retrieved from www.osha.gov/dsg/guidance/slings/index.html

WorkSafe BC. (2010). Young worker seriously injured by falling steel beam (Hazard alert: injury 2010-10). Retrieved from www.worksafebc.com/en/resources/health-safety/hazard-alerts/young-worker-seriously-injured-by-falling-steel-beam

Mitch Ricketts, Ph.D., CSP, is an associate professor of safety management at Northeastern State University (NSU) in Tahlequah, OK. He has worked in OSH since 1992, with experience in diverse settings such as agriculture, manufacturing, chemical/biological laboratories and school safety. Ricketts holds a Ph.D. in Cognitive and Human Factors Psychology from Kansas State University, an M.S. in Occupational Safety Management from University of Central Missouri, and a B.S. in Education from Pittsburg State University. He is a professional member and officer of ASSP's Tulsa Chapter, and faculty advisor for the Society's NSU Broken Arrow Student Section.



STURTI/E+/GETTY IMAGES

No matter what industry you work in, being an effective safety professional is less about enforcing regulations, programs and audits, and more about managing the different personalities one encounters in the workforce.

sionals also have the unique challenge of influencing other employees we do not directly supervise. These individuals typically include salaried team members who work in departments such as human resources, management, information technology and others. Safety professionals will inevitably work with and need the assistance of these individuals. For example, assistance from human resources counterparts could be in the form of a discipline plan for safety rule infractions, or assistance from information technology may involve a rollout of a new injury reporting software.

Following the aforementioned tips about understanding different perspectives and being relatable will help you in this mission. However, it is also important to find ways to serve these coworkers, invoking the reciprocity principle. In his book, *Influence: The Psychology of Persuasion*, Cialdini (2006) states that human beings are wired to return favors and pay back debts. In practice, if a coworker needs help coordinating an improvement project or seeks a weekend volunteer, find a way to help. The next time you ask the coworker for assistance, s/he will find it difficult to say no because, in theory, the person would feel the need to repay the previous favor. This reciprocity principle can be useful; more importantly, it works with any group of people. A word of caution: Do not be the safety professional who, in an effort to provide help, takes on more responsibility than can be effectively managed. For the reciprocity principle to work, there must be balance and repayment.

Conclusion

Employing safety professionals with a strong educational foundation in the safety sciences is the minimum needed for most workplaces today; safety professionals must have knowledge of safety principles and regulations gained through formal education. However, new safety graduates who believe that their education has prepared them for the dynamics of a real workplace may become frustrated when things are not as clear-cut as some compliance literature makes them seem.

Take what you learned in university and apply it, but also recognize that the end goal is the well-being of employees. Reaching that goal may require some adaptability, professional experience and growth. Additionally, to be taken seriously and to be most effective, safety professionals must earn the trust and respect of the people they work with. That is why one must strive to find perspective, develop trustworthiness by being relatable and honest, and, when necessary, invoke the reciprocity principle to influence the action of others. If done right, the transition from academia to the workplace can be successful in creating strong, effective safety cultures in businesses. **PSJ**

References

Cialdini, R.B. (2006). *Influence: The psychology of persuasion*. New York, NY: Harper Business.

Greengard, S. (2012, Jan. 4). Playing it safe: A look at workplace safety during the roaring '20s and now. *Workforce*. Retrieved from www.workforce.com/2012/01/04/playing-it-safe-a-look-at-workplace-safety-during-the-roaring-20s-and-now

Hill, W.E. (1915, Nov. 6). My wife and my mother-in-law. They are both in this picture—find them [Illustration]. *Puck, 78*(2018), 11. Retrieved from www.loc.gov/pictures/item/2010652001

Kory Pearson, M.B.A., CSP, is currently working as a safety specialist for a tire manufacturer, and has 10 years of experience in various roles and industries. He holds an M.B.A. from Union University and a B.S. in Occupational Safety and Health from Murray State University. Pearson is a professional member of ASSP's Augusta Chapter.

Math Toolbox, continued from pp. 48-52

Answers: The Case of the Overloaded Sling

You Do the Math

Your answers may vary slightly due to rounding.

1) $T_{per\ sling\ leg} = \dfrac{4{,}283}{2 \cdot sin\ 45} = 3{,}028.54\ lb$

2) $T_{per\ sling\ leg} = \dfrac{6{,}315}{2 \cdot sin\ 60} = 3{,}645.97\ lb$

3a) $T_{per\ sling\ leg} = \dfrac{5{,}427}{2 \cdot sin\ 20} = 7{,}933.74\ lb$

3b) Due to the extreme stresses created by sling angles of less than 30°, most standards and regulations would prohibit the 20° angle of loading unless approved by a qualified person. Note that the stress on each sling leg, individually (7,933.74 lb per leg), is greater than the weight of the entire load (5,427 lb).

How Much Have I Learned?

4) $T_{per\ sling\ leg} = \dfrac{3{,}487}{2 \cdot sin\ 48} = 2{,}346.11\ lb$

5) $T_{per\ sling\ leg} = \dfrac{4{,}092}{2 \cdot sin\ 62} = 2{,}317.24\ lb$

The Language of Sling Leg Tension

6) b; 7) e; 8) a; 9) g; 10) f; 11) c; 12) h; 13) d.