Name: ___________________________________ Date: __________

Class: _____________________________ Period: _____

Crane & Rigging

Operator Training

What is rigging and why am I here?

As we explore the manufacturing industry, you will find that many operators and maintenance crew are trained rigging professionals. They are needed to use cranes to safely transport heavy machines, engines, etc from one place to another throughout the plant. Rigging is NOT "simply hooking up a chain" to a piece of machinery and lifting it. That's a great way to endanger everyone's life, including your own.

"The cause of rigging accidents can often be traced to a lack of knowledge on the part of a rigger. Training programs such as the Infrastructure Health & Safety Association's Basic Safety Training for Hoisting and Rigging provide workers with a basic knowledge of principles relating to safe hoisting and rigging practices in the construction industry. A safe rigging operation requires the rigger to know

- the weight of the load and rigging hardware
- the capacity of the hoisting device
- the working load limit of the hoisting rope, slings, and hardware.

…Most crane and rigging accidents can be prevented by field personnel following basic safe hoisting and rigging practice." IHSA, Health and Safety Manual

Remember, when you have a several ton object suspended in midair, the safety of you and everyone else on the job site depends on how well you have performed your calculations and made your selections.

Let's begin!

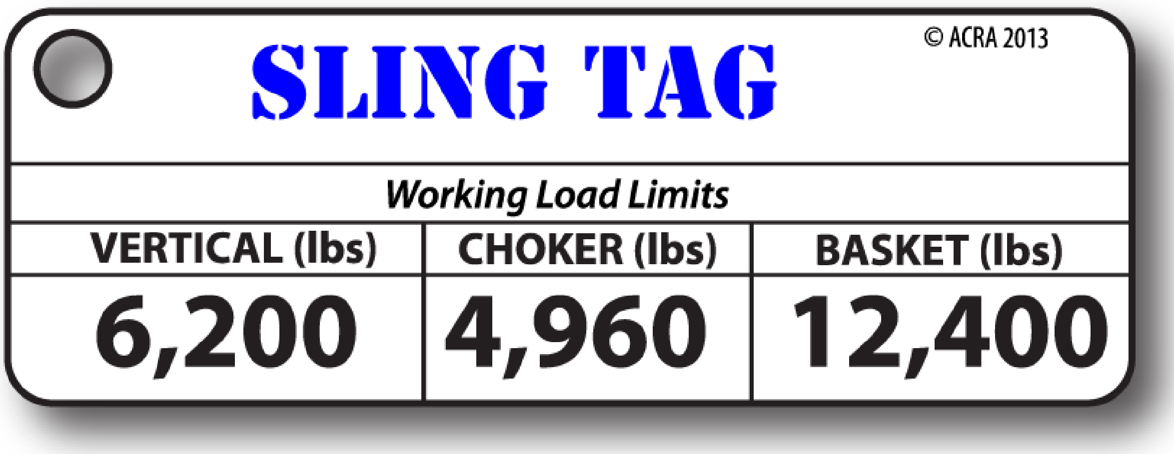
Rigging Basics

Definitions:

- WLL (Working Load Limit): The maximum amount of weight a piece of lifting equipment can handle without fear of breaking.
- Sling: The chain or rope that will be attached the object in need of lifting.
- Hitch: The way the sling is attached to the object in need of lifting.

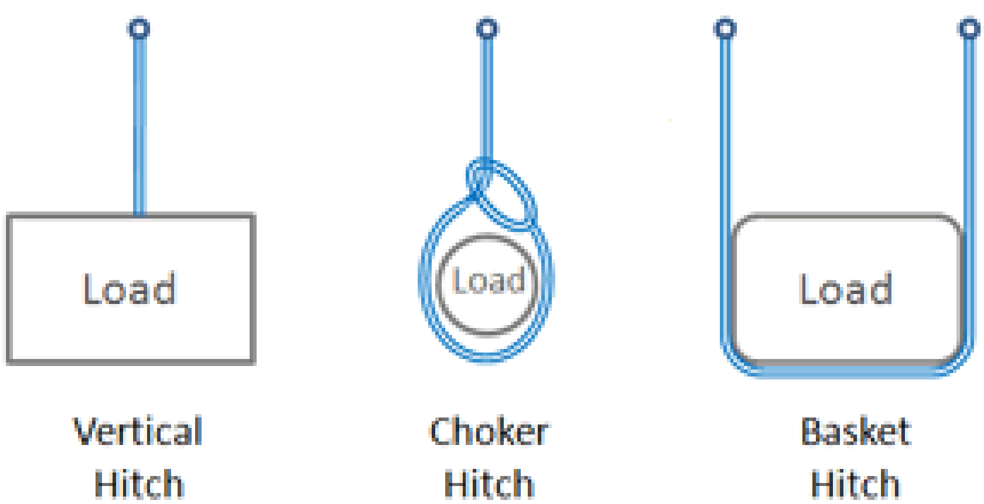
Equipment Labels:

The following is an example of a sling tag. A tag should be attached to <u>every</u> sling and a sling should not be used if it is not properly tagged.



Notice there are three numbers – these are the WLLs for this particular sling, broken down by type of hitch.

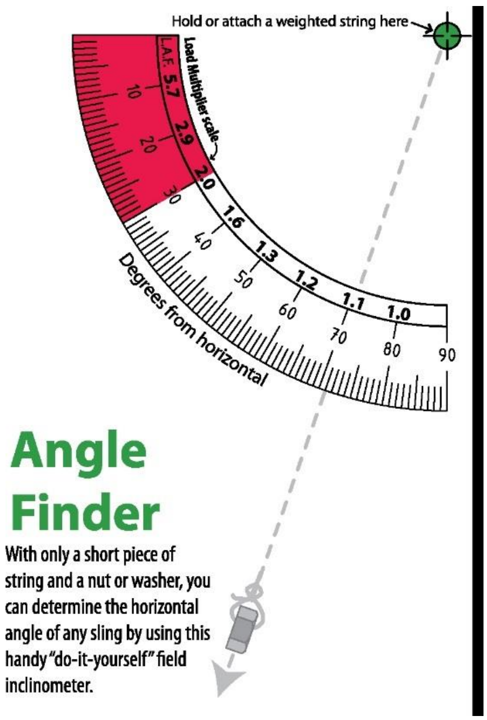
The hitch is the way in which the lifting equipment (sling, chain, rope, etc.) is attached to the load you wish to lift. There are three basic types of hitches:



Part 1: Choker and Basket Hitch Reductions

Mathematical Objectives:

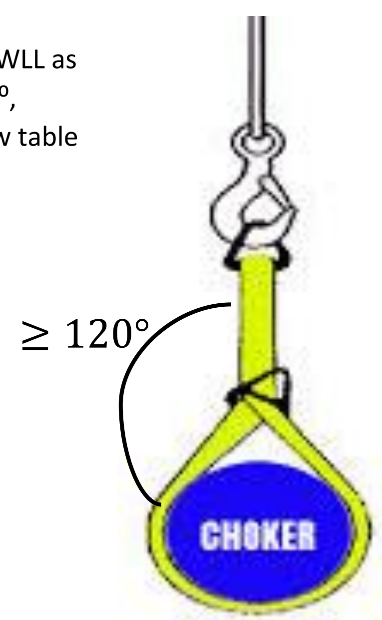
- Accurately measure angles. (TM-G2.B)
- Calculate WLLs using tables, percentages, and formulas. (TM-NS1.D, TM-BA3.A)
- Calculate the ratio of diameters. (TM-NS1.A, TM-NS1.E)



Teacher Note: Riggers measure angles using a variety of instruments depending on what is available, including protractors, inclinometers, or a "do-it-yourself" version using string, a washer, and an angle diagram or protractor (see picture). Any method would be acceptable and great practice for your students.

A rigger always checks the sling tag to make sure that the sling can handle the weight of the load. However, the rigger must also know that the WLL of a sling is MUCH LESS when the sling is used in anything other than "standard" position.

For example, a choker hitch (pictured) is able to carry 100% of the rated WLL as long as the angle is greater than 120°. When the angle drops below 120°, however, the hitch is no longer able to carry as much load. See the below table for the relationship between angle of choke and rated capacity.



Choker Hitch Rated Capacity Adjustment	
Angle of choke in degrees	Rated Capacity
Over 120	100%
90-120	87%
60-89	74%
30-59	62%
0-29	49%

To calculate adjusted choker ratings:

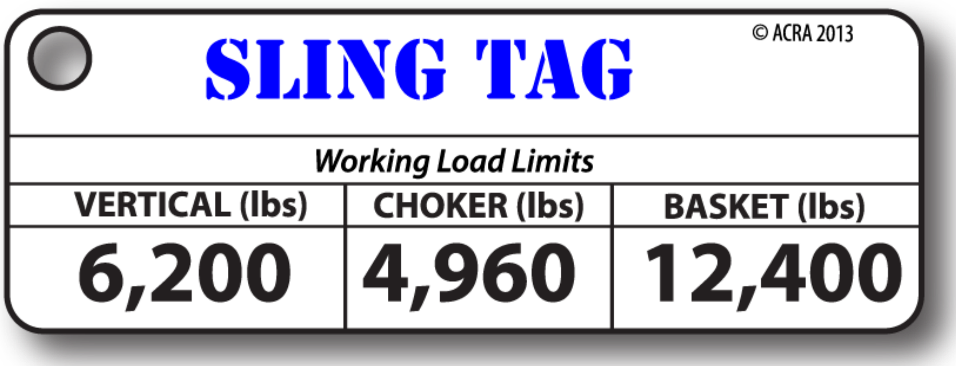
$$RC = C \times R$$

C: Choker rating
R: Rated Capacity
RC: Reduced choker rating

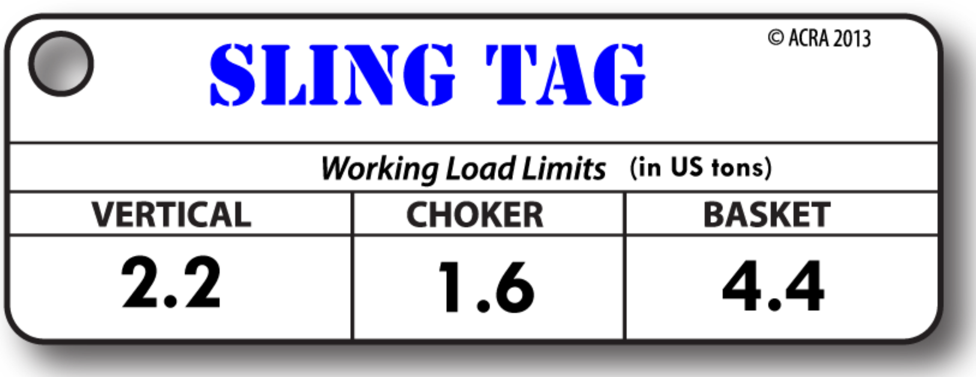
Practice

The following slings will be used in these exercises:

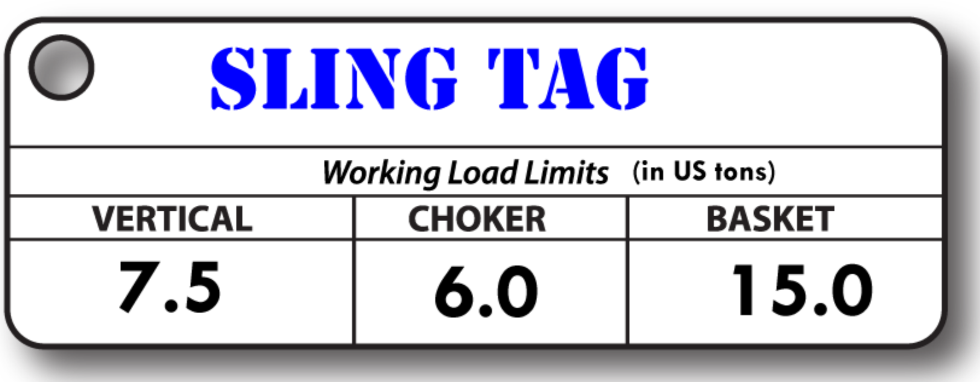
Sling #1



Sling #2

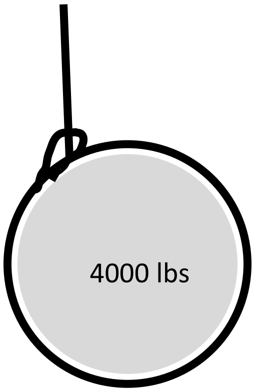


Sling #3



Measure the angle of the following choker hitches, then determine the reduced WLL of the indicated sling.

1. Use sling #1.



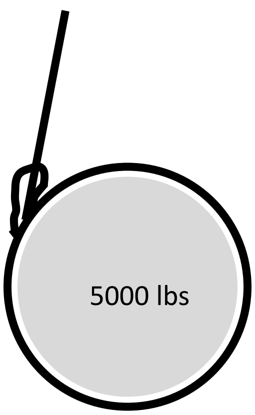
Angle of choke: ___67^{o}_________

Reduced WLL: ___3670.4 lbs__________

Will this sling be able to lift this load safely? Why or why not?

No, the reduced WLL shows that the 4000 lb load will be too much for this sling, even though the original choker load could handle it.

2. Use sling #2.



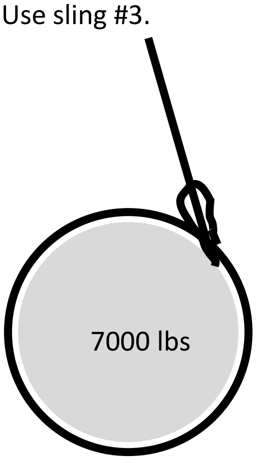
Angle of choke: ____33^{o}________

Reduced WLL: __1984 lbs___________

Will this sling be able to lift this load safely? Why or why not?

No, the reduced WLL shows that the 5000 lb load will be too much for this sling. (Note: converting from tons to pounds makes this answer possible.)

3. Use sling #3.



Angle of choke: ___30^{o}_________

Reduced WLL: ___7440 lbs__________

Will this sling be able to lift this load safely? Why or why not?

Yes, however the operator should be cautious since 30^{o} is so close to the next reduced load category. If the operator is wrong and the angle is actually 29^{o}, the WLL is 5,880 lbs and will not be able to lift this load safely.

4. A rigger measures an angle of choke and finds that it is 59.5°. Which rated capacity should he use – 74% or 62%? Justify your answer.

The rigger should use the 62% capacity. Even though 59.5° rounds up to 60°, which would be 74% capacity, there is always the realization that our measurement might not be perfect and it would be better to err on the side of caution.

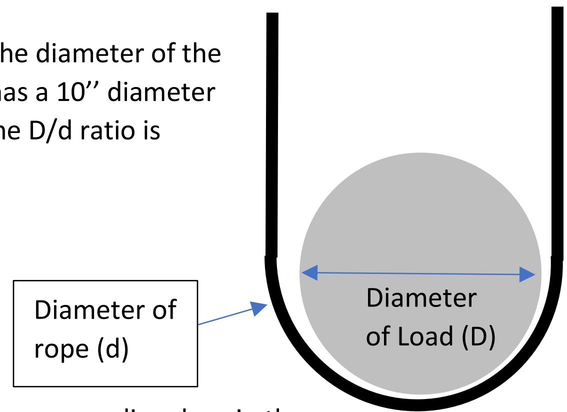
Note to teacher: this question might be a good class discussion! Be sure to highlight it is imperative to both fully understand the situation AND the math in order to make an informed decision.

Basket Hitches, as well, have reduced WLLs when used with wire rope. In the case of the basket hitch, the key measurement is the ratio of the diameter of the load to the diameter of the rope (see picture).

The D/d ratio tells the rigger how many times bigger the diameter of the load is compared to the rope. For example, if a load has a 10'' diameter (D=10) and the rope is ½'' in diameter (d=1/2), then the D/d ratio is

$$\frac{10}{1/2} = 20,$$

meaning the load's diameter is 20 times bigger than the diameter of the rope. A D/d ratio of 20 or higher is generally considered "good". When the ratio starts dropping below 20, a rigger must calculate the corresponding drop in the efficiency of their sling. The following table compares D/d ratios to sling efficiency.



D/d Ratio Strength Efficiencies	
D/d	Efficiency
30	95%
20	92%
10	86%
5	75%
2	65%
1	50%

Note to teacher: for students who lack experience in this realm, it might be helpful to bring in actual cylindrical objects and actual ropes so the students can see what measurement is the diameter of the load and rope.

Note to teacher: most rigging operators in the field would perform these calculations mentally, without the aid of a calculator or paper/pencil. It is encouraged to have your students do the same.

Practice

5. Fill in the following table given the load diameter, rope diameter, and the wire rope's basket rated WLL.

Load Diameter	Rope Diameter	Basket WLL	D/d Ratio	Reduced WLL
20''	1''	20 tons	20	18.4 tons
10''	2''	73 tons	5	54.75 tons
14''	½''	4.0 tons	28	3.68 tons
18''	¾''	8.6 tons	24	7.912 tons
11 ½''	2-1/4''	70 tons	72	70 tons

6. A rigger has a rope that is 1 ½'' in diameter and is rated at 10,000 lbs for a basket hitch. The rigger would like to be able to lift at least 8,000 lbs, using the basket hitch. What is the smallest diameter of load he can carry?

$\frac{8000}{10000} = 0.8\ or\ 80\%$, so the D/d ratio will need to be greater than or equal to 10.

$$\frac{D}{1\frac{1}{2}} \geq 10, so\ D \geq 15\ inches$$

7. In addition to performing calculations, rigging professionals use mathematics to understand the underlying relationships in rigging operations. In the following table, we will hold the load diameter and sling rating constant while changing the rope size. Notice what this does to the D/d ratio and WLL.

Load Diameter	Rope Diameter	Sling Rating for Basket Hitch	D/d Ratio	WLL
10''	¼''	1000 lbs	40	1000
10''	½''	1000 lbs	20	920
10''	1''	1000 lbs	10	860
10''	2''	1000 lbs	5	750
10''	3''	1000 lbs	3.3	650

State the pattern – as rope diameter increases, what happens to the WLL?
As rope diameter increases, the WLL decreases.

Note – usually as the width of the rope increases, the sling rating will also go up. However, the pattern you noticed in exercise 7 is still significant. It means that, if you are wanting to lift a heavier load with the basket hitch, the answer is not necessarily to reach for your thickest rope. There is an optimal zone where the rope diameter is small enough to keep the D/d high and the rope's sling rating is high enough to give you enough WLL.

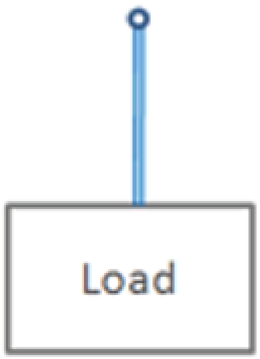
Part 2: Vertical Hitch Reductions

Mathematical Objectives:

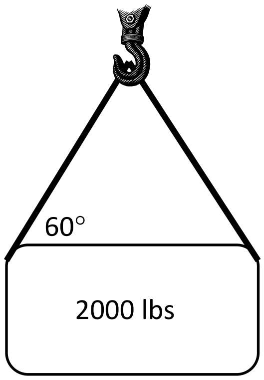
- Calculate and understand vertical hitch reductions using sin, cos, and tan. (TM-G3.B)

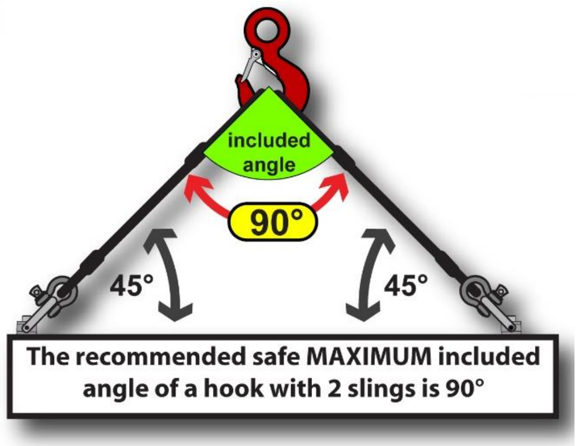
Note to teacher: for students unfamiliar with this topic, a physical example might be beneficial.

One vertical hitch can be used to lift a load, as shown in the pictures below.

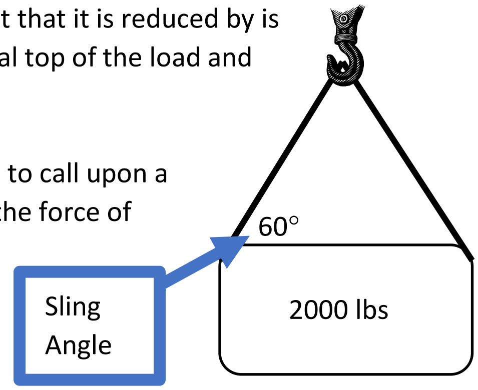


However, for stability, often two vertical hitches are attached to a load and then brought at an angle to one overhead lift point, as shown below.

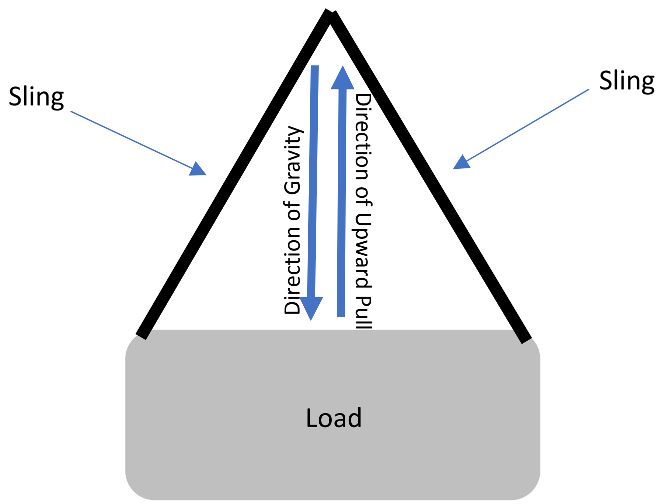




When this is done, however, the WLL of the sling is reduced. The amount that it is reduced by is dependent upon the sling angle: the angle formed between the horizontal top of the load and the sling itself (when pulled taut).



In order to understand the calculation for the reduced WLL, we will need to call upon a little bit of physics knowledge! Recall that all objects are acted upon by the force of gravity and that force acts perpendicular to the ground; in other words, everything is being pulled straight downwards. In order to keep from being pulled all the way to the center of the earth, something must be acting directly opposite that force. In the case of our loads that we are lifting, the sling must exert an equal and opposite force to gravity in order to keep the load from falling to the ground. See the following diagram for a visual of where this force is acting.



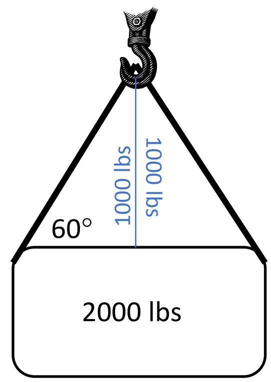
You can see that the direction of the upward pull is NOT in the same direction as the slings. Here's the interesting part – we know the force of the upward pull. It's the weight of the load. For example, if we have a 2000 lb load, it is taking 2000 lbs of upward force to keep it in the air. However, the amount of force the slings are experiencing in this configuration is much different. Not only are these slings needing to exert the upward force to keep the load in the air but they are also experiencing a certain amount of left-to-right force due to tension. To understand

this, think of the difference between carrying a heavy load with your arms at your side (only responsible for the upward force) and carrying a heavy load with your arms outstretched (responsible for upward forces and the tension of holding a heavy load away from your body).

So how do we calculate the amount of force (weight) on the sling? Here is where we take advantage of a little geometry! Notice that when we draw in the vertical force, we split the area in between the slings into two right triangles. If we assume that each triangle will be responsible for half the load (which they will be if you've properly balanced the load), then we know the value of the vertical side of the triangle. Given a sling angle, we can then use a little trigonometry to figure out the force on the sling!

$$\sin(60°) = \frac{1000}{x}$$

$$x = \frac{1000}{\sin(60°)} = 1{,}155\ lbs$$

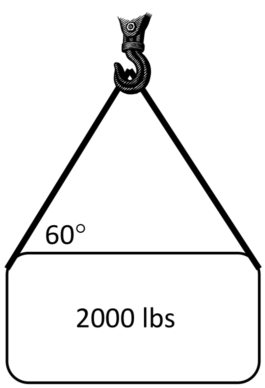


The WLL of each of the two slings will need to be 1,155 lbs in order to safely lift this load.

Practice

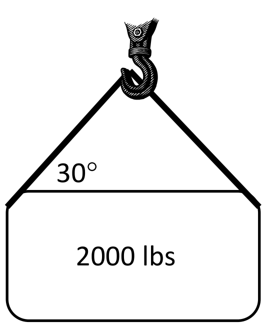
For the following scenarios, calculate the WLL of each sling needed in order to lift the load at the angle indicated. Diagrams are not necessarily drawn to scale.

1.



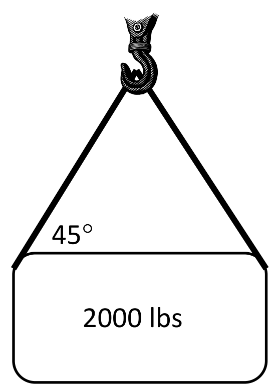
WLL of each sling: 1,154 lbs

2.



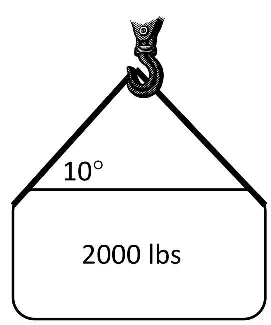
WLL of each sling: 2,000 lbs

3.



WLL of each sling: 1,414 lbs

4.



WLL of each sling: 5,758 lbs

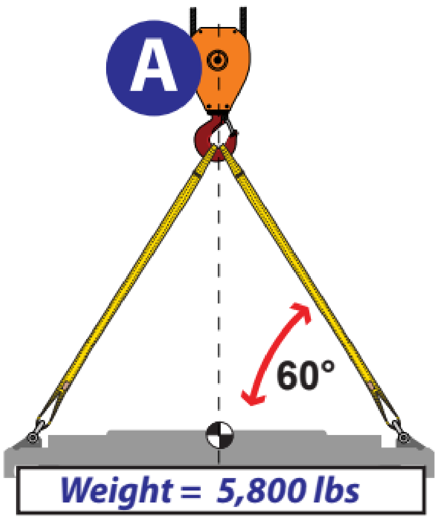
5. Based on your calculations in problems 1 through 4, generalize a pattern. As the angle at which you lift the load become larger, what happens to the amount of weight each of the slings have to handle? What happens as the angle become smaller?

As the sling angle becomes smaller, the needed WLL of each sling becomes bigger. The weight of the load and the WLL of each sling are equal at 30°.

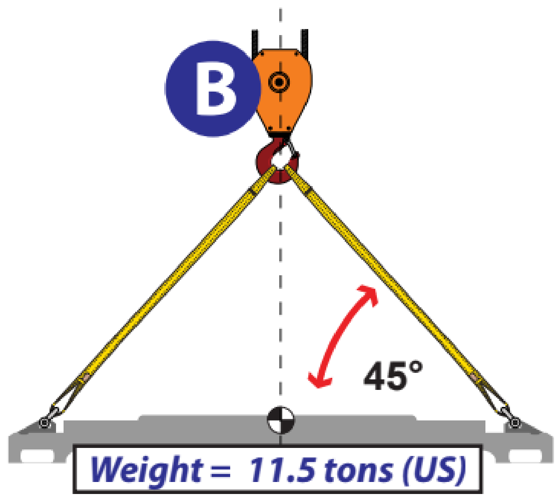
6. Now that you have done this calculation several times in exercises 1-4, you have probably noticed a pattern to this calculation. Write a formula using θ for the sling angle, W for the weight of the load, and WLL for the needed Working Load Limit of the sling.

___ $\sin(\theta) = \frac{W/2}{WLL}$ ___or___ $WLL = \frac{W/2}{\sin(\theta)}$ ___________

Use your formula on the following problems (A and B). Show all work and be attentive to units.



Tension per leg = ________________

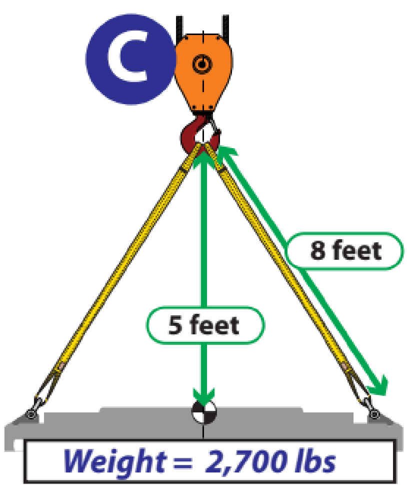


Tension per leg = ________________

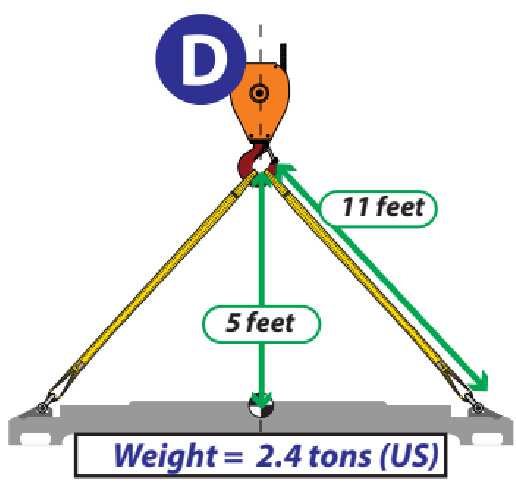
Check for student work. Answer for part A: 3,349 lbs; Answer for part B: 8.13 tons or 16,263 lbs.

7. Find the tension per leg for the following scenarios (C and D).

(Use inverse trig to find sling angle, then calculate as above.) Part C: 2,145 lbs; Part D: 2.6 tons or 5,286 lbs

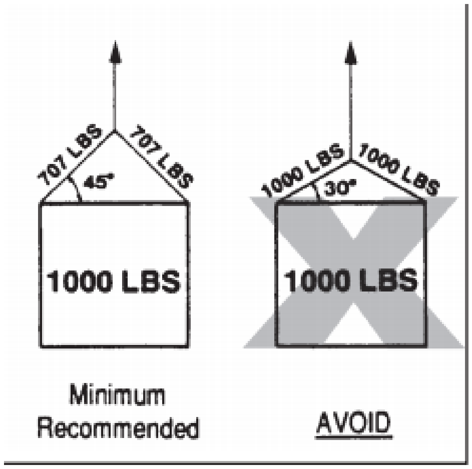


Tension per leg = ________________



Tension per leg = ________________

8. Most rigging training recommend NEVER lifting at less than a 30^o sling angle. Based on the calculations you have done in exercises 1-4 and what you know about heavy objects and human behavior, write a rationale for why you think rigging training advise so heavily against the 30^o (or less) angle.



When objects are lifted at less than a 30^o angle, the WLL of the sling has to be more than the weight of the actual object. This might feel counterintuitive to an operator (for example, having to grab two 5,000 lb slings for a 2,000 lb object) and could lead to more mistakes, which could be deadly.

9. Suppose you are a professional rigger responsible for the training of an apprentice to your trade. One day the apprentice brings you his rigging handbook with the following figure in it. He says he is a little lost and asks for you to explain the figure to him. Prepare a verbal explanation of what your apprentice has brought you.

Verbal explanations should note that the load on the slings goes up as the sling angle goes down. These calculations in columns 1 and 2 are what you've been doing in this activity thus far. Students should then explain that humans and measuring instruments are not perfect and there's a possibility that we don't measure the angle correctly. If the actual angle is 5^o less than what we measured (shown in the third column), then we could calculate the actual load per sling, which is, of course, different. What is significant, though, is how different. For a 90^o angle, being a little off isn't a big deal – it's only a 2 lb or 0.4% difference in WLL. However, at 15^o, being a little off in the angle measurement means being super off in the WLL – almost a 1000 pounds or 49% difference! That's another reason why lifting at small angles is not advisable.

Figure 23

EXAMPLE OF THE EFFECT OF SLING ANGLE MEASUREMENT ERROR ON LOADS

Assumed Sling Angle	Assumed Load (Pounds Per Leg)	Actual Angle (is 5° Less Than Assumed Angle)	Actual Load (Pounds Per Leg)	Error %
90°	500	85°	502	0.4
75°	518	70°	532	2.8
60°	577	55°	610	5.7
45°	707	40°	778	9.1
30°	1,000	25°	1,183	18.3
15°	1,932	10°	2,880	49.0

Set aside a time when you can individually interview your students to hear their responses or have them prepare a video or audio file of their explanation, which they can then submit to you. If needed, before this task, include a lesson for the students in which you model how to explain something professionally and clearly. I would require no or minimal notes. Remind the students that this exercise is of great benefit to them as everyone will need to communicate with coworkers about work-related topics and those who do it well get better results (with less frustration).

Part 3: Calculating Loads

Mathematical Objectives:

- Calculate volume. (TM-NS1.C, TM-NS3.B, TM-NS2.B, TM-BA3.D)
- Convert between units as needed. (TM-NS2.A, TM-NS2.D)

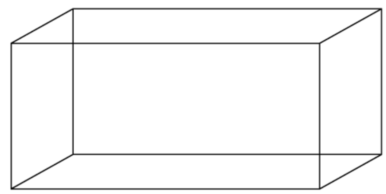
Up until this point, you have always been given the weight of the load we are asking you to lift. In reality, though, the rigging professional is often responsible not only for calculating the WLLs on his/her slings, but also for calculating the weight of the load! Finding the weight of a load is a two step process:

1. Find the volume of the object.
2. Find the weight of the object by taking volume x weight (per Cu).

The following formulas might be useful:

Cube or Rectangle

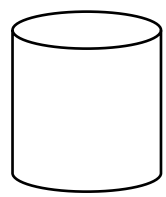
Length x Width x Height



Cylindrical/Round Shapes

0.7854 x D X D X H

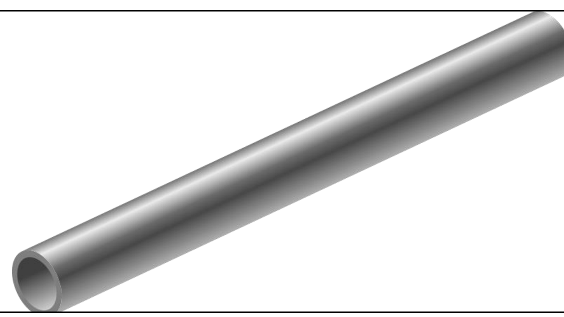
D = diameter across base
H = height



Round and Hollow (Pipes)

T X (D – T) X 3.141 X H

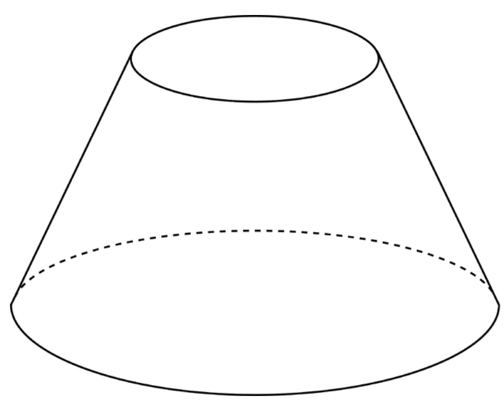
D = outside diameter
H = overall length of pipe
T = wall thickness



Frustum of a cone

0.2618 X h X (D^2 + D X d + d^2)

D = outside diameter of small end
h = overall length
d = outside diameter of large end



The following standard weights of typical materials may also be useful:

Material	Weight per Cu. Ft (in lbs)
Aluminum	165.00
Brass	535.00
Brick masonry, common	125.00
Bronze	500.00
Cast Iron	480.00
Cement, portland, loose	94.00
Concrete, stone aggr.	144.00
Copper	560.00
Earth, dry	75.00
Earth, wet	100.00
Glass	160.00
Ice	56.00
Lead	710.00
Snow, fresh fallen	8.00
Snow, wet	35.00
Steel	490.00
Tin	460.00
Water	62.00
Gypsum wall board	54.00
Wood, pine	30.00

For odd shaped objects, the following instructions are useful as well:

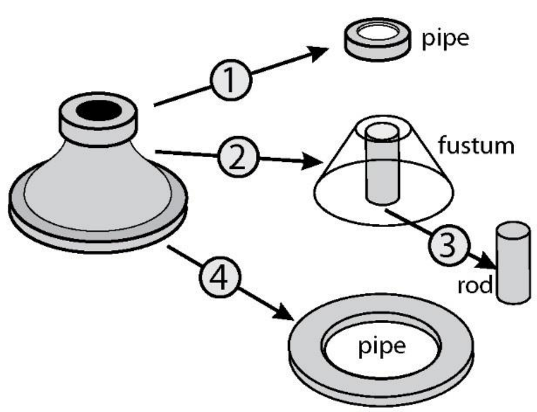
The following applies to the illustration shown below:

(1) = a round & hollow object (like pipe)

(2) = a frustum of a cone

(3) = is the hole in the center
(figure the hole as a solid round shape, then subtract its weight from the fustum.)

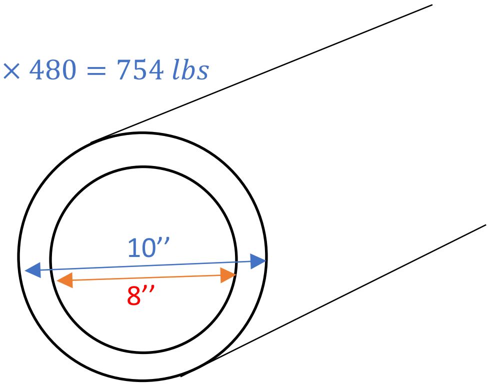
(4) = also considered round & hollow (like pipe)



Practice

1. A pipe measures 10 inches across (from outside to outside) and 8 inches across the inside. The pipe is 8 feet long and made of cast iron. How much does the pipe weigh?

$$^{1}/_{12} \times (^{10}/_{12} - ^{1}/_{12}) \times 3.141 \times 8 = 1.57\ cu\ ft\ \times 480 = 754\ lbs$$



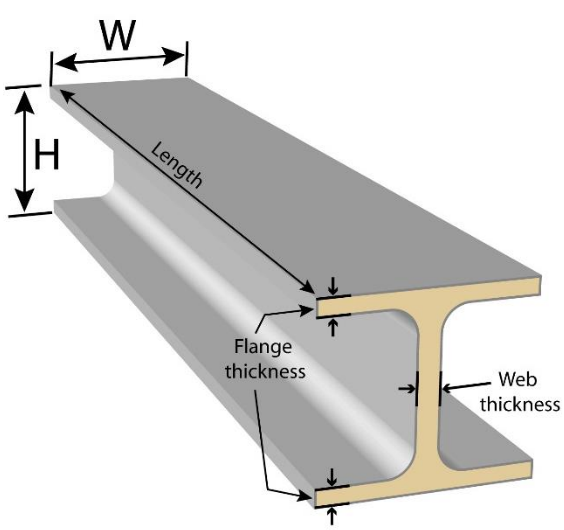
2. A rectangular aluminum bar is 1 ¾'' by 3'' by 6'. What is the weight of the bar?

$$.146 \times .25 \times 6 = .219 \times 165 = 36\ lbs$$

Note to teacher: it is an interesting discussion to have with the students about whether to give the answer in decimal or fraction and, if the answer is in decimal, how many digits to round to. Industry riggers would usually chose to convert the fraction to a decimal and use 3-4 decimal places.

3. What is the weight of the following steel I-beam?

Length = **20 feet**
Flange thickness = **3 inch**
Web thickness = **3 inch**
W = **4 feet**
H = **4 feet**



Top and Bottom:

$$4\ ft\ \times {^{3}/_{12}}\ ft \times 20ft = 20\ cu\ ft\ \times 2$$
$$= 40\ cu\ ft$$

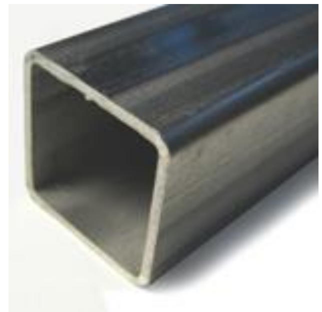
Middle:

$$4\ ft\ \times {^{3}/_{12}}\ ft \times 20ft = 20\ cu\ ft$$

Total: 40 + 20 = 60 cu ft

$$60\ cu\ ft\ \times 490\ \frac{lbs}{cu\ ft} = 29{,}400\ lbs$$

3. A hollow steel beam is 4'' by 4'' by 8' and ¼'' thick. What is the weight of the beam?



If filled: $\left({}^{4}/_{12}\,ft \times {}^{4}/_{12}\,ft \times 8ft\right) \times 490\frac{lbs}{cu\,ft} = 435.55 = 436\ lbs$

Inside: $\left({}^{3.5}/_{12}\,ft \times {}^{3.5}/_{12}\,ft \times 8ft\right) \times 490\frac{lbs}{cu\,ft} = 33.396 = 333\ lbs$

$$436\ lbs - 333\ lbs = 103\ lbs$$

Note: As with many complex objects, there are several different approaches students could take to this problem.

4. A concrete frustum has a diameter on the small end of 5 ½'' inches and a diameter on the large end of 13'' inches. The frustum is 2'5'' tall. What is the weight of the frustum?

$$0.2618 \times 2.41667 \times (1.0833^2 + 1.0833 \times .45833 + .45833^2) = 1.190 \times 144 = 171\ lbs$$

5. A shaft idler roller, exported from China, is made of aluminum. The roll is 150 centimeters long, 80 cm in diameter. The shaft is 180 centimeters long and 20 cm in diameter. The roller is hollow (except for the shaft) and the walls are 25 centimeters thick. What is the weight of this roller?

1 cm = 0.0328084 ft
150 cm = 4.921 ft; 80 cm = 2.625 ft; 180 cm = 5.906 ft; 20 cm = 0.656 ft; 80-50=30 cm = .984 ft

Roll (if filled) = .7854 x 2.625 ft x 2.625 ft x 4.921 ft = 26.63 cu ft
Center of Roll = .7854 x .984 ft x .984 ft x 4.921 ft = 3.74 cu ft
26.63 – 3.74 = 22.89 cu ft x 165 lbs/cu ft = 3,776.85 lbs (for the roller)

Shaft = .7854 x 0.656 ft x 0.656 ft x 5.906 ft = 1.996 cu ft
1.996 cu ft x 165 lbs/cu ft = 329.36 lbs (for shaft)

3,776.85 + 329.36 = 4,106.21 lbs

Part 4: Replacing Equipment at your Manufacturing Plant

Mathematical Objectives:

- Use computations to make decisions. (TM-NS4.A, TM-NS4.D)

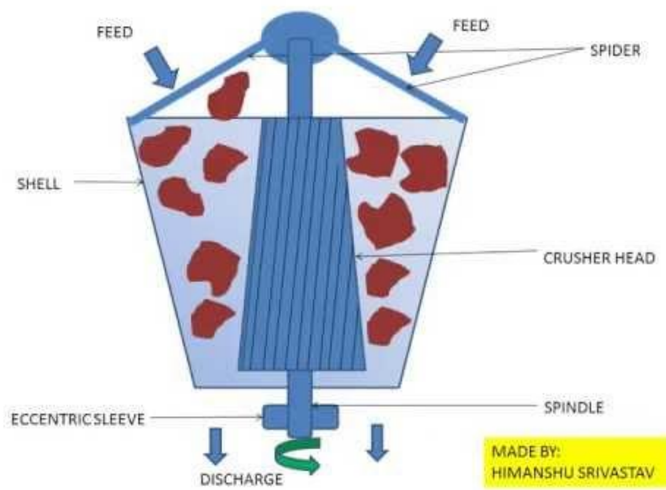
Throughout this unit, you have been developing costs and analysis for your own manufacturing process! A fact of owning a manufacturing plant is that machines will break or new machines will be required to make your product. In such cases, you'll need to rely on your rigging knowledge to safely bring the machines into the plant and install them.

To upgrade your process, let's imagine that you'll need to install a machine that weighs 10,000 lbs. The machine is 12 feet tall, 6 feet wide, and 8 feet long. The crane will need to ease it through an opening that is 20 feet tall. Allow 2 feet for the hook and upper portion of the crane.

In addition, for a new process, you'll need to transport the following raw materials into your plant on a regular basis:

- Solid Steel Rods, 1.5'' diameter, 12' long
- Solid Steel Bars, 5'' by 5'' by 8'
- Copper Pipe, 2'' outside diameter, 1 ¼'' inside diameter, 10' long
- Cast Iron Frustums, small side diameter 8'', large side diameter 2', 3' high

Last but not least, there is an old gyratory crusher that needs to be removed. Assume all the parts are made of steel. At its widest point, the crusher is 126 inches; it is 36 inches at its narrowest. The crusher head is 30 inches at its widest and 25 inches at its narrowest.



Your current maintenance materials budget is $2000. The following table may be helpful:

Sling	Size	Vertical	Choker	Basket	Price
Chain Sling	9/32'' by 4'	3500 lbs	2800 lbs	7000 lbs	$250.00
Wire Rope	3/8'' by 4'	1.4 tons	1.1 tons	2.9 tons	$28.00
Wire Rope	¾'' dia (26 lbs), 20' long	5.6 tons	4.1 tons	11 tons	$112.00
Wire Rope	1-1/4'' dia (83 lbs), 20' long	15 tons	11 tons	30 tons	$355.00
Web Sling	1'' wide by 4'	2400 lbs	1960 lbs	4800 lbs	$15.00
Roundsling	4' long	2600 lbs	2100 lbs	5200 lbs	$16.00
Mesh sling	2'' wide by 4'	2300 lbs	2300 lbs	4600 lbs	$280.00
TwinPath ® Sling	8 lbs	10,000 lbs	8,000 lbs	20,000 lbs	$594.00
TwinPath ® Sling	14 lbs	30,000 lbs	24,000 lbs	60,000 lbs	$1400.00

Your Task:
Create a presentation for the co-owners of your manufacturing process. In it you'll need to include how you plan to lift the new machine, new materials, and old gyratory crusher. Be sure to include all relevant calculations. Also include a budget of what slings you intend to purchase for the plant.

Teacher Notes on Presentations:

- It would be ideal if, by this time in the course, students know what "all relevant calculations" are and include them. However, if you feel your students will need some scaffolding to achieve the desired end product, include a rubric that specifies that we are looking for the hitch reduction calculations needed for the new machine, weight calculations for the gyratory crusher, weight calculations for the new materials, and any conversions needed between tons and pounds in order to properly select slings.
- There can be some variety in student presentations. For example,
    - The easiest way to lift the new machine is with a vertical hitch at a 60 degree angle. However some may choose to do a basket hitch. They should not choose a choker hitch, since this is not a circular object.
    - Student could get a range of answers for the weight of the gyratory crusher, depending (a) on how many pieces they break it into and calculate and (b) some of the part sizes they might have had to estimate. We recommend accepting any reasonable answer that is explained well.