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!

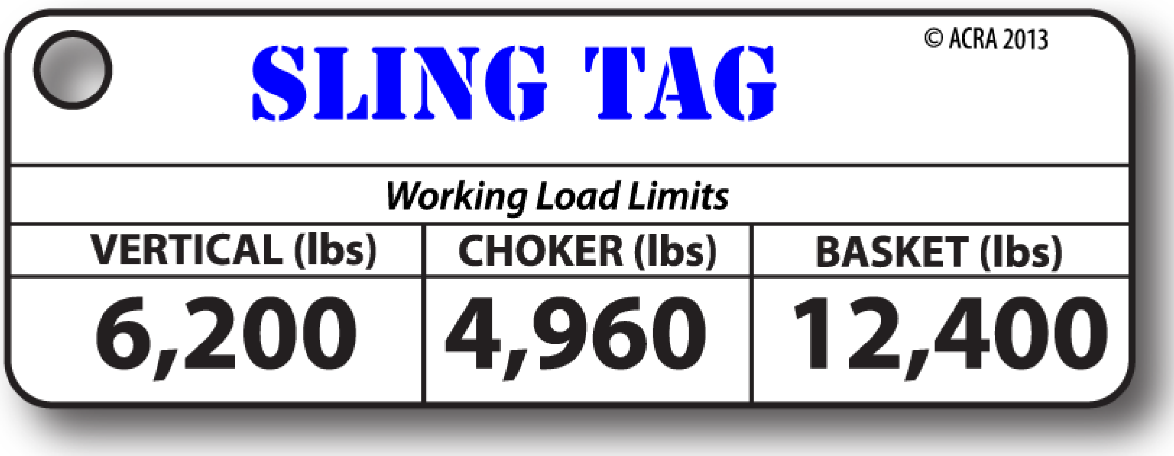
Rigging Basics

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.

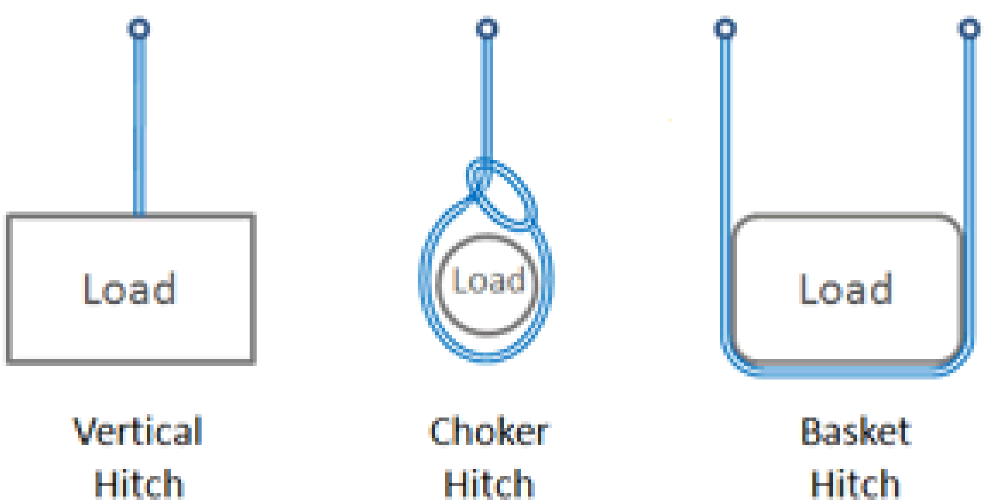
Equipment Labels:

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:



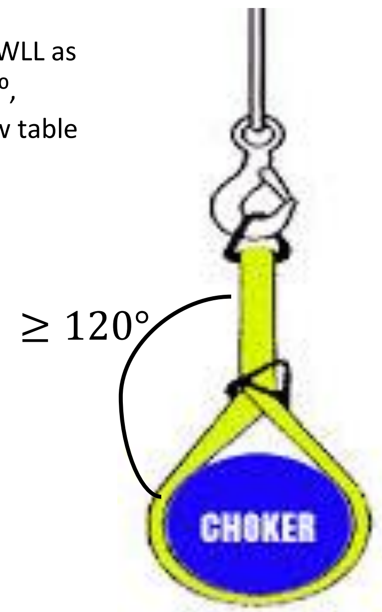
Part 1: Choker and Basket Hitch Reductions

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)

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 x R

C: Choker rating

R: Rated Capacity

RC: Reduced choker rating

Practice

The following slings will be used in these exercises:

Sling #1

SLING TAG © ACRA 2013

Working Load Limits		
VERTICAL (lbs)	CHOKER (lbs)	BASKET (lbs)
6,200	4,960	12,400

Sling #2

SLING TAG © ACRA 2013

Working Load Limits (in US tons)		
VERTICAL	CHOKER	BASKET
2.2	1.6	4.4

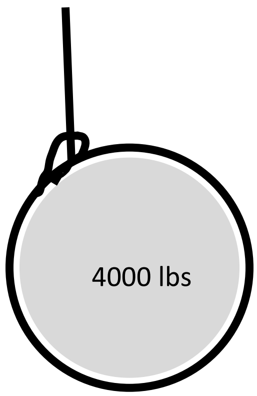
Sling #3

SLING TAG

Working Load Limits (in US tons)		
VERTICAL	CHOKER	BASKET
7.5	6.0	15.0

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

1. Use sling #1.

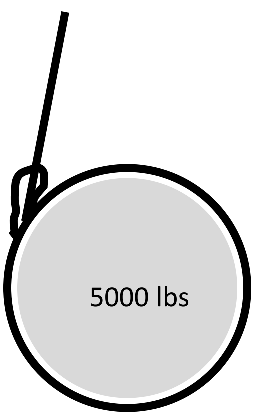


Angle of choke: ____________

Reduced WLL: ______________

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

2. Use sling #2.

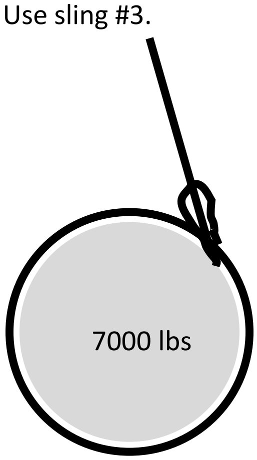


Angle of choke: ____________

Reduced WLL: ______________

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

3. Use sling #3.



Angle of choke: ____________

Reduced WLL: ______________

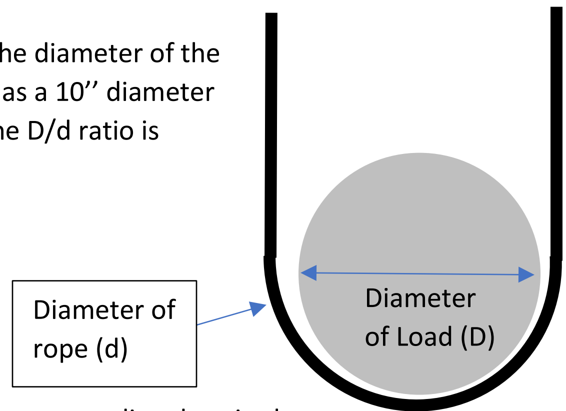
Will this sling be able to lift this load safely? Why or why not?

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.

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%

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		
10''	2''	73 tons		
14''	½''	4.0 tons		
18''	¾''	8.6 tons		
11 ½''	2-1/4''	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?

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		
10''	½''	1000 lbs		
10''	1''	1000 lbs		
10''	2''	1000 lbs		
10''	3''	1000 lbs		

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

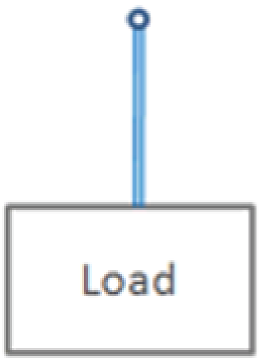
Note – usually as the width of the rope increases, the sling rating will also go up. However, the pattern you noticed in exercise 7 is still significant. It means that, if you are wanting to lift a heavier load with the basket hitch, the answer is not necessarily to reach for your thickest rope. There 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

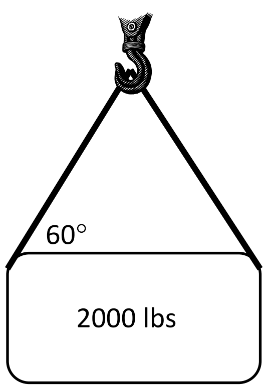
Mathematical Objectives:

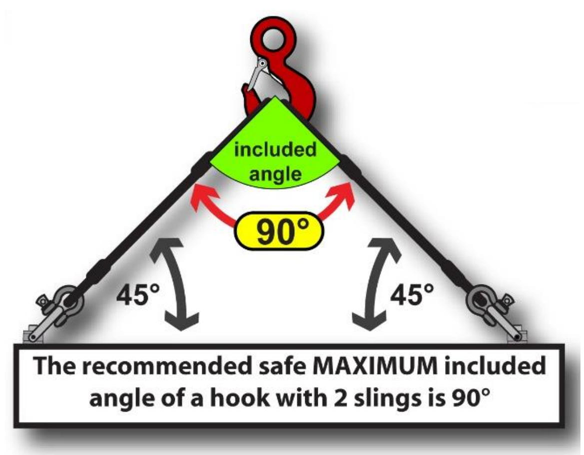
- Calculate and understand vertical hitch reductions using sin, cos, and tan. (TM-G3.B)

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

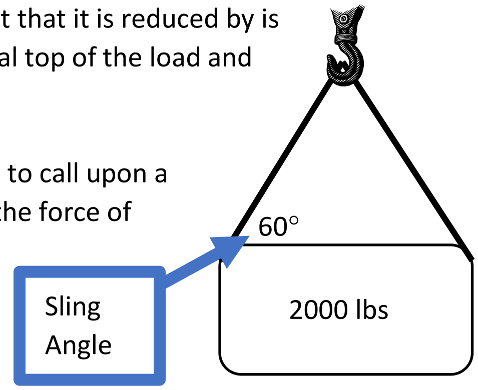


However, for stability, often two vertical hitches are attached to a load and then brought at an angle to one overhead lift point, as shown below.

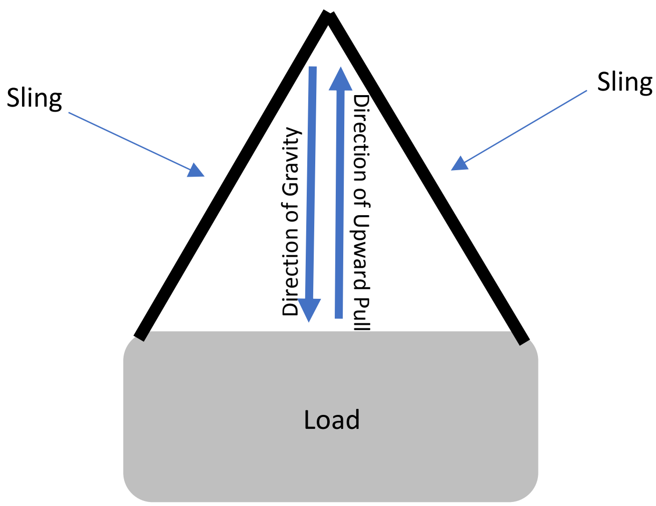




When this is done, however, the WLL of the sling is reduced. The amount that it is reduced by is dependent upon the <u>sling angle:</u> the angle formed between the horizontal top of the load and the sling itself (when pulled taut).



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.

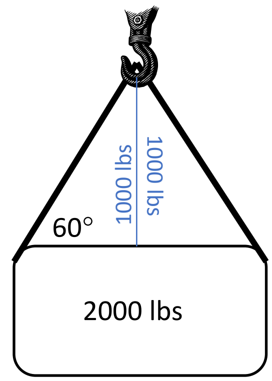


You can see that the direction of the upward pull is NOT in the same direction as the slings. Here's the interesting part – we know the force of the upward pull. It's the weight of the load. For example, if we have a 2000 lb load, it is taking 2000 lbs of upward force to keep it in the air. However, 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!

$$\sin(60°) = \frac{1000}{x}$$

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

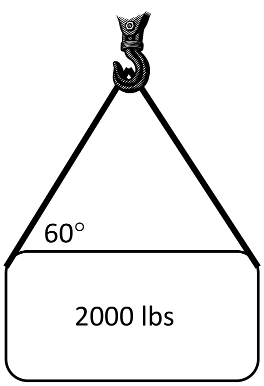


The WLL of each of the two slings will need to be 1,155 lbs in order to safely lift this load.

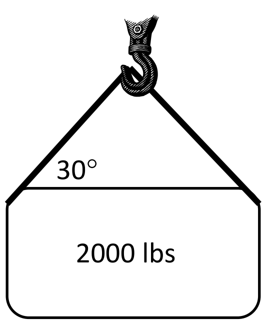
Practice

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.

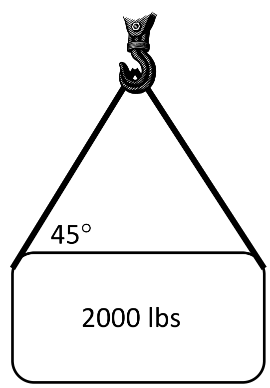
1.



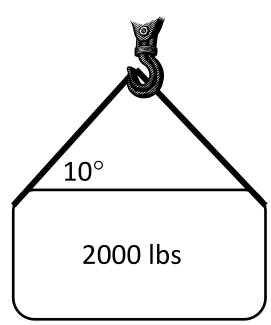
2.



3.



4.

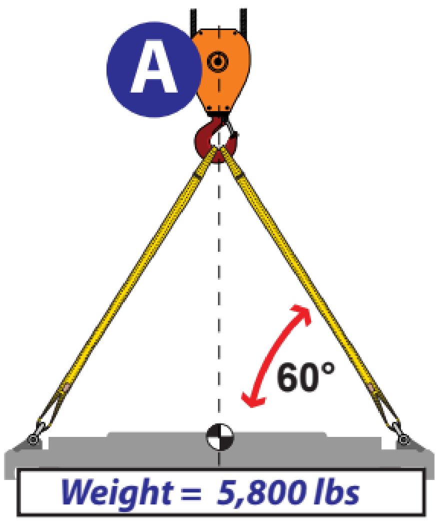


5. Based on your calculations in problems 1 through 4, generalize a pattern. As the angle at which you lift the load become larger, what happens to the amount of weight each of the slings have to handle? What happens as the angle become smaller?

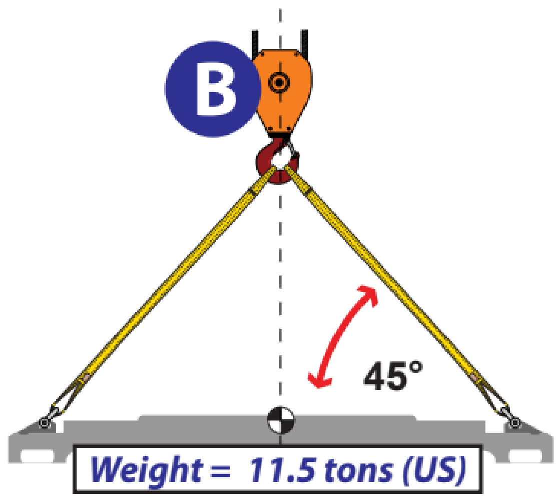
6. Now that you have done this calculation several times in exercises 1-4, you have probably noticed a pattern to this calculation. Write a formula using θ for the sling angle, W for the weight of the load, and WLL for the needed Working Load Limit of the sling.

____

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

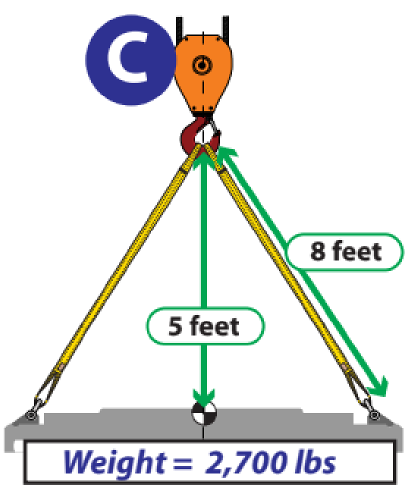


Tension per leg = ________________

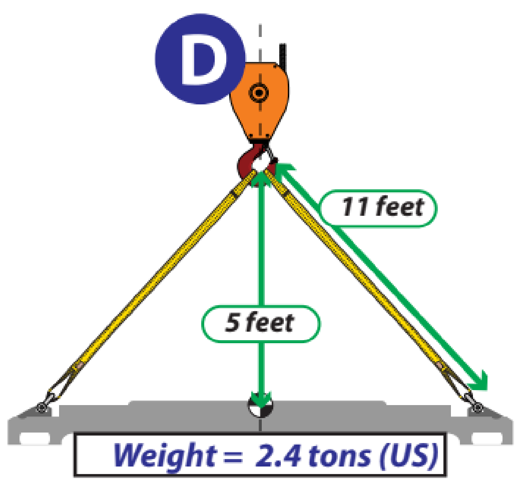


Tension per leg = ________________

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

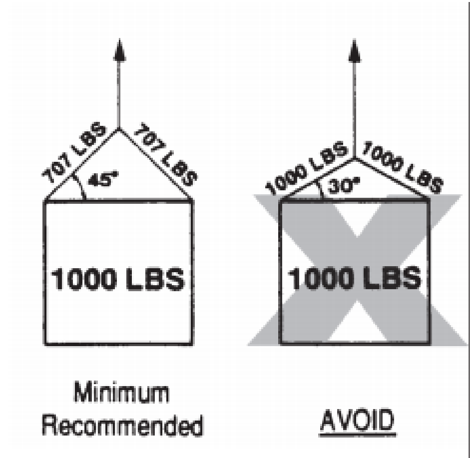


Tension per leg = ________________



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.



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.

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

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)

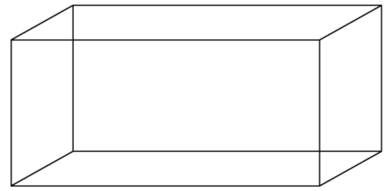
Up until this point, you have always been given the weight of the load we are asking you to lift. In reality, though, the rigging professional is often responsible not only for calculating the WLLs on his/her slings, but also for calculating the weight of the load! Finding the weight of a load is a two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

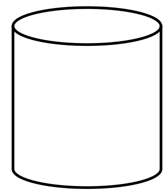
Length x Width x Height



Cylindrical/Round Shapes

0.7854 x D X D X H

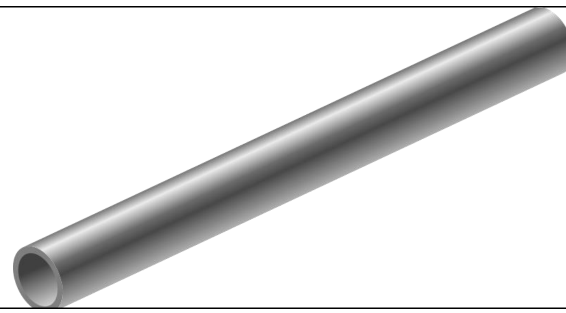
D = diameter across base
H = height



Round and Hollow (Pipes)

T X (D – T) X 3.141 X H

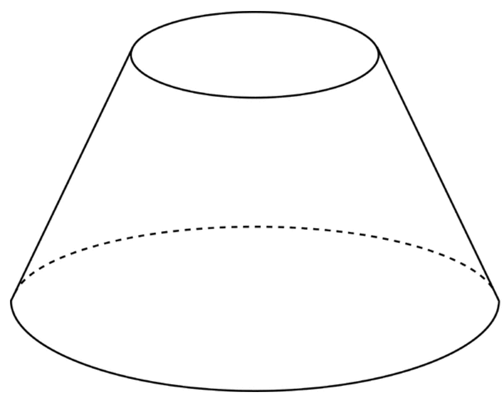
D = outside diameter
H = overall length of pipe
T = wall thickness



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:

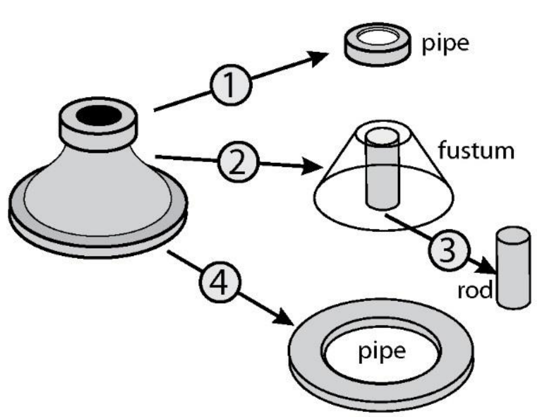
(1) = a round & hollow object (like pipe)

(2) = a frustum of a cone

(3) = is the hole in the center

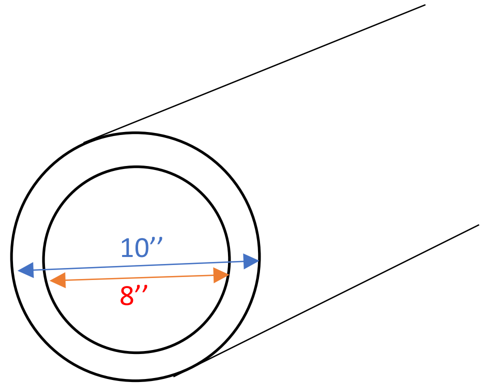
(figure the hole as a solid round shape, then subtract its weight from the fustum.)

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



Practice

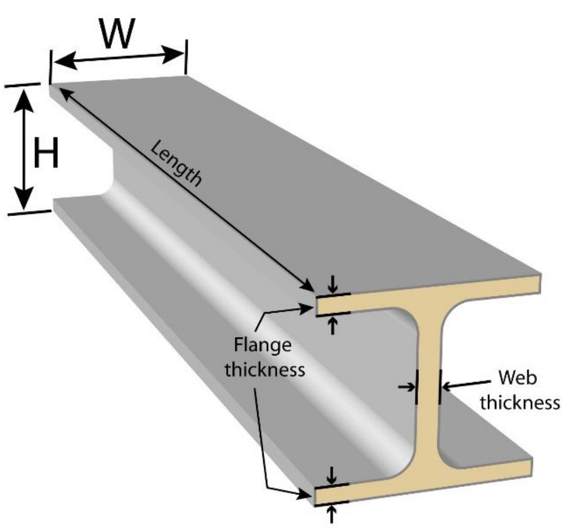
1. A pipe measures 10 inches across (from outside to outside) and 8 inches across the inside. The pipe is 8 feet long and made of cast iron. How much does the pipe weigh?



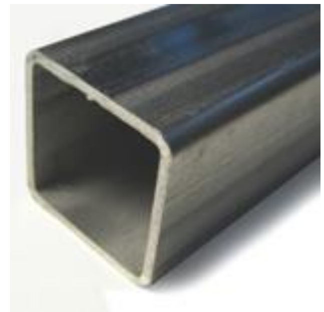
2. A rectangular aluminum bar is 1 ¾'' by 3'' by 6'. What is the weight of the bar?

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**



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



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?

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. The roller is hollow and the walls are 25 centimeters thick. What is the weight of this roller?

Part 4: Replacing Equipment at your Manufacturing Plant

Mathematical Objectives:

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

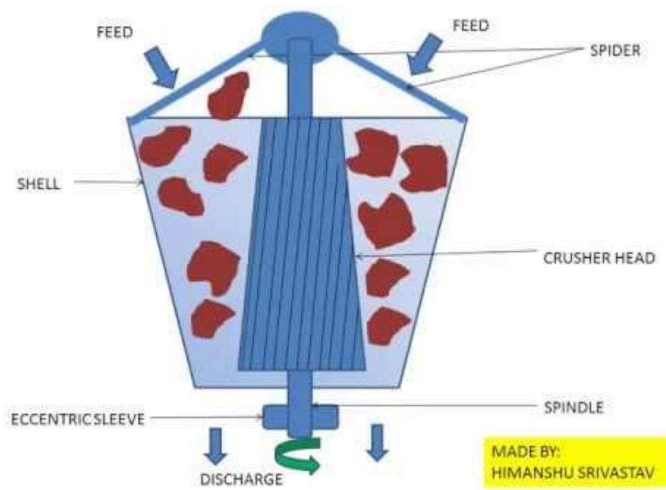
Throughout this unit, you have been developing costs and analysis for your own manufacturing process! A fact of owning a manufacturing plant is that machines will break or new machines will be required to make your product. In such cases, you'll need to rely on your rigging knowledge to safely bring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