Vector Analysis

For Rope Rescue Systems

We have already learned, that angles in rope systems, affect the actual forces at work, within those systems. Since life safety, is the driving goal of rope rescue, it is imperative that we understand the actual forces at work, in the rope systems we design. The purpose of this article, is to set forth a variety of methods, that can be used to ascertain the actual forces at every point in a rope system.

Two basic Methods

Empirical

Empirical methods rely less on math, and more on simple, practical methods. As a result, these methods are well suited to use in the field, when rigging on the fly. They are not as accurate as math based methods, but, if you stick to good safety factors and sound rigging principals, they can get you close enough, to discover the weak links, even in asymmetrical systems.

Mathematical

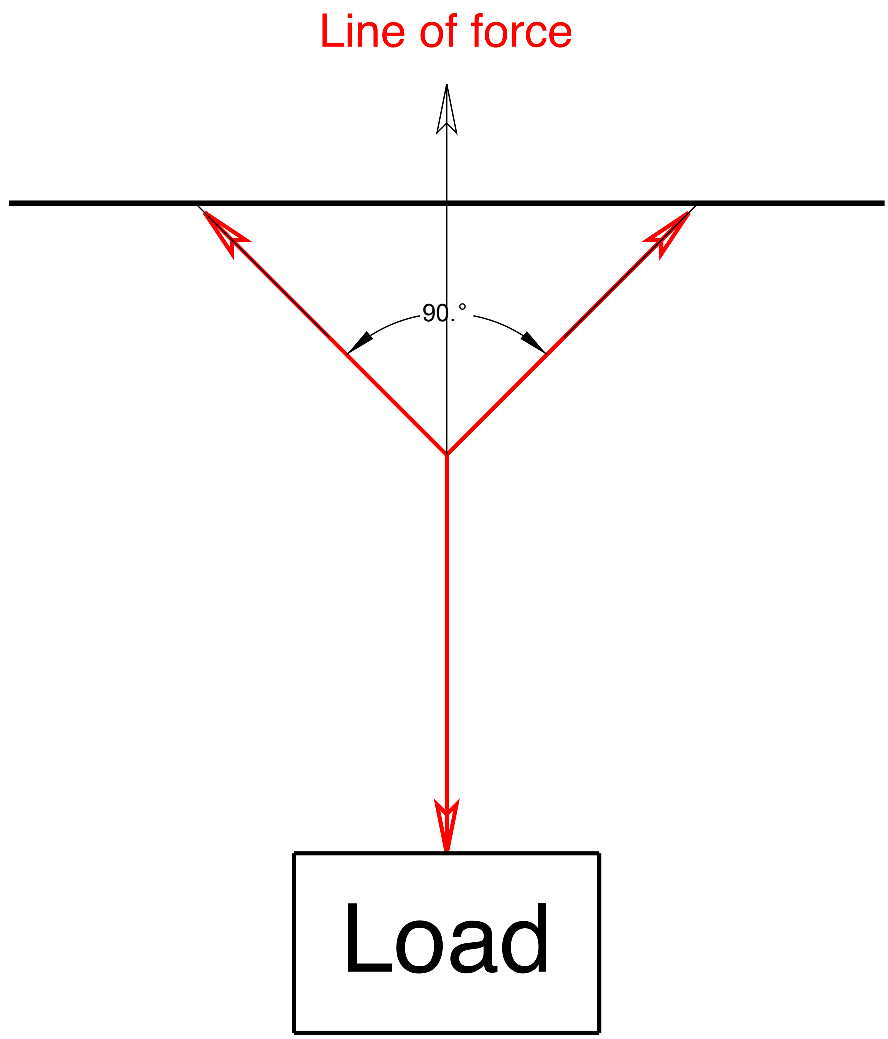
These methods yield the most accurate results, but, can become cumbersome in the field, especially when applied to complex asymmetrical rope systems. They are best used for pre rigged systems, that will be deployed the same way every time, from known unchanging anchors. A main line haul system, that is designed to attach to fixed anchors, on a ladder truck, for example. You have the time to lay the system out on paper, and run the math, and find the areas of concern, well in advance.

The more you use either method, the greater your understanding of the forces at work, becomes. It really doesn't take long before you will be able to see the weak links, from experience alone.

Symmetrical Forces

Symmetrical 2 point load Sharing Anchor System

Fig.1



In Fig.1 we can see the line of force bisects the angle formed by the anchor's legs equally. Our goal is to find the actual forces at each anchor point, for a given load.

Method 1 Mathematical

Using this method, finding the force at the anchor points for the example in Fig.1 is pretty straightforward.

Since the line of force, bisects the angle between the legs of the anchor system equally, the force on each anchor point, will be equal as well. So, if we determine the force on one point, we know the force on other.

We begin by dividing the angle between the legs by 2.

(90 divided 2 = 45)

Next, we find the Cosine of 45 degrees, a science calculator will come in handy here.

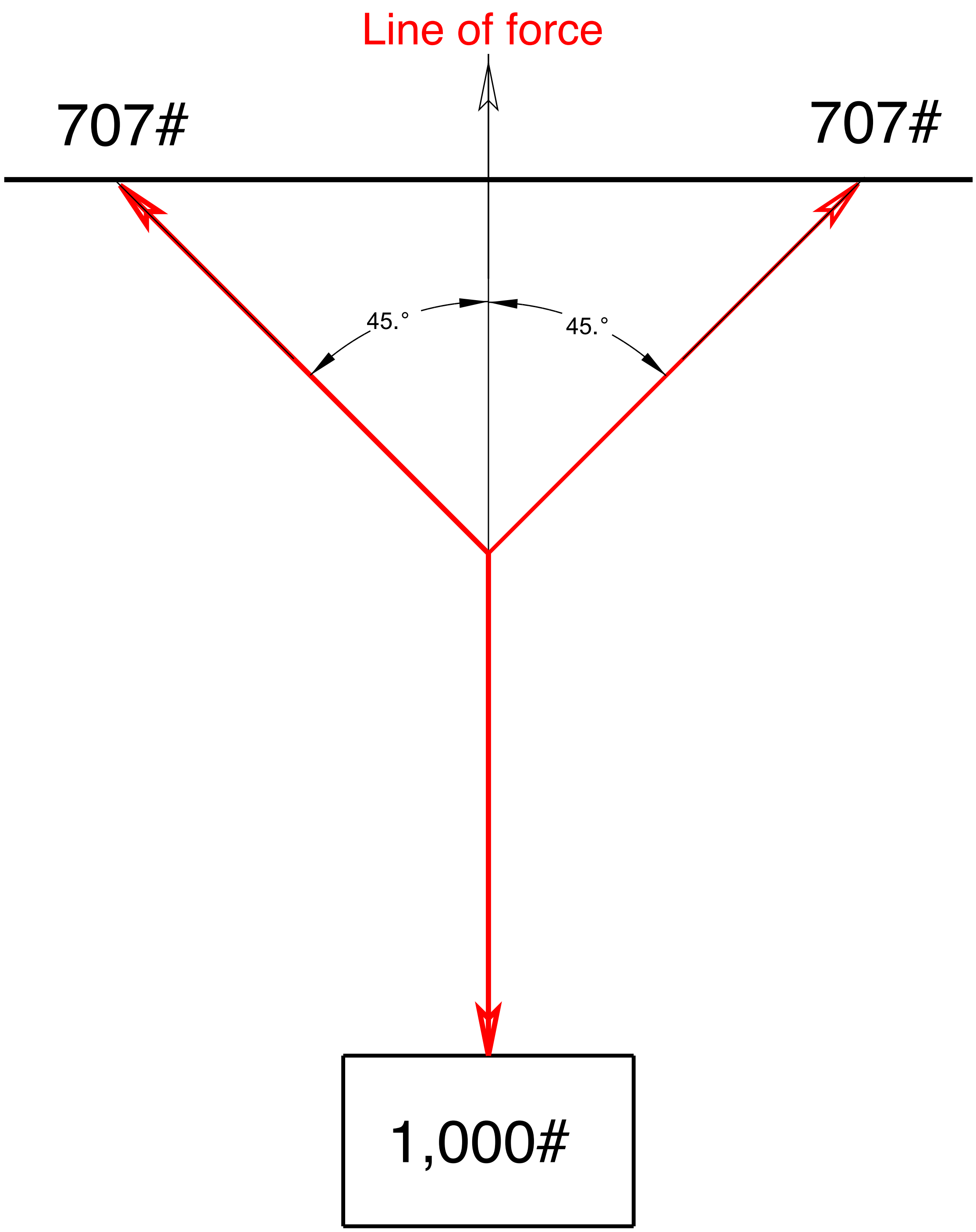
(Cos 45 = .7071)

Next we square this number (.7071 x 2 = 1.414)

Lastly, we divide the actual load, by the result

(1,000 divided by 1.414 = 707.)

Fig. 2



Method 2 Graphical

This method, relies on the relationship between the sides of right triangles, in a visual way. It is also the basis for a method, called the hand method, that is often used in the field. (more about this later)

We begin, at the point the anchor legs converge, by measuring an arbitrary distance, along the line of force. line A (the blue line in Fig.3). The length of this line, represents 100% of the actual load, or 1,000# in Fig.3

Next, we extend a line, from the end of this line, at a right angle, to the point at which it intersects one of the anchor legs, (line B)

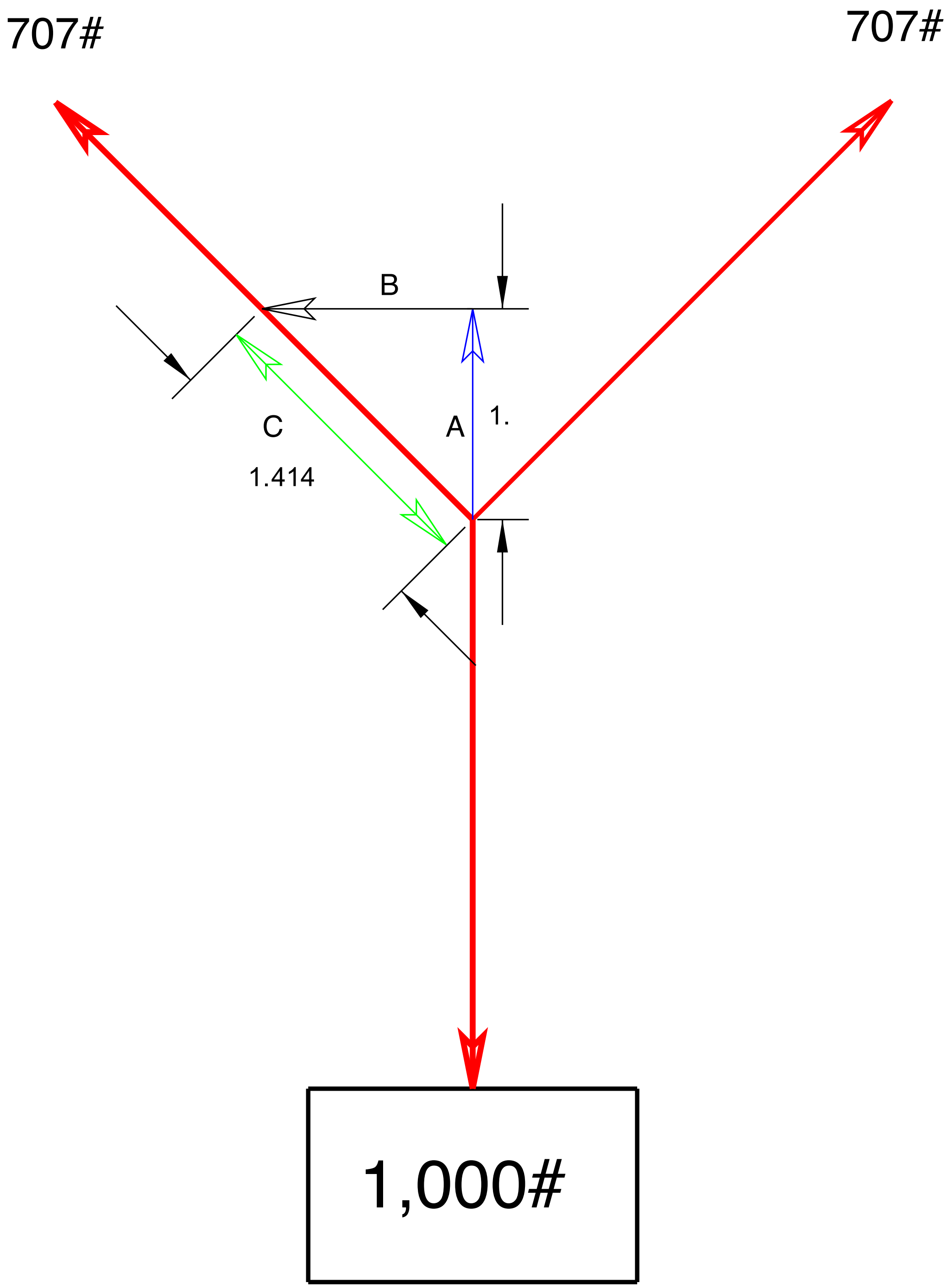
Next, we measure the length, along the anchor leg, between that intersection and the point at which the anchor legs converge. Line C (the green line in Fig.3) This distance, is used to determine the actual load, on the anchor point.

It works like this, the blue line is 1 unit in length, and represents 100% of the actual load 1,000# The green line is 1.414 units in length. Notice this number is the Cosine of 45 degrees squared.

We simply divide 1,000 by 1.414

1000 dived by 1.414 = 707

Fig.3



The Hand Method

The Hand Method, is a way of using the Graphical Method, explained above, in the field. The units of measure, used to make the calculations are based on the dimensions of the human hand. The length of your hand, from it's base to the tip of your longest finger, is one unit of measure. The width of your hand, is one half unit of measure. And each knuckle, across the width of your hand, is one tenth unit of measure.

You begin by measuring from the point the anchor legs converge, you can transfer this point to the ground, with a coin, a rock, make a mark in the dirt, whatever. Then using your hand, measure along the line of force, starting at this point. It doesn't matter how many hands it measures, this length represents 100% of the load. Transfer this point to the ground, as well. This establishes Line A in Figure 3.

Next, you draw a line at a right angle, from this point, to the point it intersects the leg of the anchor. Again, you can transfer this point to the ground. This establishes Line B in Figure 3.

Now, using your hand, measure from the point the anchor legs converge, to the point the anchor leg intersects, with the line you just drew. This represents Line C in Figure 3.

If your line of force, is one hand long, and your anchor line is one hand plus 4 knuckles, and the load is 1,000#, divide 1,000# by 1.4 hands = 714# Pretty close to the Mathematical and Graphical Methods.

Asymmetrical Forces

Asymmetrical 2 point Load Sharing Anchor System

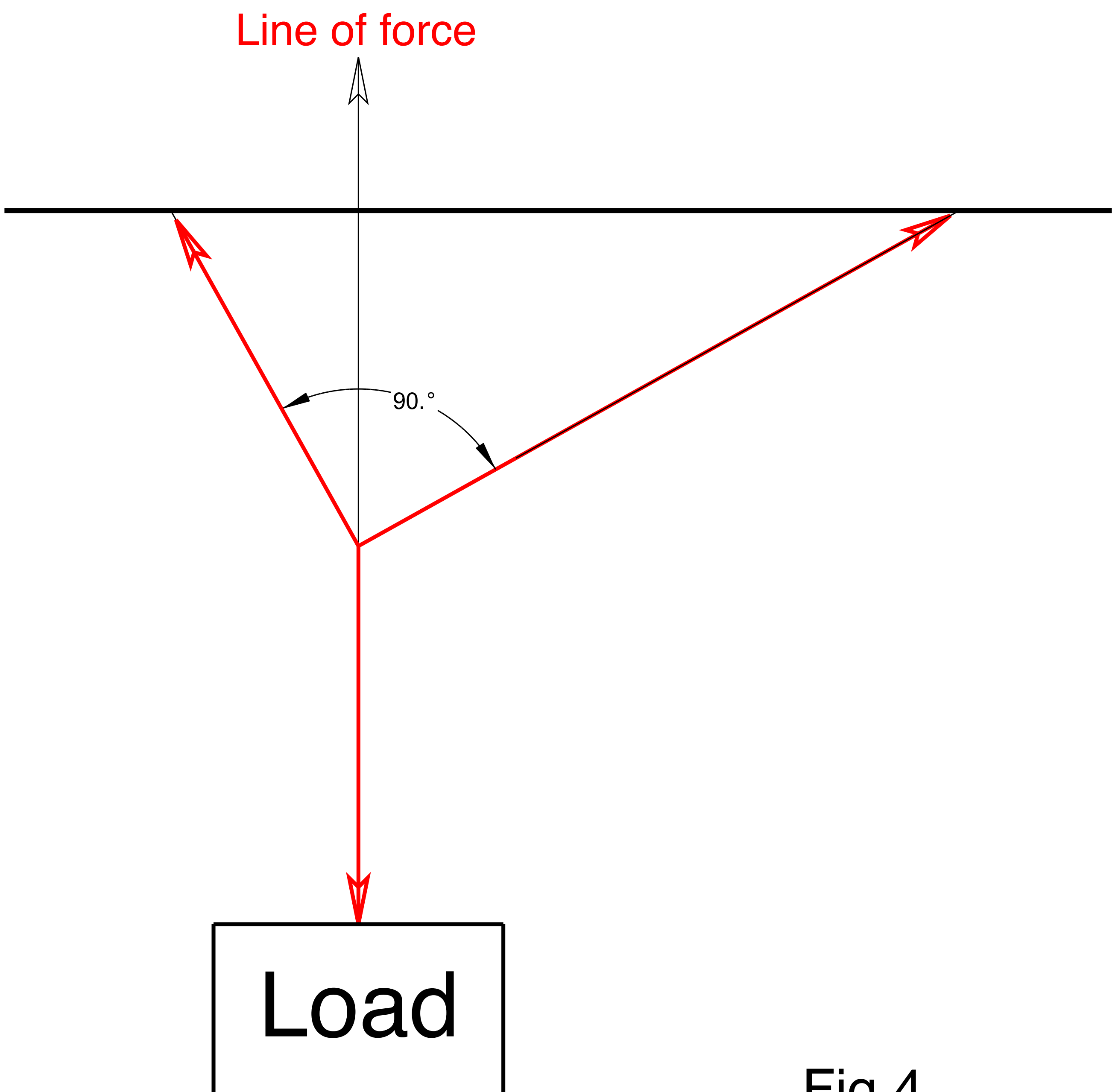


Fig.4

In Fig.4, we can see, the line of force does not bisect the legs of the anchor system equally. This means, the forces on each anchor point will be different.

Graphical Method

As before, we begin by drawing a line, starting at the point the anchor legs converge, following the line of force, the length of this line represents 100% of the actual load. (The dark blue line)

Again, we draw a line perpendicular to this line, this time extending in both directions.

Next, we measure each anchor line, from the point they intersect that line, back to the point the anchor legs converge. (The light blue and pink lines)

And lastly, we divide the actual load, by each of the anchor line distances, to find the actual load, for each respective anchor point.

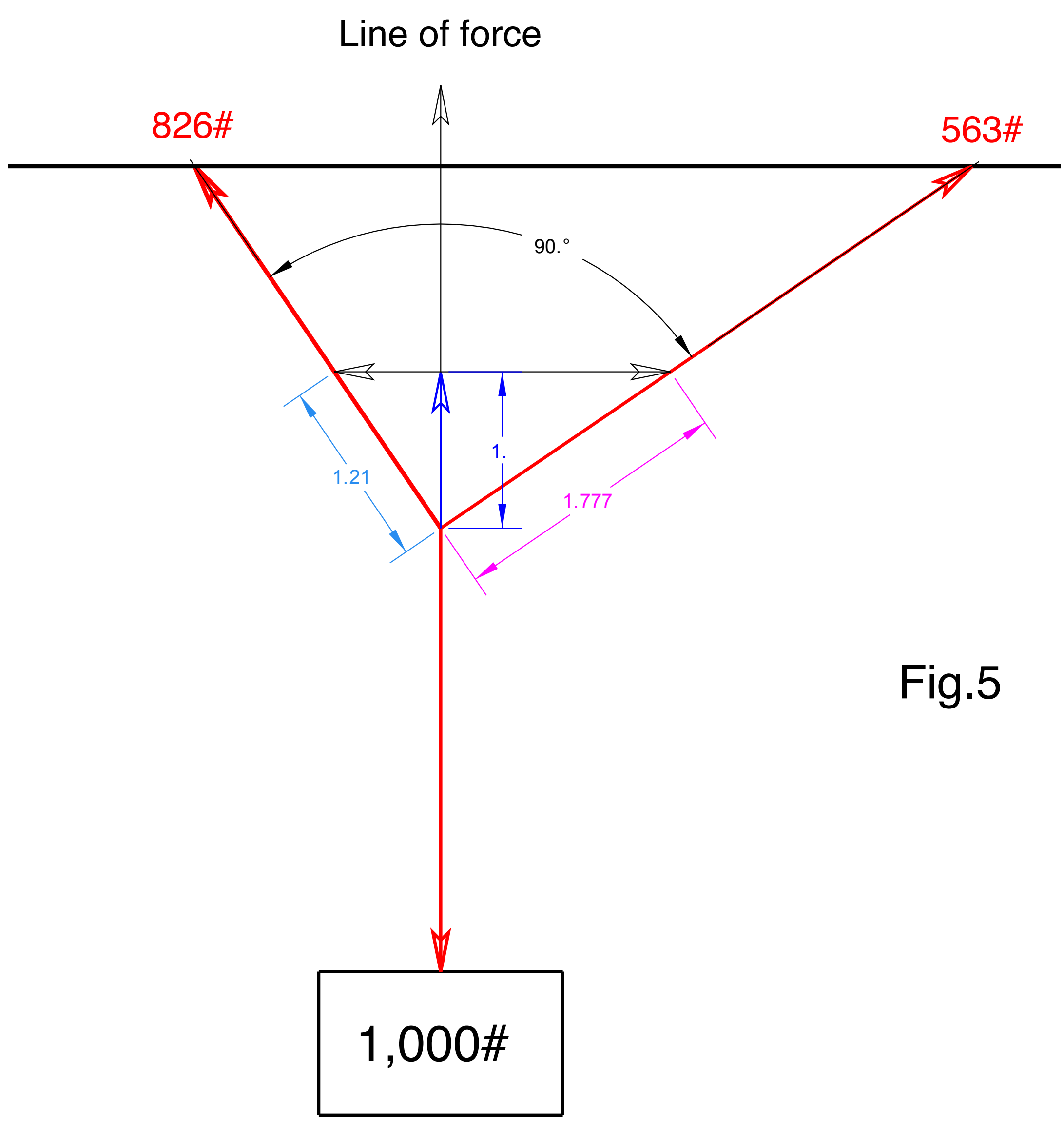


Fig.5

1,000 divided by 1.21 = 826   1,000 divided by 1.777 = 563

Even though the angle, 90 degrees, and the load 1,000#, are the same as we used for the symmetrical system, you can see, the actual loads at the anchor points are much different. One of the great advantages of this method is, you don't have to know the angles you are working with. This makes it quite easy to calculate asymmetrical forces, even in the field, using the hand method.

Pulling it all together

Any of these methods, when used in combination with the T Method of force calculation, for mechanical advantage systems, will allow you to fully understand the forces at work in any rope system.

If you are designing a system to be pre rigged, lay it out on paper, draw the angles accurately, show all the components, carabiners, rigging plates, pulleys, anchor slings, rigging rings, and, the rope it's self, then, use the expected load to do your calculations.

We need to know, the minimum breaking strength of every component. Since m.b.s is most often expressed in kn., we must first convert this number to something easer to work with.

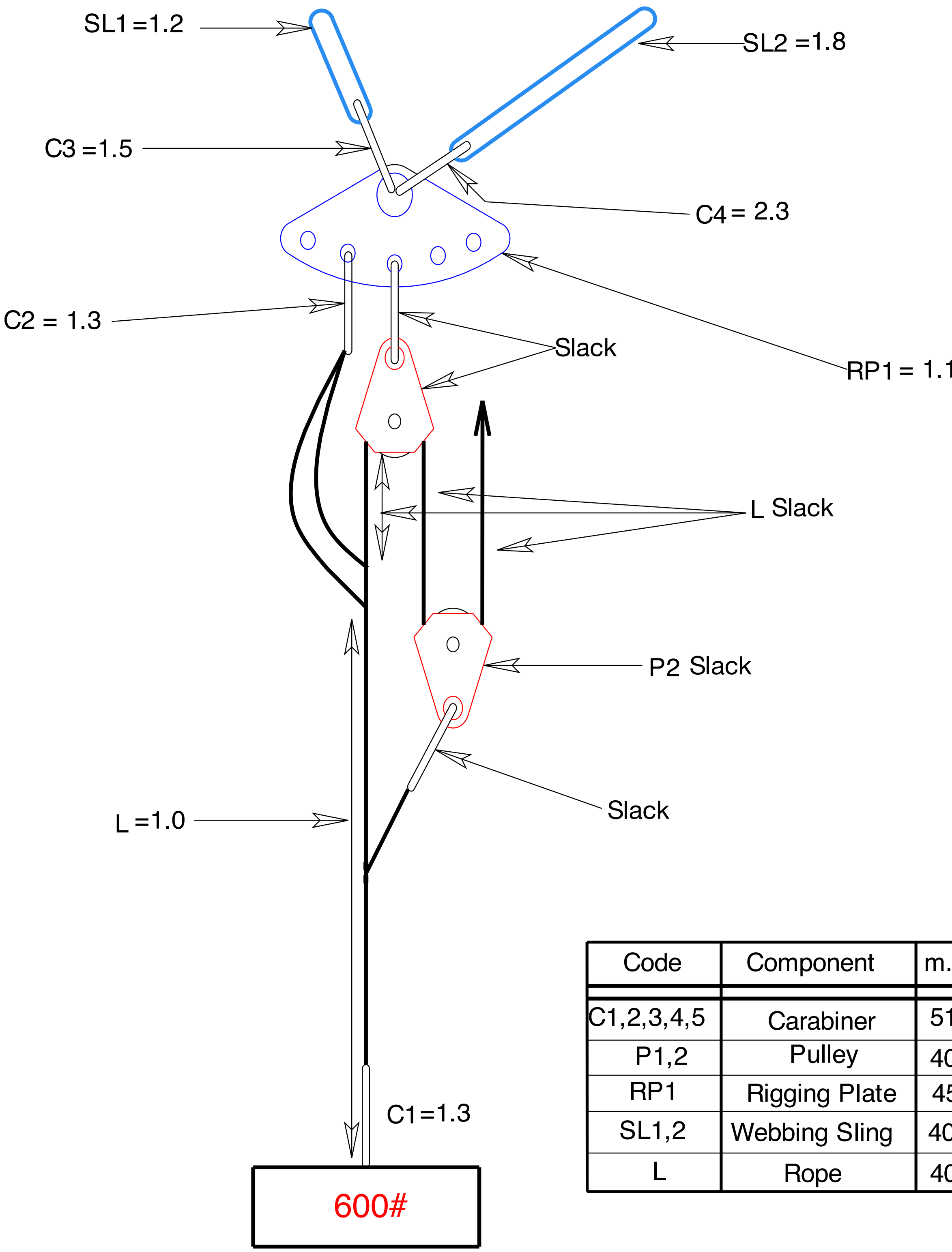
1 kn. is roughly equal to 224.9 pounds. Example, a carabiner, with a m.b.s. of 51kn.   To find the m.b.s. in pounds, we simply multiply 51 by 224.9   51x 224.9 = 11,469 m.b.s in pounds.

Next, we must find the "safe working load" for the carabiner. To do this, we divide the m.b.s by 15, this is the NFPA "safety factor".   11,469 divided by 15 = 764.66. This is the "safe working load" for this carabiner in pounds.

Once we know the safe working load, for every component, we can begin to analyze the system, to see the actual forces, each component is subject to.   We do this, by using the T method, and one or more of the methods described above, to find the actual force, on every component in the system.

We then divide, the "safe working load" by the actual load, for every component. The result of this calculation, expresses the actual "safety factor" relative to the actual load, for each component. Example, if the result is 1.0, that component has a 15/1 safety factor. If the result is 2.0 the actual safety factor is 30/1. So, the lower the number, for a given component, the less strength it has in the system. This number MUST NEVER dip below 1.0 for ANY component.

Fig.6 depicts the forces through a simple 3/1 haul system, with the load being suspended by the progress capture system.



Code	Component	m.b.s.
C1,2,3,4,5	Carabiner	51kn
P1,2	Pulley	40kn
RP1	Rigging Plate	45kn
SL1,2	Webbing Sling	40kn
L	Rope	40kn

Fig.6

Fig. 7 Depicts the forces through the same system, with the load being suspended, by the haul team.

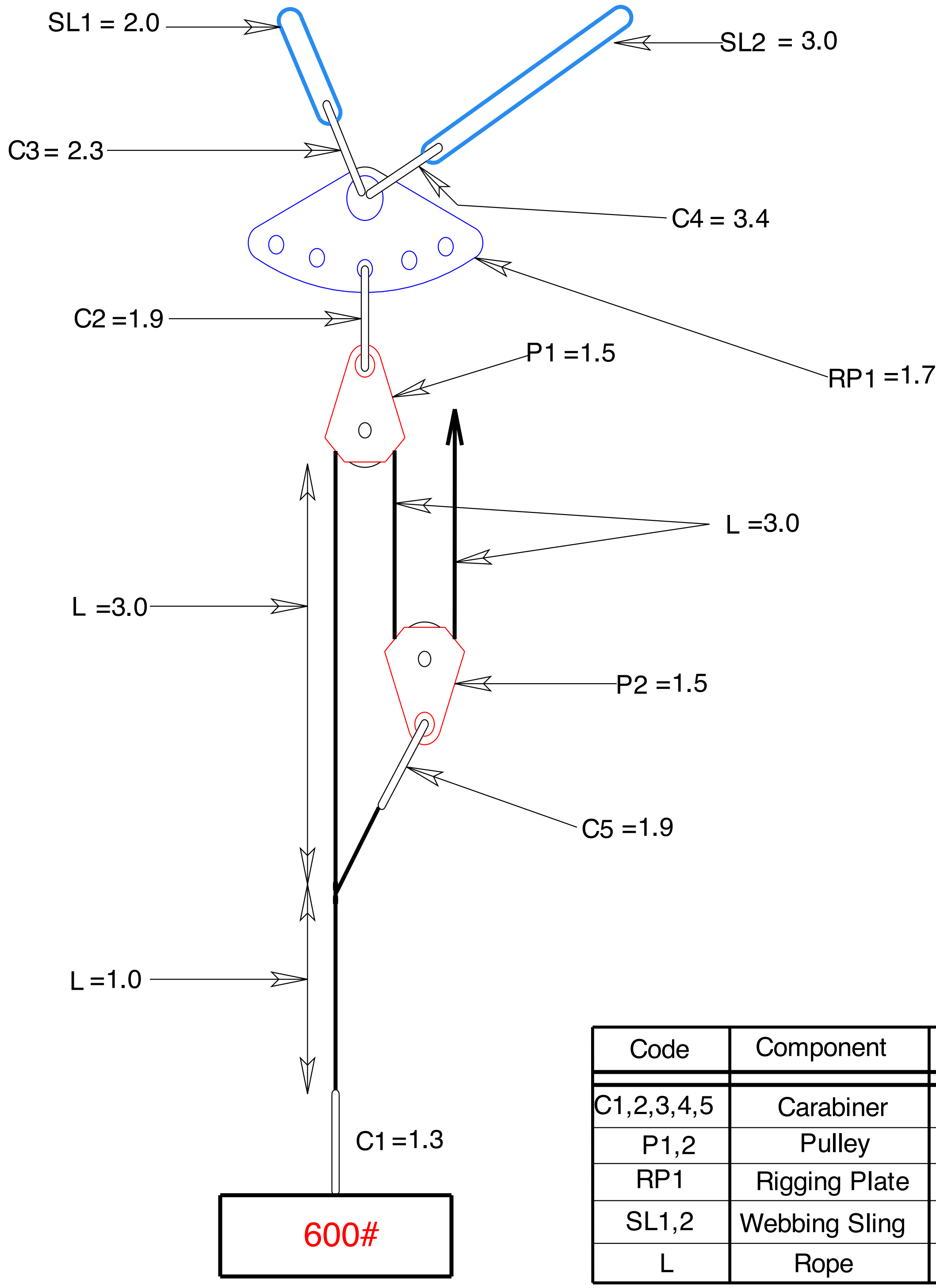


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Fig.7

Fig.6 / 7 Illustrate, how the forces change, through a rope system, depending on it's "state". Notice the forces on the anchor related components, change significantly. It seems counterintuitive, that the forces on the anchors, would actually decrease, when the haul team is pulling on the rope, and increase, when the system is just holding the load, on it's own. The reason is simple, in Fig 6. 100% of the load, is transferred to the anchor, through the progress capture system, by C2 in Fig.6.   In Fig 7., when the haul team is pulling on the rope, they are supporting 1/3 of the load, in this case. The anchor, must only support 2/3 of the load. If the system incorporated a change of direction pulley, attached to the main rigging plate (RP1), the forces on the anchor carabiners C3-C4, and the anchor slings SL1-SL2, would increase to 660#, and 450# respectively, when the haul team is holding the load. The forces on C3, would bring it's value down to 1.0. Just enough to maintain the NFPA safety factor.   Setting up a separate, change of direction anchor system, is often good practice.

A Few Final Words

If all this, seems like a lot of work to go through, Well... I guess I can't argue, it is! But...considering that someone's life hangs in the balance, and since we are charged with safeguarding life, it is our responsibility, to do everything we can, to minimize risk in any way we can.