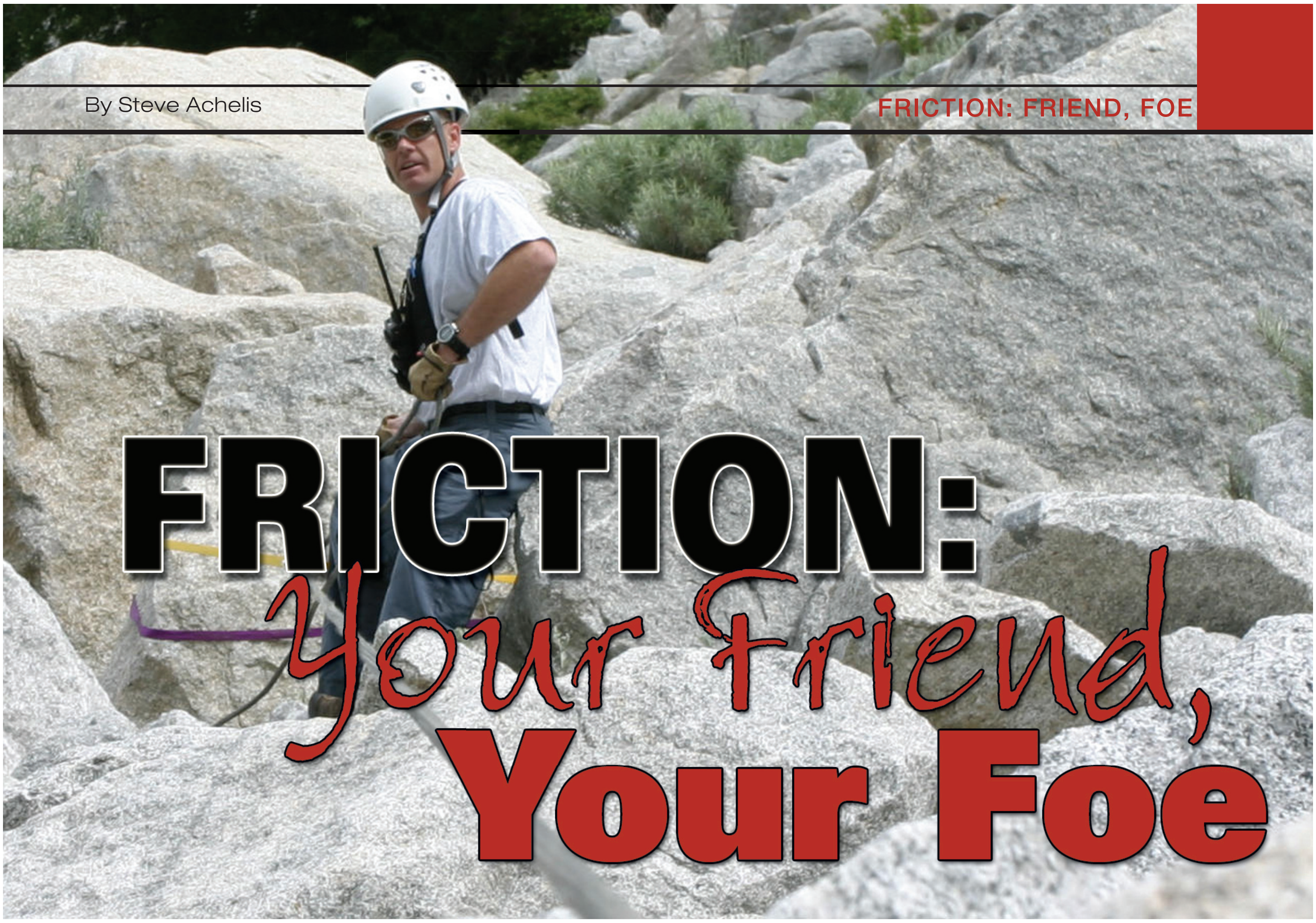
By Steve Achelis



FRICTION: Your Friend, Your Foe

Friction is the resistance to motion that occurs when two objects touch. It is the resistance you feel when you drag your hand across your desk, the resistance between your tires and the road that enables your car to move when the tires rotate, and the resistance that occurs when your rope touches your rescue gear. To a rescuer, friction is both friend and foe.

Sometimes a Friend…

During a rope rescue, friction allows us to slowly lower a litter through a brake bar rack and to maintain control as we rappel. Imagine what would happen if you reduced the friction in the brake bar rack by smearing grease on the rope and rack—yikes! Or consider how worthless your Rescue 8 would be if it were coated in Teflon. Even the ability to control how fast a rope slides through our gloved hand depends on friction.

Visualize that you're ascending a rope using Prusiks or mechanical ascenders. Now visualize this in a frictionless world, in which the Prusiks or ascenders slide up and down the rope with the ease of a pulley. It is not a pretty sight. Likewise, the thought of using a pulley rather than your Rescue 8 for a long rappel should create an image of crushed bones.

Devices used for belaying and rappelling are sometimes referred to as descent control devices (DCDs). This includes brake bar racks (also referred to as rappel racks), brake tubes, figure 8s, Rescue 8s, etc. *Figure 1* shows two descent control devices.

Figure 1

Black Diamond ATC-XP

CMI Rescue 8

There is a collection of hundreds of these devices at http://storrick.cnchost.com (click on "Vertical Caving & Climbing Devices Collection"). This site includes many one-of-a-kind and discontinued devices.

We need more than friction to slow our descent, though. We also need the ability to control the amount of friction applied to the rope. If we could not change the amount of friction being applied, the load would descend at a steady, yet unstoppable, rate.

Figure 2

Many DCDs let us regulate the amount of friction based on how the rope is threaded through the device. In the case of a brake bar rack, we can increase or decrease friction by adding or removing friction bars. Many Rescue 8s can be rigged as either a traditional 8 or a Sticht plate by passing a bight of rope through the smaller hole and clipping the bight into a carabiner (*Figure 2*).

We can also control the amount of friction by changing the angle at which the rope enters the device. *Figure 3* shows how the friction applied by a Rescue 8 changes dramatically based on the angle at which the rope enters it. Similarly, changing the angle on a brake bar rack squeezes the bars closer together, which increases the friction.

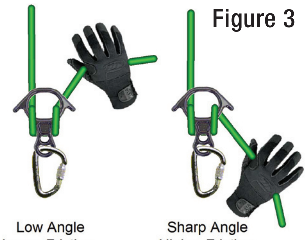
Finally, we can increase or decrease friction by applying force to the rope entering the device. As we pull harder with our hand, we not only create friction between the rope and our hand, we increase the friction between the rope and the descent control device.

Friction helps control the rate of descent.

…Sometimes a Foe

Alas, our friend friction can

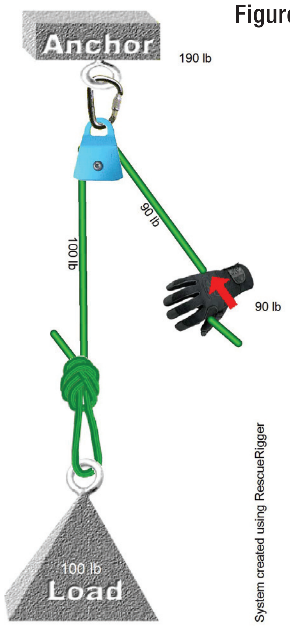
Figure 3



also be a thief, stealing our energy throughout rescue. It resists movement when our ropes slide over rocks and the edges of buildings, through carabiners and pulleys, and eventually wend their way to our victims.

Once again, the angle at which the rope encounters other objects can have a profound effect on the forces being exerted. For example, if the rope in your raising system must bend 90 degrees over the edge of a cliff, it will typically

Figure 4



double the force required to raise the object.

When raising a load, friction is our foe.

Calculating Friction

To understand the impact of friction on our rescue systems, we need to learn how to calculate its effect on the forces in our systems. The friction calculation depends both on the friction imposed by the objects and the direction the rope is traveling through the gear. The following formulas calculate the change in the rope's forces based on the friction between the rope and one other object. Calculating the effects of friction on a system with multiple pieces of gear using the T system (e.g., a 3-to-1) is explained later in this article.

Friendly Calculations

Friendly friction occurs when we are lowering a load. The formula for friction when releasing rope is:

Releasing force = load's weight x (1.0 minus friction loss)

Math reminder: Do the math inside the parentheses (i.e., one minus the friction loss) first, then multiply this number by the weight of the load.

In *Figure 4*, we're lowering a 100-pound load through a pulley with 10% friction. Using the preceding formula, we substitute 100 pounds for the load's weight and 0.1 (i.e., 10%) for the friction loss. We can then calculate the resulting releasing force as 90 pounds. The missing 10 pounds (i.e., the difference between the 90 pounds we are holding and the load's weight of 100 pounds) is lost to the pulley's friction.

90 lbs. = 100 lbs. x (1.0 - 0.10)

In this case, friction is our friend. The resistance in the pulley consumes 10 pounds of force, reducing the force we need to hold from 100 pounds to 90 pounds. That's probably still more than we want to hold, but it is a reduction in force.

Figure 5 shows a brake bar rack lowering a 500-pound load. Unlike the meager 10% friction imposed by our pulley, this brake bar rack provides 90% friction. Using the same formula, we can see that we only need to hold 50 pounds of the 500-pound

Figure 5

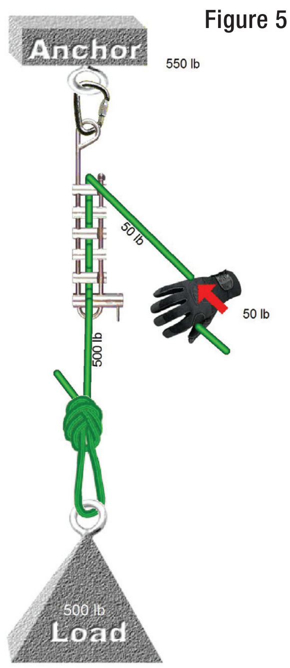
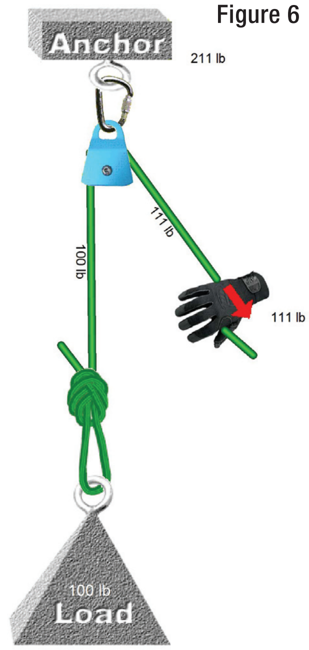


Figure 6



load. The rack is absorbing the other 450 pounds.

50 lbs. = 500 lbs. x (1.0 - 0.90)

Foe Calculations

When raising a load, friction is no longer our friend. The formula to determine the effect of friction when raising a load is:

Raising force = load's weight/(1 minus friction loss)

Math reminder: The slash in this formula means you divide the top number (the weight of the load) by the bottom number (i.e., 1.0 minus the friction loss).

Figure 6 shows the same system as *Figure 4*, but this time we're pulling the rope through the pulley rather than releasing it (note the arrow on the hand). Using the preceding formula, you can see that we must pull 111 pounds to raise our 100-pound load. The pulley's friction requires us to pull an extra 11 pounds.

111 lbs. = 100 lbs. / (1.0 - 0.10)

Friend Turned Foe

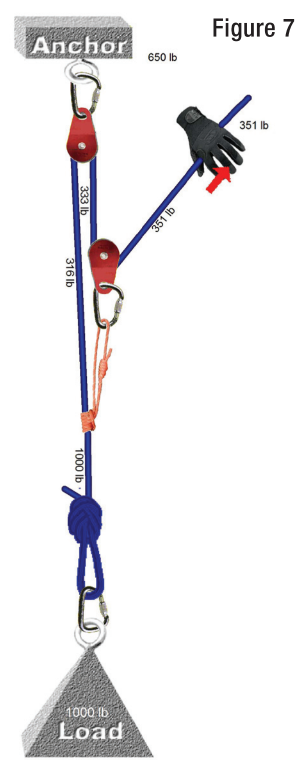
Figure 5 had us lowering a 500-pound load through a brake bar rack with 90% friction. That 90% friction was our friend. However, what if we attempted the insane by trying to raise the load through the rack? The following equation shows we would have to pull a whopping 5,000 pounds to raise our 500-pound load.

5,000 lbs. = 500 lbs. / (1.0 - 0.90)

Is It Really a 3-to-1?

Figure 7 shows a basic 3-to-1 raising system. You would expect to pull 333 pounds to raise the 1,000-pound load (i.e., one-third of the 1,000 pounds). However, if each of these pulleys induces a meager 5% friction, then our pulling team is really pulling 351 pounds to raise the 1,000-pound load. In fact, we have effectively created a 2.8-to-1 system. And if we increase the friction in the pulleys to 30%—a not-unheard-of value for some smaller pulleys with brass bushings—we will need to pull 457 pounds to raise our 1,000-pound load. Our 3-to-1 system is now only providing a 2.2-to-1 mechanical advantage! The pulleys' 30% friction has

Figure 7



added 124 pounds to the 333 pounds we expected.

The T System

The preceding formulas let you determine the effect of friction as a rope passes through a single device. We use a different method to determine the friction on an entire system, such as the preceding 3-to-1. This relies on the popular T system of determining mechanical advantage, albeit with a slight twist.

The T system is a technique used to calculate the mechanical advantage of a rope system. For example, you can use it to determine that a "Z" rig really does create a 3-to-1 advantage. The T system was explained in my article *What's the Advantage? Calculating Mechanical Advantage With the T-System* in the June/July issue of *ART*.

First we will determine the mechanical advantage while ignoring friction using the T system. In *Figure 8*, the rope segments have each been labeled T1. The Prusik is labeled T2, because it is holding both of the T1s above it. And the load is labeled T3 because it is holding the T1 and T2 above it. The T3 tells us this is a 3 (the force on the load)-to-1 (the force on the hand) system.

Figure 9 (on page 40) contains the same 3-to-1 system as *Figure 8*, but this time with 10% friction in each of the pulleys. T values have been displayed using the same method, but this time we reduced the T value each time the rope passes through a pulley using the following formula:

New T value = previous T value x (1.0 - friction)

We start by labeling the rope segment at the hand with T1. Next, we use the preceding formula to determine the T value of the segment on the other side of the pulley. The formula takes our previous T value (1.0) and calculates the new T value (0.9). We label the next segment T0.9:

0.90 = 1.0 x (1.0 - 0.10)

As this T0.9 passes through the top pulley, we lose another 10% to the pulley. Using the same formula but specifying the previous T value as 0.9, we find that the third rope segment gets T0.81:

0.81 = 0.90 x (1.0 - 0.10)

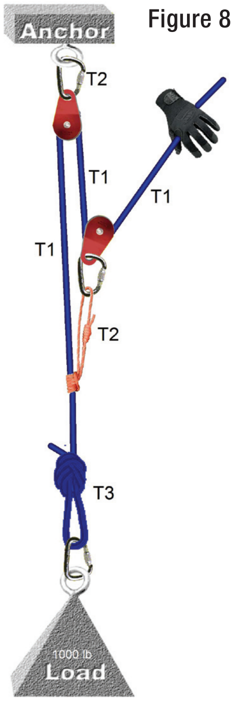


Figure 8

Typical Friction

Brake bar rack: 75%–98%
Carabiner (180° bend): 40%–60%
Figure 8: 89%–96%
Pulley (ball bearing): 5%
Pulley (bronze bushing): 30%
Rescue 8: 82%–94%

Figure 9

Figure 10

By adding the T values of the first two segments (i.e., T1.0 and T0.9), we can see that the Prusik is holding T1.9. We then add the Prusik's T1.9 value and the third rope segment's T0.81 and determine that the load receives T2.71. This tells us this is a 2.7-to-1 system, not the 3-to-1 system we expected. We can divide the load's weight of 1,000 pounds by 2.71 to see that the hand will be holding 369 pounds, rather than the 333 pounds we expected.

The basic process to determine the effects of friction on a raising system using the T values is as follows:

1. Assign the rope segment nearest the puller's hand T1.0.
2. Each time the rope passes through a device with friction, reduce the value by the amount of friction.
3. Sum the T values to arrive at the load's T value.

Biners for Pulleys

It should be obvious by now why friction is a foe when raising. And the preceding examples should have made it clear that minimizing friction in pulleys is a good thing. But there may be times when we do not have low-friction ball-bearing pulleys and are forced to use lesser gear, like carabiners, for pulleys. This often happens on a pickoff where you need to raise the victim a few inches to transfer their weight onto your system. As shown in *Figure 10*, when you attempt to lift a 200-lb. victim on a “3-to-1” created with carabiners (which typically have 50% friction), you will be lifting a surprising 114 pounds, not the 67 pounds (i.e., one-third of 200 pounds) you may have expected. Your system is no longer a 3-to-1 or even a 2-to-1—it is a discouraging 1.8-to-1.

Lost Forces

Regardless if friction is friend or foe, the energy consumed by friction is not just lost, it’s converted into heat. The heat is absorbed by the objects that are rubbing against each other and then dispersed into the air. The smaller the objects generating the friction, the hotter they will become. For example, given the same friction and forces, a small ATC (air traffic controller) will become much warmer than a brake bar rack, simply because the rack has more mass to absorb, and more surface area to dissipate the heat.

Make Friends, Ditch Foes

The next time you set up a system, don’t forget your friend and foe friction. If you’re lowering a load, think about ways to increase friction, which will decrease the forces you must hold: Change the angle of the rope, route the rope differently or add bars to your brake bar rack. And when raising, think about ways to decrease friction. Use low-friction ball-bearing pulleys, use rollers or rope protectors, minimize angles and think about friction as resistance to accomplishing the task at hand. Those pulleys might be making your 3-to-1 less efficient than you think. ■

Steve Achelis is vice commander of the Salt Lake County (UT) Sheriff’s Search and Rescue Team. He is also the author of the RescueRigger software program that was used to generate the illustrations and calculate the forces in this article. For more information, visit RescueRigger.com or e-mail info@RescueRigger.com.

To purchase a copy of Steve Achelis’ article in the June/July issue of *ART*, call Maribel Lopez at 800/224-4367.