Nylon Highway

Issue #46

... especially for the Vertical Caver

#46

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Some Thoughts on Using Rappel Racks as Belay Devices

(Presented to the Vertical & Rescue Sections, NSS 2000 Convention)

By Carroll Bassett, NSS #34462

Over the period of the last year we have been investigating the use of closed frame racks as belay devices for technical rope rescue. Since open frame racks can permanently deform under loads as low as 1000 lbs. we chose not to test this concept on them and believe that there may be a significant safety risk in using this form of rack for belays. Further work needs to be done in this area.

The original idea came from the realization that if a rack is rigged upside down a load would tend to squeeze the bars together generating friction in proportion to the load applied. This "self compensating" action was recognized during the development of our personal escape decent control devices, the Nano and Pico-Racks.

Our initial tests proved that the concept worked extremely well in that a dropped 600 lb. load could be successfully arrested with acceptable slippage of rope through the device (see fig. 1).

BMS Nano-Rack in Belay Configuration

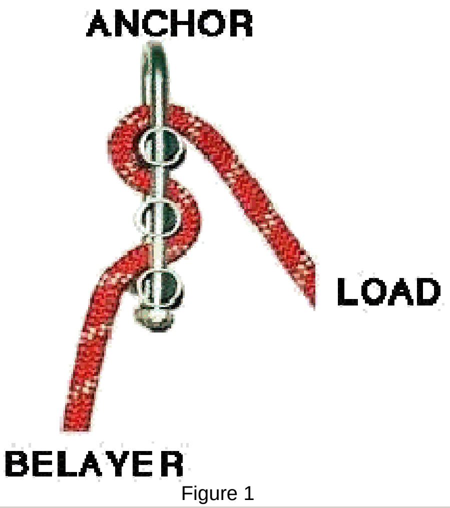


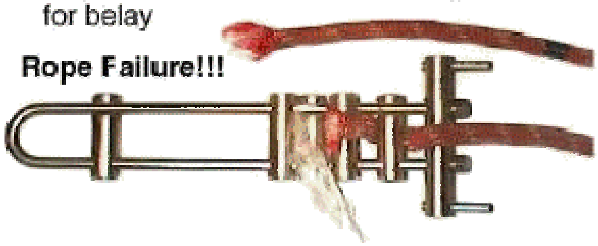
Figure 1

We used one of our Nano-Racks for the first tests which, because its bars do not open, had to be rigged by passing the end of the rope through the rack to be rigged in our new "belay configuration". It was found that the device fed rope easily and and did not need to be attended to catch the load (passes the "whistle test")

Encouraged by these results and wishing to eliminate the need to feed an end of a rope through the rack we experimented with rigging 4 bars of one of our Rescue-Racks (see fig. 2). By adding a fourth bar to the configuration we introduced much too much friction to the system which did not allow for the necessary rope slippage to dissipate some of the energy generated in the drop.

In our extensive test program this is the only failure we have witnessed. Using four bars in this "belay configuration" does not work and is extremely dangerous!

Fig.2 Rescue-Rack w/ 4 bars rigged for belay



Clem, a high speed (1,000 samples / sec.) digital force measuring system, enabling us to accurately measure the forces acting on our anchor point (see fig. 3).

With the installation of the load cells and some minor structural changes to our drop tower, we were able to add to our previous rope length of 72 inches another 24 inches of rope, 96 inches, bringing it a little closer to the standard of 3 meters (118.1 inches) suggested by Arnor Larson of the British Columbia Council of Technical Rescue (BCCTR) in his Aug. 2, 1990 paper, "Rescue Systems Testing". This test also calls for the maximum force transmitted through the system to the anchor point to be no greater than 15 kN (3,375 lbf.) We again used our 600 lb drop weight on all the 1/2 (12.5 mm) inch rope tests and constructed an additional 300 lb weight for the tests involving 7/16" (11 mm) rope . These loads and ropes correspond to NFPA specified one ("P") and two ("G") person use. The BCCTR calls for a 200 kg (440 lbs.) load for two person loads as well as a maximum rope slippage of 1 meter (39.3 in.) As in our previous tests the drop weight was raised a distance of 36 inches and released. Our test is some what more demanding of a belay device in that our fall factor (ratio of drop distance to rope length) is .375 as opposed to .333 for the BCCTR test and our drop weight is 160 lbs. heavier.

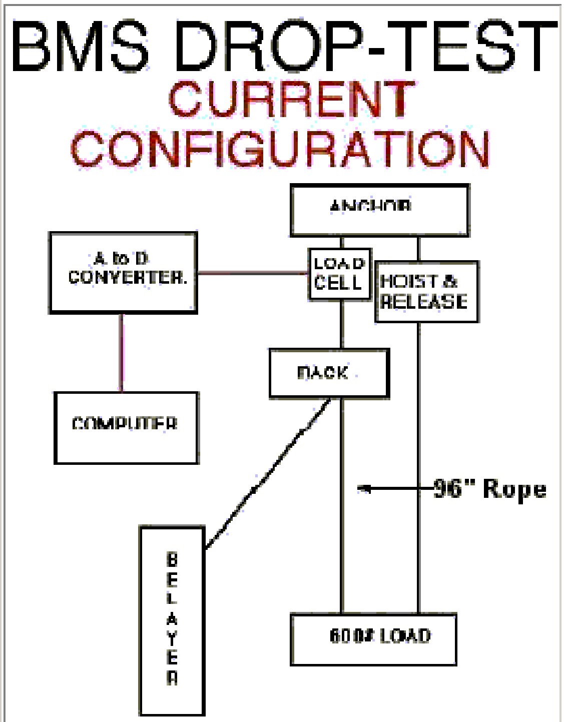


Figure 3

As you will see , most of these tests were carried out in the "Whistle Test" mode which leaves the rope usually held in a belayers hand unattended when the load is released. The "Belayed" test involved holding the rope in one gloved hand when the load was released. Each test was carried out in a series of three drops after which the rope was changed. The rope was not advanced during these three drops to see the effect of repeated "drops" on the same area of rope. With the exception of the 4 bar test, rope damage was minimal involving some glazing and minor sheath damage. We also employed an initial "half drop" to take out the slack in the bowline knot attaching the rope to the drop weight. This eliminates the shock absorbing effect of the knot and gives more of a worst case scenario to the test. We also did not employ a LRH (load releasing hitch) which also would have lowered peak anchor forces as it functions as a shock absorber. Special thanks to Kristin Pilotte for her invaluable help in compiling this data and to Steve Hudson of PMI for supplying the rope used in these tests.

A recent modification, suggested by John Kerr, to the Nano-Rack eliminates the Nano's limitation of not being able to be rigged in the middle of a rope (see fig. 4). To accomplish this the second bar of the Nano is replaced with an openable bar (swing) and the frame has been modified to allow the rope to pass inside the frame at the attachment point. This configuration is identical functionally with the belay configuration used on the Micro-Rack and will yield the same results. The price of this modification to allow midline placement, is that the belayer must be more attentive to the possibility of the second bar opening during operation. This in effect would render the belay ineffective. This should also taken into consideration when using a regular closed frame rack for a belay. To remedy this situation BMS has devised a spring latch for the second bar making it much less likely to open inadvertantly.

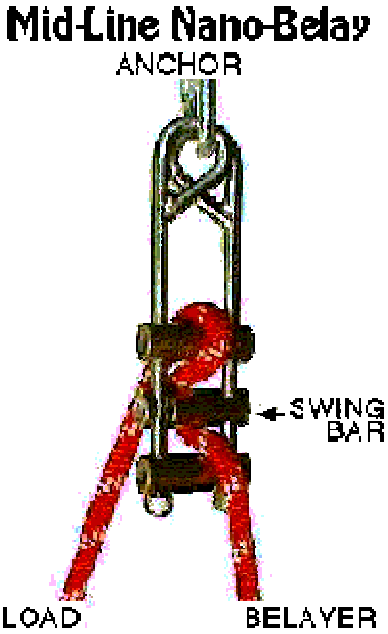


Figure 4

ALL TESTS FALL FACTOR .375
(3 ft. drop on 8 ft. rope)

"WHISTLE TEST" MODE
USING 1/2" PMI EZ BEND
WITH 600 LB. DROP WEIGHT

Using a BMS NANO-RACK

DROP #	ROPE SLIP	MAX. ANCHOR FORCE
1	17"	1713 lbf.
2	19 1/4"	1559 "
3	21 3/4"	1673 "
Using a BMS RESCUE-RACK		
1	22 1/2"	1650 "
2	22 1/2"	< 1583 "
3	22 3/4"	1539 "
Using a BMS MICRO-RACK		
1	21"	1625 "
2	26 3/4"	1345 "
3	28"	1136 "

Users of these belay devices should make their choices between the two carefully. If the ability to be placed midline is a prime consideration users must be vigilant not to allow the rope to become disengaged as above. A careful assessment of a teams skills and requirements will be helpful in making this decision.

With the conclusion of this series of tests, we believe that this technique offers rescuers a viable option over prussik knot belays . These rack belays eliminate three of the common problems found with the use of prussikms:

1. Speed in rigging. Can be rigged in less than half the time required for tandem prussiks.
2. Proper knot dressing. Often not dressed tight enough by inexperienced or occasional users.
3. Compatibility of prussik cord with rope. Stiffer or larger diameter cords can allow excessive slippage especially when combined with 2.

Additional advantages include, less damage to ropes, thus providing greater margins of safety, and simplicity in rigging.

As with the tandem prussik belay, a load releasing hitch should be added to the system to enable the transfer of weight in the event of a "lockup". This can happen with inexperienced belayers or of course with a failure of the haul or lower system. Not including this component will necessitate higher skill levels of operators or the repair of the failed system before lowering or raising proceeds.

All of these tests were performed on BMS closed frame racks equipped with tubular stainless steel bars. We have no experience with other manufacturers equipment and as such cannot recommend the use of these techniques with their equipment.

Comments on the above will be appreciated and can be made to:

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WHISTLE TEST" MODE USING 7/16" PMI EZ BEND WITH 300 LB. DROP WEIGHT Using a BMS NANO-RACK		
1	15 3/8"	817 "
2	18 5/8"	866 "
3	24 3/4"	812 "
Using a BMS MICRO-RACK		
1	22 1/4"	694 "
2	18"	795 "
3	14"	951 "
"WHISTLE TEST" MODE USING 7/16 PMI IMPACT WITH 300 LB. DROP WEIGHT Using a BMS NANO-RACK		
DROP #	ROPE SLIP	MAX. ANCHOR FORCE
1	5 1/2"	1263 lbf.
2	3 1/4"	1210 "
3	3 1/2"	1371 "
BELAYED MODE USING 1/2" PMI EZ BEND WITH 600 LB. DROP WEIGHT Using a BMS NANO- RACK		
1	17"	1632 lbf.
2	17"	1599 "
3	18 1/2"	1648 "

The Mechanics of Friction in Rope Rescue

Stephen W. Attaway, Ph.D.
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International Technical Rescue Symposium (ITRS 99)

Frictional forces play an important role in rope rescue. Friction force helps control the lowering of rescuers, however, friction force fights against the rescuer during a raise. Since friction in rope rescue can change exponentially with the rope geometry and the coefficient of friction, understanding the factors that affect rope friction is essential in technical rescue.

By applying a simple friction law derived for a capstan to friction forces in a break tube, rappel rack, and a figure-eight, we gain a better understanding of the behavior of these devices. While the conclusions drawn from this study are not counter to the current beliefs and practices within the rescue community, this study quantifies why some friction devices perform better than others.

In addition, these same friction laws can be used to better understand the frictional force for a rope going over a rock face. For example, the interaction of static and dynamic coefficients of friction can explain the bouncy ride that rescuers sometimes feel when they are at the end of a long haul system. Rope dynamics generated by friction can be estimated given the amount of rope, the weight of the load, the rope modulus, and the frictional force.

Friction Law

Tangential forces generated between contacting surfaces are known as frictional forces. These tangential forces resist motion up to a point. Experiments have shown how the limiting tangential force that can resist motion is proportional to the normal force along the contact surface. Thus, for impending motion the frictional force, F_f is proportional to the normal force,

F_N

$$F_f = \mu F_N \qquad (1)$$

where μ is called the ***coefficient of friction***.

Once the maximum frictional force is exceeded, then sliding will occur. There will still be resistance to slippage, and the magnitude of the tangential force for a sliding surface will also be proportional to the normal force. However, the frictional force for sliding contact will be lower.

The ratio of the limiting frictional force to the normal force for no slipping is called the static coefficient of friction. For sliding surfaces, the term dynamic coefficient of friction is used. The transition between static an sliding coefficient of friction is shown in Figure 1.

Automobile drivers know when the tires are sliding a car will have less breaking power than if the tires are not locked. Anti-lock breaks take advantage of the fact that sliding friction is less than static friction.

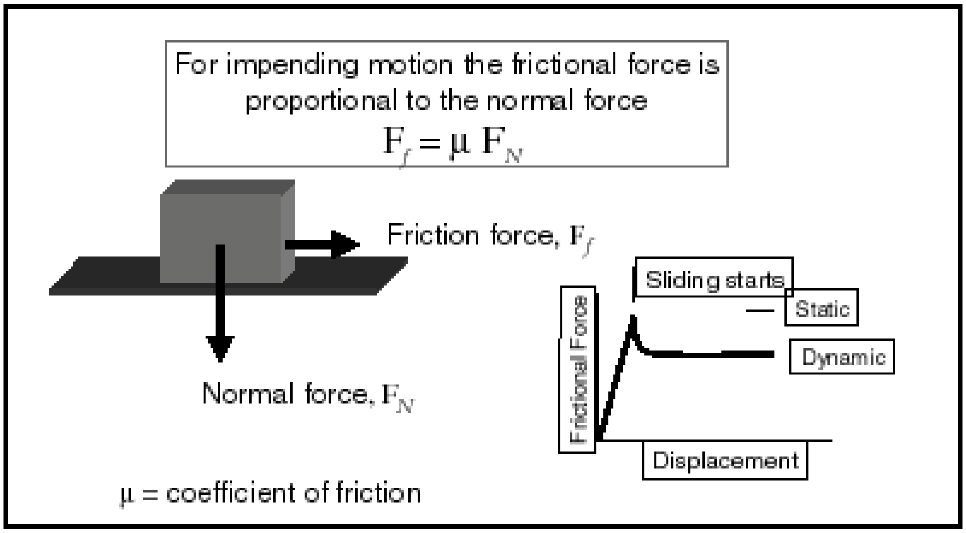


Figure 1: Friction Law.

Figure 2 shows a friction example for a brick that must be slid across a floor. We all know from real life experience that even though the two different block orientations will have a much different contact areas, the amount of force required to start the block sliding will be the same for both orientations. If the forces were different, then construction workers would always try to stack material so that they would be easy to slide.

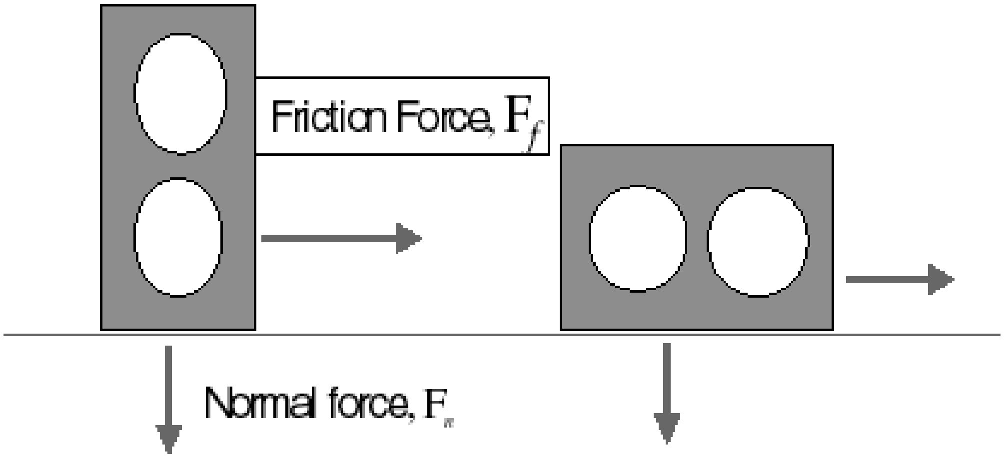


Figure 2: Friction Example.

The force required to slide the blocks depends only on the weight of the block and the coefficient of friction between the block and the sliding surface. In order to see how the contact area cancels from the friction equation, consider the normal stress defined as:

$$\sigma_n = F_n/A \tag{2}$$

The friction stress will be $\mu\sigma_n$ and the frictional force will be $F_f = \mu\sigma_n A$ to give:

$$\frac{F_f}{F_n} = \frac{\mu\sigma_n A}{\sigma_n A} = \mu \qquad (3)$$

When the frictional forces are computed using the assumption that the limiting tangential stress is proportional to the normal stress, the areas council to give the ratio of the tangent force to the normal force independent of the contact area.

To a good first approximation, the independence of the friction law to contact area also applies to ropes. If the load is extreme, then the above equations may not be accurate. However, the friction law presented here should provide a very good approximation for most loads.

The Capstan Friction Equation

In Figure 3, the differential forces for tension of a rope over a drum are shown assuming impending slipping and no bending strength. Figure 4 shows the finial equation which is known as the capstan friction equation. Note that in order to understand the rest of this paper, the reader need not understand the derivation of these equations. The derivation is presented for completeness and can be found in J. L. Meriman.

As a rope bends over a small segment of a drum, the tension in a rope will increase from T to T+dT in an angle $d\theta$. The normal force is the differential dN, since it acts on a differential of area. The frictional force is μdN, and acts to oppose slippage.

Equilibrium in the x direction requires the sum of forces in the x direction equal to be zero,

$$\sum F_x = 0 \qquad (4)$$

$$T\cos\frac{d\theta}{2} + \mu(dN) - (T + dT)\cos\frac{d\theta}{2} = 0 \qquad (5)$$

which reduces to

$$\mu dN = dT \qquad (6)$$

if one recalls that cosine of a differential is unity and the product of two differentials can be neglected. Equilibrium in the y direction, similarly, gives

$$dN - (T + dT)\sin\frac{d\theta}{2} + T\sin\frac{d\theta}{2} = 0\,, \qquad 7$$

which reduces to

$$dN = Td\theta. \qquad (8)$$

The normal force can be eliminated from equation 6 and 8 to give a differential equation for T in terms of the contact angle θ.

$$\frac{dT}{T} = \mu d\theta\,.$$

Integration over the total contact angle gives the ratio of the tension force in terms of the coefficient of friction, μ, and the contact angle β.

$$\int_{T_1}^{T_2} \frac{dT}{T} = \int_{0}^{\beta} \mu\, d\theta \tag{9}$$

or after integration of equation 9 we get,

$$\ln\frac{T_2}{T_1} = \mu\beta, \tag{10}$$

which reduces to the capstan equation:

$$T_2 = T_1 e^{\mu\beta}. \tag{11}$$

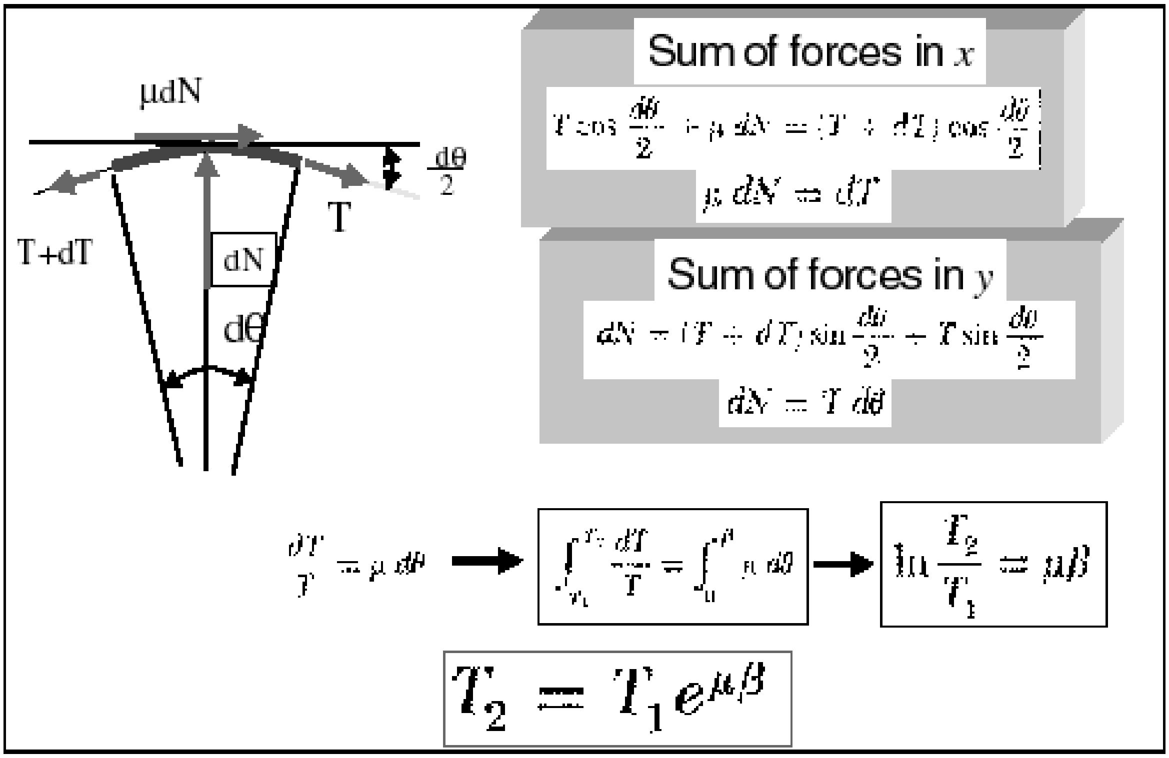


Figure 3: Amontons' friction law for a flexible belt. (J. L. Meriam)

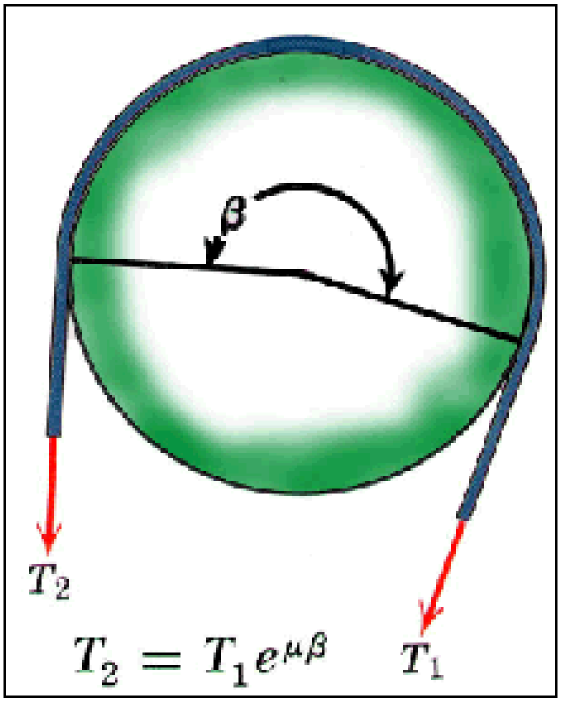


Figure 4: The capstan equation for belt friction.

Figure 4 summarizes the capstan equation for friction over a drum. Using this simple friction law leads us to conclude that the frictional forces for a rope depends only on three things:

- the tension in the rope
- the coefficient of friction
- the total angle of contact

For the friction model we have considered, the friction will increase exponentially with the coefficient of friction and the contact angle. Just like the sliding contact block, the solution is independent of the contact area, and thus independent of the radius of bend and the size of the rope.

The friction on a rope can vary greatly depending on the rope conditions. If the rope is muddy or wet, then the friction will be reduced. If the rope is old or the outer sheath is worn, then the friction may increase. For the examples shown here, we will assume that the rope is uniform and that the friction is constant over the length of the rope. The real world will be different; however, we will still be able to gain understanding of the real world by studying some "ideal" friction cases.

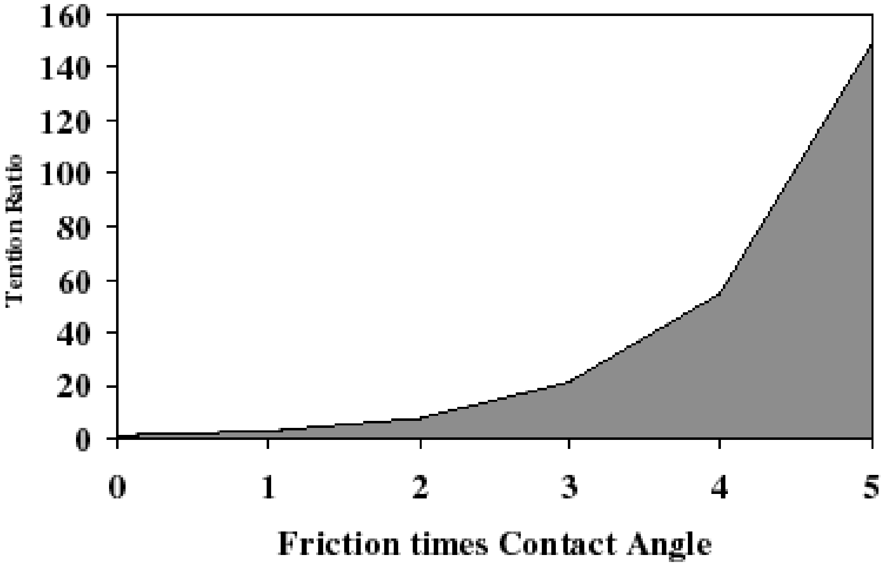


Figure 5: Example of exponential function of contact behavior.

The plot in Figure 5 illustrates the dramatic increase of an exponential function. For this graph, the x axis represents the coefficient of friction times the contact angle. The Y axis gives the ratio of the tension force T_1/T_2. Note that for a contact angle of zero or a friction coefficient of zero, the ratio is 1.0. That is expected. As the product of the coefficient of friction and the contact angle increase, the function increases slowly at first. Then, as with any exponential function, the value grows rapidly.

For the capstan equation, the contact angle must be in radians. Recall that 360 degrees or one revolution is equal to 2 π radians.

Capstan Equation applied to breaking devices

In this section, I apply the capstan to some of the common breaking devices used in rope rescue. For comparing these different devices, I assumed the same coefficient of friction for each device. I assumed (did not measure) the coefficient of friction to be 0.25. The coefficient of friction for rope on aluminum can vary according to the rope type and condition. Mud, water, ice, and oil can all affect the coefficient of friction. I used $\mu = 0.25$ as an average number for comparison.

The Tube

The break tube is designed for lowering rescue loads. The idea for the tube was borrowed from the sailor's capstan. As can be seen in the calculations shown in Figure 6, the number of wraps will dramatically increase the frictional force.

For one wrap, the estimated ratio of holding force to load would be 10-to-1. For two wraps, the angle of turn increases to $\beta = 5\pi$ or 900 degrees. This will generate a 50-to-1 load holding capability. The effects of the exponential can really be seen when three wraps are used. For this case, the holding ratio jumps to 250 to 1.

For a 600-pound rescue load, one would expect to use 60 pounds of holding power if only one wrap is used. For two wraps, only 12 pounds would be required. If the three wraps are used, then only two to three pounds of holding force are required. The nice thing about the tube is that the large bending radius makes it easy to feed the rope, which means that three wraps are very easy to use.

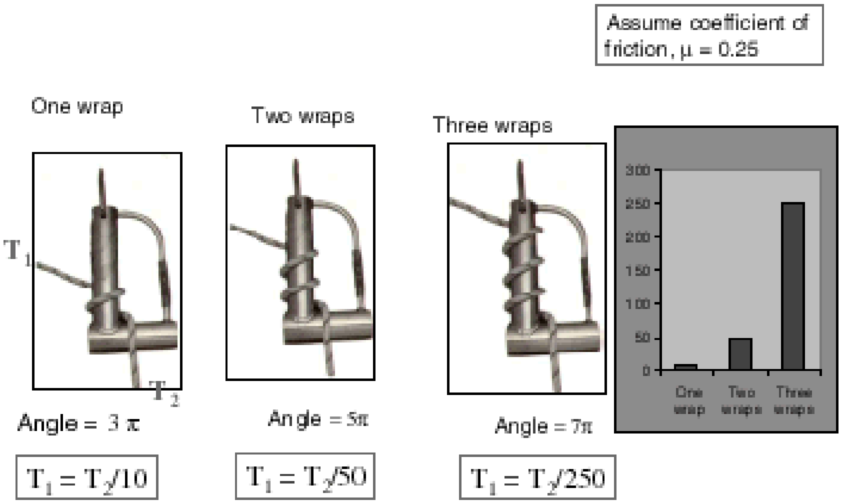


Figure 6: An analysis of the break tube for different frictional geometries.

The Rappel Rack

Figure 7 shows different geometries for the rappel rack. As can be seen in this illustration, one advantage of the rappel rack is the ability to increase the friction by changing the geometry. Simply sliding the bars changes the contact angle. For the average bar position (center of figure), I estimated the total contact angle of a rack to be $\beta = 560^o$ or 3.2 π radians. This total contact angle would give an average breaking force of 12-to-1 for a coefficient of friction of 0.25. The maximum angle change should be about 800 degrees, which gives a breaking force ratio of 31-to-1. The minimum angle change with only 5 bars fully spaced is about 4-to-1. This configuration could be very useful for a particularly heavy rope. Note that if only 4 bars are used, then the breaking force could drop to a dangerously low level.

For a 600-pound rescue load, the maximum holding geometry would require a 30-pound breaking tension. For a load of 30 pounds below a rappeller, the minimum friction geometry would allow a 120-pound weight to slide down the rope.

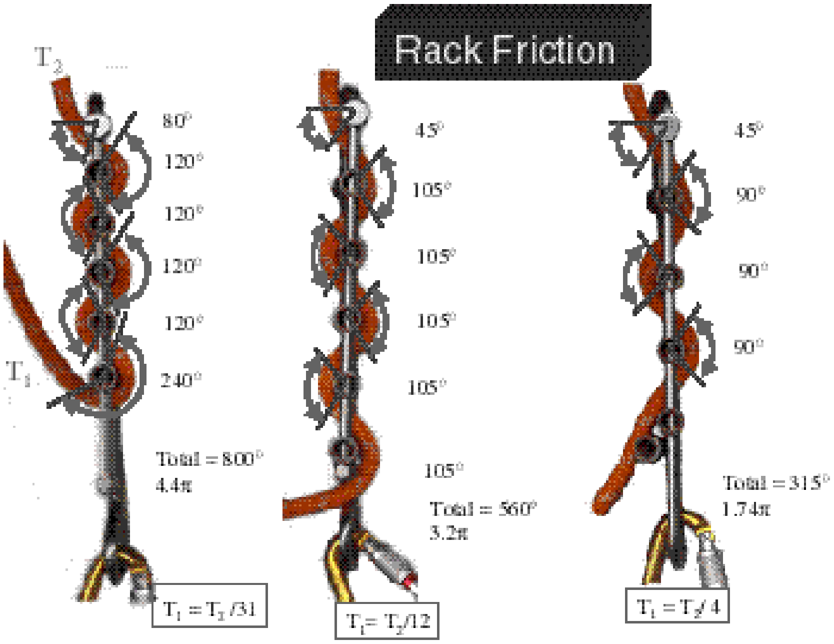


Figure 7: An analysis of break rack friction for different frictional geometries.

The Figure-Eight

The geometry of the figure-eight breaking device makes it difficult to estimate the contact angle. My estimate was 540 to 630 degrees for the configuration shown in Figure 8. This should give a holding ratio of 10-to-1 to about 15-to-1, which is comparable to the mid-range contact angles for a rappel rack. For a 600-pound load, a 40- to 60-pound holding force will be required.

For a heavy rope, the holding ratio cannot be reduced. For a 30-pound load hanging below the rappeller, the rappel weight would weigh about 450 pounds. The only solution is to “pull” oneself down the rope.

Which breaking device is best?

The break tube with three wraps has by far the greatest ratio of friction to load. The large bends in the tube also make it easy to control. Even though a tube with three wraps can generate a holding ratio of 250, it is still very easy to feed the rope into the tube.

The advantage of the rack is that moving the break bars can change the contact angle. For rappels where the rope has considerable tension, the ability to adjust the friction can be an advantage.

Figure-eight descending devices cannot be adjusted under tension, tend to twist the rope, and can be difficult to control. Based on these calculations, one can conclude that the figure-eight does not have a large range of frictional adjustment when compared to the break rack or the break tube.

While no conclusions should be based on calculations alone, these simple idealized examples show the effects of the exponential relation between the friction contact angle and the minimum/maximum breaking power of these devices.

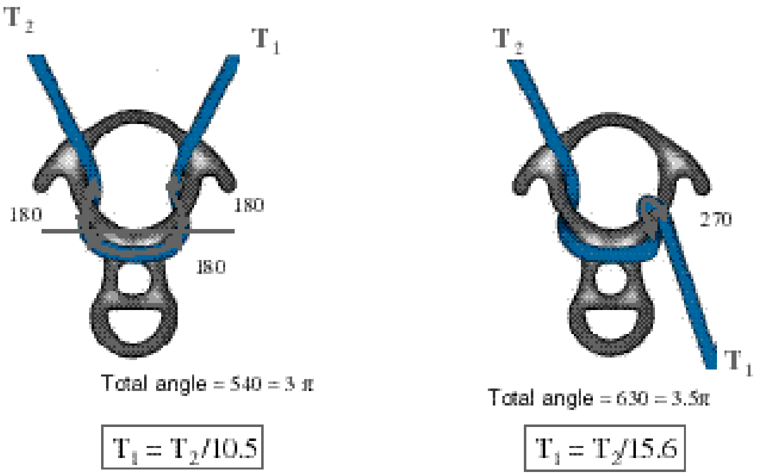


Figure 8: An analysis of the figure-eight breaking device for different frictional geometries.

Rope Edge Friction

Next we turn our attention to the mechanics of friction as a rope goes over the edge of a cliff or rock face. As you might expect, the angle that a rope turns as it goes over the edge can greatly effect the frictional force. What is unexpected is that the contact area does not affect the frictional forces.

The example shown in Figure 9 is intended to illustrate the frictional forces generated as a rope contacts a cliff face. For this example, the coefficient of friction was assumed to be 0.4. First a 45-degree change in angle was considered. The increased/decrease in tension due to friction was only 1.36. For a more typical 90-degree turn, a 1.87 change in tension occurred. The effect of contact angle really stands out when for a 135-degree change in angle. This geometry results in 2.60 times more tension. While this high ratio may be great for lowering, the resulting tension for a rescue load of 600 pounds would be almost 1,560 pounds. Remember that a single prusik will usually slip below this load.

The most common rescue situation that could generate a greater than 90 degree bend would be a ridge that has an anchor located downhill from the top of the ridge line. **Bottom line: avoid large changes in rope angle.**

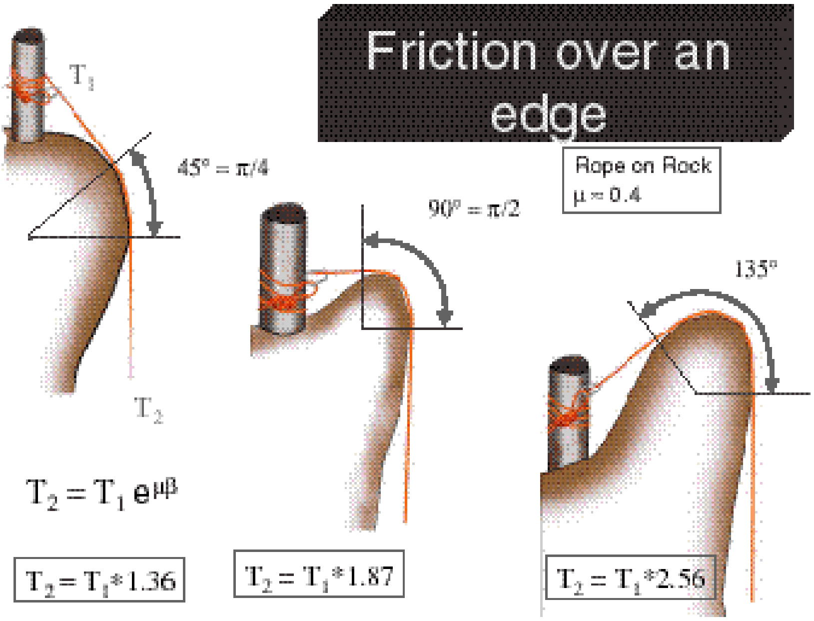


Figure 9: An analysis of friction for a rope that goes over an edge.

Typical Z-System Forces

The next example is intended to illustrate the effect high frictional forces can have on a typical haul system. The geometry for a typical Z-system raise is shown in Figure 10. A 600-pound rescue load was used in the computations. The resulting rope tension generated by two contact points with 45-degree bends was computed assuming a range of coefficients of friction. Figure 11 shows the resulting tensions for each rope segment plotted relative to each other.

For a coefficient of friction of $\mu = 0.45$, the maximum force in the rope as almost 1,500 pounds. This high frictional force almost cancels the mechanical advantage gained by the 3:1 Z-system.

If we assume that the edges have been protected, then the friction will drop. Assuming that the friction coefficient drops to 0.25, then the maximum load would be less than 900 pounds, which is still high, but nowhere near the 1,500-pound load. The required haul force would still be 300 pounds, which results in only a 2:1 haul system instead of the ideal 3:1. (I did not account for the loss in the pulleys.)

The example shown in Figure 10 also illustrates that the frictional force depends only on the total change in angle.

$$T_3 = T_2 e^{\mu\beta_{23}} = T_1 e^{\mu\beta_{12}} e^{\mu\beta_{23}} \quad (12)$$

$$T_3 = T_1 e^{\mu(\beta_{12} + \beta_{23})} \quad (13)$$

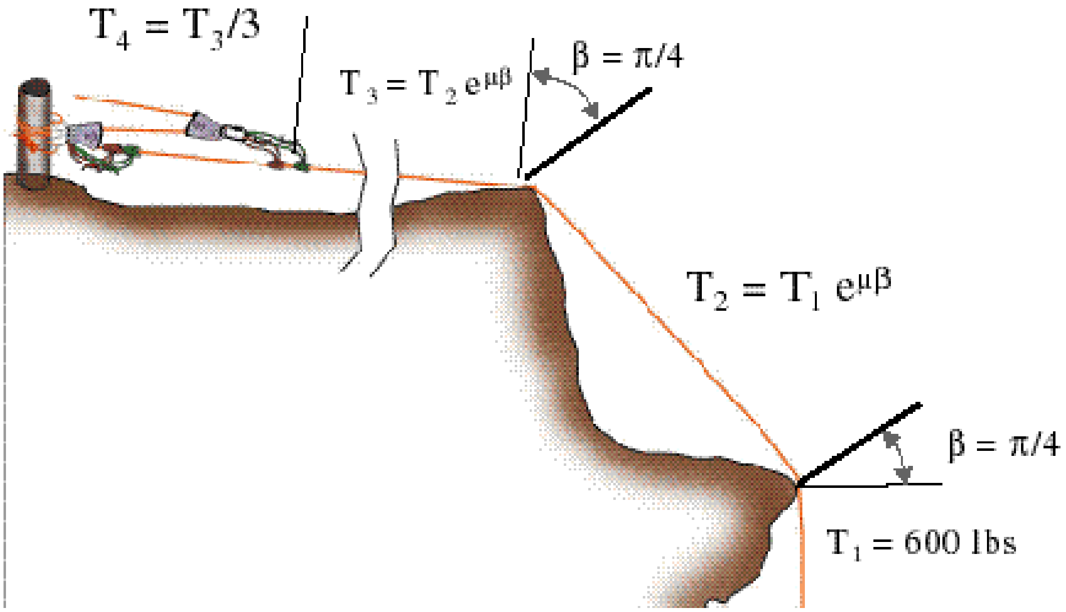


Figure 10: Rope tensile loads for a typical haul system.

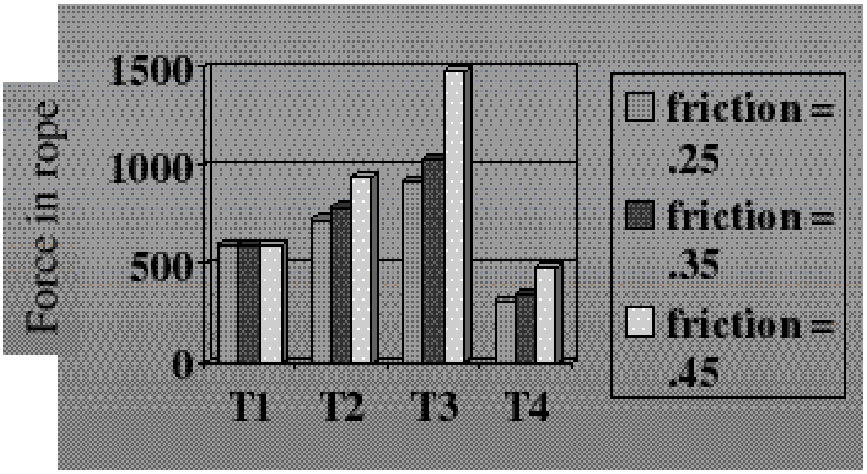


Figure 11: The force in rope segments T1 though T4 for the geometry shown in Figure 10.

Rope Stretch and Bounce due to Friction

Rope stretch can interact with friction in strange and sometimes dangerous ways. In this section, the forces and strain energy stored in a rope will be computed and used to predict the amount of bounce in a rope system.

Rope Stretch

Ropes can be viewed as a spring because they stretch as they are loaded. The amount of stretch depends on what is called the spring rate or stiffness. Rope stretch is a function of the rope size and construction. In general, a larger diameter rope will have less stretch under a given load than a smaller diameter rope. Figure 12 shows a plot of rope stretch for different ropes. From this plot, we see that static ropes all fail at about the same percent stretch. The higher loads for the larger diameters are the results of more nylon fibers. The twisted construction of the dynamic rope allows it to stretch more before it fails.

The ***stiffness*** of a rope can be used to compute the tension based on the change in length

$$T = K^*d \qquad (14)$$

The stiffness depends on the length of rope and the rope modulus. The ***rope modulus*** is the slope of the load deflection curve for a unit length of rope. The stiffness is defined as

$$K = M/L. \qquad (15)$$

A long rope will not be as stiff as a short rope. PMI 11 mm static has a modulus of about 19555 lbs. As an example, a 200 ft rope would have a stiffness of

$$K = 19555\text{lbs} / 200\text{ ft} \qquad = 97.7\text{ lbs/ft} \qquad (16)$$

A 200 ft rope supporting 1000 lbs would stretch:

$$T = K^*d \qquad (17)$$

or

$$d = T/K \qquad (18)$$

to give E = 1000/97.7 = 10.2 ft.

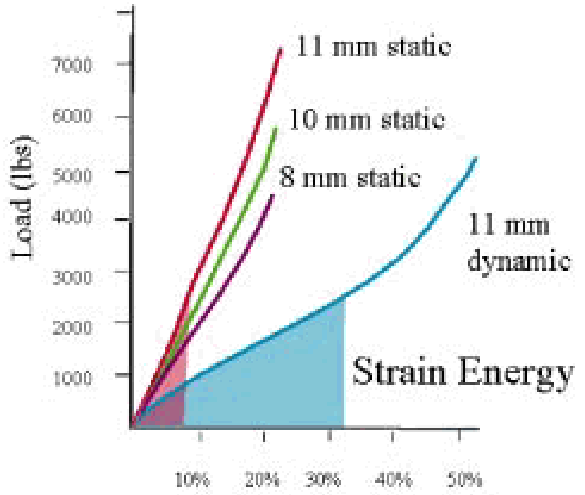


Figure 12: Tensile load for different ropes as a function of rope stretch.(William Strorage and John Ganter)

The strain energy in a rope is energy that is stored as the rope is stretched. A good analogy is the rubber band on a sling-shot. As the rubber is pulled back, the stretching stores elastic energy that is released when the sling shot is released. For the sling shot, the strain energy is converted to kinetic energy and results in the projectile being `shot'.

The strain energy is the energy that is stored as rope is stretched. The energy is the product of the stretching force times the distance that the rope elongates.

$$SE = \int T d\delta \qquad (19)$$

Substituting equation 14 and 15 in to 19 gives

$$SE = \int \frac{TL}{M} d\tau \text{ or} \qquad (20)$$

$$SE = \frac{L}{2M} T^2 \qquad (21)$$

Equation 21 allows the strain energy to be calculated once the load and rope type is known. From these formula, we see that the longer the rope, the more strain energy stored for a given tension. A stiffer rope will have a higher modulus and will not store as much strain energy. (You do not see sling-shots made of steel.) The amount of strain energy depends on the square of the tension.

Recall from figure 1 that the static coefficient of friction (non-sliding) is higher than the dynamic coefficient of friction (sliding). When the sliding starts, the litter will jerk upwards, even if the haul team is pulling smoothly.

When the static slipping force is exceeded, the energy is released. The strain energy is exchanged for kinetic energy. This results in a rescue load being sling-shot upwards. The change in strain energy can be computed by solving for the tension in the ropes before and after the slip.

$$\Delta SE = \frac{L(T_b^2 - T_a^2)}{2M} \tag{22}$$

where T_b and T_a are the rope tensions before and after slip. If we assume that the change in strain energy is converted in potential energy (bounce), then the height of bounce is given by

$$\Delta SE = \Delta PE = Wh \tag{23}$$

where W is the weigh and h is the change in height.

Figure 13 shows a typical three-point contact problem for a lip. Shown in Table 1 is an Excel spread sheet that can be used to compute the tension in the rope, as well as the bounce that results when the rope slips.

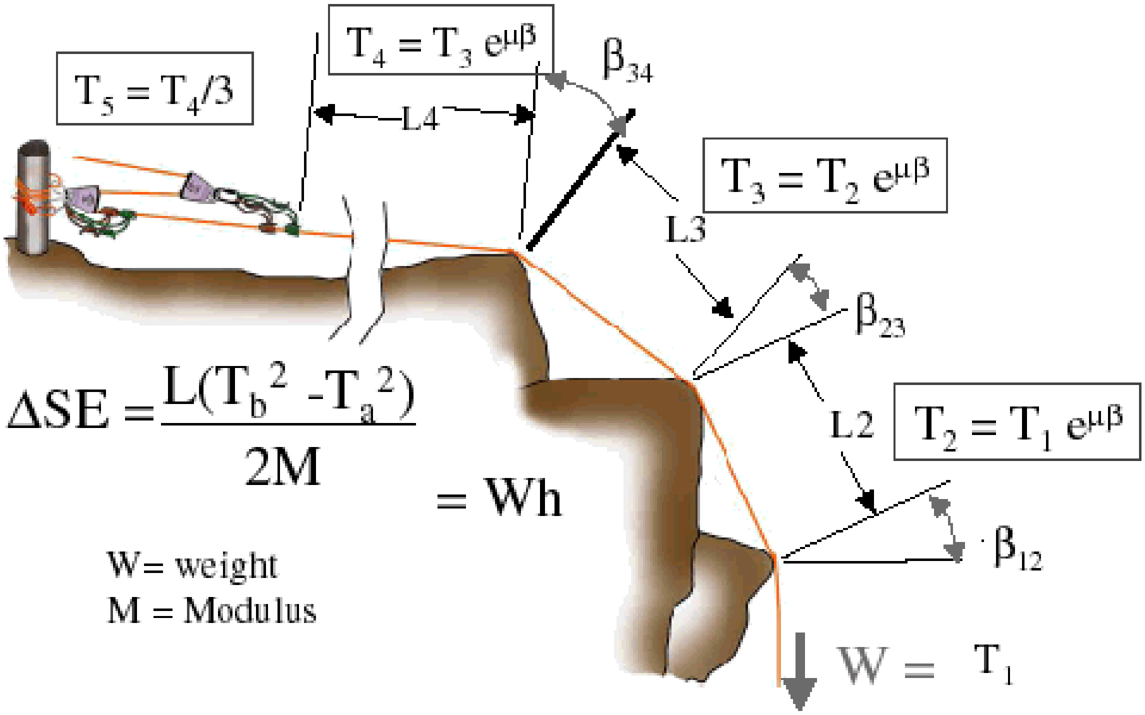


Figure 13: An analysis of stain energy, friction and bounce

Different lengths, angles, and coefficients can be entered, and the table will re-compute the forces and the bounce.

The change in strain energy before and after the slip is assumed to be equal to the change in the potential energy. The bounce will be roughly twice the height of the change in potential energy predicted.

Table 1: Tension and Bounce for Z-System.

Rope Segment	Length (feet)	Change in angle (degree)	Static Coefficient of friction	Dynamic Coefficient of friction	Tension Before Slip	Tension after slip	Modulus (lbs/ft/ft)	Change in strain energy	bounce (feet) = 2*
T1	0				600	600		0	
T2	100	30	0.35	0.25	721	684	19555	132.03	
T3	100	30	0.35	0.25	866	780	19555	362.022	
T4	150	30	0.35	0.25	1040	889	19555	1117.75	
Z System	80				347	296	19555	66.237	
Total								1678.04	5.59

When the haul system is tensioned, the rope will slide at the top two points. However, the lowest point will not slip until the friction is exceeded. The strain will build up, and energy will be stored in the rope. When the tension in the rope exceeds the slip tension, the rescue load will slip. This motion reduces the coefficient of friction and allows the rope to slide past the friction points until the tension is reduced. This sudden slip will occur even if the haul rate is very slow.

This stick/slip type motion is similar to the dynamic release of energy during an earthquake. The rope stores its energy until the slip friction is exceeded and allows it to release. For 600-foot haul systems, a bounce of over 6 feet is not uncommon.

Since the dynamic bounce due to stick/slip depends on the square of the tension, the best way to minimize this bounce is to reduce the tension in the system. Using fewer litter attendants, lighter liters, and hauling packs separately will all reduce the primary load. Reducing the friction by use of pulleys and edge rollers will also reduce the total tension in the system. Dynamic bounce can also be reduced by using shorter hauls. A short Z-system may have to be reset more often; however, short Z's will not store as much strain energy. In cases where system dynamics cannot be avoided, the litter attendants should be aware that they will experience a bouncy ride.

Summary

Friction force in a rope depends primarily on three things:

- The load on the rope
- The coefficient of friction
- The angle that the rope turns through

The angle and coefficient of friction can cause an exponential change in rope tension!

We have used a simple friction law for a flexible belt over a drum and applied it to several different rescue situations. The exponential change in rope tension that results from a change in contact angle or coefficient of friction can drastically affect the behavior of all rescue systems.

As a first example, we compared the ideal frictional force for lowering devices. The break tube, the rappel rack, and figure-eight all can work well when supporting loads in the 100- to 200-pound range, provided that 10 to 20 pounds of breaking force can be maintained. However, when much higher rescue loads are involved, we see that the tube has the best ratio of breaking force to rescue load. The adjustable spacing on the bars of the rack give it a great range of frictional force.

The frictional forces that are generated as a rope goes over a lip were computed using the capstan friction equation. While it is counter intuitive, the capstan frictional equation predicts that force going over a edge is independent of the edge radius. The validity of these equations still need to be field tested to see if these ideal friction laws indeed apply to rescue rope.

The exponential change in friction forces with the angle of bend is quite surprising and can catch the most experienced rescuer off guard.

1. *Engineering Mechanics Volume 1, STATCS*, J. L. Meriam, J. Wiley & Sons, pp 301-302, 1978.
2. *Physics for Cavers: Rope, Loads and Energy*, William Strorage and John Ganter, Http://nerve-net.zocalo.net/jg/c/pubs/R1energy/Ropesloads.htm

Notes on Alpine-style SRT

Reprinted from Sherry Mayo's Cave Page

These notes are the result of three of us here in Canberra teaching other members of NUCC alpine style SRT techniques. More specifically the SRT manoeuvres as described here are the result of me, Mark and John arguing about the best way to do things while our hapless victims were strung up in trees struggling with our SRT obstacle courses - so credit should be given here to all those people (Mark, John and our NUCC guinea pigs). These notes assume a certain amount of fore-knowledge, that you know how to abseil and how to prusik using a frog rig. Please don't try and learn SRT from scratch using these notes, you will just hurt yourself. Get someone who knows to show you how to do it (and if you can't find someone, I'll do my best to give you a contact if you send me email).

Thanks to Nigel Whittington (N.P.Whittington@spps.hull.ac.uk) for helpful input and comments.

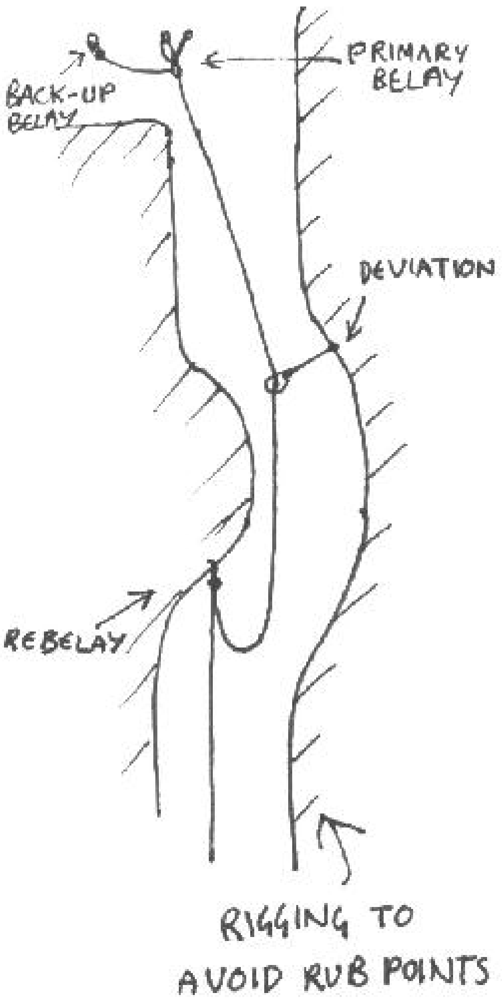
Introduction

These are some very short notes to summarise the basic manoeuvres of alpine-style SRT. They are no substitute for practicing the techniques and are intended just as a reminder. If you want more detailed info read a good SRT book such as "Vertical" by Al Warild.

The best way to learn SRT is to get lots of practice and get a feel for it rather than trying to learn the moves "by numbers". If you encounter any difficulties underground, familiarity with the basics will get you over them.

Why Bother?

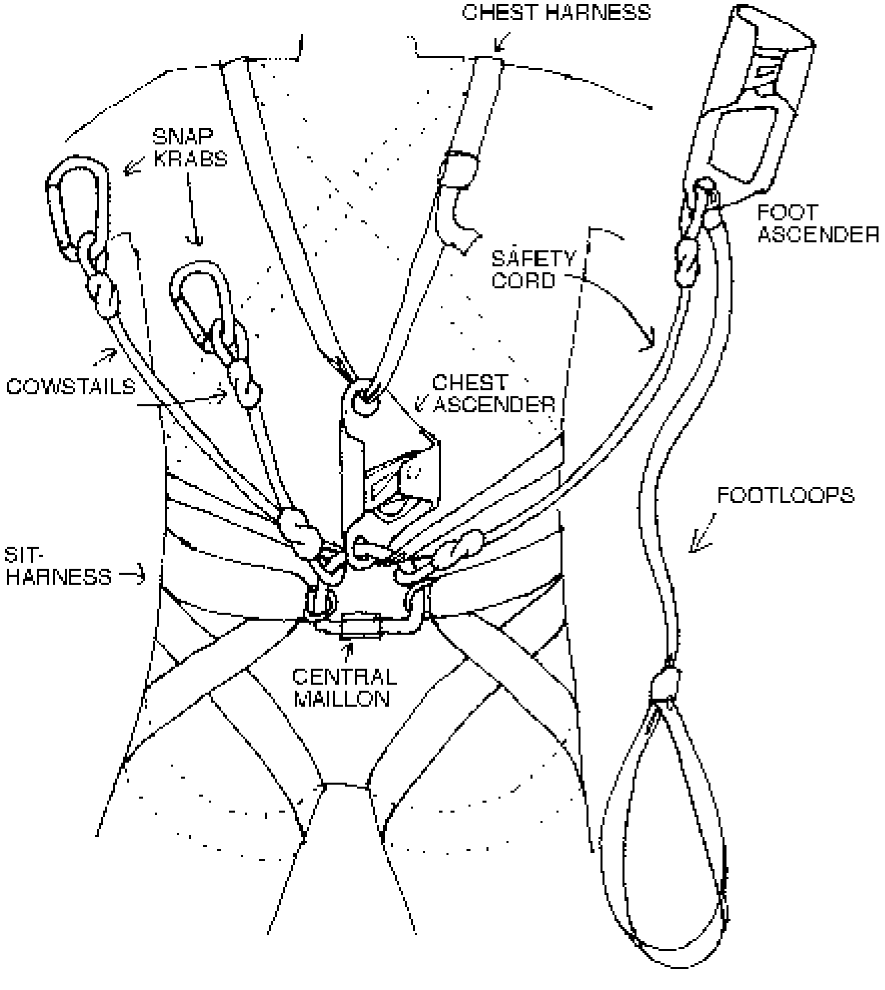
Unlike indestructable rope technique, alpine-style SRT makes use of rebelays and deviations so that the rope hangs freely down the pitch avoiding rub points and other hazards such as waterfalls. This has the advantage that much thinner rope can be used which is much lighter and more compact to carry (or alternatively you can carry much more rope - useful if you are exploring a deep cave). Another plus is that abseiling or prusiking on a free hang is easier than abseiling or prusiking against an uneven wall. The (slight) downside is that you have to learn how to negotiate



rebelays & deviations - the techniques and equipment used for these manoeuvres are summarised in these notes.

SRT Equipment for ascending/descending:

Apart from lots of practice, the thing that will make the most difference to the ease which which you can do SRT manoeuvres is having the right equipment and having it correctly set up and adjusted. Properly set up gear will not only vastly improve the efficiency of prusiking and changeovers, but will also minimise the risk of cock-ups (i.e. getting your gear in a tangle and getting stuck on the rope). The diagrams show the set up of gear for a frog-rig, the most commonly used SRT set-up in alpine caving. IRTers sometimes prefer ropewalking or other types of SRT rig which can sometimes have slight speed advantages on long pitches, but which make it difficult to negotiate rebelays etc.



SRT ascending/descending kit (descender omitted for clarity)

The Harness:

this should be a purpose designed caving sit harness. A sit harness is fairly snug fitting and designed so that the central attachment point (i.e. the central maillon to which the chest ascender etc is attached) is fairly low on the body. This is important because the length of a prusik step is determined by the distance between the chest and foot ascender when the foot ascender is raised on the rope. If the chest ascender sits too high on the body this distance is reduced and the caver can only take short prusik steps which is inefficient. Several designs of harness suitable for caving are shown in the diagrams. A climbing harness is also shown for comparison. These can be used for SRT, but are far from ideal because the central loop is too high on the body. Also there is no central maillon and an intermediate krab or maillon has to be used to attach the chest ascender to the harness resulting in it sitting even higher on the body.

The chest ascender:

As outlined above, for efficient prusiking the chest ascender must sit fairly low on the body (about on the stomach, just below the sternum). For this reason its is best to use an ascender without a handle, and better still, a purpose-built chest ascender such as the petzl croll which is designed to lie flat on the chest when clipped through the central maillon.

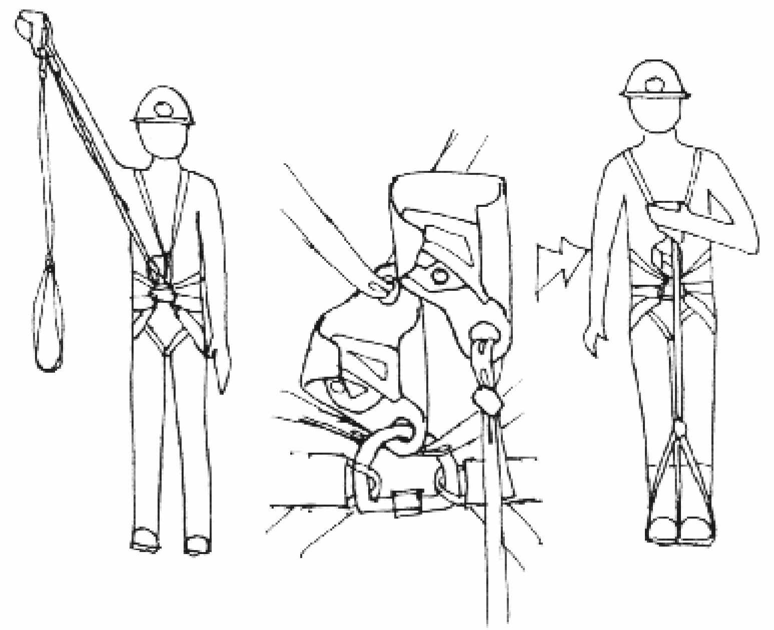
The chest harness:

The purpose of the chest harness is to keep the chest ascender in position on the body so it moves cleanly up the rope when the caver stands in the footloops. It also holds the caver in more upright position on the rope which makes prusiking easier. If the harness is too loose, or the chest ascender too high, the caver will tend to lie back of the rope when sitting on the chest ascender, which is both uncomfortable and inefficient for prusiking. The chest harness should be done up sufficiently tightly that it is uncomfortable to stand in when you're not on the rope. Most people use a length of tape with a buckle as a chest harness (see picture). Purpose built chest harnesses are available but don't seem to work any better than the plain tape variety, and don't fit at all if you're female (i.e. if you have a bust). The chest harness isn't intended to be load-bearing and some people use a piece of bungee cord instead of a tape. This doesn't give the caver as much support on the rope but can be better for pulling the croll smoothly up the rope. Some cavers choose to use both a tape and a bungee cord (or similar) and have the best of both worlds.

Foot ascender, footloops and safety cord:

The foot ascender can be a handled or standard (non-handled) ascender according to personal preference. It is attached to the caver via a safety cord of dynamic rope (8-9mm is suitable). The cord can either be clipped in directly to the central maillon by the knot in the end, or via an intermediate krab or maillon. There is no hard and fast rule about which is best, it comes down to personal preference. Clipping it in via a krab or maillon means that it can be unclipped from the central maillon while on the rope, however extra ironmongery on the central maillon can also cause problems if you get into a tangle. However, there are definite advantages to attaching the other end of the cord (and also the footloops) to the ascender via a maillon or krab, particularly if you're doing a rope rescue (see rope-rescue section on the pulley-style footloops rig).

The foot loops can be made of either tape or rope. Tape tends to be more hardwearing and if a rope is used, the bit that you stand on is best protected by a length of tubing. There is a risk with tape footloops that the tape can get jammed behind the chest ascender cam (this was the cause of an accident in the UK a few years ago), however, many cavers do use tape footloops and this type of incident seems to be rare.



CORRECT ADJUSTMENT OF SAFETY CORD AND FOOTLOOP
FOR PRUSIKING

Footloops can either be two separate loops, one for each foot, or a single loop for both feet (as in picture). It is important to get the lengths of the footloops and the safety cord just right. When standing in the footloops (off the rope) lift the foot ascender up till the footloops are taut. If the length is correct the camming part of the foot ascender should be just above the camming part of the chest ascender(see picture). Adjust the safety cord so you can reach the foot ascender when hanging from it on the rope by your safety cord.

Cowstails:

These are a pair of safety cords used for protection during manoeuvres. The long cowstail is used for general security when passing rebelays, deviations and knots. The short cowstail is used specifically for passing rebelays while descending, during which your weight is hanging from the short cowstail alone. Cowstails should be made of 10-11mm dynamic rope with snap krabs clipped through the knot loop at the end of each cowstail (some cavers use 9mm rope in which case fig 9 knots should be used for tying the cowstails). A screwgate krab can be used as an alternative to a snap krab on the long cowstail for extra security while rigging. The krabs can be secured to the knot loops with snoopy loops (loops of tyre inner tube rubber) which hold them in place.

The picture shows how the cowstails are tied (there are alternative methods of tying cowstails but this method is the most common one). To tie the cowstails take a piece of dynamic rope about 2.5-3m long, and tie a double figure 8 (or figure 9) knot in one end, tie another double figure 8 (or figure 9) knot as close to the original knot as you can. Then tie a third double figure 8 (or figure 9) knot leaving about about 40 cm of rope between it and the second knot. Swami knots can also be used for the ends of the cowtails - these help hold the krabs in place. Some cavers use overhand knots for the ends of the cowstails as they are less bulky than fig 8's etc, but these do reduce the strength of the rope more than other knots (bear in mind the thickness of the rope you are using).

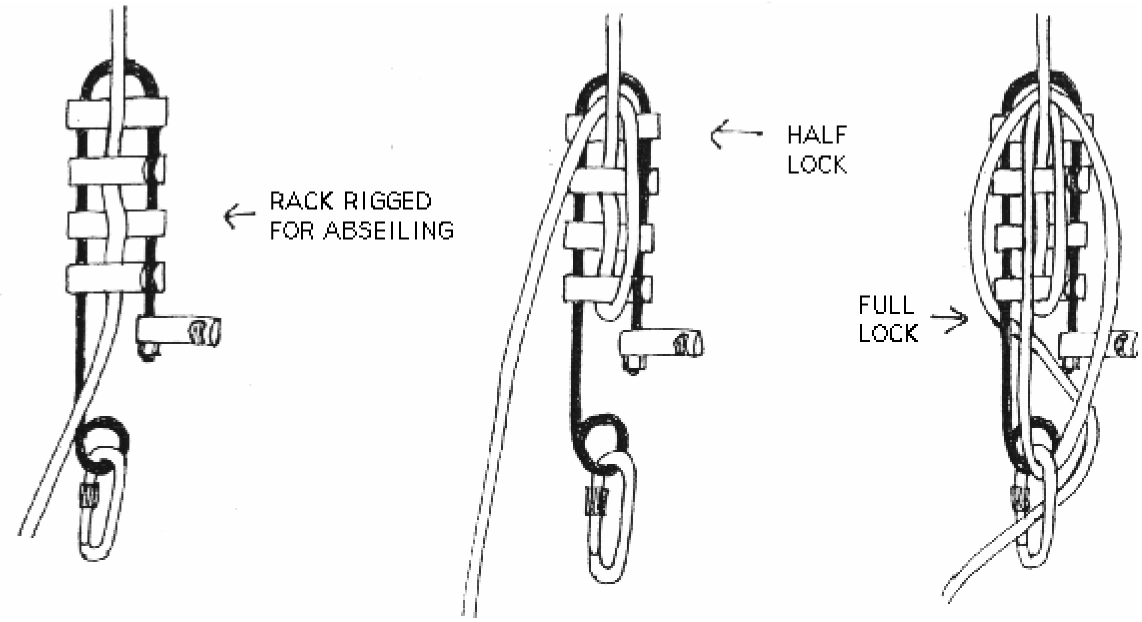
Make sure all the knots are correctly stacked and then tension the cowstails by hanging your weight from them. The lengths should now be about right. Remove any excess tail rope using a hot knife to seal the ends (the tails needn't be more than 10cm long) and tape the tails of rope to the cowstails. The short cowstail should be about 25-45cm from knot loop to knot loop, and the long one about 50-70cm (it should be at least short enough that you can reach the krab when it's taut). If you clip the cowstails to your central maillon via a krab or maillon you'll want them a bit shorter than if you clip the knot loop into the central maillon directly (see comments about attaching the safety cord above).

Descenders:

There are many kinds of descenders that can be used for caving but most alpine cavers use bobbins, autolock descenders ("stops"), or racks. The pictures show the way a rack and bobbin are rigged, for abseiling and for locking off (i.e. to lock the descender so it cant move on the rope). The stop works in basically the same way as the bobbin, except it also has a brake lever.

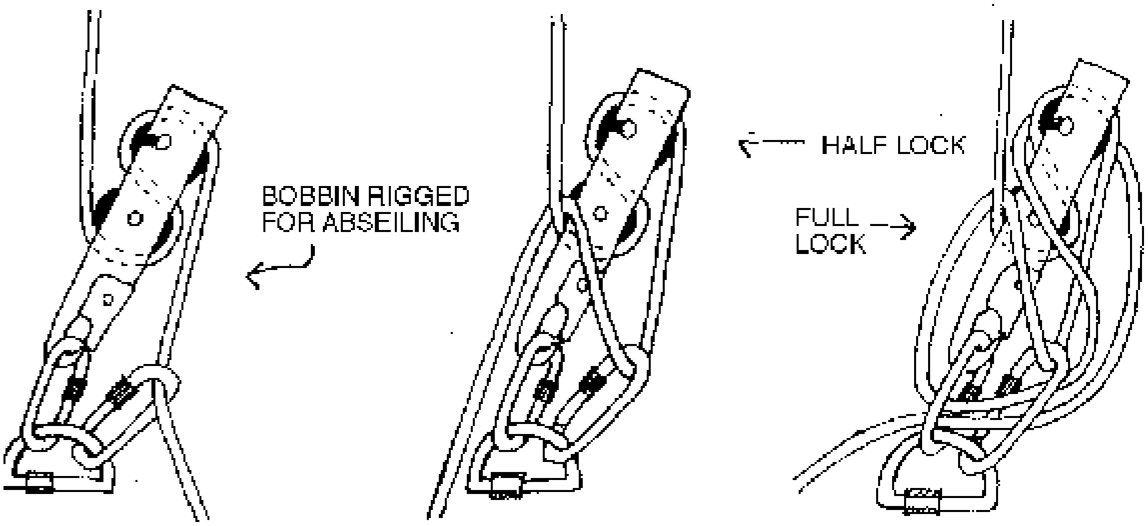
Racks:

These provide friction by weaving the rope around a series of aluminium (or sometimes steel) bars. Commonly the first (uppermost) and third bars on a rack are fixed, and the second, fourth and fifth bars unclip on one side allowing the rope to be looped behind them. It is possible to "suicide rig" a rack by looping the rope around the wrong side of the bars - this will undo itself as soon as any weight is put on it so always check you've rigged it right!



Bobbins:

The rope is wrapped around two fixed wheels to provide friction and then clipped through a braking krab (see picture). One side of the bobbin can be unclipped at the bottom allowing it to be swung open for attaching or detaching the rope. If the rope is very "slow" (i.e. fat and stiff therefore slowing the descent) a bobbin can be "C" rigged with the rope passing around both wheels in a "C" rather than "S" configuration. If the rope is very fast, abseiling with the bobbin on half lock can be used to slow down (see picture).



Rigging and locking off a bobbin

Autolock descender ("stop"):

These are a more sophisticated version of a bobbin with a brake lever. When the lever is squeezed you will "go" and when the lever is released you will stop. If you're going too fast remember to let go, it sounds obvious but "it isn't always the most natural reaction" as it says in the Petzl catalogue (people sometimes squeeze the handle thinking it will brake their descent). Some versions of this type of descender are designed to stop when the handle is either squeezed or released and only "go" in the middle position, but these tend to be much bulkier.

Other descenders:

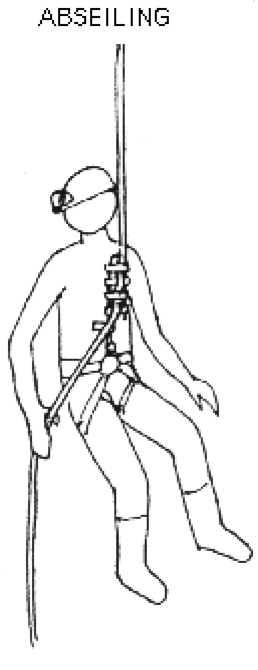
Descenders that are often popular with climbers such as Figure 8s, or stitch plates are not ideally suited to caving as you have to unclip them completely to get them off the rope (making dropping them more likely on a rebelay). They also tend to twist the rope which is really annoying when you're spinning round on the prusik back out. Whaletails also deserve a mention, if only because of their mysterious popularity with Australian cavers. These are OK for caving, but they are very heavy and bulky (machined out of a solid block of aluminium) and also they are very long which can make otherwise straightforward SRT manoeuvres surprisingly difficult since they take up so much room on the rope.

SRT basics

Notes on abseiling

Controlling speed while abseiling:

Once you have attached your descender to the rope you are ready to abseil. The principle is the same for all descnders - it is the tension of the rope runningthrough the descender that determines your speed. The tension is controlled using the rope *below* the descender. When abseiling hold the lower rope firmly with one hand down away from the descender. If you hold the rope taut you shouldn't move at all, and to move just let the rope slip slowly through your hand. With a bit of practice you should have no trouble controlling your speed. As well as being able to control speed you also need to know how to lock off a descender so that you can "park" on the rope without needing to hold the rope below you. Methods of locking off a bobbin and a rack are shown in the diagrams



Bottom belaying:

This can be used to provide extra security for novice abseilers. The belayer standso holding the bottom of the rope. If the abseiler gets out of control and starts going too fast the belayer can slow them down (and stop them if need be) by pulling on the rope. This tensions the rope passing through the descender which increases the friction and slows the descent.

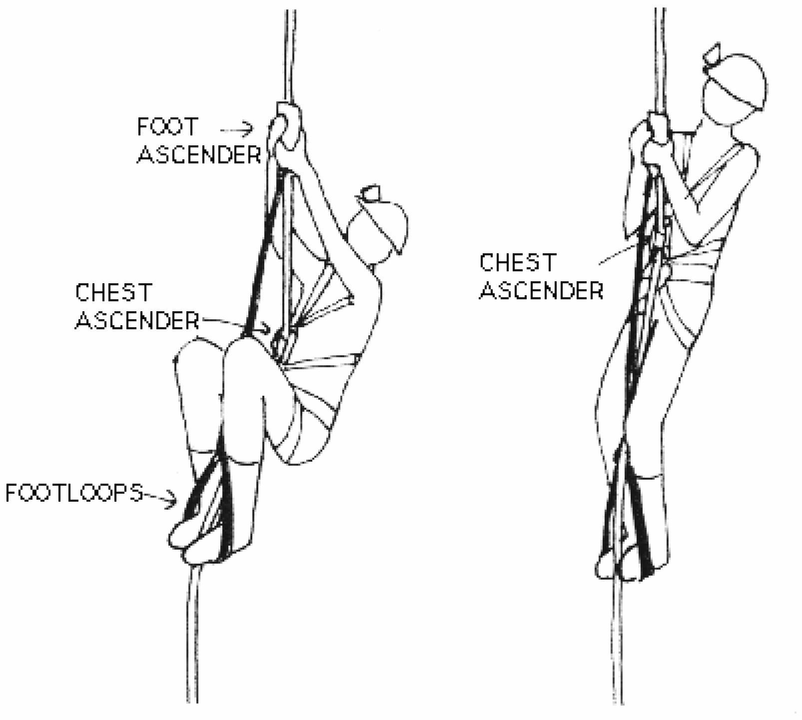
Prusiking

Prusiking is the method of ascending the rope in SRT. Traditionally this was done using prusik knots which was slow and awkward, but mechanical ascenders have made prusiking much easier. The ascenders have a sprung loaded cam which slides up the rope but not down it. The caver wears a chest ascender attached to the sit-harness and held in place with a chest harness (see picture). A second ascender is attached to the caver via a safety cord. A pair of footloops are attached to this ascender (the foot ascender). The ascenders are put onto the rope by opening the cam, slipping the rope in and letting the cam close on the rope. The cam is usually prevented from opening fully by a safety catch which has to be disengaged for getting the ascender on and off the rope - for any other manoeuvres the safety catch chould be left in place.

The chest ascender is put on the rope below the foot ascender. The caver sits down on the chest ascender which will be supporting their weight on the rope. The feet are put in the footloops. While sitting on the chest ascender the foot ascender in raised up the rope (you will need to lift your feet at the same time to take the weight off the foot ascender). Then the caver stands up as far as possible in the footloops and the chest ascender slides up the rope. The caver sits back down onto the chest ascender. This sequence is repeated over and over to progress up the rope. The footloops need to be adjusted so that when standing up in them the chest ascender almost meets the foot ascender.

Sometimes the rope won't slide freely through the chest ascender, particularly when you are at the bottom of the rope. With practice you can grip the rope between your feet while standing up in the footloops which will pull it through the chest ascender. When standing up in the footloops, push your feet downwards under your bum rather than out forwards as it makes prusiking easier and more efficient.

TAKING A PRUSIK STEP



RAISE FEET IN FOOTLOOPS AND SLIDE FOOT ASCENDER UP ROPE

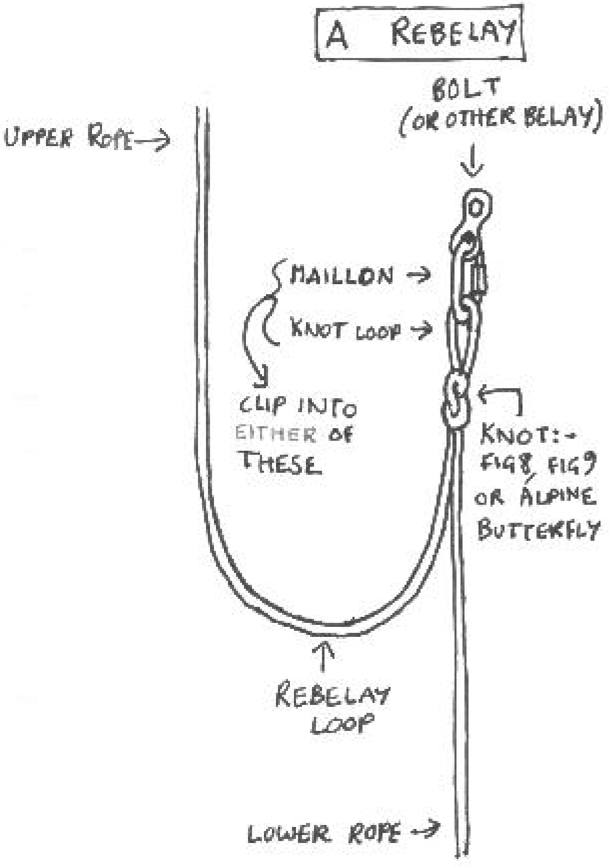
STAND UP IN FOOTLOOPS CHEST ASCENDER WILL SLIDE UP ROPE

Approaching pitch-heads

Pitches rigged for alpine-style SRT will have back-up belays usually a little way back from the pitch-head, with a rope runing from the back-up to the primary belay at the pitch-head. When approaching a pitch-head always clip your long cows-tail into the rope between the back-up and primary belays for safety. Leave it clipped in until you are sitting on your descender on the rope ready to abseil. If the back-up belay is right next to the primary a separate traverse line to the pitch-head should still be rigged for safety .

Passing Rebelays

A rebelay is where the rope is re-attached (belayed) to the rock part way down a pitch (see picture). If the rope from the top of the pitch meets a rub point/ waterfall/loose rock etc. the rope is rebelayed to the rock over to one side so that the lower part of the rope (which hangs down from the rebelay) avoids it.



Abseiling:

- Abseil until you are level with the rebelay knot - DON'T abseil past it!
- Clip short cowstail into rebelay (into the knot or the maillon)
- Abseil until your weight is taken by short cowstail
- Take descender off upper rope and put it on lower rope
- Lock descender off (full lock)
- Unclip short cowstail by standing in rebelay loop or on handy ledge to take your weight off it.
- Transfer your weight onto the descender
- Unlock descender and away you go...

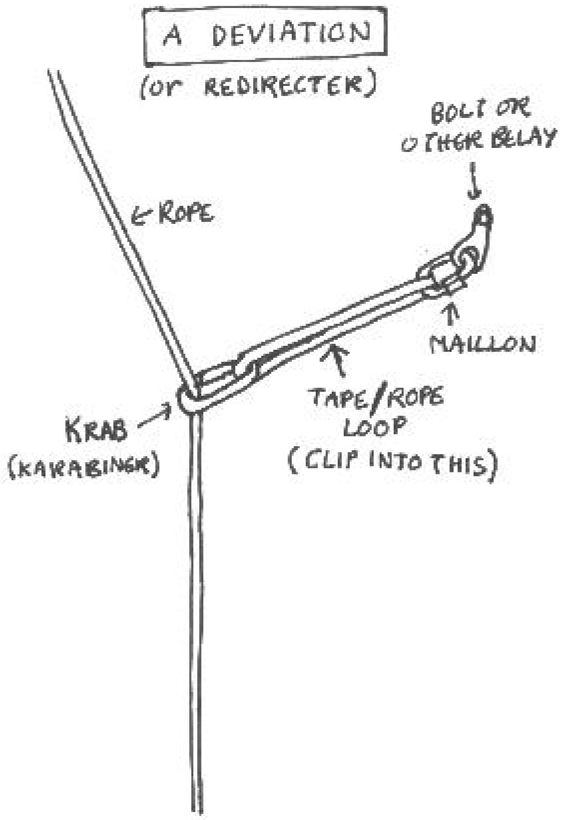
NOTE: The long cowstail can also be used for extra safety during this manoeuvre: Clip it in initially at the same time as the short cowstail and leave it clipped in for the whole manoeuvre, only unclip it just before abseiling when the descender is half unlocked. This will give you protection should you fail to rig your descender properly.

Prusiking:

- Prusik up to just below rebelay knot.
- Clip long cowstail into rebelay
- Take weight off chest ascender by standing in footloops
- Transfer chest ascender from lower to upper rope
- Transfer foot ascender from lower to upper rope (watch that the safety cord isn't wrapped round the lower rope)
- Unclip long cowstail from rebelay (you may need to prusik up a little to do this until it is slack)

Passing a deviation:

A deviation (or redirector) is another means of avoiding rub points and other hazards by altering the hang of the rope down the pitch. The rope runs freely through a krab which is attached to a belay via a tape or rope-loop. This deviation pulls the rope away slightly from its natural vertical hang to move the rope below the deviation away from a rub-point. A deviation never bears the full weight of a caver (only a fraction of it) and consequently deviations can sometimes be used where there isn't a sufficiently strong belay for a rebelay. Since deviations sometimes use poor belays you should never load them with your full weight. In the description below, the cowstail is clipped into the deviation merely to stop you swinging away from it - at no point should you be hanging from the deviation itself, your weight should always be taken by the rope.



Abseiling:

- Abseil down to the deviation (you may want to lock off your descender)
- Clip into the deviation with long cowstail
- Unclip deviation karabiner from the rope below you and clip it in on the rope above you
- Unclip cowstail and continue abseiling

Prusiking:

- Prusik up to the deviation
- Clip into the deviation with long cowstail
- Unclip deviation karabiner from rope above you and clip it into the rope below you
- Unclip cowstail (you will find that you swing away from the deviation) and continue prusiking

Changing from ascending to abseiling:

This on its own is not a common manoeuvre underground, but it is the basis of other manoeuvres such as knot passes and it is essential in rope rescue. Being able to change over easily from ascending to abseiling and vice versa is also very useful if you ever have a cock-up (get stuck on the rope) as it will usually enable you to extracate yourself.

- Make sure your foot ascender isn't a long way above your chest ascender
- Put your descender on the rope below your ascenders and lock it off
- stand in footloops to unweight chest ascender and unclip chest ascender from rope
- Sit back down until weight is taken by descender
- Unclip foot ascender from the rope
- Unlock descender and abseil

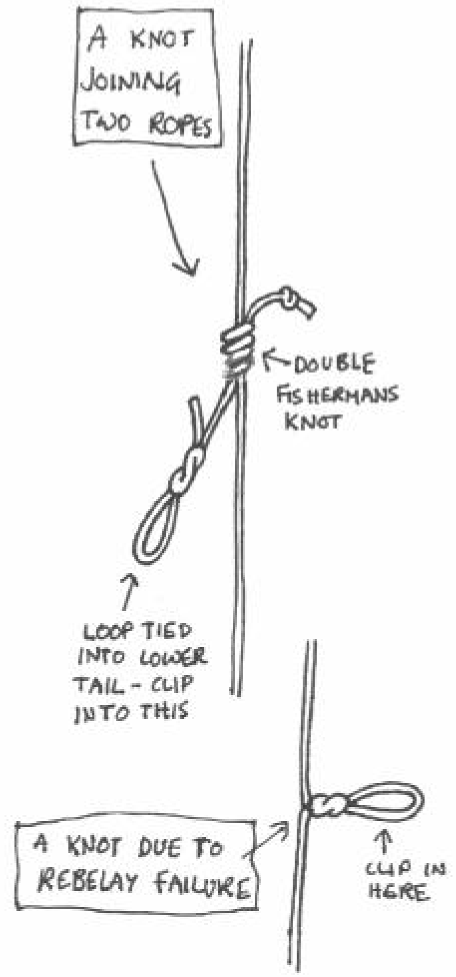
NOTE: You will find this manoeuvre difficult (or impossible) if you use a long descender such as a whaletail which takes up a lot of space on the rope. It is difficult to rig it far enough up the rope so that your foot ascender safety-cord is slack when you sit back on the descender, particularly if your safety-cord is on the short side. One way around this is to stand in your footloops and clip your short cowstail into your foot ascender. Remove the chest ascender from the rope and sit onto the cowstail. Removing the chest ascender makes more room on the rope for rigging the descender. When the descender is rigged (as high up the rope as possible, just below the foot ascender) stand in the footloops to unclip the short cowstail and sit back down onto the descender. The safety cord should now be slack allowing the foot ascender to be taken off the rope. This "sneaky" method of doing a changeover can't be wholly recommended as you are hanging from a single ascender at one point, which strictly speaking isn't safe. A variant of this technique can also be used for speeding up knot passes (provided you have a short descender!).

Some notes on down-prusiking

Down-prusiking is used for passing knots when descending, and also used if you need to descend a loaded rope for any reason (i.e. unconscious person on rope below you that needs rescuing). To down-prusik, unweight your chest ascender by standing in your footloops, depress the chest ascender cam from the top to release the rope and slide the ascender down the rope. Release the cam so the chest acender grips the rope and put your weight on it while you move the foot ascender down the rope. Repeat as often as necessary!

Passing a knot:

You may encounter a knot mid-rope for a number of reasons. Usually it is where two ropes are tied together as a single rope isn't long enough to reach the bottom. You may also encounter a knot where a rebelay has failed or where a damaged section of rope has been tied out.



Abseiling:

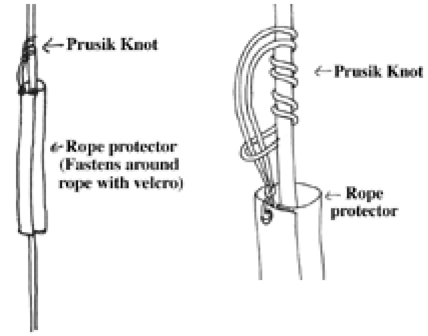
- Abseil down to knot
- Clip long cowstail into the loop tied in the tail emerging from the knot (see pic)
- Put foot ascender on the rope a few inches above descender
- Stand in footloops and clip chest ascender into rope between foot ascender and descender
- Take descender off rope
- Down-prusik to knot
- Transfer ascenders (chest ascender first then foot ascender) from above to below the knot
- Put descender on the rope below your ascenders and lock it off
- Unclip long cowstail
- Stand in footloops to unweight chest ascender and unclip chest ascender from the rope
- Sit back down and transfer weight to descender
- Remove foot ascender from rope
- Unlock descender and continue abseiling

NOTE: There is a "quick and sneaky" way of passing a knot (while abseiling) that can be used by people with short descenders (and not-too-short safety cords). Abseil onto the knot and put the foot ascender on the rope just above the descender. Clip the long cowstail into the knot-loop for protection. Stand in the footloops, clip the short cowstail into the foot ascender and sit back down on the short cowtail. Take descender off the rope, put it on the rope below the knot and lock it off. Stand in the footloops to unclip the short cowstail, and sit back down (hopefully) onto the descender. Unclip the footloops and long cowstail and abseil. If your descender is too long, or your safety loop is too short you won't be able to do this - it's the kind of thing you should try out in a tree before having a go underground!

Prusiking:

- Prusik up to just below the knot (not hard up to the knot)
- Clip long cowstail into the loop tied in the tail emerging from the knot.
- Transfer foot ascender from below to above the knot
- Transfer chest ascender from below to above the knot
- Unclip cowstail and continue prusiking

Passing a rope protector



Ideally you shouldn't need rope protectors to rig a pitch, but some rub point are very hard to avoid, and a rope protector can be much simpler than trying to rig the rope around them. To pass a rope protector when abseiling:

- Abseil down until you can reach the rope protector knot and lock off your descender - DON'T abseil onto the knot!
- Unfasten the rope protector and untie it from the rope (don't drop it!)
- Abseil to below where the rope protector was tied on and lock off.
- Tie the rope protector back onto the rope above your descender using a prusik knot.
- Fasten up the rope protector as you descend past it, checking that it is correctly positioned.

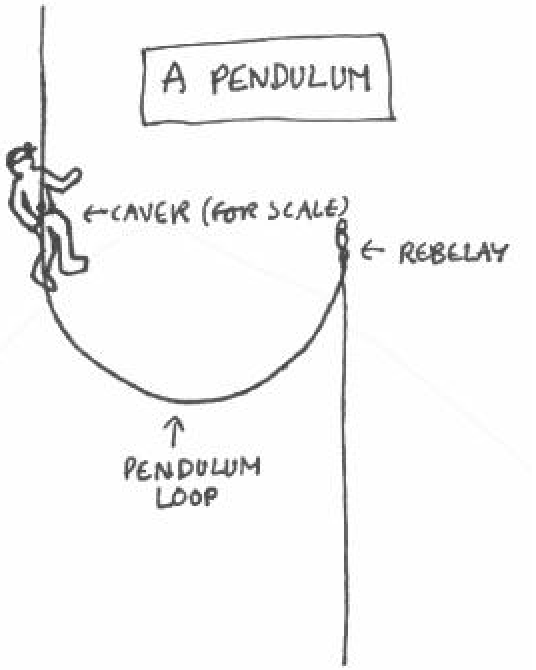
When prusiking the procedure is almost the same:

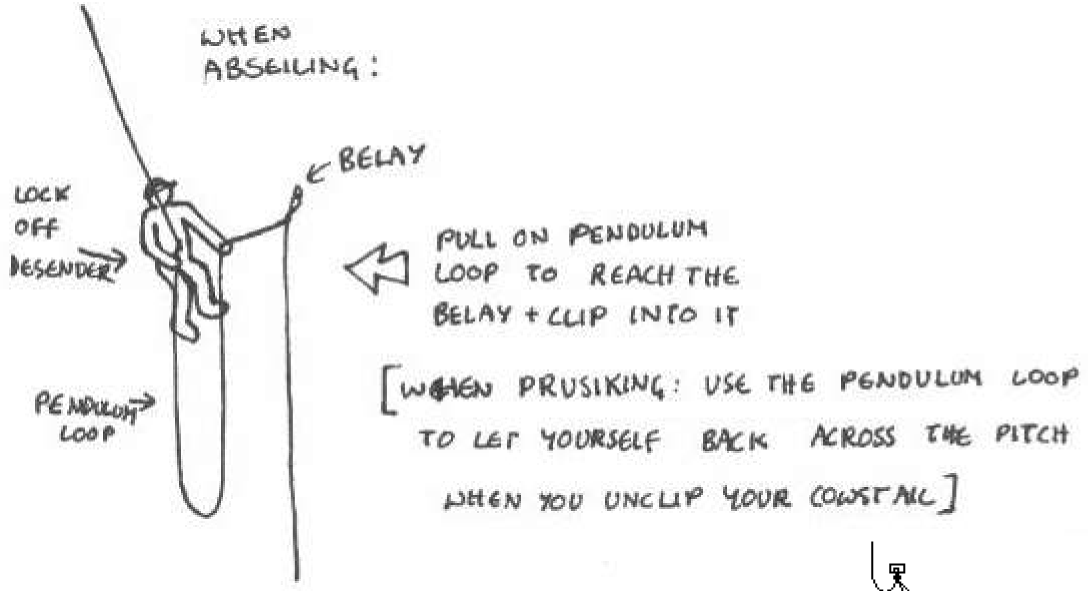
- Unfasten the rope protector when you reach it and prusik up to just below the rope protector knot.
- Untie the rope protector
- Prusik up a little
- Retie the rope protector on below you and fasten it around the rope.
- Check the rope protector is positioned properly before carrying on up the pitch.

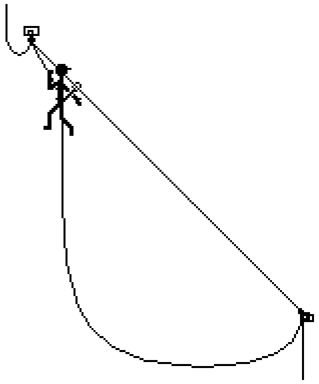
A note on pendules (or pendulums):

A pendulum or pendule is basically a variant of a rebelay where the upper and lower ropes are much further apart horizontally (see pic). If abseiling on the upper rope you wont be able to reach over to the rebelay knot to clip in. When level with the knot lock off your descender and pull yourself towards the rebelay using the pendulum loop. Clip in your short cowstail and continue as if you were passing a normal rebelay.

If prusiking, start as if passing a normal rebelay (use the pendulum loop to pull in the slack on the upper rope). When your ascenders are on the upper rope you will find your cowstail is taut. Pull yourself towards the rebelay to slacken and unclip your cowstail and then use the pendulum loop to let yourself out across the pitch (otherwise you will go flying across the pitch which is rather unpleasant).







A note on tyroleans:

This is similar to a pendule in that is is a means of negotiating a rope where there is a significant horizontal distance as well as vertical distance between two belays. A

Tyrolean *(NB I'm not actually sure if his is the correct name for it)* can be rigged much like a pendule (see above) with the addition of a **taut** rope rigged between the upper and lower belay. To descend, the caver rigs their descender onto the slack (pendule) rope and clips their short cowstail onto the taut rope. The slack rope takes most of the weight of the caver as they descend and the taut rope pulls them over toward the lower belay, so the descent is roughly diagonal.

A tyrolean can be rigged as an alternative to a pendule where the large horizontal distance makes it difficult for the caver to pull themselves across the pitch towards the lower belay (see the pendule above). In these cases it is easier to *ascend* the tyrolean as a conventional pendule without using the taut rope. In other cases a Tyrolean is rigged as a means of pulling the caver away from a hazard such as a waterfall, in which case the caver would clip into the taut rope when ascending as well as when descending. Prusiking up whilst clipped into a taut rope is strenuous but is preferable to being soaked or prusiking up the wall of hanging death etc.

Rescuing an unconscious caver from a rope

If a caver is knocked out by a falling rock while on a rope, or becomes unconscious for some other reason, you need to be able to get them off the rope as fast as possible. A person lying unconscious in their SRT harnesses may start to suffocate due to construction of the chest by the chest harness, or possibly due to choking on their tongue. If the casualty is not breathing at all you have 4 minutes to reach them (and you'd have to be bloody fast to figure out what was wrong and get there in time to do anything about it). If the casualty is breathing you have a little longer. The procedure described below assumes you are at the bottom of the pitch, below the casualty. If you are at the top you would have to down-prusik to the casualty, clip their short cowstail into you, and then continue as from step 4. I have also assumed that the casualty was prusiking. If they'd been abseiling they would a) have been using a stop in which case once you reach them, clip into them and use their descender to get down the pitch. b) be stuck in a rebelay loop, in which case the procedure is much the same as if they'd been prusiking, or c) have ended up at the bottom of the pitch.

- Prusik up to below the casualty and clip their short cowstail into your central maillon.
- Remove the casualtys foot ascender
- Move your foot ascender and then chest ascender past the casualtys chest ascender onto the rope above the casualty (as if you were passing a knot).
- Continue prusiking until you have taken the weight of the casualty on their short cowstail (which is clipped into you). This is strenuous.
- Remove the casualtys chest ascender from the rope.
- Put your descender on the rope below your chest ascender, and lock it off (full lock off).
- Stand up in your footloops (you'll be taking the weight of the casualty) and remove your chest ascender. This is the difficult part.

- Sit back down onto your descender (your footloops safety cord should be slack when you've sat down).
- Unclip your foot ascender, unlock your descender and abseil to the bottom of the pitch with the casualty.

If you can't lift the casualty:

Lifting someone by standing in your footloops isn't easy. If you cant lift them you can re-rig your footloops to give a 2:1 pulley advantage which should enable you to lift almost anyone. To re-rig your footloops, unclip the safety cord and footloops from the foot ascender and tie the footloops to the safety cord. Run the safety cord through a krab (or if you have one, a pulley) which is clipped to the foot ascender (see picture). Now when you stand in the footloops you'll find you are expending less effort in standing up (although you'll only move half as far). You may find the footloops are too long in this arrangement and you'll need to tie out a small section to shorten them. With this re-rig, you effectively have no safety cord between you and your footloops. You could clip in your long cowstail to your foot ascender as a safety cord (otherwise you'll spend a short period during the manoeuvre attached to the rope only by one ascender which is unsafe).

If your footloops safety cord is taut when you sit onto your descender:

Conventionally you would stand in your footloops, re-attach your chest ascender, move the foot ascender down a bit and try again (i.e. stand in footloops, remove chest ascender and sit back onto descender). At a pinch (and time is of the essence here) you could just stand in your footloops to slacken the safety cord, unclip the safety cord from the foot ascender and sit down onto the descender, It is possible that you would be unable to recover the foot ascender if you did this, but don't forget you have a spare attached to the casualty.

Rebelays:

If possible derig any rebelays/deviations between you and the casualty on your way up. This wont be possible if the pitch has been well travelled, or if you approach the casualty from the top of the pitch. If you do have to pass rebelays on the way back down, treat the casualty as a heavy tackle-bag and proceed as usual. You may need to use your footloops to unweight your short cowstail prior to unclipping it, and re-rigging your footloops as described above would help.

Use your brain (& practice lots):

You may not be able to do this manoeuvre exactly as described here, but if you are familiar with the basic techniques and equipment you should be able to work around any difficulties in safety with a bit of cunning.

Alternative Prusiking techniques

It is assumed in most of the sections above that you are using a "Frog rig" for prusiking.

This is just one of numerous prusiking rigs, but it is one of the most popular as it is simple and versatile, less prone to "cock-ups" and easy to pass rebelays etc with. Of the alternative prusiking set-ups, "ropewalking" systems are the most popular, especially with US cavers. Ropewalking systems are generally more complex than the frog rig, but they do have a speed advantage provided there are no rebelays or deviations (which is why ropewalking and "indestructable rope technique" are popular with the same people!). Described below are two methods for turning a frog-rig into a rope-walking (or semi-ropewalking) rig.

Hybrid Frog-ropewalker

All this requires in addition to the frog-rig in an extra ascender which is attached to the foot firmly with a webbing strap. The other foot still uses the footloops as is the conventional frog-rig. If you use a single footloop rather than a pair, you will probably need to shorten it a little to make it the correct length for use with one foot only.

Clip in the chest ascender and footloop foot ascender as usual. Also clip in the ascender attached to the other foot. Instead of ascending by standing up with both feet at the same time progress is made by a walking motion, first lifting the footloops then standing up in the footloops and raising the other foot sliding its ascender up the rope ready for the next step.

This is a very simple modification to the frog-rig which can give some of the speed advantages of rope-walking, however it is not really a true rope-walking rig.

The 'Caving Supplies' Combination rig

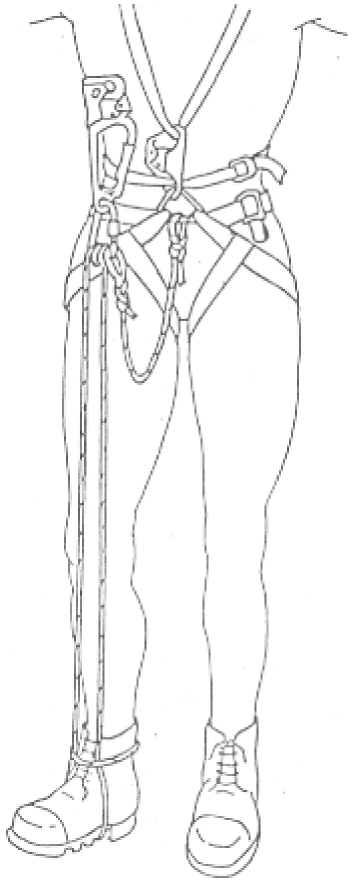
Thanks to Nigel Whittington for this description which I've quoted straight from his email.

This is a simple modification of the 'Frog' rig that enables energy~efficient ropewalking technique to be used on long pitches and Frog technique to be used on alpine style deviations and rebelays using the same personal rig.

It uses the standard 'Frog' rig with the addition of an extra jammer, buckled footloop, elastic cord and two carbine hooks. A slight modification to the footloop is also made.

Make or buy a webbing strap (load bearing!) that will wrap around your ankle and foot in a fig 8 pattern. Use this to fix a non-handled Petzl (tm.) jammer to your LEFT foot.

Modify the footloop on your top jammer so it can be shortened to about 15-20 cm. This can be done several ways, e.g. an extra knot or just clipping the lower loop into the crab or mallion on the jammer. The jammer is attached BELOW the chest jammer and the footloop should be ajusted so that with the right foot raised the janner is just below the chest jammer, with the right foot raised the foot mounted jammer should not foul the floating jammer.



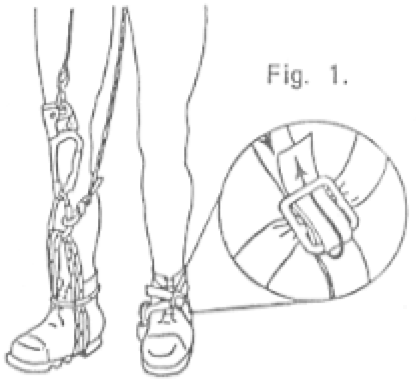


Fig. 1.

Fig. 2.

a) set-up for frog rig with slightly altered footloop
b) alteration to footloop and addition of left foot ascender for ropewalking

Attach an elastic cord to the top of the jammer with a carbine hook, run the cord over your shoulder and attach to the back of your harness via a second carbine hook.

A crab on the chest harness can be used to clip onto the rope to prevent the possibility of inversion and hanging from ones ankles in the event of the chest jammer accidentally opening.

USE

Clip in all three jammers as described, and take short, alternating steps. At the foot of a pitch you may need to weight the rope to ensure the rope runs through the foot jammer.

To transfer to Frog:

- Disconnect the floating jammer.
- Lengthen footloop.
- Remove elastic cord (optional)
- Connect floating jammer above chest jammer.
- Disconnect foot jammer.
- Feet in footloop.

Et Voila, Frog!

To transfer to ropewalking:

- Connect foot jammer.
- Shorten footloop on top jammer.
- Disconnect top jammer.
- Connect top jammer on rope between foot jammer and chest jammer.
- Pass elastic cord from back of harness, over shoulder and clip to top of what is now the floating jammer (was top jammer).
- Right foot in shortened loop.

Et Voila, Ropewalking.

N$$ VERTICAL $ECTION

TREA$URER'$ REPORT

JULY, 1998

By David Joaquim

INCOME:

NEW MEMBERSHIPS & SUBSCRIPTIONS	957.00 *
VERTICAL TRAINING COURSE SALES	201.00
CONSIGNMENT SALES 1996 CONVENTION	173.70
CONSIGNMENT SALES 1997 CONVENTION	144.00
VERTICAL TECHNIQUES WORKSHOP	465.00
BANK INTEREST (BB&T)	14.51
BANK INTEREST (GMAC) till July 98	131.76 *
SYMBOLIC ITEM SALES	408.00 *
BACK ISSUE SALES	28.00 *
TOTAL INCOME	**$ 2,522.27**

EXPENSES:

T-SHIRT & SWEATSHIRT PURCHASE & PRINTING	$1,000.00
PRINTING BASIC VERTICAL TRAINING COURSE	765.73
VERTICAL WORKSHOP TRAINING BOOKLETS	103.66
BULK MAIL PERMIT	170.00
SHIPPING INSTRUCTOR COURSE MATERIALS	23.00
SYMBOLIC ITEMS POSTAGE	45.85
1997 WORKSHOP EXPENSES	32.50
NYLON HIGHWAYS #41 & 42 RESENDS	91.75
PICK UP BACK ISSUES FROM CINCINNATI	29.11
BANK FEES ANG CHARGES	24.00
BAD CHECK	20.00
RETURNED CHECK	40.00
COPIES	21.72
POSTAGE	75.76 *
SHIPPING	45.37 *
STAMPS & ENVELOPES	38.24 *
TOTAL EXPENSES	**$ 2,526.69**

ACCOUNT BALANCES:

BANK ONE (AZ)	$2,402.94 *
GMAC	$5,964.93 *
CASH ON HAND	**$8,367.87 ***

* changes

NSS VERTICAL SECTION

SECRETARY'S REPORT

JULY, 1999

By David Joaquim

NUMBER OF SINGLE MEMBERSHIPS	 749
NUMBER OF FAMILY MEMBERSHIPS	 52
TOTAL VOTING MEMBERS	.... **801**
LIBRARIES	 11
NYLON HIGHWAY SUBSCRIBERS	 43
NYLON HIGHWAYS EXCHANGED	 33
NYLON HIGHWAYS TO BE MAILED	.... **888**
SUBSCRIBERS PAID THROUGH:	
# 46	 244
# 48	 176
# 50	 103
PAID BEYOND #50	 33

NSS VERTICAL SECTION

TREASURER'S REPORT

JUNE, 2000

By David Joaquim

INCOME:

NEW MEMBERSHIPS & RENEWALS		$1,427.00
BVTC SALES @ 1999 CONVENTION		$ 40.00
BASIC VERTICAL TRAINING COURSE		$373.50
BVTC Net Sales	$1,908.25	
Total Costs	$1,869.02	
Net Profit	$ 39.23	
VERTICAL TECHNIQUES WORKSHOP		$525.00
BANK INTEREST (GMAC) July 99-March 00		$200.00
SYMBOLIC ITEM SALES AT 99 CONVENTION		$512.00
SYMBOLIC ITEM SALES TOTAL		$639.70
BACK ISSUE SALES		$ 69.70
DONATIONS		$ 6.60
TOTAL INCOME		**$3,281.50**

EXPENSES:

VERTICAL SECTION VERTICAL GEAR -- (2) 3-Knot Rigs, (2) Mitchell Rigs, (7) SS 6-bar racks	$1,032.82
1999 CONVENTION PRIZES	$ 90.00
PATCHES (Aztec Graphics)	$615.47
POSTAGE & SHIPPING COSTS	$170.23
NSS WEB SPACE	$ 12.00
DONATIONS	$ 15.00
BANK FEES AND CHARGES	WAIVED
TOTAL EXPENSES	**$1,935.52**

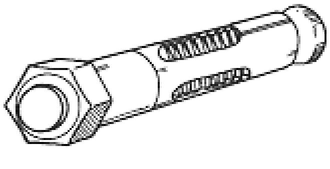
ACCOUNT BALANCES:

BANK ONE (AZ)	$1,989.08
GMAC	$6,547.81
POSTAGE ON HAND	$ 2.31
CASH ON HAND	**$8,536.89**

Bolts To Avoid

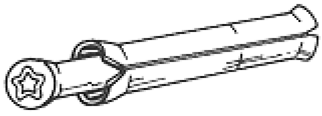
by Duane Raleigh

Externally threaded sleeve anchors
You can find externally threaded sleeve anchors in almost any hardware store. These take the same effort to place and cost about as much as the Hilti HSL and Rawl Bolt, but are only about half as strong because their external threads reduce the effective diameter of the bolt where it contacts the hanger, giving it a low bending strength and making it prone to shearing off.

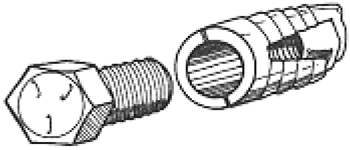


Externally threaded sleeve bolt

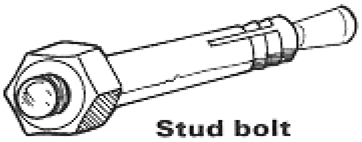
Torque bolts
We didn't find any dependable torque bolts, although some climbers use and swear by the USE Diamond Taper Bolt, which can be strong but usually isn't. To place a torque bolt you tap the bolt into the hole and then torque it down, spreading an expansion cap at the back of the hole to create a friction hold. Sounds good enough, and USE Diamond touts this anchor as the strongest expansion bolt made, but the problem is these bolts don't have any leeway for user error. Torque the bolt too tight and you strip the expansion cap, ruining the placement. Get the bolt too loose and the cap will hold a pullout load about as well as bubble gum on the end of a nail.



Star Dryvin bolt



Drop–in bolt



Stud bolt

We really gave Taper Bolts a chance, setting dozens of them in their optimum substrate, hard rock. We tried to set the bolts by "feel," just as you would when climbing. Half the time we got it right and the 3/8inch Taper Bolts held up to 3000 pounds in a straight pull out. But we blew it with the other half and the bolts slid out of the hole at only 700 pounds. Worse yet, we couldn't tell the good placements from the bad until we ripped them all out.

USE Diamond Taper bolt

The Wejit Anchor Bolt is another variety of torque bolt, bur fortunately most climbers have more sense than to use it. This anchor has two pushwires running down the shaft that culminate in a pair of tangs that splay out when you crank the bolt down. Tested in shear, the 3/8inch Wejit Anchor Bolt held around 2600 pounds in hard rock but broke or pulled out at an average of 1300 pounds in tensile.

Sleeve-and-nail bolts
The Star Dryvin is the only sleeve-and-nail bolt we found. This anchor, once commonly used in sandstone, utilizes a lead sleeve and a steel nail. You tap the sleeve in the hole,

and then hammer the nail in, spreading the sleeve. In the best rock the 3/8inch Dryvin only holds 1400 pounds in shear and less than that in pullout. In sandstone, where Dryvins were thought to be a good alternative for drilled angles these bolts are unbelievably weak- we pulled one out with our fingers.

Rickety and somewhat expensive at $2 each, there's no excuse for ever using a Dryvin. If you see a star icon on a nail head that's embedded in a sleeve, yank the sucker out and put in a real bolt.

Drop-in bolts

These are the soft lead "shells" you see in the anchor department at the hardware. To use these bolts you drill a hole, hammer the shell in, and then screw a machine bolt into the sleeve to expand it. Drop-ins in the 3/8inch and 1/2 inch sizes can be strong, but for the size holes they require (a 3/8inch bolt takes a 1/2inch hole) these anchors are inefficient. Also, drop-in sleeves can crack or strip out when you insert the machine bolt. Save your money for better bolts.

Studs

Stud bolts expand, creating a friction grip, when you hammer them onto an expansion pin set in the back of the hole. We tested Rawl, Star, and Ramset/Red Head stud bolts, although Stud bolt you can find similar bolts from almost any bolt manufacturer.

Stud bolts can be strong in hard rock, but suffer from several maladies that make them unsuited to rock climbing. First, you have to drill the hole to an exact depth to make sure the expansion pin engages the stud. Second, the exposed threads on these bolts makes them subject to work fatigue. Third, you can't remove or countersink these anchors without destroying the rock around them. And last, you can't buy studs in stainless steel.

Self Drills

The self-drill bolt serves as both a drill and a bolt. Sounds good? It isn't.

In medium rock these bolts pull out around 700 pounds. In hard rock the "bit" dulls easily and usually two or three are needed to finish the hole. But, in most cases, climbers only drill the bolt half-way before they become frustrated with the system and stop; leaving a hideously weak and botched bolt. Even when placed correctly the strongest self drilled bolt only holds 3000 pounds shear - which is not much considering the amount of effort required to drill the hole and the other superior bolts available.

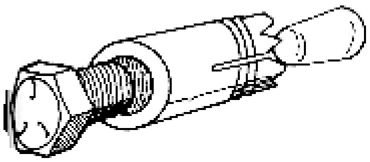


Figure 6. A self–drill serves as both drill and bolt. We mention these relatively weak bolts because you can place them by hand.

Reprinted from *Climbing* - October/November, 1992

Editors Note: Be aware this article was written for rockclimbers and all comments may not apply to the cave environment. Being sedimentary rock, limestone is generally soft. Make sure the bolt you choose is designed for the hardness of rock into which it is to be placed.

Slow-Pull Testing Of The "Double Overhand On Itself" Tie

by Collin O'Neill

Introduction

Over the past few years of my caving experience I have witnessed several cavers using an unconventional knot on the terminations of their cow's tails. I tied the knot on my own while searching for a termination that would grab a carabiner better than the figure eight on a bight, and soon afterward noticed others using the same knot. When questioned about its use, few of the knots users knew about the safety of the knot or its practical applications. This knot can be best described as a *double overhand on itself* (DOI) or more obtusely as a *half double overhand* or *half fisherman knot*. The nomenclature could be confusing and admittedly is not adequate, but for this paper I will use the double overhand on itself because it is the most descriptive of the three. One ties it by taking a bight of rope, and tying a double overhand with the short end back onto the standing line (Figure 1). A carabiner or other anchor point is placed through the bight and the knot is set by dressing the double overhand portion and tugging on the standing line to cinch it against the carabiner.

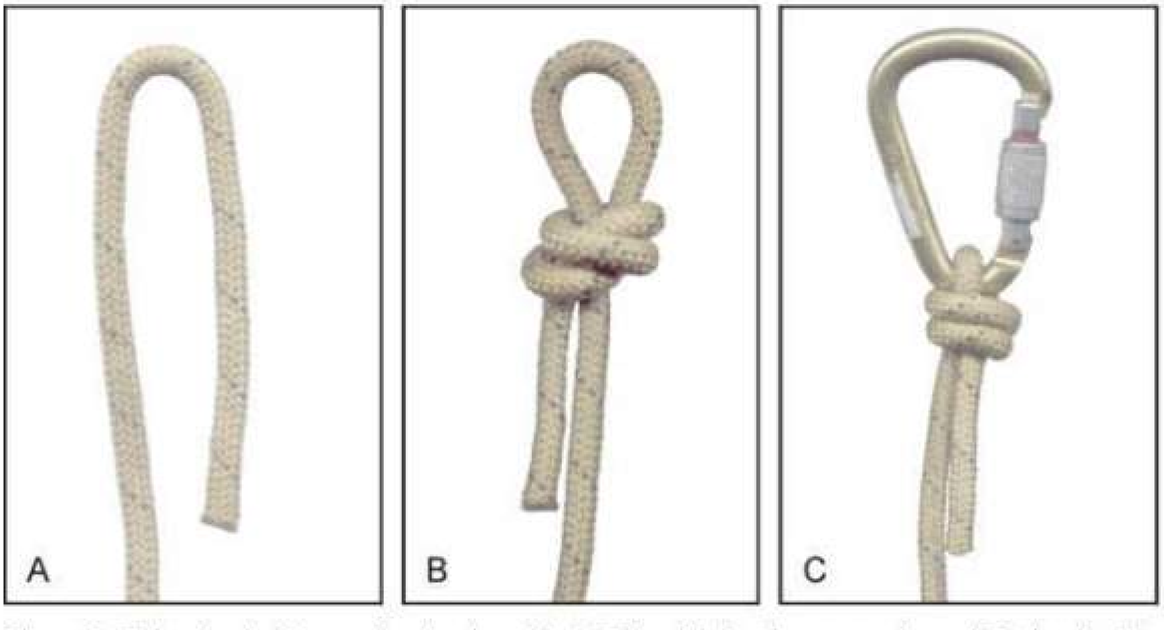


Figure 1. Tying the double overhand on its self. A) Take a bight of rope near the end, B) tie a double overhand around the standing line, and C) clip in a carabiner and cinch the knot down with body weight.

Although I used this knot for several years, I've always wanted to know exactly how strong this knot is! It has many advantages for a cow's tail termination. It is compact and creates a sturdy grasp when handling a carabiner; it has a low gain, and it is easy to inspect. The knot also has other uses, such as a termination for a quick-attachment safety (QAS), pre-tensioned back-tie (similar to a trucker's hitch), load-release hitch for rescue use or a termination on a piggyback haul system. In my experience, the knot handles repeated loading and unloading well, provided it is properly dressed and set. Like the double overhand bend (a.k.a. fisherman's knot), the double overhand on itself can be difficult to untie. However, taking the carabiner out of the bight causes the knot to fall apart.

This study represents a test of the slow-pull breaking strength of ten samples of this knot tied with 8 mm prusik cord, similar to cord used on cow's tails. Although the methods used do not strictly match any federal testing, and they were completed using older (but unused) cord, the results offer a great start into understanding this knot.

Methodology

The cord used for this test was 8 mm prusik cord manufactured by CMC Rescue, Inc. and purchased in either 1995 or 1996. It was originally tied into prusik loops, but the cord proved to be too stiff for use as prusik loops in rescue systems, especially after a few uses. The unused loops were untied and stored, and later donated for testing by the San Bernardino Sheriff's Cave Rescue Team. It was always stored in either a storage shelf away from chemicals and sunlight, or in a private garage, also away from chemicals and sunlight. The manufacture's rated breaking strength of the cord, calculated as the mean of samples tested according to Federal Test Standard 191A, Method 6016 minus three standard deviations, was 2875 lbf (12.8 kN).

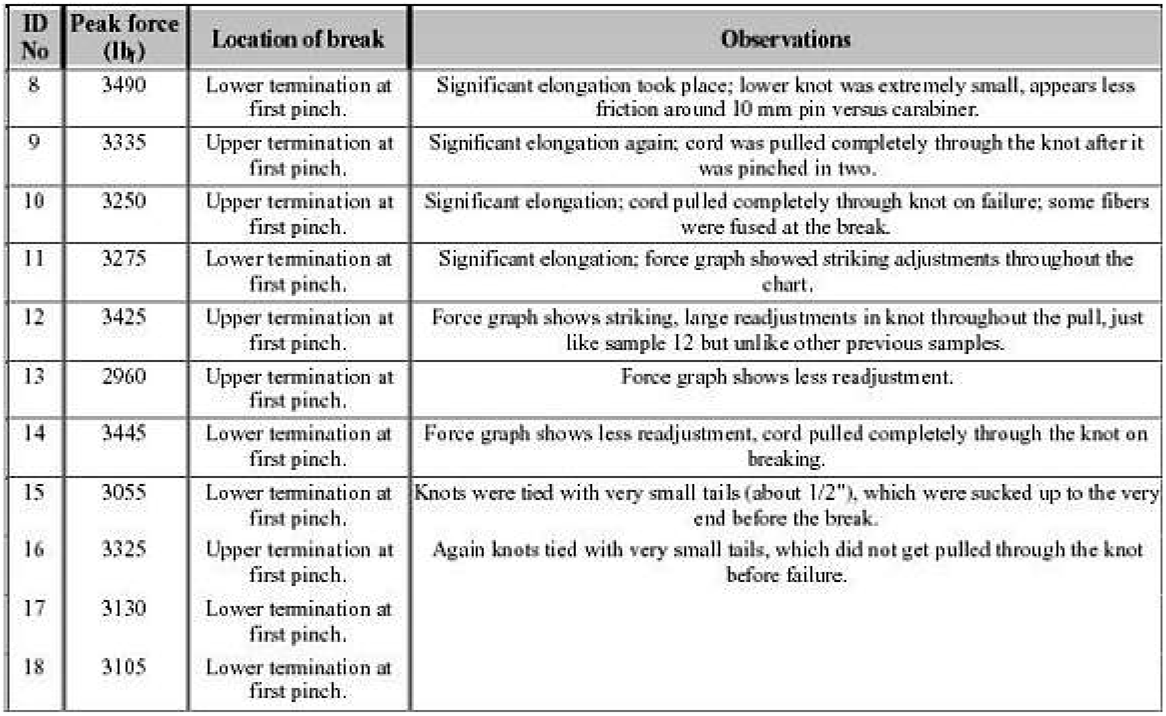
The machine used for the slow-pull strength testing was an Instron Universal Testing Instrument model TT-CL at the University of California, Riverside College of Engineering. The machine pulled the samples apart at a rate of 2" per minute (5.08 cm/min). Forces were plotted on a paper strip 10" wide with a pen plotter.

The top end of each sample was a DOI tied over a steel D-shaped Stubai carabiner. Instead of a round cross-section, the Stubai carabiner had a T-shaped rod, and the D-shaped bends offered a simulation of the knots use in the real world. The bottom end was also tied with a DOI, but this time over a pin 3/8" (9.5 mm) in diameter, offering a comparison between the breaking characteristics of the knot over a carabiner versus a cylindrical attachment point. In practical use, it was necessary to use the DOI on both ends because a figure eight on a bight and a clove hitch both proved to be weaker than the DOI on the first tests! Both knots were dressed and set properly, but tails were only 1" long in order to conserve rope.

Eleven samples were pulled on July 25, 2000. After breaking, each sample was issued a number and stored for later study. As an afterthought, five samples were marked to measure the amount of cord pulled through the knot after it readjusted. It became apparent early on that this knot stretches significantly.

Results

The eleven samples failed between 3490 lbf (15.5 kN) and 2960 lbf (13.2 kN), a range of 530 lbf (2.4 kN). The average breaking strength was 3254 lbf (14.5 kN). The minimum breaking strength of this knot on this cord could be expressed as the average minus three standard deviations, equaling 2737 lbf (12.2 kN). Overall, this knot reduced the rated breaking strength of the cord by only 5%. However, this comparison is flawed because a control of the cord was not tested in conjunction with the DOI knots. It is possible that the strength of the cord in our tests may be higher than the manufacturer's rated breaking strength.



ID No	Peak force (lb$_f$)	Location of break	Observations
8	3490	Lower termination at first pinch.	Significant elongation took place; lower knot was extremely small, appears less friction around 10 mm pin versus carabiner.
9	3335	Upper termination at first pinch.	Significant elongation again; cord was pulled completely through the knot after it was pinched in two.
10	3250	Upper termination at first pinch.	Significant elongation; cord pulled completely through knot on failure; some fibers were fused at the break.
11	3275	Lower termination at first pinch.	Significant elongation; force graph showed striking adjustments throughout the chart.
12	3425	Upper termination at first pinch.	Force graph shows striking, large readjustments in knot throughout the pull, just like sample 12 but unlike other previous samples.
13	2960	Upper termination at first pinch.	Force graph shows less readjustment.
14	3445	Lower termination at first pinch.	Force graph shows less readjustment, cord pulled completely through the knot on breaking.
15	3055	Lower termination at first pinch.	Knots were tied with very small tails (about 1/2"), which were sucked up to the very end before the break.
16	3325	Upper termination at first pinch.	Again knots tied with very small tails, which did not get pulled through the knot before failure.
17	3130	Lower termination at first pinch.	
18	3105	Lower termination at first pinch.	

More interesting than the numbers, and the high strength of the knot during slow pull tests, is the behavior of the knot as it tightens to failure. Five of the eleven tests broke at the upper knot, while six of the tests broke at the lower knot, around the 3/8" diameter (9.5 mm) pin. It appears the shape of the attachment point had little to do with the knot strength.

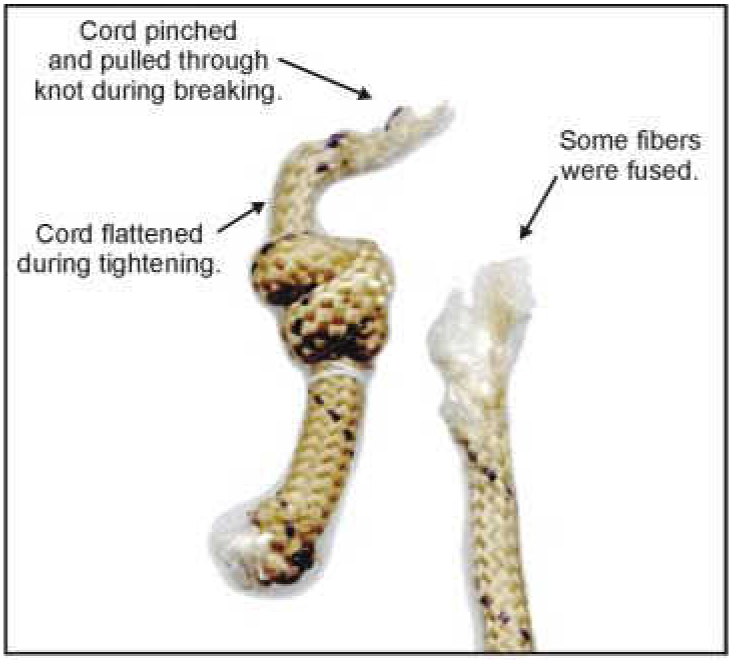


Figure 2. Double overhand on itself after failure (sample 9). The cord always broke where standing line enters the knot.

The double overhand on itself adjusted and slipped noticeably. As the knot was pulled tighter, the cord slipped completely through the knot, pulling the tail about 1/2" (1.76 cm) into the knot. The standing line elongated significantly, as much as 17.2" (18.3 cm). Eventually the knot was tight enough that the tail was pinched. All of the samples failed at the point where the standing line enters the knot; a breaking characteristic similar to figure eights, bowlines and butterfly knots (Figure 2). Although strands within the core were sometimes heard breaking (mirrored by drops in force on the chart), the rope did not appear damaged where it bent over the carabiner or pin. The breaking of the knot fused some of the fibers in most cases, indicating a brief temperature jump in excess of 250 °F (482 °C; the temperature at which nylon becomes sticky).

The force chart illustrates an exponential increase of force as the knot adjusted and tightened on its self. As the knot approached failure, momentary slipping of the various bends caused the force to jump predictably (Figure 3).

Interpretations

This experiment is esoteric, given the slim chances of a caver pulling on his cow's tail in excess of 2737 lbf (12.2 kN). However, it is useful because it measured the strength of this knot on a commonly used cord. The original concern was that this knot may be somehow very weak, but instead it appears to be stronger than other knots in the same cord. During preparation for testing, a sample was pulled in which a DOI was tied on one end and a figure eight on a bight on the other. The figure eight on a bight failed before the DOI. Likewise, a clove hitch failed before its DOI counterpart. The knots strength appears to come from its ability to readjust until it is constricts itself to pieces. Although it was not measured, the DOI stretched significantly more than its figure eight or clove hitch counterparts. Of the three, the clove hitch had the least cord to adjust and failed earlier than the figure eight or DOI. Also, the breaking point on the clove hitch was cleaner and had more fused fibers than the others.

Although testing of this knot is far from complete, my conclusion is that it is an excellent choice for a cow's tail or QAS termination. It provides the above-mentioned advantages of low gain, compactness, ease of inspection and easy grasping point, and the knot is assured to fail after other critical components start to fail. If forces great enough to break this knot were applied, they would be caused only be negligence.

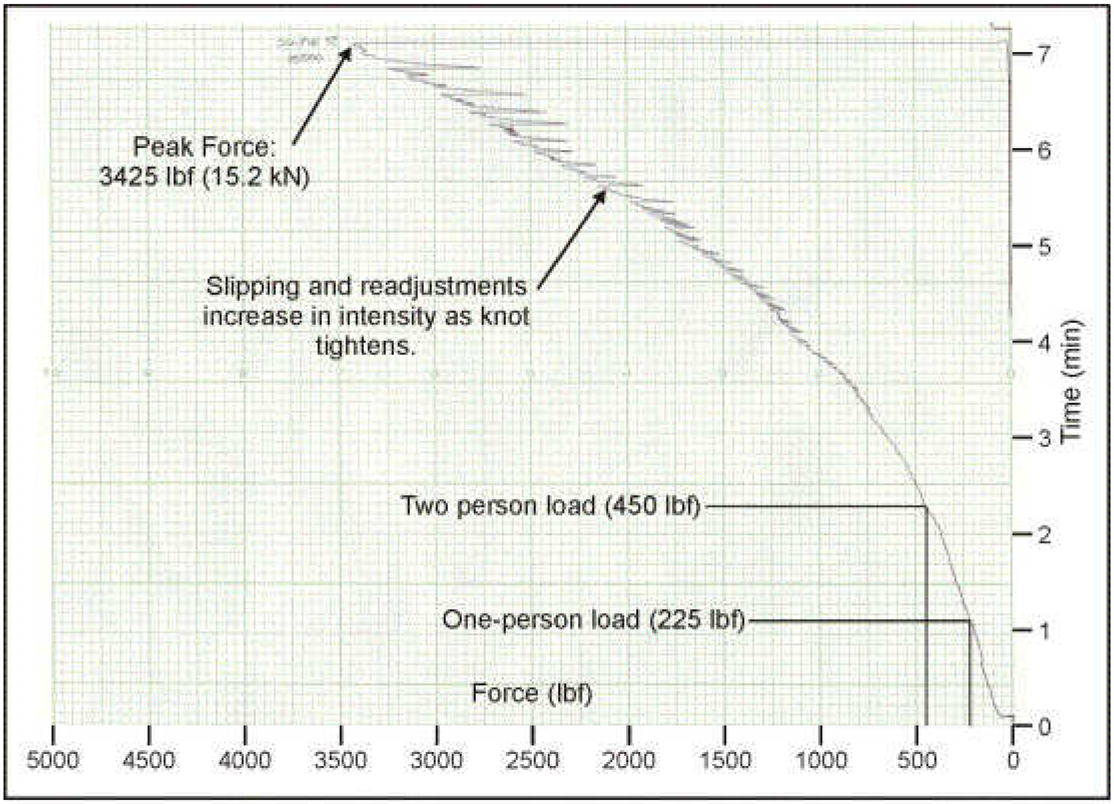


Figure 3. Example of a force graph (sample 12). The pattern of readjustments, slipping and core breaks is very regular.

Further Studies

As useful as this study was, it misses an important point: knowing how this knot performs under a shock force is more important than its slow-pull strength. One function of the cow's tail is to catch a climber when he or she is attached to an anchor over a fall hazard. Typically, the attachment point is above the harness attachment, yielding a low fall factor should the climber slip and fall. However, it is common to be attached at the same level of the anchor, and, although not recommended, I have witnessed many cavers climbing above their anchors, potentially incurring a fall factor of 2! So, does this knot stand up to falls? My guess is that its steady elongation characteristics make it a good energy-absorbing knot. Does the cord adjust similarly in a dynamic event? Probably not, and it may have less time to stretch, therefore dissipating less energy than observed in the slow-pull tests. This may be true of most knots.

In any fall, the rope dissipates kinetic energy of the falling mass. Ropes stretching less absorb less energy, resulting in much higher peak forces than high-stretch ropes. That is precisely the reason climbers love high-stretch rope! It is also for this reason that low-stretch cords such as Spectra and Kevlar should never be used if the caver wishes to maintain a 2:1 safety factor during dynamic events (i.e. slipping down a pit). But energy is dissipated throughout the entire system. In the case of a cow's tail, a falling caver stretches the standing line and tightens two knots, resulting in even lower peak forces. If one knot stretches more than most, which I suspect is the case of the double overhand on itself, it will provide greater energy dissipation and result in lower peak forces.

There are still other problems with this study that must be considered. First, the cord tested was older and no doubt did not allow the testing method to isolate the behavior of this knot completely. Second, a control test was not performed. Ideally, this test would use new 8 mm cord from one coil, and a control would consist of testing the strength of the cord itself according to federal standards yet on the same machine. Third, the correct number of samples to yield statistically significant results should be determined and followed. In this experiment the number of samples was determined by the time available on the testing machine.

Acknowledgements

I would like to thank the San Bernardino Sheriffs Cave Rescue Team for donating cord used for testing, and Paul Stovall and the UCR College of Engineering for donating the use of their testing machine.Additional equipment was donated by Tad Gallistel and David Owens. Thanks to Paul Stovall, Bryan Lavender and Jeff Lehman for editing comments.

Water Knot Testing

1999 International Technical Rescue Symposium

by Tom Moyer

Summary

Anecdotal evidence exists to suggest that water knots - commonly used to join webbing into a sling - sometimes fail by slipping. I have found through testing on a load frame that this knot gradually slips when cycled repeatedly with loads as low as body weight. When the tails have slipped all the way into the knot, the knot fails. This resolves the concern I have about "mysterious" failures of this knot. I believe it is completely safe as long as it is checked and found to have sufficient tails before loading.

Background

I have been told many anecdotal stories of accidents caused by the failure of water knots (also called ring bends or overhand follow-through bends) by slipping. Understanding these failures is of some concern to mountain rescuers who use this as a standard knot for tying two ends of a webbing sling together. Many climbing and rescue texts recommend leaving plenty of tail with this knot and pretensioning it carefully to avoid possible slipping, but none of them provides any detail on failures. Past pull-testing I have done on water knots (with sufficient tails) showed no slipping failures - no matter how poorly the knot was dressed or how poorly it was pretensioned. This caused me some consternation. If a knot occasionally has mysterious failures that I can't duplicate, should we be using that knot for rescue work? Suggestions by other climbers (and the temporary availability of a programmable load frame) prompted me to look at the possibility that these knots were slipping over time under repeated loading and unloading cycles, rather than by slipping when loaded for the first time.

Test Methods

I used a small MTS load frame to pull on a loop of 9/16" tubular webbing tied with a water knot The load was cycled from 0 to 250 lbs at a fairly slow loading and unloading rate (about two seconds per cycle). Loads and extensions were measured directly by the load frame. The test was halted automatically upon failure of the knot.

Results

The test showed consistent slipping of one of the tails into the knot at an average rate of 0.0035 inches per cycle. A knot that started with tails almost three inches long had one tail gone after 806 cycles. It was interesting to note that only one of the tails slipped into the knot - the one on the "top" side of the knot.

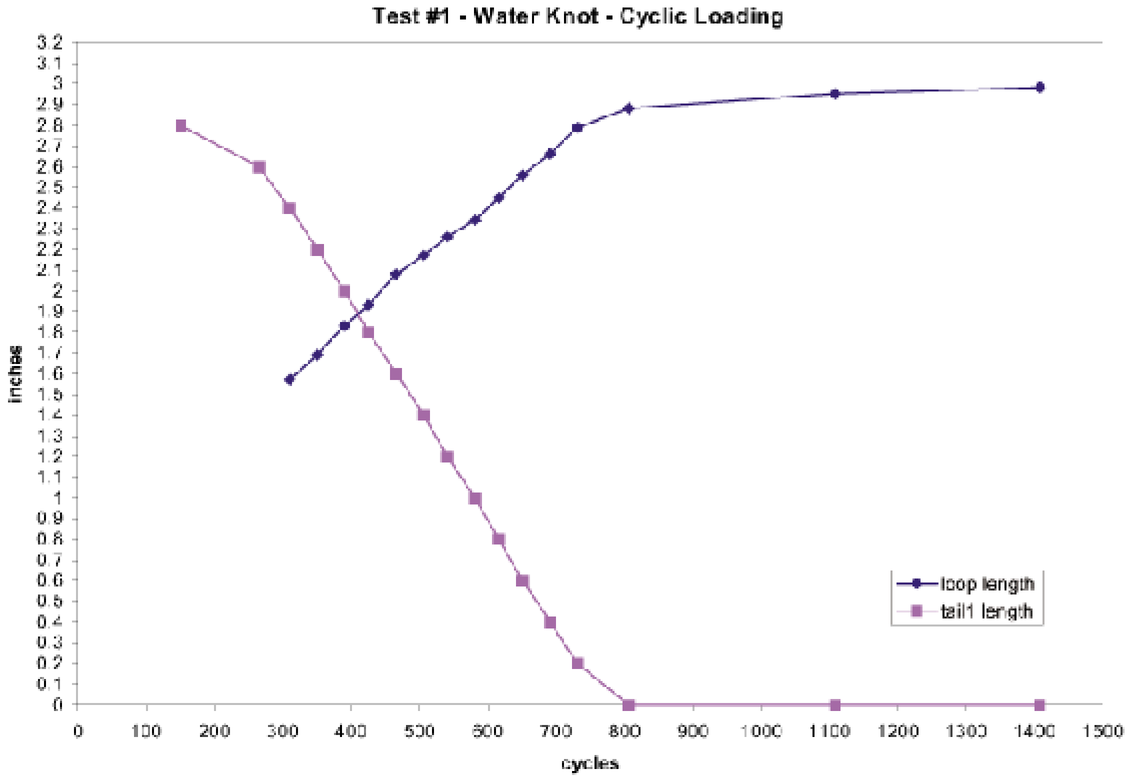
A test with overhand safeties on the water knot gradually slipped through 1.75 inches of tail, and then cinched and did not slip any further. Interestingly, the slip rate was not linear as in the first test, but decreased as the safeties gradually tightened.

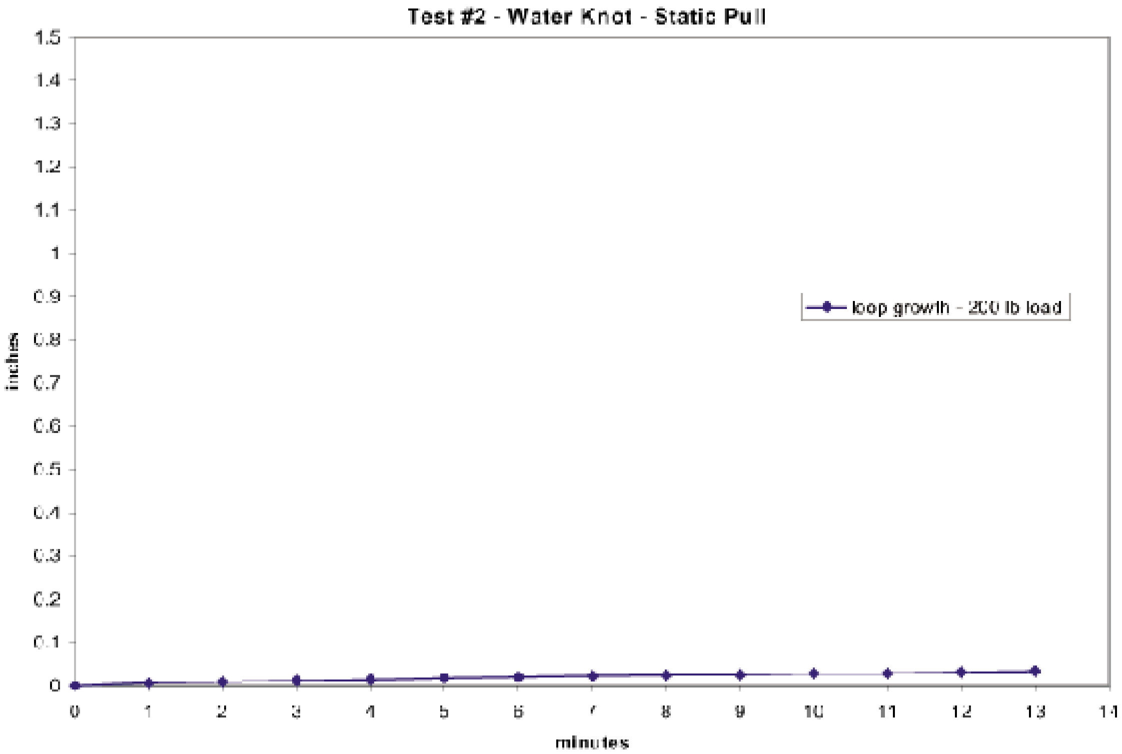
A loop tied with a water knot was loaded with a static pull of 200 lbs. to check whether the knot was slipping by creeping. The test was run for thirteen minutes. After an initial period of setting the knot, no further slipping occurred. The water knot seems to be affected by loading and unloading, not by a static pull.

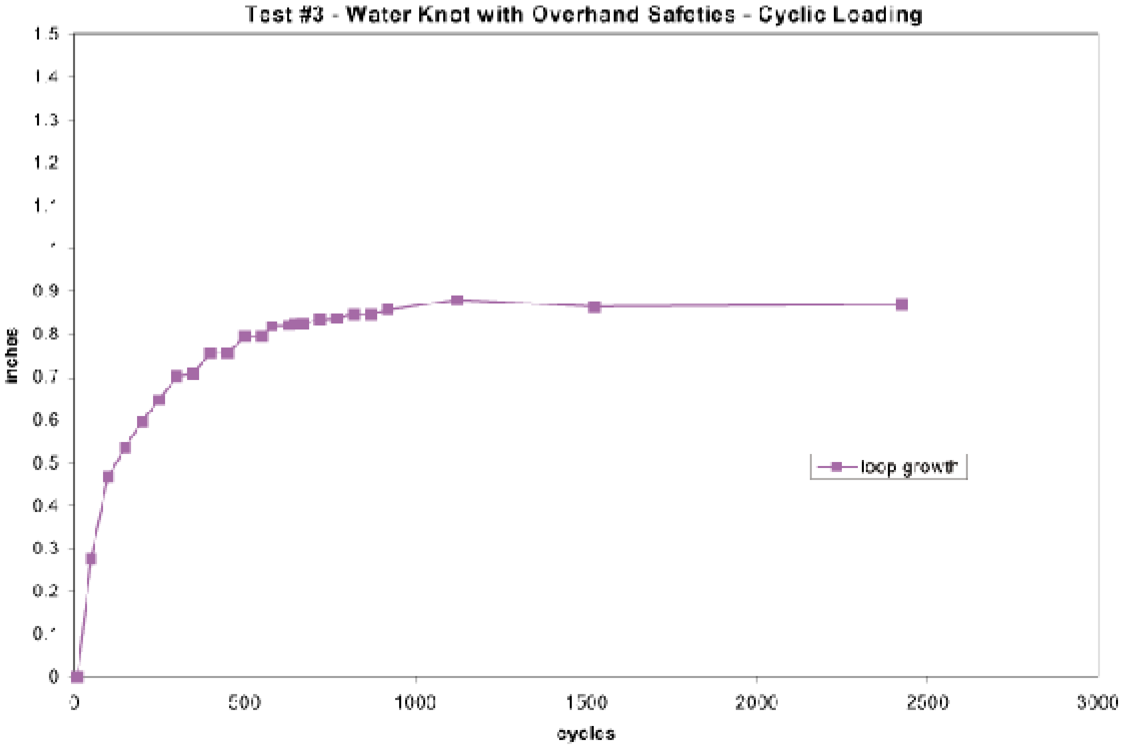
Another cycle test was done on a loop tied with a single fisherman's knot. Over the first 1000 cycles, the loop elongated by 1/4 inch as the knot set. After that, no further elongation occurred. The test was discontinued at 1630 cycles.

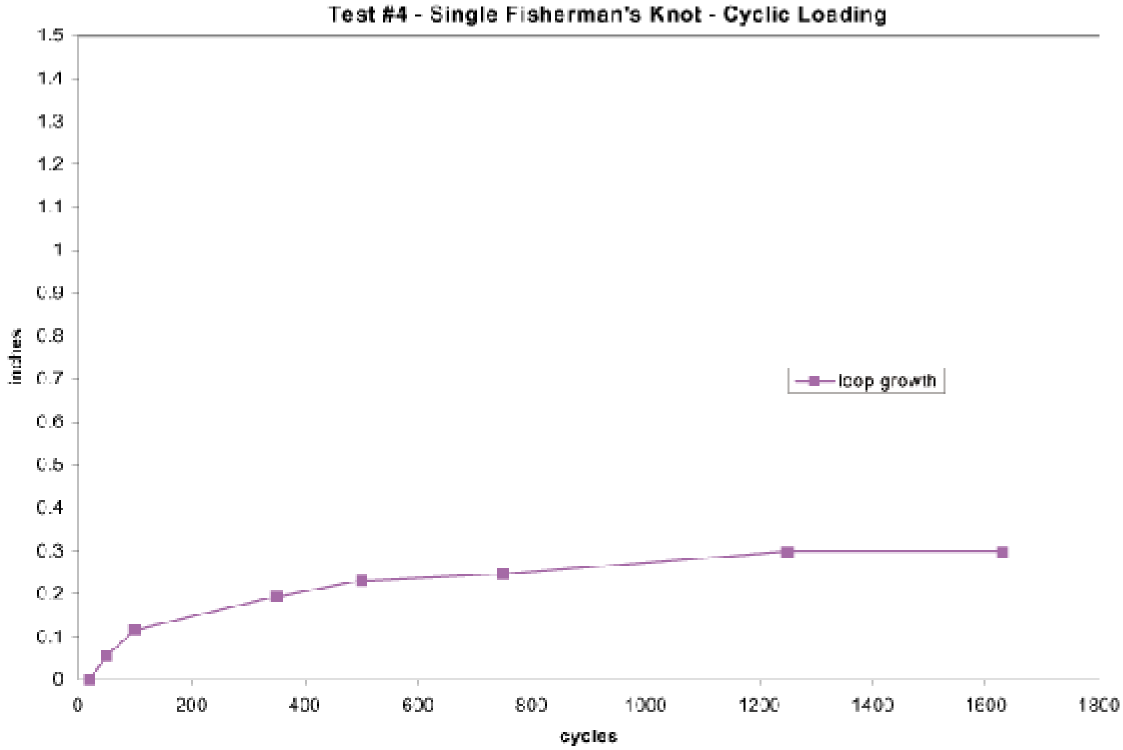
Conclusions

Water knots definitely fail by slipping under cyclic loading. Low loads, such as body weight, are sufficient to cause failure. Other knots (such as a single fisherman's) tied in the same material do not exhibit this kind of failure. Overhand safeties tied on top of a water knot may prevent the failure, but do not guarantee it. This is not all bad. news for water knots. I now understand the mechanism of failure and know how to prevent it. This is a lot more comforting than using a knot about which I have suspicions. I will always chek the length of the tails on every water knot - and particularly every fixed rappel anchor tied with a water knot. - before trusting my life to it. We will continue to use water knots in Salt Lake County, and continue to require long tails on this knot as we always have.


Test #1 - Water Knot - Cyclic Loading
inches
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
cycles
loop length
tail1 length


Test #2 - Water Knot - Static Pull
inches
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
minutes
loop growth - 200 lb load


Test #3 - Water Knot with Overhand Safeties - Cyclic Loading
inches
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
500
1000
1500
2000
2500
3000
cycles
loop growth


Test #4 - Single Fisherman's Knot - Cyclic Loading
inches
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
1400
1600
1800
cycles
loop growth