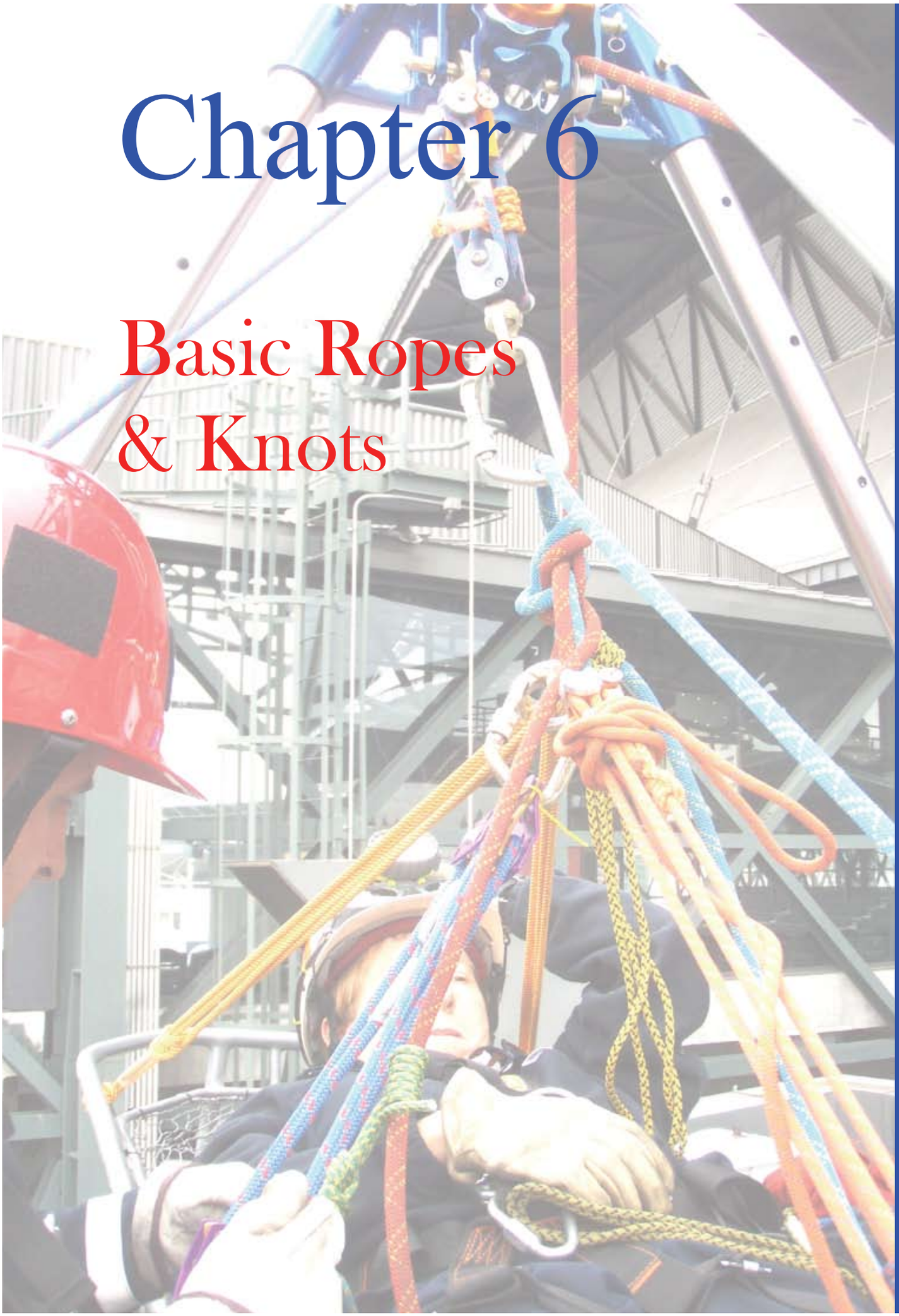
Chapter 6

Basic Ropes & Knots



ROPE

Introduction

In the Fire Service, the knowledge of how to tie and use knots is essential. While there are many knots available, the following knots described in this section should be adequate to meet the needs of Seattle firefighters in most situations

Keep in mind that it is more important to be able to tie these standard knots automatically, while under the stress of an emergency, than to know a greater number of knots and yet have failed to acquire skill in their use.

The ropes used on operation companies range in size from 1/4” woven cotton tie ropes to ½”” kernmantle nylon life safety rescue ropes. They can vary in length from just a few feet to 300 foot lengths. Ropes and knots are used daily in securing equipment, fire suppression, rescue work, and emergency medical applications.

Whether working with rope or knots in an emergency or training, SAFETY should be on the mind of all involved.

Rope Usage

The Seattle Fire Department separates the use of ropes into two categories: Utility and Life Safety.

Utility

A utility rope is a rope that is used for any function other than that of life safety. Tie ropes, practice ropes, RIG ropes, roof ropes and other ropes that are marked as such all fall under the umbrella of utility rope.

Life Safety

Life Safety rope is defined as any rope used to support the weight of members or other persons during rescue, fire fighting, other emergency operations, or during training evolutions. Operations companies use ½” static kernmantle life safety rope for all operations level rescues. In addition, some accessory cord such as 8mm guide sling for the Load Releasing Hitch and prussik loops are used in life safety applications.

Common ***Breaking*** Strengths of Rescue Rope:

- 8mm – 3,100 lbf (Accessory Cord)
- 1/2" – 9,000 lbf

Rope Characteristics

A point to remember is that the words "static" and "dynamic" are misleading. Static means non-moving. There is no such thing as a static rope system, for example, even steel is not considered to be static. Low-stretch and high-stretch more accurately describe and identify real world conditions.

Low Stretch (Static)

Operations life safety ropes have a relatively low stretch ratio, (usually between 10 and 20 percent till failure) due to a non-spiral constructed core bundle. Two to five percent elongation will occur with a working load (200 lbs.). Low stretch ropes are called "static".

High Stretch (Dynamic)

High stretch or "dynamic" ropes have a relatively high stretch ratio, (usually between 20 and 50 percent till failure) due to a spiral constructed core bundle. Operations utility ropes are "dynamic" high stretch.

ROPE SAFETY

- Avoid walking or standing on the rope
- Do not drag the rope. Added abrasion leads to less sheath life
- Do not leave a rope under tension for any extended period of time unless necessary
- Remove all knots as soon as possible
- If rope cleaning is needed, clean by rinsing with clean fresh water
- Dry wet rope (**hang dry**) before bagging
- Exposure to the sun's ultraviolet radiation will damage the rope, keep exposure to a minimum
- Nylon moving across nylon can melt through the stationary piece. Be careful when running nylon over nylon, for example moving rope over stationary webbing
- Be sure to pad sharp edges
- Avoid adding twists and kinks when bagging/coiling the ropes

TYPES OF ROPE

1/2” (Low-Stretch) Static Kernmantle Rescue Rope

All operations ladder companies carry 3 bags of life safety rope. These ropes may vary in color as well as length. Typically, most ladder companies will carry (1) 150’ and (2) 300’ life safety ropes. This is a life safety rescue rope that is rated at 9000 lbs. breaking strength, in slow pull tests. A rescue load is considered to be 600 lbs. In order to meet NFPA certifications, the rope has a 15:1 safety factor (600 lbs. x 15 = 9,000 lbs.)

Accessory Cord

Guide-Slings – One of the primary uses for 8mm Accessory Cord is the prusik loop and the 25-30 foot guide-sling. The guide sling is used primarily for tying a load releasing hitch, however, the guide sling can also be used for any accessory rigging need (anchors, fall restraints, etc.).

System Prussik Loops – The short prusik loop is 57” and the long prusik loop is 71”. They are tied (created) with a double overhand bend and are tightened down using a compound 9:1 pulley system until 2 inches of tail remains protruding from the bend. The strength of 8mm material is (3630 lbf) according to the manufacturer.

Utility Rope

Any rope that is not classified as “life safety” rope will fall under the category of “utility” Utility ropes have multiple uses such as hoisting equipment, stabilizing vehicles, medical calls, salvage, etc. They are usually made of manila, nylon or other synthetic materials.

BREAKING STRENGHTS

To achieve a functional breaking strength, the rope or other material is placed in the position of function and slow pulled to failure. A rope can stand more force in a shock load situation than in a slow pull test. The reason, according to one theory, is slow pull testing allows fibers to change alignment and move in relation to each other. In testing that involves shock loading, the shock occurs in less than .5 seconds and the fibers do not have time to realign.

Dynamic Forces

Dynamic energy may be explained as the energy generated by movement (for example, a falling object). If a rope was attached to this falling object and used to arrest its fall, then the energy of the object would be transferred to the rope. In effect, this transference would be dynamic tensioning of the rope.

Residual Strength

Residual strength is the remaining strength in a rope that has been used for a period of time. As a rope is used; high load forces, abrasion and other factors combine to reduce the strength of the rope. Factors that affect the residual strength are: arresting falls, corrosive chemicals, sunlight, abrasion, etc.

Resistance to Cutting (Life Safety)

Demonstrations have shown modern rescue ropes are capable of sustaining considerable damage, without failure. One experiment showed a 13mm low-stretch rope sawed 88% through, was able to statically hold a 600 lb. rescue load. This was repeated over a 90 degree edge and the same 12% remaining material was able to hold the same 600 lb. rescue load without failure. Failure did not occur until the utility knife was used to saw through the balance of the material. But still, care should be taken to protect ropes from sharp objects!

ROPE CARE

Life Safety Rope

Rope Markings (Life Safety)

Low stretch life-safety ropes are marked on each end with a number for inventory and the date the rope was placed in service. Each rope end is also marked with either ‘End A’ or ‘End B’. To evenly distribute wear along the length of the rope over the life of the rope, alternate ends after each use. Mark the middle as recommended by the manufacturer.

Rope History Log (Life Safety)

Washington State Law requires members to record what the rope was used for after every use. The rope's history is one of the elements that will contribute to the decision of when to retire a rope from service. In the rope log, note the date, the use, condition, which end and length used, followed by the recorder's name.

Cleaning (Life Safety)

Should life safety rope become dirty, washing with clean water and allowing to "air" dry. A mild detergent may be used if the rope is extremely dirty and water alone will not remove the dirt/debris. Questions regarding which detergent to use should be directed to on duty personnel at Rescue 1 at Station 14.

Cleaning a rope is done by brushing the dirt off with a nylon brush, while rinsing with lots of clean fresh water. Do not use water hotter than 110˚ F. The rope is dried away from direct sunlight in a hose tower or heated room. Finally inspect the rope prior to bagging and record the washing in the rope log.

Service Life (Life Safety)

A block of raw nylon will last many years on the shelf, however, in rope making the manufacturers add a lubricating compound that leads to nylon degradation. This lubricant is an aid in manufacturing, but leads to "programmed obsolesce"; the ropes become weaker over time. While no conclusive evidence has been presented concerning the optimal service life of rescue ropes, the conservative side is the safer side.

Washington State mandates that life safety ropes be removed from service as a life safety rope after 6-years of service.

Utility Rope

Utility ropes do not have either end marked. Also, they do not have a dedicated service life either. Utility ropes are cared for based on the material in which they are made from. For instance an old manila roof rope (still carried by some ladder companies) should never be put away wet and is acceptable to be daisy chained for storage whereas a nylon rope is usually bagged for storage. Additionally, utility ropes do not require a rope history log that tracks its use.

WEBBING

1” Tubular Webbing

Webbing is the primary material used for rigging anchors in operations. It is light, can be used for most rigging situations, and it is strong. Since tight radius bends cause larger diameter materials to lose strength, the 1mm diameter of 1” tubular webbing makes this material an excellent choice in rigging for rescue.

Pick-Off Straps

The pick-off strap is a general purpose utility strap made of 1-3/4” flat webbing. Though the webbing is rated at 10,000 lbs., when tested for breaking strength in a slow pull test, the buckle slips at 4500 lbs. Uses for this strap range from clipping an attendant into the litter for high/low angle evacuations (clip doubled end to the load and obtain a 2:1 mechanical advantage), to an adjustable attachment point for the edge attendant. The buckle could be tied off with a double overhand, to achieve a strength closer to that of the webbing if needed.

Anchor Straps

Anchor straps are 2” high strength nylon straps. They have link connection points at both ends to receive carabiners. When used in the “basket U” configuration as in operations, they are rated at 12,500 lbf.

TERMS

Running End – (Working End) The end of a rope that you will manipulate the most to actively tie a knot.

Bitter End – (Standing End) The end of the rope not being used in the knot you are tying. The opposite end to the "running end".

Bight – Any rope that doubles back on itself without actually crossing over.

Loop – Created when a bight crosses itself.

Knot – An intertwined loop of rope, used to fasten two such ropes to one another or to another object. A knot, even when not in use, will hold its shape or form.

Bend or Hitch – Ways of fastening or tying ropes together. A hitch will not hold its form when not in use or "wrapped" around something.

Splice – Made by untwisting two rope ends and weaving them together.

Kernmantle – (literally "core–sheath") rope is a balanced construction consisting of continuous filament polyester cover braided over a unidirectional nylon core. It is designed to meet the rigorous requirements associated with rescue and rappelling operations.

HARDWARE

Carabiners

Carabiners are central to rigging for rescue. Each type has advantages and is useful in different situations. It is important to know and understand the uses and differences for each. All carabiners should be loaded along the spine, that is, from end to end.

Additionally, use caution with the squarish Rescue Carabiners, like many carabiners, they tend to rotate the load on the opposite side of the spine causing incorrect loading. Incorrect loading greatly reduces the carabiner's strength by as much as 50%. One test found a 10,000 lb. steel carabiner broke at 4700 lbs. as a result of three-way loading. See illustrations below for examples of incorrect loading.

Off Axis Loading – Caution!

Three Way Loading – Caution!

Locking "D" Rescue Carabiner

This carabiner is the preferred link in our rigging systems. It is very strong: 9000 lb. breaking strength. The large gate opening allows it to fit over litter rails.

Always:

- Lock the gate for maximum strength;
- Use extreme caution to load the carabiner along the spine; never load a carabiner from side to side or across axis;
- These carabiners are prone toward off axis loading, (see Figure 6.1 above). Use caution to avoid the use of rigging material more than two fingers wide or distributed from two different directions on the same end (see illustration 6.2 above). Three way loading can reduce the strength of a carabiner by as much as 47%

KNOTS, HITCHES AND BENDS

Knots must be tied, dressed (cleaned up so there are no twists, and the knot flows correctly with the tension on the correct strand) and set (tensioned to remove any slack in the knot).

Do not fall into the trap of "the myth of knot strength." While it is of interest to be aware of how strong one knot is in relation to another; it is imperative to note that knots do not break in the field. People are not found at the bottom of a fall with a broken knot coming from their harnesses. The criteria for knot selection is:

- The ability to tie
- The ability to inspect
- The ability to adjust
- The ability to untie
- The last is the strength of the knot

Touch Check

Check your teammate's knots with the "touch" method to be sure they are dressed and set. The touch method is a tactile review of each element. If the component hasn't been touched by the reviewer, then it hasn't been checked.

Dressing the Knot, Hitch, or Bend

Dressing is the process of cleaning up the knot, bend, or hitch so that the rope flows smoothly through the many turns and bights. **Setting the knot** refers to putting a strain on each leg of the knot. One theory suggests that failure to dress and set the knot, bend, or hitch reduces its strength. However, drop tests have shown that the knot, bend, or hitch actually ends up in a contorted configuration that has little resemblance to the original. Without dressing and setting the knot, they are difficult to inspect, and there is little way to determine how the resulting configuration will react once shock loaded. At least with a dressed and set knot we have some data on their performance in a given position of function.

Relative Strengths of "Knots" for Single Kernmantle Rope

No Knot	100%
Figure 8	75-80%
Bowline	70-75%
Double Overhand Bend	65-70%
Ring Bend	60-70%
Clove Hitch	60-65%
Overhand	60-65%
Two Half Hitches (tested over 16mm diameter ring)	60-70%
Square Knot	43-70%

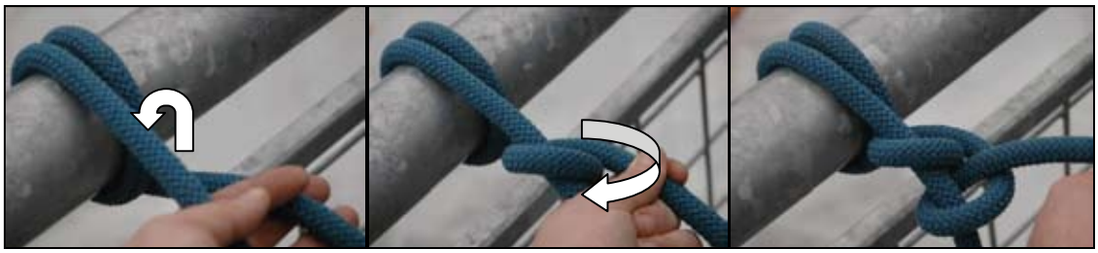
Microys, Helmut; "Climbing Ropes;" American Alpine Journal 51 (1977) p. 140
2 "Rope Technical Data;" brochure by the Cordage Group, Division of Columbian Rope Company; Auburn, New York (March, 1977)

KNOTS

A knot is a rope intertwined with itself, e.g. bowline, and figure 8. A bight is a "U" shape in the rope. A loop is the rope forming a loop and continuing on. Running end describes the end actively being tied. Standing end describes the non-moving part.

Round Turn with Two Half Hitches

A utility knot used in many applications where a quick non-slip attachment is required in non-life safety situations.



The Round Turn **One Half Hitch** **Second Half Hitch**

Bowline with a Yosemite Finish

Used because of its adjustability, ease of inspection, and ability to be untied after being loaded. The bowline must be backed-up with a Yosemite Finish or a double overhand. The longtail bowline doesn't require a back up knot. The end of the bowline must be secured. The Yosemite Finish is an easy way to tie off the bowline and is less bulky than a double overhand. Essentially, the tail is rewoven thought the knot until it surfaces in parallel with the standing end.

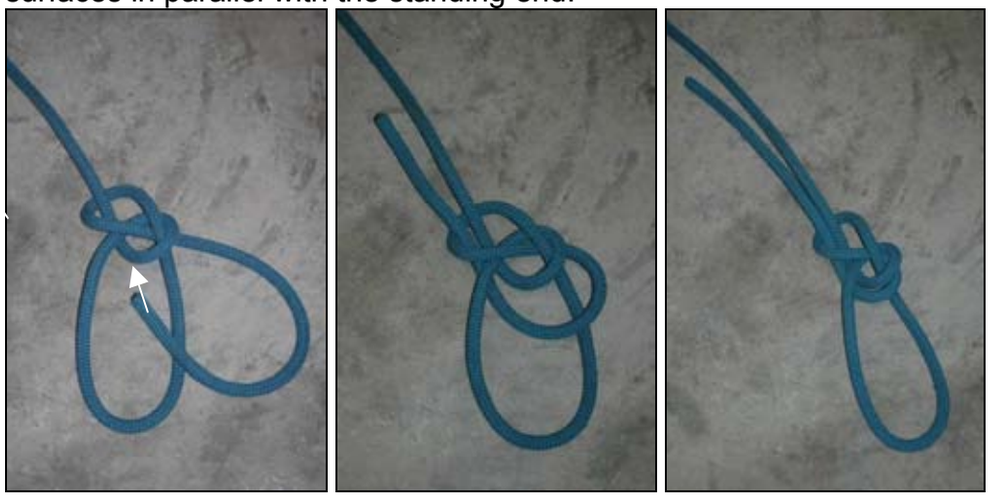
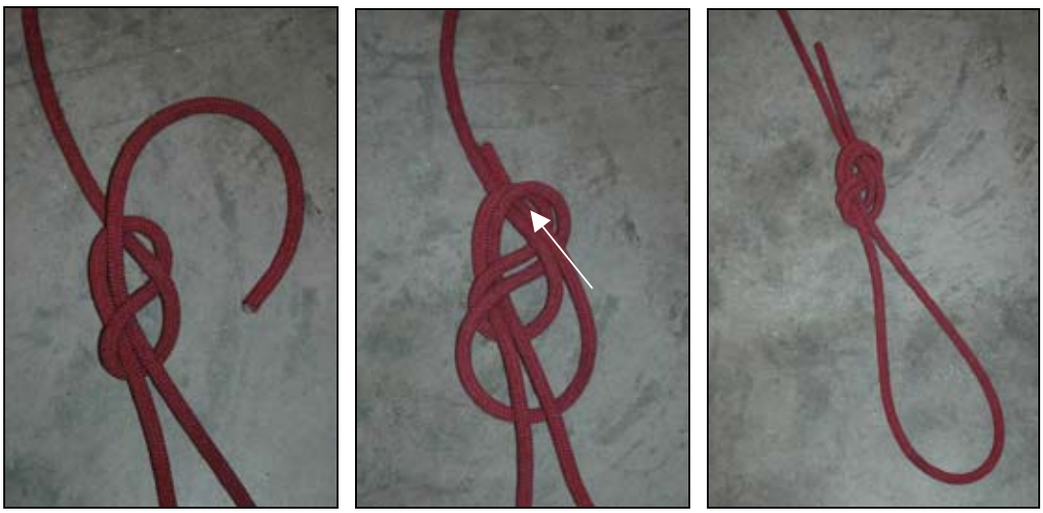


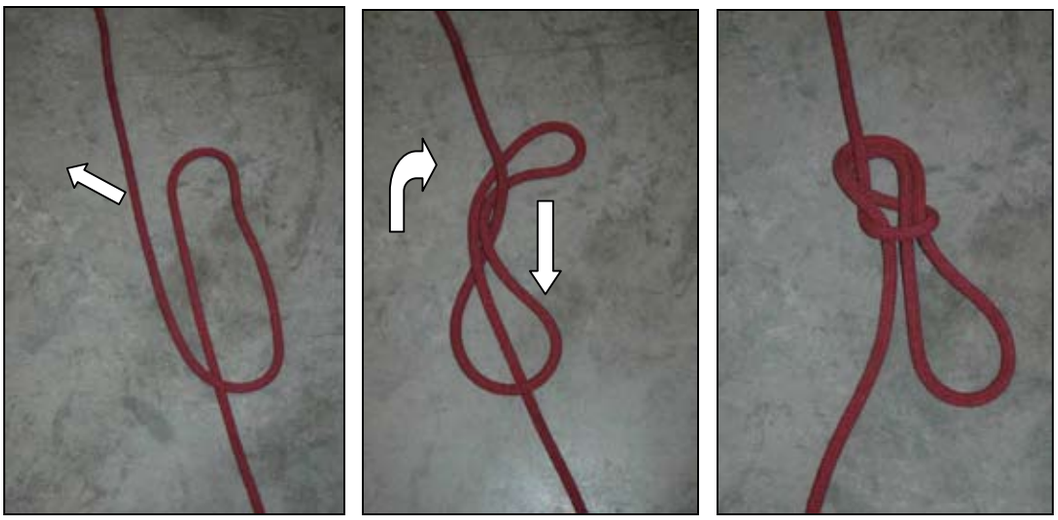
Figure-Eight Follow Through

Double Figure Eight is used as an end knot to form a loop to connect the rope to an anchor or harness. Generally, the Double Figure 8 is an easy knot to tie, inspect, and untie. This is one of two tie-in knots recommended for tie-in to a single person belay line. It may also be used to tie off the running end of a rappel rope so the person is not able to slide off the end of the rope.



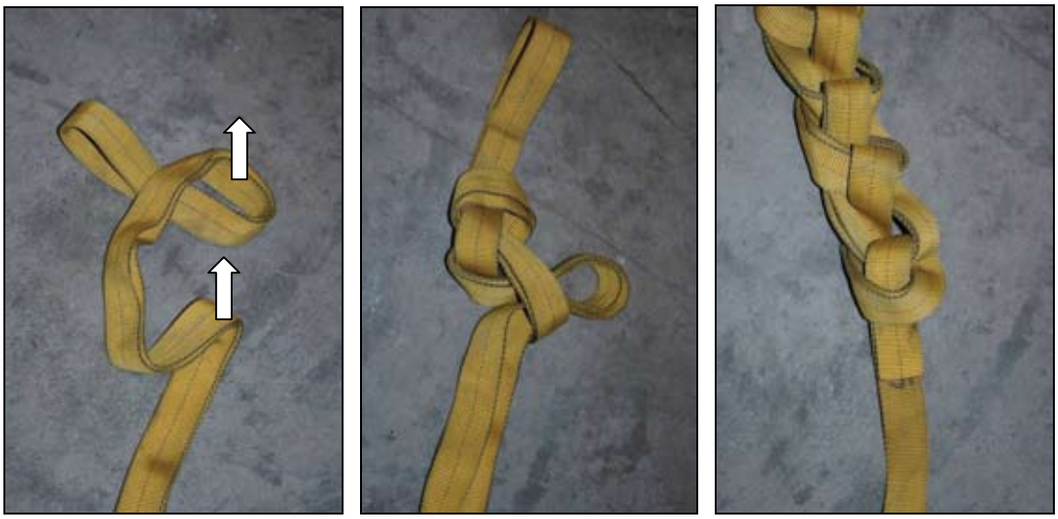
In-Line Figure Eight

A mid-line attachment point that can be used for rescue systems and life safety or any place where a midline loop may be of use.



Chain Stitch with Webbing

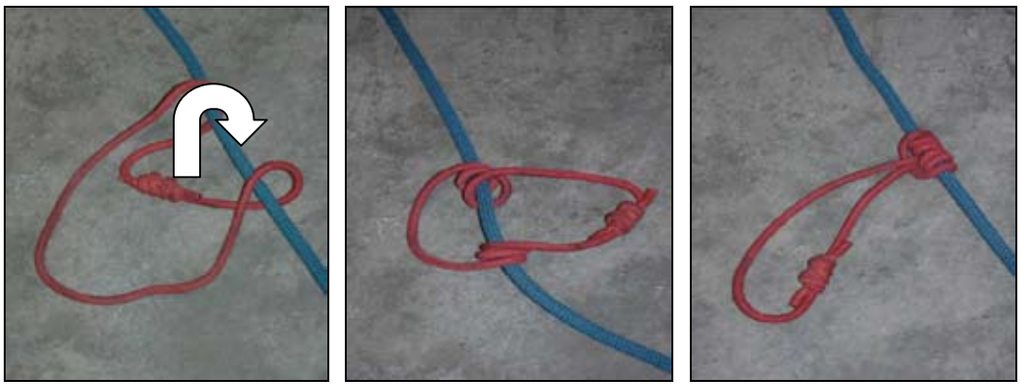
The preferred method of storing webbing. Start with an overhand slip knot and stitch back through the eye of the slip knot. Repeat with each successive loop.



A hitch incorporates something within it to maintain shape, if the center element is removed, the hitch will fall apart (e.g. Prusik and Clove Hitch are tied around another rope or object).

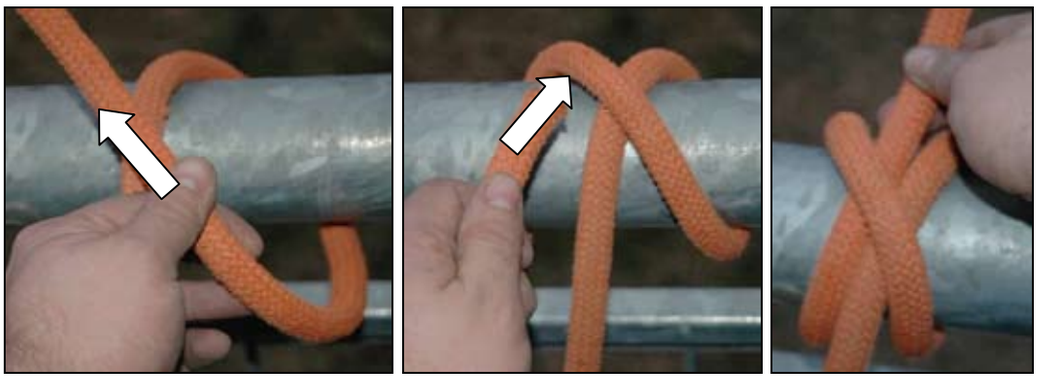
Prusik Hitch

The prussik hitch or “prussik” is formed from pre-tied 8mm accessory cord. Operations company members should only use the three-wrap prussik. The three wrap Prusik Hitch is for rescue loads up to 600 lbs.



Clove Hitch

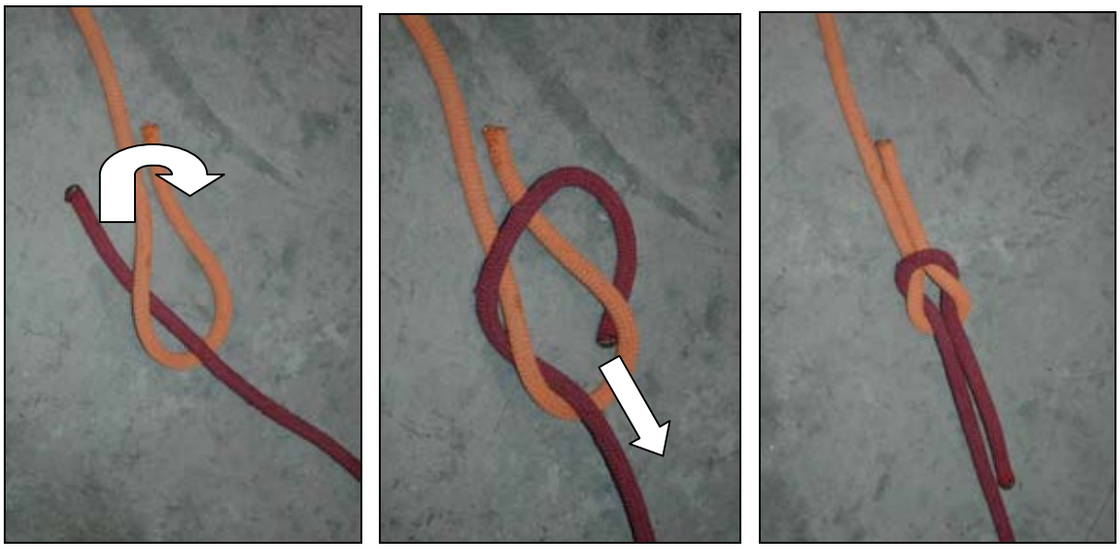
It is useful to quickly tie-off the end of a rope so it will not fall out of your reach, and still easily adjustable. Also, it is a good beginning for wrapping and frapping. However, the clove hitch has been known to slip and untie. It is not used as a tie-off, or in place of an anchor knot, like the Figure Eight.



BENDS

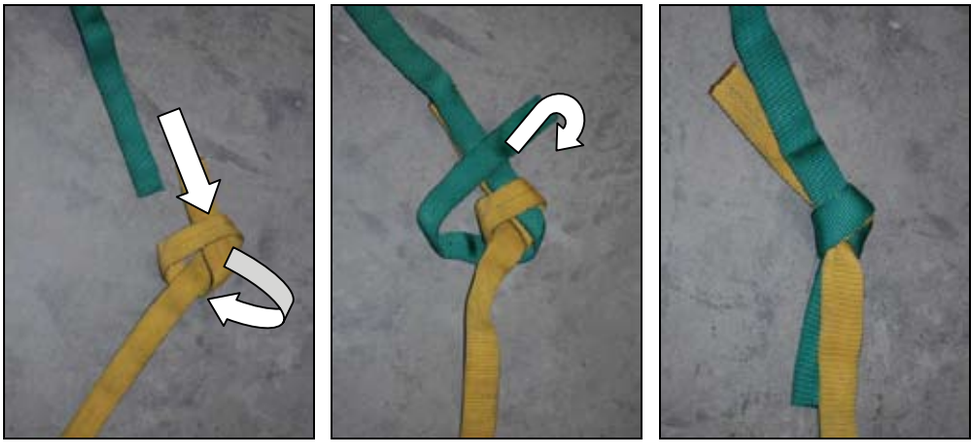
Square Bend

While historically called a knot, this bend is used to tie two strands together. Used primarily for non-life safety situations.



Overhand Follow-Through Bend

Used to tie two webbing ends together to form a “runner,” tie a multipoint anchor together, etc. Tubular webbing is slippery so leave a hand width, or two inches of tail as a minimum. Also, because of the slippery material, dressing and setting this bend is very important.



Double Overhand Bend

This bend is used to tie two ropes together. For the fire service, it is primarily for prusik loops, it can also be used to tie high/low-stretch materials together. It is preferred for use with single person loads. Because of the tight arcs within the bend, it is very difficult to untie once loaded.

However, if the Double Overhand Bend is used for rescue loads, a prusik by-pass is recommended. Otherwise, you may need to cut this bend out of the rope once it is set with a rescue load.

Double Becket Bend

Used for joining two unequal sized diameter material together. It is easy to tie, inspect, and untie after weighting with a rescue load. One may wish to backup the Double Sheet Bend with Double Overhands on the two tails.

STEP BY STEP PICTURE GLOSSARY

Round Turn with Two Half Hitches

Bowline with a Yosemite Finish

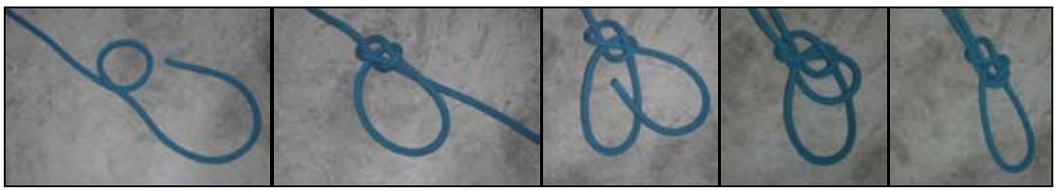
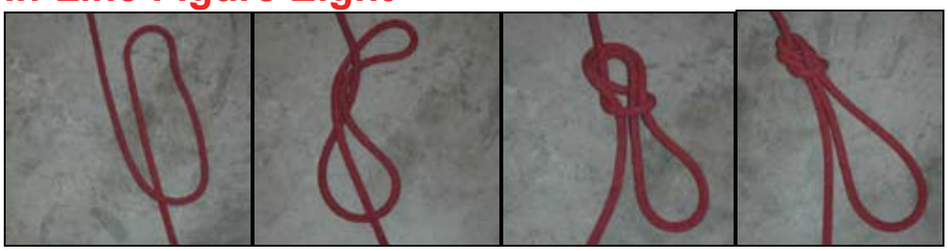


Figure-Eight Follow Through

In-Line Figure Eight



Chain Stitch with Webbing

STEP BY STEP PICTURE GLOSSARY

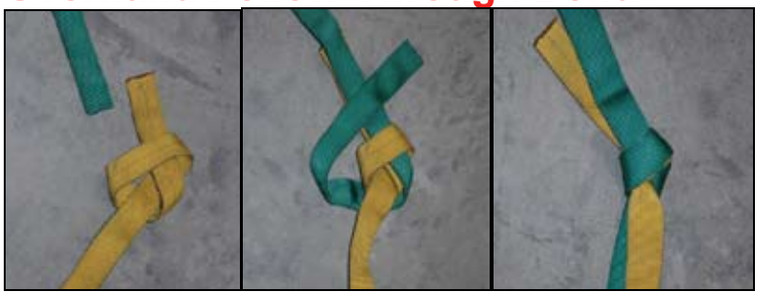
Prussik Hitch

Clove Hitch

STEP BY STEP PICTURE GLOSSARY

Square Bend

Overhand Follow-Through Bend



Double Overhand Bend

Double Becket