TeTech

Constantijn Huygensstraat 20
3601 SC Maarssen
Nederland
Tel: +31 (0) 346 284004
E-mail: wimtel@tetech.nl
Web: www.tetech.nl

Useful knots and applications for Radio Amateurs

Version 1.7, April 2025, Wim Telkamp, PA3DJS
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Summary

This document discusses ropes, knots and their application within the Radio Amateur community. It also has a chapter on mast climbing as many HAMs have a mast with antennas. The information can also be helpful for HAM's with a Scouting background, as it discusses knots and techniques that may not be part of the Scouting program.

First; rope, rope materials and knot related terminology and techniques are explained. Radio Amateurism is discussed briefly for those who arrived here via a non-ham related search.

Discussed are: hitches, bends, knots, eyes and nooses based on the half hitch, overhand knot and figure eight knot, on a bight, follow through or retraced. Also discussed are: dedicated bend knots (Flemish, Butterfly, Zeppelin, (double) fisherman's), friction hitches (think of Distel, Prusik, Autoblock, Hedden, etc), whippings, (double) constrictor hitch, Daisy chaining, non-spliced Soft Shackles and square lashing.

Calculation of mechanical advantage using pulleys for both friction and frictionless situation is explained. Ham specific topics are discussed: getting a pulley in a tree, mounting fiber glass poles onto other (wood) poles, Overhead transmission line/cable suspension, raising masts using a tripod, building wire antennas with friction hitches instead of egg or bone insulators, impregnating rope to improve electrical performance and robustness, measuring rope tension.

Some knots and hitches are discussed that work very well with Dyneema and Kevlar rope (guy wire application).

Several annexes are present that go deeper into things (shock load, elongation of shock absorbers, units used in yarn/fiber technology, discussion of safety factors, adjustable loops).

As many Radio Amateurs have fixed masts or towers, a section on climbing is added. First terminology regarding climbing is discussed such as: fall height, fall distance, fall factor, fall clearance, fall restraint vs fall arrest, types of rope (dynamic, semi-static, accessory, industrial), shock load and resultant peak force, shock absorbing devices, rope grabs, work positioning and slack free climbing.

When you decide to climb after reading the introduction, materials (harnesses, ropes, lanyards, shock absorbers, connectors, etc) are discussed, followed by: whether or not climbing, preparation before climbing, how to climb safely (onto ladders, lattice masts and short pipe sections), and how to work safely in your mast.

This is a young document. It is likely that there are errors, or that things can be described better. Your feedback to make this document better is appreciated.

Make sure that your waves travel around the world and beyond!

Wim Telkamp, PA3DJS

Content

1. Introduction

Reading this document goes best by opening it twice. You may need to rename one of the two. References to figures are made throughout the text. The second document you can use to view the figures so that you don't have to scroll through the first opened document.

1.1. Rope and knots

Sooner or later, you will meet rope and knots during your life. Many clothing contains rope sections to make temporary connections. Many people wear shoes and a necktie. Several free time and work related activities require you to know knots. To name a few:

- Sailing
- Scouting
- Sports climbing, canyoning, wall climbing, mountaineering, etc
- Industrial climbing (Fall protection or restraint and Rope Access)
- Closing tissues and arteries, etc (Surgeons)
- Kiting
- Knitting and textile related activities
- Decorative art using rope or leather
- Fishing
- Camping, primitive living, survival
- Horticulture and gardening

When passing your twenties, you know several knots without knowing it. Almost everyone knows the square or reef knot, a shoelace knot and the figure 8.

The function of most knots is to make a temporary connection

- between rope and an object, via a hitch, or a loop knot
- between two or more ropes via bends
- between two or more objects, via hitches, loops or constricting loops around all objects.

Many knots are also used for permanent connections, such as in:

- fishing nets,
- Slings out of rope or webbing with double fisherman's bend or water knot
- rope terminations, think of eye splices,
- (impregnated) lashings in mechanical constructions
- fiber reinforced plastic (FRP)

There exist thousands of knots. Many of these knots can be used for the same purpose. It is therefore better to know a limited amount of knots very well, instead of knowing very much knots only half.

Some things to consider when using a knot

1. What type of rope (construction and material) is used? Not every knot works well with every rope. Most knots do not work well with Dyneema (even when it has a sheath). Kelvar rope also has its difficulties.
2. How easy is the knot to learn/remember?
3. How easy is it to tie the knot under actual working conditions? At the end of the day you may be tired and then a difficult knot may not be the best option.
4. How good is it to inspect. Some knots have “false” versions that look like the correct one, but are less reliable. The figure of eight is an example of an easy to inspect knot.
5. How reliable is the knot? A sheet bend and bowline may work itself loose under dynamic load. A clove hitch on its own is also a hitch that works itself loose.
6. How easy is it to untie? A double fishermen’s bend and barrel knots are very hard to untie, while Butterfly, zeppelin and Carrick bends are easy to untie.
7. How strong/efficient is the knot? Efficiency (knot strength / rope strength ratio) depends on the type of knot and type of rope. An offset flat overhand bend is a relative weak knot, but useful in certain circumstances. A double fisherman’s bend has good strength, but is difficult to impossible to untie after heavy load.
8. What are the consequences when a knot fails? The combination of rope type, diameter and knot should provide sufficient Safety Factor for the job. For lifting a safety factor (SF) of 6 is generally acceptable while for persons SF > 12 is generally required.

1.2. Radio amateurism

What has radio amateurism to do with knots? Believe it or not, radio amateurs use rope and knots. First lets discuss Radio Amateurism.

What is radio amateurism?

Radio amateurism is a so-called “radio service” within the ITU (International Telecommunication Union). The ITU is an agency of the United Nations.

It is defined by the ITU (International Telecommunication Union) as:

> *A radio communication service for the purpose of self-training, intercommunication and technical investigations carried out by amateurs, that is, by duly authorized persons interested in radio technique solely with a personal aim and without pecuniary interest”*

It is a technical hobby with lots of social aspects involving

- Building and modifying radio equipment. One can think of restoring old WW2 equipment or converting professional radio equipment to equipment than can operate on amateur radio frequency bands.
- Building and erecting antennas
- Making radio contacts with other radio amateurs, frequently around the world directly or via satellites. Radio amateurs also make contact with the ISS. Even the moon is used as a reflector.
- Radio wave propagation experiments
- Acquiring radio operating practice (for example via radio contests). Radio amateurs still use Morse code.
- Helping other people to gain better technical skills and or preparing them for the obliged examination.
- Assisting in emergency communications and general technical help to the community.
- Setting up temporary amateur radio stations, also at near impossible locations, such as rocks, or even in trees.
- Organizing meetings and so called Hamfests.

Available frequencies and call signs

Radio amateurs have access to small parts of the MF (medium wave), HF (short wave), VHF, UHF and even the SHF spectrum to do their experiments.

Before you may operate an amateur radio station, you need to pass an exam with technical and regulatory questions. When you don't know what you are doing, your activities may interfere with other radio systems, or electronic equipment in general (EMC issues). After passing the exam you can apply for a station license with a worldwide unique call sign.

The first part of an amateur radio call sign (so called "prefix") determines the country, type of license, and/or region within a country. Countries can have several prefixes. The last part (so called "suffix") identifies the station. Some examples of prefixes:

Prefix	**Country**
VK	Australia
EA	Spain
KF	United States
ZS	South Africa
SU	Egypt
PY	Brazil
PA	Netherlands

The amateur radio service is a worldwide service as it is supported by more then 150 countries with partly overlapping frequency bands. This allows radio amateurs to make international contacts via radio.

Many countries have mutual recognition agreements to enable overseas short stay visits (mostly maximum 90 days) without the need for a local license. As an example the European CEPT recommendation T/R 61-01 is also adopted by: US, Canada, New Zealand, Australia, South Africa and some other countries. So when you plan your vacations in a country that adopted T/R 61-01, you can operate without having to fulfill long administrative procedures.

Antennas

Radio amateurs need antennas to make sure their radio signals are heard. When you see real estate containing lots of metallic tubes and wire constructions, not being a military installation or mobile internet (cellphone) mast, it is likely the antenna installation of a radio amateur.

Radio amateurs call themselves also HAM's. Worldwide there are about 3 million licensed radio amateurs. Besides the licensed radio amateurs there are also a lot of citizen band amateurs. Citizen Band (CB) communication focuses on the communication itself (social aspect), and not onto the technical details. CB doesn't require you to pass an exam in most countries.

"CB" is frequently used as a step to Radio Amateurism. Many Scouts are also introduced to Radio Amateurism via the worldwide JOTA event (Jamboree On The Air).

1.3. Radio Amateurs, rope and knots

Antennas and masts as fixed or temporary installation require rope

1. For safely climbing into your mast a good harness and rope is required. Many people make safety lanyards and work positioning lines/lanyards themselves out of (for example) climbing rope.
2. They use carabiners with rope and other rope sections to temporary fix constructions or tools onto themselves or onto the mast.
3. Metallic guy wires frequently interfere with the antennas. To avoid that, synthetic rope (frequently out of Kevlar or Dyneema) is used as guy wire.
4. Antennas out of metallic wires are suspended using synthetic rope frequently. Synthetic fiber rope doesn't conduct electricity.
5. Hoisting parts into and out of a mast or other elevated structure is mostly done via a pulley system containing synthetic rope. One can use steel rope, but synthetic fiber rope works very fine and weighs less.
6. Rope is used for (temporary) fixing of objects during construction of radio equipment and antennas. Permanent fixtures with rope are mostly impregnated with (epoxy) resin to make them long lasting and weather resistant.

These examples show why radio amateurs may need to know something about rope and knots.

1.4. Ashley Book Of Knots (ABOK)

The Ashley Book of Knots is considered the knot reference, first published in 1944. When you encounter something like: ABOK #331, the number refers to the number of the knot in the Ashley Book of Knots. #331 is the (alpine) butterfly or lineman's knot/bend/loop.

When you would like to meet knot enthusiasts and professionals, you may join the International Guild of Knot Tyers.
https://igkt.net/

Animations of many knots can be found here:
https://www.animatedknots.com/

When you work at height, you may like to see rope related materials tested to destruction, go to the YT channel of how not 2 (climbing related)
https://www.youtube.com/@HowNOT2

1.5. Discarding rope

At certain moment, maybe after years of trouble-free service;

- rope reaches end of life and needs to be removed or replaced by new rope,
- An (antenna) system containing rope has to be removed before end of life.
- You are left with short pieces that you cut during work.

You are working in a mast and fixed something with rope, or remove a rope construction. What do you do with the rope? Just drop it and continue to work.

No, that is a bad habit!

1. Animals may eat the rope by accident. Also thick rope will unravel into thinner strands. Rope doesn't belong in a digestive system.
2. Animals may get entangled in rope sections. I feed some pigeons. Now and then I have to remove thin rope from their toes. It is really painful for the birds as it impedes blood flow, resulting in loss of a feet or toes.

So:

Do not leave rope in the environment (valid for large and small pieces)! Collect it and dispose it of according to your local regulations.

2. Definitions related to rope and knots

2.1. Ropes, cords and strands

2.1.1. Very short history

Use and manufacture of ropes started at least 50.000 years ago. “mass” production using special tools took place in Egypt around 4000 BC. “manila” rope was invented in china about 2500 BC.

In the Middle Ages rope walks were invented to make long runs of rope. During the industrialization era, rope production and textile production exploded due to mechanization.

Another step forward was the invention of fully synthetic fibers. Synthetic fiber rope was quickly used for parachutes (Nylon, PA). Nylon is brand name of DuPont for Polyamide (PA).

Swiss Mammut made the first “nylon” (PA) climbing rope in 1952. Gleistein patented the core-mantle construction in 1953. In the same year, German Edelrid introduced the twist-free kernmantle rope (core covered with braid) for climbing as we know today.

Using “Nylon” for climbing rope was a big step in making climbing and rescue much safer. It is abrasion resistant, doesn’t rot, stretches a lot during a fall, and it is strong compared to natural fibers.

In the seventies Aromatic Polyamide fibers (Aramids) came on the marked. It was the first super strong, very low stretch, very low creep, temperature resistant synthetic fiber. When blended with other fibers, it makes excellent ropes for specialist applications that outperform ropes using traditional synthetic fibers by far.

The well-known low-loss dielectric Polyethylene (PE), as used in coaxial cables, can be made having very long molecules (UHMWPE). It is spun into fibers with near same strength as Aramids, but with less weight. It became widely available in the nineties under the brand names Dyneema (Royal DSM, patent holder) and Spectra (Honeywell). It makes light-weight super strong rope with low stretch.

It became also clear that knots that work well using natural fiber rope, don’t work so well when using synthetic fiber rope. Most synthetic fibers are slippery compared to natural fibers. This is especially true for Dyneema. Dyneema is therefore mostly spliced instead of knotted.

2.1.2. Rope construction

A **strand** is a thin wire consisting of many more or less parallel oriented fibers. There can be a twist to keep them together. A strand is also called **yarn**.

When several strands are twined/twisted/braided to form a thicker/stronger construction, it may be called **rope** or **cord**. Several ropes can again be twined/braided to form a heavier rope.

When the rope has a spiral/helical appearance it is **twisted** or **laid** rope.
When it has the braided zig-zag pattern, it is called **braided** or **plaited** rope.

When rope/cord is oriented in a more or less straight fashion, it may be called a "**line**". This is frequently used in a nautical environment (think of mooring line). Very thick ropes for mooring or towing are called **hawsers**.

The definitions are not very strict. Several communities call every thin (1..6 mm) twisted or woven/braided rope, just **cord**. Heavy woven or twined rope is just called **rope**.

Besides "simple" twisted or woven/braided rope/cord there are hybrid constructions.

Kernmantle rope has a core of near parallel running strands that are inside a woven braid. That braid is frequently called **sheath**. The **braid/sheath** keeps the core strands together and protects them from the outside. Most of the strength is provided by the strands inside the core in most cases.

Double braid Instead of a core out of near parallel running fibers, the core can also be a braided rope. So you have a braided sheath on top of a braided rope. This is called "**double braid"** or **"braid on braid**" construction.

The core can also exist of several separate strands that are individually twisted. All the individually twined strands are within a single braided sheath. That twisting is done to get certain properties (think of large elasticity, as in **dynamic climbing rope**).

monofilament That is just a thin wire of one fiber. It is frequently used in fishing and decoration. It is only available is small diameters, otherwise it becomes very stiff (will not bend).

Rope examples
Figure 2.1 shows various rope examples. The helical/spiral or zig-zag braided pattern is clearly visible.

The brown rope is 8 mm thick 3 strand twisted rope out of UV-stabilized Polypropylene (PP). It has a breaking strength of 1030 kg. It looks like natural fiber rope and is used for lashings in a Scouting environment and rigging on classic ships.

The yellow rope is 6 mm, 12 strand braided rope out of SK78 Dyneema. It has a breaking strength of 4000 kg (yes, 40 kN, no typing error). It is used in applications where high strength and low stretch is of importance.

The green rope is so called “accessory cord” of 7 mm according to standard EN564. It has 9 individual twisted cores protected by a braided sheath. It has a breaking strength of 1200 kg. This version is made from Polyamide (PA). It is certified for use in climbing applications (but not as climbing rope!).

The red rope is decommissioned kernmantle rope with a core of near parallel running fibers and braided sheath out of polyester (PES/PET). Breaking strength is unknown. This was used for climbing also (but not as climbing rope!).

The very thin white cord is 0.5 mm, 3 strand twisted cord out of Polyamide (PA). It has a breaking strength of 15 kg. It is used for decorative purpose. You may use it on a sewing machine for stitching of heavy loaded cloth (tents, sailing, etc).

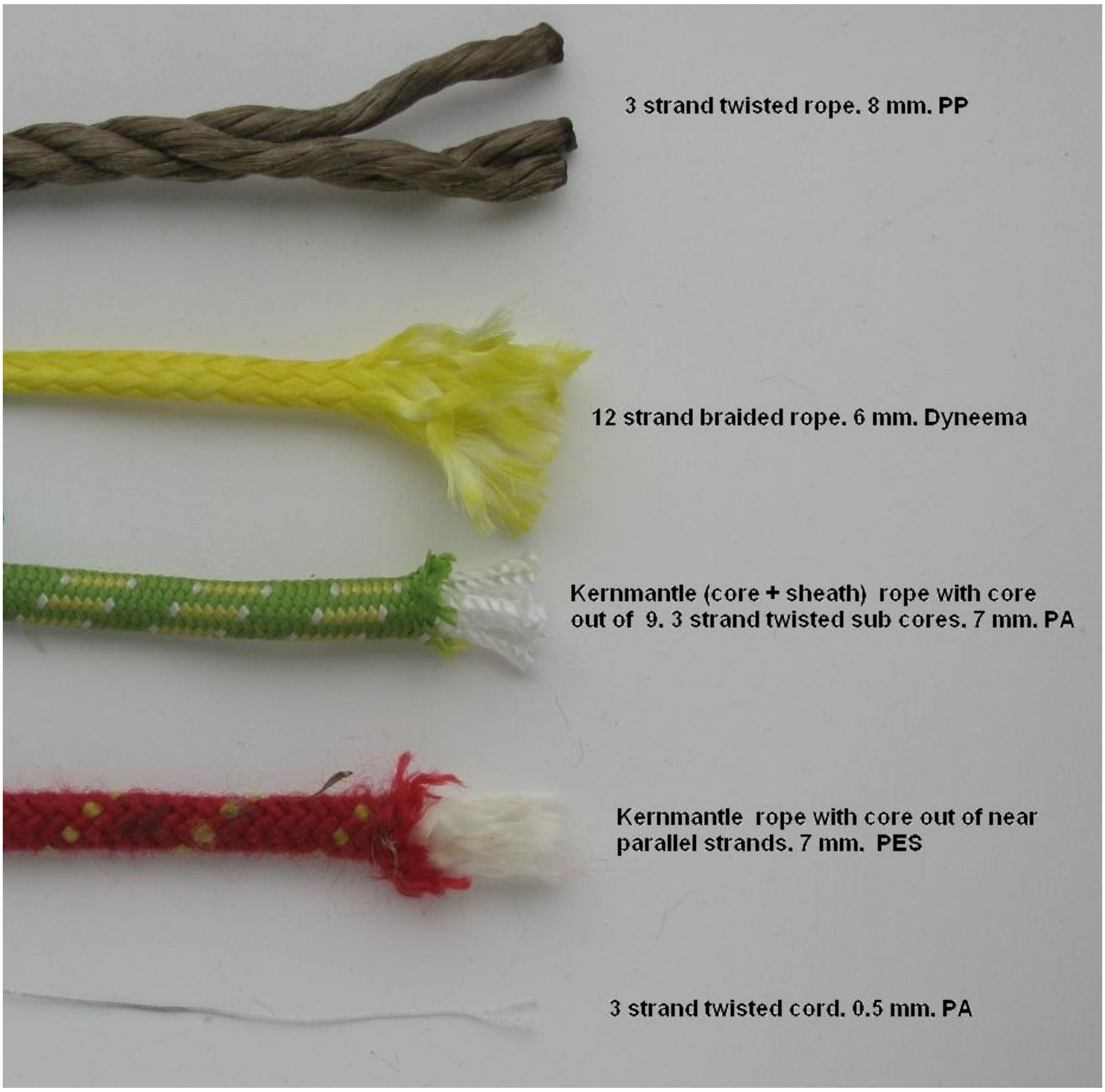


Figure 2.1, various rope/cord constructions

2.1.3. Yarn and thread

In the textile industry thin rope is called **yarn** or **thread**. The name **thread** is mostly reserved for very fine rope that is used on sewing machines. Yarn is thicker then thread and is used for knitting (by hand).

Rope manufacturers talk about yarns. They manufacture their rope out of yarns.

Polyester thread can be used for very fine applications, such as (temporary) clamping things together using whippings.

2.1.4. Sleeve vs sheath

Sleeves have a similar function as the sheath/mantle of kernmantle or double braid rope. There are differences.

- A sleeve is added after rope production. A sheath is part of the rope itself.
- A sleeve does virtually not contribute to the rope strength.
- A sheath covers always the complete rope. In most cases a sleeve covers only parts of the rope that are subjected to high wear. Think of sleeves around eye terminations, or splices.

There is another use for sleeves.
A sleeve can also be used to increase the strength of a knot. If the wall thickness of the sleeve is half the rope diameter, or more, the bend radius of the rope increases. This increases the knot efficiency (= stronger knot).

The risk of knot slipping increases by adding thick sleeves.

2.2. Hitches, knots and bends

When reading literature discussing knots, you will encounter: "hitch", "knot" and "bend"

Definition of "knot"

> *An interlacing, twining, looping, etc., of a cord, rope, or the like, drawn tight into a knob or lump, for fastening, binding, or connecting two cords together or a cord to something else.*

Within the communities that use rope, definitions are more detailed.

Figure 2.2 shows a hitch, knot and a bend.

Hitch

A hitch is a knot tied around an object. When you remove the object, a hitch collapses. It is no longer the intended knot. Examples: clove hitch, constrictor hitch, Distel hitch, Cow hitch, Prusik hitch.

Bend
A bend is a knot that connects two ropes to each other so that you have a longer length of rope. Examples: square bend, sheet bend, butterfly bend, zeppelin bend, figure of eight bend, flat overhand bend, etc.

A bend can also be used to form an endless loop of rope (such as a Prusik loop).

Knot
A knot is a knot tight in the rope itself. Examples: figure of eight stopper knot, overhand knot, barrel knot, monkey fist knot, figure eight on a bite, button knot, etc.

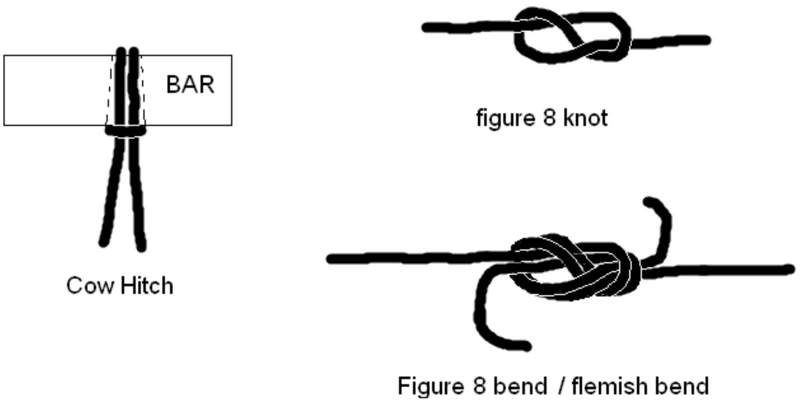


Figure 2.2, Hitch, Knot and Bend

2.3. Loops, bights, follow through / retrace method

Figure 2.3 shows two loops and a bight (also written as “bite”).

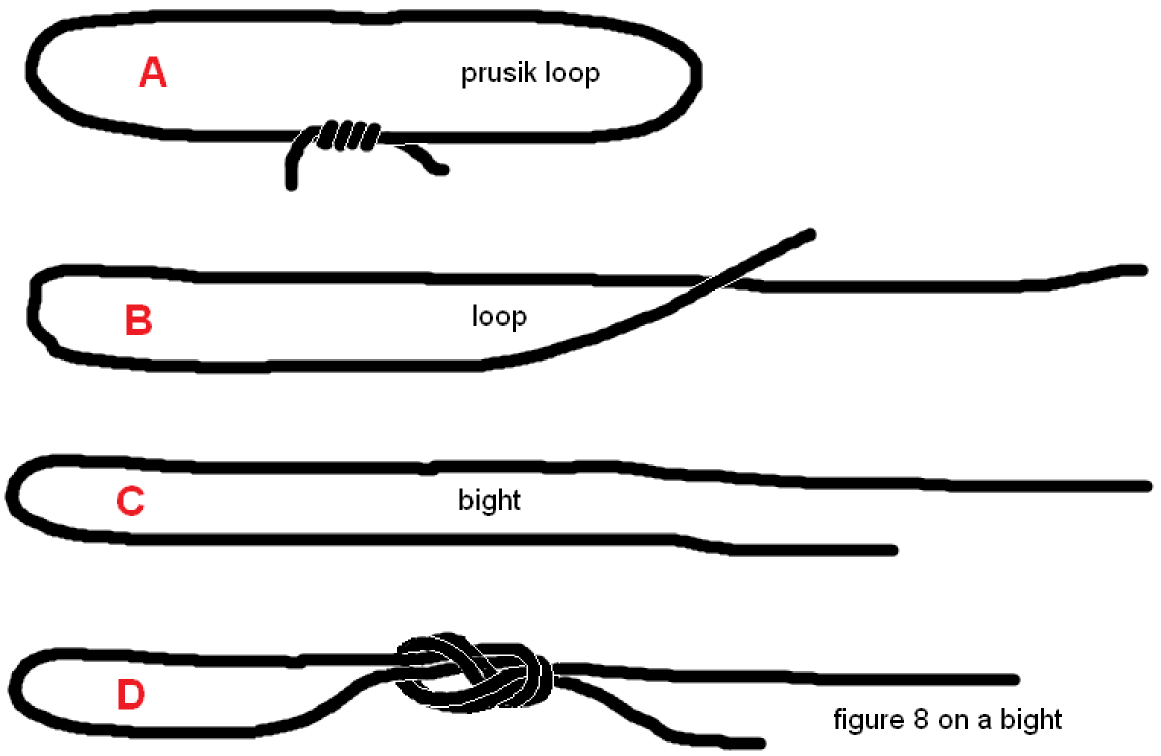


Figure 2.3, Loop, Bight and figure 8 on a bight

As soon as there is a crossing, as in the B figure, it is called a loop.

A bight creates a double rope section. You can tie whatever knot in that piece of double rope. This creates a loop or eye as shown in de D-figure. A knot tight on a bight, gets the extension; “on a bight” so the figure eight knot in the D figure is called: “**figure 8 on a bight**”.

A loop at the end of rope is frequently used to connect the rope to a fixed point (anchor point). Think of mooring lines that hold a ship parallel to the quay, or guy wires to support an antenna mast.

Note:

Several rope constructions allow splicing an eye into the end of a rope. A spliced loop termination is much stronger then a loop knot, such as a figure eight on a bight forming a loop/eye.

Knots in Dyneema rope weaken the rope significantly. An eye splice (or stitched eye) generally maintains over 80% of the rope strength. Professionally made eye splices can reach over 90% of rope strength. Knots in Dyneema, provided they hold, may reduce the strength to just 20% of breaking strength (so you lose 80% of the strength).

Retrace method
Tying a figure 8 on a bight is the easiest way to make a loop/eye termination. It just takes some seconds.

Sometimes you can't put the loop over something, think of a vertical bar in a fence, or a tree. In that case you need to retrace the working and back through the knot towards the standing end. This is shown in figure 2.4. This method can be used with many knots, think of: overhand, barrel/stopper, figure 8, figure 10, etc.

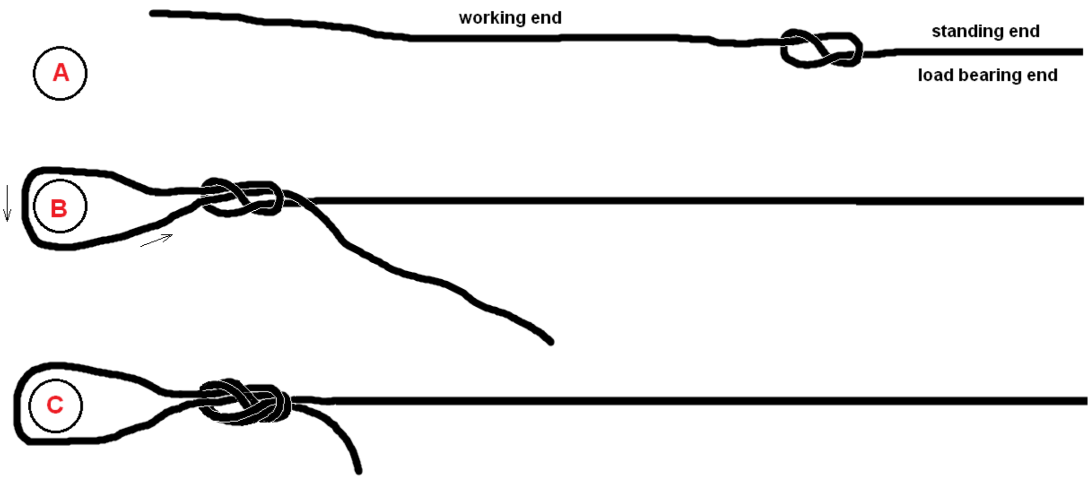


Figure 2.4, Follow through method to create a loop around an object

Start with your favorite knot and make sure the working end is long enough (figure 2.4.A.

Wrap the working end around the object and push it back into the knot where it came from (B figure).

Work the rope end completely back through the knot following the original rope so that the end leaves the knot parallel with the standing end (C figure). This process is also called “retracing a knot”. You also encounter “reverse tracing” or just “follow through”

The knot is exactly the same as the “on a bite” version, but the procedure is different.

Follow through method
You can also work through a knot another rope section to connect two ropes together. This is “to follow through a knot” The resulting knot is now a bend as it connects two ropes. The example in figure 2.2 is a **follow through figure 8 bend**, and is mostly called **Flemish Bend**. “To retrace” and “To follow through” are used in lots of literature for both making an eye and making a bend.

IMPORTANT NOTE

Do not use the figure 8 on a bight to form a loop where the force is inside the loop, so called "ring load" or "cross load". When the figure 8 is offset from the center line of the rope (flat figure 8 bend), it may capsize. That is the knot may roll-off the rope tails, resulting in knot failure. When using a figure 8 to form a loop where the forces are inside the loop only, it must be aligned with the rope as in figure 4.11C (Flemish bend).

When a non-bulky offset bend is required, use the flat overhand bend with long tails and/or a backup knot.

When used as a loop/eye to terminate a rope, the figure 8 on a bight is a very reliable and easy to inspect knot.

Tails

Tails are the remaining ends after tying the knot. Due to slippage a knot may eat some of the tail. When the tail is too short, the knot fails. The amount of slippage / tail eating, depends on the dressing of the knot, its internal pretension, the peak load and most important the type of load. Dynamic loads increase the risk of tail eating.

After several load cycles most knots don't eat the tail(s). Some knots may very slowly eat up the tail after many load/unload cycles. Tails should therefore be sufficiently long, depending on the type of knot and usage.

Noose (knots)

A noose is a knot around the rope itself that creates a loop that tightens when pulling the working end. The loop with the knot on the rope is called noose. A very simple noose is the slipknot, also known as overhand noose.

2.4. Number of turns

Many knots involve applying turns around an object (that can be rope). See it as winding turns around a (ferrite) core to make a coil or transformer.

Definition of turns varies between communities. When winding a transformer, each time the wire goes around the core counts as a turn. This definition is also used by most climbers.

However in a marine environment a single turn around an object is more or less considered a bight. You need to pass the rope two times around the object to call it a single "round turn". We as radio amateurs see this as two turns.

The reason for this is that when you look to the contact angle between rope and object, a single turn doesn't always make 360^0 contact with the object. When you look to figure 2.3, and assume a round object inside the loops, the rope makes contact over 180^0, so it is not called a round turn.

See also "round turn with two half hitches"

Within this document the transformer/coil winding convention is used for counting turns.

2.5. MBS, SF, DF, WLL and knot efficiency

When reading climbing or rigging related articles or product manuals, you will encounter several definitions and acronyms. You need to know them, as the way of specifying products vary between (industry) sectors.

2.5.1. Minimum breaking strength (MBS)

Rope and hardware manufacturers <u>may</u> specify a so called "**Minimum Breaking Strength" (MBS)** or "**Minimum Breaking Load" (MBL)** for their products. Its definition varies slightly between industry sectors.

It can be the average value from many break tests, minus 3 standard deviations. It assures that 99.7% of break test results will have a value greater then MBS.

How it is done?

- Carry out several strength tests (generally at least 5)
- Calculate the average value and the standard deviation.
- MBS = (average value) – 3·(standard deviation)

Other definition uses the lowest value out of 5 break tests.

MBS or MBL is mostly used for ropes, rope assemblies and hardware (carabiners, pulleys) that are used in safety, rescue, climbing, rigging, hoisting, etc.

When a label says "strength: 150 kgf", you don't know what you have. Is it average, effective, minimum, WLL, etc?

Note:

> You never use rope or hardware up to the minimum breaking strength. Safety Factors need to be applied depending on the application!
>
> Why?
> Rope, rope assemblies and hardware wear during use. Therefore breaking strength reduces over time. Wear is also the reason that many products have a limited life time, even when sitting on the shelf. MBS in case of rope doesn't take into account plastic deformation (flow and long term creep).

A related definition is the "**characteristic strength**". It is also a statistical parameter such as MBS, but the 95% value is chosen. So 95% of the test samples have breaking strength greater then the characteristic strength.

2.5.2. Force units

Strength can be specified in N, kN, daN, kg and Pound. N or kN are preferred. You may also find “Ton”.

Why Newton instead of kg or pound (lb)?

The kg and pound are units for expressing mass (that is matter). The force that acts on mass depends on the local acceleration or gravity.

On our earth a mass of 1 kg exerts a force of about 10 N on the surface where it is sitting on. However on the moon, the force is just 1.6 N. When you are in free fall (or circling earth), there is zero force.

From physics:

$$F = m \cdot a \quad = m \cdot g \qquad [N]$$

F = force in N, m = mass in kg, a = acceleration in m/s^2, g = gravitational acceleration in m/s^2.

The gravitational acceleration (g) is about 9.81 m/s^2 on earth, frequently approximated to 10 m/s^2, as this makes conversion very simple.

People with a mechanical background are familiar with forces and stress. In the world of fiber/yarn research and production, other units are used. Annex 4 gives an overview of units and definitions that are used in fiber/yarn production and research.

Conversion from pounds (lb) to kilograms (kg) and vice versa.

$$1\,Pound \;\equiv\; 0.455 \cdot kg, \quad 1\,kg \;\equiv\; 2.2 \cdot pound$$

The three horizontal bars means: “is equivalent to”

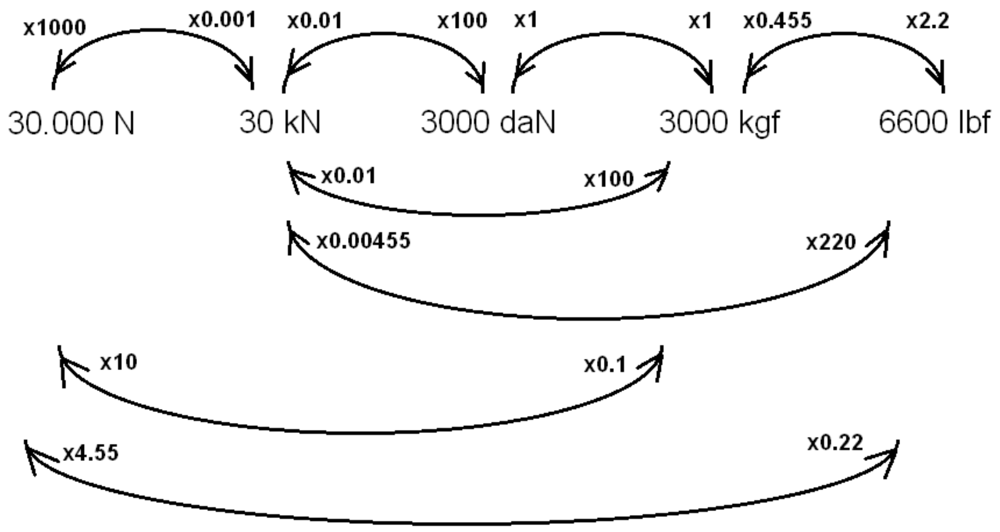
Check when converting that the number of pounds is always larger then the equivalent number of kilograms.

To make numbers easy readable, multipliers are used. Lower case “k” represents factor 1000. “da” represents a factor 10. This makes that 1 daN equals the gravitational force of a mass of 1 kg on earth. So daN ~ kg on earth.

A rope with MBS = 15 kN (=15000 N = 1500 daN) can hold a mass of 1500 kg, 1500 kgf or 3300 pound-force (3300 lbf).

When forces are expressed as mass on earth, “f” is mostly added so you get the unit kgf or pound-force (lbf)

Everything in one graph:



daN = deca Newton, equals kgf
kgf = kilogram-force (force of 1 kg on earth
lbl = pound-force = force of 1 lb on earth

Preferred way of expressing Minimum Breaking Strength (MBS) is in N, or kN

Figure 2.5, Force conversion factors

You may encounter force expressed in Ton (or Ton-force). For example, breaking strength of a sling of 4.5 T.

1T is equivalent to 1000 kg, so 4.5T equals 4500 kg(f), and that equals about 45 kN

The MBS of a rope is the rope strength when the line/rope/cord is fully straight, without any bend or knot. In real world you will never reach that, unless you use very well made spliced eyes and the eye is around an object that has a diameter of at least 2 times the rope diameter. Both metallic and synthetic ropes have to be used with a significant safety factor.

“Synthetic fiber rope” may be called “synthetic textile rope” in several standards and recommendations.

2.5.3. Knot efficiency

$$Knot\ Efficiency = \frac{breaking\ strength\ of\ knot}{MBS\ or\ MBL} \qquad [\%]$$

$$Strength\ reduction = 100 - Knot\ Efficiency \qquad [\%]$$

The figure 8 bend has a knot efficiency of around 60% (PA rope), so its strength reduction is 40%.

Make sure to read text on knot strength very well to make sure you don't confuse knot efficiency with strength reduction.

Knot efficiency depends on many factors:

- Rope material (for example Nylon (PA) or polypropylene (PP)). Knots in PA have better efficiency in general. The same knot tied in Dyneema and Kevlar will have significantly lower efficiency, or may even fail.
- The way it is dressed and preloaded. Most knots require good dressing to get the stated efficiency
- Rope construction (single braid, kernmantle, twisted, etc)
- Wet or dry
- Diameter of the rope.

A knot that has say 65% efficiency in certain nylon (PA) rope, may have only 30% efficiency in Dyneema, or slips. Keep this in mind when applying safety factors.

Many knot strength tests have been carried out onto ropes and webbing used in climbing, rope access, rescue and rigging. This isn't strange, as you put your life onto such ropes. The standards for these ropes allow variation of rope properties to suit special needs. This also affects the efficiency of knots, but there are some minimum values within a rope family.

For example a figure 8 on a bight to form a loop/eye termination has an efficiency >60% when using dynamic climbing rope (to std EN 892), semi-static climbing rope (to std. EN 1981) or PA or PES accessory cord (to std. EN 564).

You can't assume efficiencies based on climbing rope for other rope. Virtually all dynamic and semi static climbing rope is made out of PA (Nylon). PA has good knot efficiency. PP (polypropylene) rope has lower knot efficiency. Knots in Aramids (Kevlar) and UHMWPE (Dyneema) perform really bad.

Rope construction (twisted, braided, kernmantle, etc) also affects knot efficiency.

Eye terminations versus bends

Though a knot on a bight can have exactly the same appearance as the knot in a bend, they behave different.

When a knot forms an eye termination: one end carries full load, two ends carry half load, and one end is not loaded at all. The end that is not loaded at all gets half load on the other side of the knot.

When a knot forms a bend: two ends carry the full load, and two ends carry no load at all.

Eye termination. The rope section that passes through the knot that carries full load on one side and half load on the other side, tightens the knot well. This reduces the change that the rope section that carries no load at one end is pulled out of the knot.

Bend: Two rope sections carry no load at all, while the other ends carry full load. This increases the change that the bend slips. That means one of the ropes is pulled out of the knot (100% failure).

So a knot that performs very well when used in an eye termination, may fail when used as a bend. This is especially true for Dyneema. The difference can be huge. A knot using 100% Dyneema can have an efficiency of >60% when used in an eye termination, but has <30% when used in a bend (due to slipping).

2.5.4. Working Load limit (WLL) safety factor (SF) and design factor (DF)

Rigging hardware may have a **WLL** rating. This stands for **Working Load Limit**. They are related to the **Safety Factor (SF), or Design Factor (DF)**. A manufacturer may use a certain Level of Safety. That is mostly called the Design Factor. Depending on the application additional safety may be required. Then it is mostly called Safety Factor.

$$Safety\ \ factor\ (SF), Design\ Factor\ (DF)\ =\ \frac{MBS}{Working\ Load\ Limit\ (WLL)}\qquad []$$

Instead of MBS, **Minimum Breaking Load (MBL)** may be used.

You should be very careful using WLL when you don't know what safety or design factor is used. A manufacturer may design a turnbuckle for tensioning a fence with SF = 3, so the Design Factor (DF) = 3. Using this turnbuckle up to the WLL in a climbing situation (life at stake) is absolutely not done. Turnbuckles for rigging have generally a Design Factor (MBL/WLL ratio) of factor 5,. During production they are "proofed" at about 2.5·WLL to determine production issues (such as cracks).

For life support application the manufacturer's **Design Factor** of 5 for movable thing (rope, slings, carabineers, etc) is considered insufficient. It is generally SF > 10. The maximum load is then half the WLL as stated by the manufacturer.

Generally spoken; **Design Factor** is determined by the manufacturer, **Safety Factor** is based on the application. The application can be different from what the manufacturer had in mind.

For rope:

$$Safety\ \ factor\ (SF)\ =\ \frac{MBS}{working\ load}\qquad []$$

Synthetic fiber rope is mostly operated with safety factor 7 to 14 for lifting. The factor 14 is when loads are lifted above people. You may encounter safety factor 10….20 for climbing.

The safety factor must be based on the minimum breaking strength of the rope with knots, terminations, bends, etc included. This is the reason that 11 mm semi static (LSK) rope has a breaking strength of around 30 kN (3000 kgf).

When tying a figure 8 on a bight (figure 2.3.D), you can expect a strength of 18 kN (based on 60% knot efficiency). This assures a Static Safety factor of 18 for a 100 kg person (including gear)   See annex 7 for some discussion on safety factors.

Guy wire example

Guy wires out of synthetic fiber rope need a safety factor of about 3..5. This is based on the strength of the rope with the knots/splices in it. When the mast is in an open area without people, you may go down to factor just under 3 if you can accept the loss in case of failure. When you climb in such a structure, do not use safety factor <3.

Assume a guy wire is subjected to a peak force of 500N during storm. The eye knots have an efficiency of 60%. Safety factor = 5.

That means that rope MBS > 5000*5/0.6 = 4.2 kN (420 kg).

A sheathed Dyneema rope (SK78) with 3 mm thickness will handle this, but the challenge is to make an eye with >60% efficiency using Dyneema.

Options

- Sheathed Dyneema rope cannot be spliced in most cases. The sheath is too tight.
- Several fist grip clips or several duplex wire clips with an additional protective sleeve may do the job. U-bolt steel wire clips are not recommended because of the clamping force acts on a small area. The challenge with (steel) wire clips is the amount of torque. Too much will damage the fibers, too little cause slipping.
- The double clove hitch or constrictor hitch with backup stopper will exceed 60%, but you need a metallic former (see paragraph 6.6). Advantage is that this termination is good to inspect.
- Figure 10 on a bight using a sleeve to increase efficiency may slip. When it does not slip, efficiency is >60%. Figure 8 will slip.
- 2x2 overhand on a bight using a sleeve may do the job, efficiency exceeds 60% and it is unlikely to slip. Disadvantage is that you can't inspect the rope inside the sleeve.

On may think that the black polyester sheath "solves" the rope slipping, but it doesn't. The Dyneema core just slips inside the sheath transferring the stress onto the sheath. The sheath breaks, and after that the Dyneema core is pulled out of the knot.

See paragraph 8.8 and 8.9 for the effects of sleeves and the use of Dyneema.

Characteristic load

You may also encounter the term "**characteristic load**". Its definition varies among industries and standards.

In Structural engineering it is mostly the load that will only be exceeded during 5% of the time in the lifespan of the structure. It consists of several partial contributions (think of snow, wind, seismic activity, own weight, etc). This is a useful concept for an antenna mast (wind load).

Besides the number, you also need to know how the load is statistically distributed (Gaussian is frequently assumed). Gaussian load distribution is far from reality for a climbing rope, as most of the time there is no load. Peak loads only occur during falls.

In rigging the characteristic load is mostly the sum of
- Own weight (think of cables, and other rigging hardware)
- Actual load
- Dynamic load due to acceleration/deceleration

All the above is under normal operating conditions. In fact it is the peak load that may occur under normal working conditions. When you have just the number, you don't know how the load is statistically distributed over time.

A Safety Factor is applied that gives the **Design Load**. The Design Load is used by the engineers that design/develop the equipment.

Especially with synthetic fiber rope you want to know how the load is distributed over time as rope has more problems with long duration static load (because of creep).

2.5.5. Entertainment Load Limit (ELL)

Entertainment Load Limit (ELL) is a sector specific definition used in theatre, (TV) productions, concerts, stage building, etc. Within Entertainment, lots of hoisting is done: lifting platforms, lifting trusses full of speakers and lighting, moving decorations, flying people using winches, etc. This all happens frequently above people.

Safety of equipment used in Entertainment is regulated in Std EN 17206 (Entertainment technology, Machinery for stages and other production areas)

ELL is also an MBS/SF ratio (as is WLL), but the safety factor is set for a specific use (the "Use Case"), including dynamic forces. Where ELL is for the moving case, ELL/R is applied to equipment that holds a load at rest.

A product/machine may be used for different applications within the Entertainment sector. This leads to different ELL values that are specified in the user manual of the product. This takes out the Safety Factor discussion. Know your Use Case and the static load, and use equipment that has ELL > static load for your Use Case.

2.5.6. Dynamic Load Factor (DLF)

A load may introduce peak forces (see chapter 2.6) due to dynamics. These can be expressed in the Dynamic Load Factor (DLF):

$$Dynamic\ Load\ Factor\ (DLF)\ =\ \frac{Peak\ Force}{Static\ Force} \qquad []$$

A safety factor is set for both the static load and the peak load. This results in two MBS values. The largest of the two is used as actual MBS. The safety factor for the peak load should be based on the frequency of occurrence of the peak load. It is generally between 2 and 5.

Some examples

- Lifting goes slowly in most cases. Therefore, DLF is generally well below 1.5.
- Industrial fall protection equipment in Europe limits the peak force to 6 kN. So DLF is in the range of 6. SF> 2.5 is generally used. So MBS of a fall protection lanyard should be > 15 kN.
- Aerial Acrobatics can generate DLF = 8 under normal circumstances. So an 80 kg acrobat may generate 6.4 kN onto equipment.
- Sports climbing where dynamic rope is used to catch a fall has DLF < 5 under normal fall conditions (that is when you follow the guidelines and fall).

2.5.7. SWL

SWL (Safe Working Load) is not used frequently in new documentation. It is replaced by WLL (Working Load Limit).

2.6. Types of load

- A static load is near steady over time
- A dynamic load varies over time
- A shock load is a high short duration load impulse due to a falling weight that is caught by the rope due to slack.

Figure 2.6 shows some rope load examples

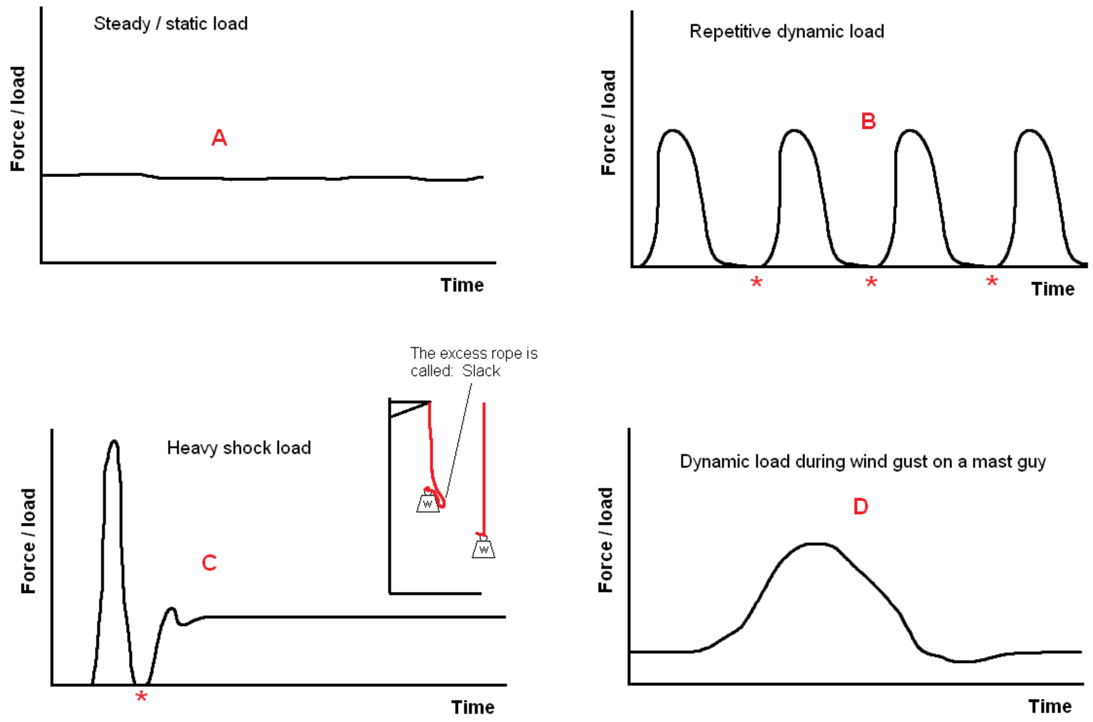


Figure 2.6, Types of rope/knot loading

The A-figure shows a near steady load. Almost all knots perform well in such case. There is no movement or varying stretch of fibers inside the knot, during a static load.

The only "danger" for static load is creep rupture. When the combination of load, temperature and rope material is not well selected, a rope may fail after long time due to very slow continuous elongation (called creep).

The B-figure shows a repetitive dynamic load, where the load varies between its maximum and zero. **This is very demanding for bends and knots in general**. It also gives more wear on the rope due to fibers that rub each other.

Knots that are easy to untie repeatedly give out some rope, and take in some rope. They may give out somewhat more then they take in during each load/unload cycle. This process goes faster when the rope force goes to zero (see the red stars). The tails of the knot will gradually creep/crawl into the bend / knot, until there is no tail anymore (knot failure).

One may add a backup knot. This can be a stopper knot in each tail, or the tails are fixed to the standing ends using a double overhand knot around the standing ends. Knots that are hard to untie also show "give out, take in" behavior, but before the tails are "eaten", the rope is likely beyond its service life.

A well-made splice can handle dynamic load much better, as the fibers don't rub each other much. The difficulty is to see whether a splice is well-made.

The C-figure shows a typical hard shock load. The weight is released suddenly. It first falls freely over a vertical height equal to the excess rope length. It gains speed / momentum during that fall and it suddenly caught by the rope. This gives a huge peak force. Due to the stretch, the weight bounces upwards releasing all tension/force from the rope. When the shock is over, there is a steady / static load.

Situations were rope catches an already falling weight can be very dangerous. During climbing and work at height, limiting the peak force during the shock load is of prime importance.

See annex 2 for more information on shock load.

The D-figure shows the force in a mast guy wire. There is a steady load due to the pretension in the guy wires. During a gust the force increases. After the gust the load may drop somewhat below the pretension load due to the swinging of the mast. When that drop (reduction) is relative large, the pretension of the guys should be increased.

Slack

Excess rope in a system is called “**slack**”. Slack in combination with moving (or swinging) masses can be very dangerous because of shock loading. The allowable amount of slack depends on the weight/load, length of rope, rope construction and rope material.

So called dynamic climbing rope is rather elastic. It can therefore catch a fall by spreading out the momentum over time, reducing the peak force. The same fall in polyester, or Dyneema rope (very low stretch) will likely kill you. Your back, the rope, or the anchor will break.

When rope is no longer able to “absorb” the force impulse to get an acceptable peak force, so called shock absorbers (load limiters) are used. They are standard in industrial fall arrest systems.

When you climb a mast, or other construction using a harness and lanyards, there will be (dangerous) slack. You should be well trained/informed, or you create a false sense of security.

Slack in guy wires also introduce shock loads on the guy, but also onto the mast and antennas. Slack can occur because of creep of a ground anchor, or permanent stretch or creep in synthetic rope.

Rope wear

Dynamic load causes fibers to move with respect to each other. In other words, they rub each other. This gives a kind of abrasive action resulting in damage to the fibers.

Excessive static loading can also cause wear. A long duration load at say 40% of MBS will permanently stretch synthetic fiber rope. So when you remove the load, the rope will be permanently longer due to creep. You can't see that when you buy used rope, but the rope's properties are sure degraded when permanent elongation has occurred.

So it is not only how you maintain your rope, but also how you use it. Also very frequent bending under load (such as occurs using a pulley) introduces dynamic load. Very small particles between the fibers (contamination) will accelerate damage to the fibers.

> Be very careful using rope in critical applications when you don't know the history.

See also Annex Shock Load and paragraph 3.2.6 on elongation for more information.

2.7. Knot Dressing

The knots shown in the drawings are deliberately shown very loose. This is to show how to tie them. In real world most knots, bends and hitches need to be tightened before applying the intended load.

Simple knots as the overhand knot and figure 8 knot can be tightened just by pulling the rope ends, and they form into the right geometry/appearance.

However, the more bends twists and loops are in a knot, the bigger the change that the knot forms into another geometry/appearance then expected. This will affect strength and reliability. The same happens with retraced knots, or knots on a bight.

> Tightening should be done gradually where you manipulate the bends and twists in the knot, so that the knot gets its intended geometry/appearance. Rope torsion should also be removed. This process is called "dressing".

Figure 2.7 shows 4 knots.

Figure 2.7, Wrong and good dressed knots

WF10 A and WF10 B look like different knots, but they are the same! They are both Wrong Figure 10.

DF A and DF B look like different knots, but they are the same! They are both double overhand knots, also called stopper knot or two turn barrel knot. Most strength (in a bend or on a bight) you get with geometry B.

Figure 2.8, Good and wrong dressing of Figure 8 on a bight

Figure 2.8 shows the well-known figure 8 on a bight.
A1 and A2 show the front side and backside of a very well dressed knot. The ropes run perfectly parallel everywhere in the knot.

B1 and B2 also show the front and backside of a figure 8on a bight. The front side (B1) looks good, but B2 shows a twist (or crossing). When the Red marked leg carries the load. The efficiency will sure drop from 60% to about or below 40% (that is a strength reduction of 33%). The reason is that the bend radius at the position of the twist (B2 figure) becomes smaller compared to the A2 knot. That reduces the strength of the rope.

C1 and C2 are “wrong figure 10” when used in a bend. Due to the many bends inside the knot, this knot is time consuming to dress well. It isn’t therefore used frequently.

Knot setting/tightening
When the knot is dressed and tightened enough, the final tightening (or setting) can be done with larger force. Final tightening is done via loading of all ropes that leave the knot. In case of a bend, or knot on a bight, you have mostly 4 ropes (2 load bearing ends and 2 tails).

Tightening/setting a knot is important. When not properly done, the knot geometry may change when loaded.

So knot tying is a three step process:

1. First tie the knot/hitch/bend
2. Then dress is so that it has the right geometry/appearance
3. Then tighten/set it so that it becomes compact.

A well-dressed knot not only looks better, but also functions better.

3. Rope (material) properties

3.1. Introduction

Long time ago the dominant rope construction was twisted rope out of hemp, manila (abacá) or sisal for rigging, construction and climbing. To make it long lasting it is impregnated with preserving oil. That gives the typical smell of many natural fiber ropes. Cotton, bamboo, Jute, Flax and others are used for clothing as the fibers are very thin.

Nowadays we have kernmantle, double braid, single braid, plait, and several other hybrid constructions. We now use Aramide/Kevlar, Vectran, Dyneema/UHMWPE, PA, PES/PET, PP, PE and even more.

Natural fiber rope/cord has its share in decorative and gardening use, but for radio amateur application synthetic fiber rope is mostly used. Most synthetic fibers are made from fossil oil, but bio-based and recycled materials can also be used.

Over here (Netherlands) rope from recycled PET bottles is available from several sources. The material is called rPET (the “r” is from recycled). Some Dyneema varieties are also made from bio-based materials (wood pulp to produce ethylene).

3.2. Materials

Short overview of materials used for rope production. Brand names are between brackets.

PA, Polyamide (Nylon, Ertalon)

It is the most flexible rope material with good availability. Due to water absorption its strength reduces and it becomes longer. It also has relative high creep (PA 6). So it is not a good idea to use in guy wires for antenna masts, or other applications where longtime static load is present.

Due to the stretch/elongation when loaded it is the preferred material for making ropes that should be able to handle shock loads. Dynamic climbing ropes are all made out of nylon.

Due to the stretch, it has good knot strength.

It sinks in water.

PP, polypropylene

Well known from the DIY stores as a cheap rope made of split film. There is also PP rope out of spun PP that has better properties. It is more stiff then nylon (less elongation), but less strong and has relative bad abrasion resistance. Without UV stabilizers it has poor UV-resistance. In case of using it outside, buy yourself black rope. If possible use something else.

As is has less elongation than PA, the knot strength is less compared to nylon. It melts at lower temperature compared to PA. It shows more creep then nylon. It is not used for climbing.

It floats on water.

Polyester (Dacron, Diolen, Tetoron)

Polyester was long the preferred line in marine applications. It has the highest density of the polymer ropes (1.38), so it sinks rapidly.

It was the lowest stretch thermoplastic fiber of the pre-Dyneema era, is just a little less strong then PA, but is UV-resistant, doesn't swell when wet and has good abrasion resistance and has low creep compared to PA and PP.

Due to its good UV-resistance, low creep and negligible elongation when wet, it can be used for guy wires. Many Radio Amateurs used Polyester guy wires for field day applications, but they may switch to Dyneema.

UHMWPE, HMPE (Dyneema, Spectra)

Dyneema changed the rope world. It has 4 times the strength (vs cross section) of polyester with significantly less stretch. As its density is about 0.97, it is lighter then polyester. So compared to the weight it is 6 times stronger then polyester.

With the advent of Dyneema SK 78, creep is significantly reduced compared to SK75. DM20 has negligible (practically zero) creep and is used in new off-shore mooring applications.

Disadvantage is its slippery nature (like Telfon, PTFE), so it has very poor knotability. The knot will slip, or break well below the rope's MBS. You need eye splices for good connections between Dyneema rope sections. The well-known figure 8 on a bight that has about 60% efficiency for Nylon, but has about 30% efficiency for 100% Dyneema. Sleeves can increase the knot efficiency. This is standard practice within the kite community.

As it is a variety of Polyethylene (PE), its melting point is the lowest of all fibers that are used for rope manufacturing.

Spectra is a similar fiber, but thicker. It has higher creep then Dyneema, so not so good for longtime static loads (think of guy wires).

Aromatic Polyamide, Aramid (Kevlar, Technora, Twaron)

These are practically thermoset plastics and don't have a melting point, they just turn into carbon when heated. Mechanically they are most like Dyneema. They sink in water as density is 1.45, vs 0.97 for Dyneema. Kevlar is yellow, Technora is black or dark yellow.

They show virtually no creep up to 200 ^{0}C (where all other plastics for common rope fabrication are liquid or very soft).

Abrasion resistance and UV-resistance is really bad (for Kevlar). Knotability is also bad, you lose lots of strength. All Kevlar ropes for outdoor application have a sheath (out of polyester or other UV resistant material). That sheath also improves knot efficiency.

Technora has better abrasion resistance and is in general more durable then Kevlar. It has low to moderate UV resistance (but better then Kevlar). Technora is used as sheath material to protect a core from heat and as a core. An example is Technora hitch cord for making friction hitches to be used with climbing rope.

Lots of applications are taken over by Dyneema, except for application where high temperature can occur. Kevlar became on the market around 1970, where Dyneema came on the market around 1990. Because of its good adhesion to epoxy, Kevlar is also used in strong composite materials.

Cellulose (Rayon, Viscose, Tencel)

This is a half-synthetic fiber mostly used for fabric as it has good moisture absorption. You may encounter Rayon/Viscose yarn (for sewing), but it is not used for rope production.

It is not suited for outdoor application as it absorbs lots of moisture. When wet, you lose more the 50% of its strength. It swells when wet, shrinks after drying, and creep is also large. Rayon is not recommended for radio amateur applications.

There are other materials, but you may likely not see them in ropes intended for marine, DIY, industry or climbing.

Below some material/rope properties are highlighted to help you decide what rope material you should use.

Please note that rope construction is also an important factor that determines the properties of rope (especially the stretch/elongation properties). Many straight fibers show less stretch compared to fibers at an angle with respect to the length direction.

3.2.1. Strength

Se paragraph 2.6 for strength definitions used in fiber research.

Materials in order of strength based on cross section.

- Aramide = Aromatic Polyamide
- UHMWPE = Ultra High Molecular Weight Polyethylene (Dyneema/Spectra)
- PA = Polyamide (Nylon, Cordura, Ertalon)
- PET/PES = polyethylene terephthalate (polyester, Dacron)
- PP = polypropylene
- PE = Polyethylene

Please note that in mechanical construction PES = polyethersulfone.

Kevlar is 15% stronger then Dyneema, based on diameter. Dyneema is about 15% stronger over Kevlar/aramide based on its weight.

Dyneema is about 4 times stronger then polyester based on diameter.

Due to poor UV resistance of Kevlar, Kevlar rope for outdoor use must always have a protective sheath (mostly polyester). Therefore the breaking strength (MBS) of thin Kevlar rope with sheath is about half that of Dyneema. Dyneema may be used outdoors without a sheath.

The strength of rope quadruples for each doubling in diameter. The same does its weight. Twice the diameter gives 4 times the original weight/m Sheathed rope has stronger strength increase, as with larger diameter, the sheath contributes less to the cross sectional area for many rope types.

Though nylon/PA is little stronger then polyester/PES/PET, there is big difference between them. Due to the stretchy nature of nylon, nylon can absorb shock loads significantly better then polyester. It is the reason that dynamic climbing rope is made of nylon. When made from polyester, the rope, anchor, or your back will break.

3.2.2. UV-resistance

Fibers degrade when exposed to UV radiation from the sun. All fibers do degrade in strength and flexibility, but some degrade faster. Material with best UV-resistance is on top.

PET/PES = polyethylene terephthalate

UHMWPE = Ultra High Molecular Weight Polyethylene = Dyneema/Spectra

PA = Polyamide

PP = polypropylene

Aramide = Aromatic Polyamide

This list is very indicative as it depends heavily on additives to the fibers, coatings, color and presence of a sheath.

Twisted and braided rope with its fibers exposed to the sun degrades faster then a rope with a core-sheath (kernmantle) construction.

Thick rope lasts longer, as only the outer fibers receive UV radiation.

In a marine environment, polyester ropes are prized because of its UV resistance. (Carbon) black rope also lasts significantly longer.

So when you need rope that lasts 10...20 years outdoors, use a relative thick rope that has a black polyester braid.

Manufacturers may apply (silicone) coatings increasing the UV resistance.

3.2.3. Abrasion resistance

Abrasion is when the rope moves under load over an object. Think of tree branches rubbing against rope that suspends an antenna.

UHMWPE = Ultra High Molecular Weight Polyethylene = Dyneema/Spectra

PET/PES = polyethylene terephthalate

PA = Polyamide

PP = polypropylene

Aramide = Aromatic Polyamide

Actual abrasion resistance depends on rope construction. The abrasion resistance of Dyneema is because of it is very slippery (low friction coefficient to many other materials, and itself). Coatings may be applied to improve abrasion resistance.

3.2.4. Knotability

This is a measure of how easy it is to knot, and how much strength is retained. Material with best knotability on top.

PA = Polyamide

PET/PES = polyethylene terephthalate (Polyester)

PP = polypropylene

Aramide = Aromatic Polyamide

UHMWPE = Ultra High Molecular Weight Polyethylene = Dyneema/Spectra

Knotability depends heavily on rope construction and the tightness of the weave. High fiber tension during production, gives stiff rope with not so good knotability.

PA has best feeling in the hand, this is because of its flexibility. PP and PET also have good knotability, but are more stiff.

Thé big gap regarding knotability is between polyester and Kevlar. Knots that do well in PA, PP, PET, do not so well in Kevlar, and are even worse in Dyneema.

Dyneema is so slippery that most knots just slip well before reaching the rope's MBS. Kevlar doesn't slip, but due to the low stretch (similar to Dyneema) the fibers just cut themselves.

Depending on rope construction, both Dyneema and Kevlar/aramide/Twaron/nomex can be spliced to get strong eye/loop terminations.

Due to the slippery nature of Dyneema a splice will fail well before reaching MBS when not made correctly. When in doubt, don't trust a splice in Dyneema.

Making knots with sheathed Dyneema may suggest you that problems solve themselves. They do generally not. When increasing the load onto a knot out of sheathed Dyneema, the Dyneema will slip/move inside the sheath, resulting in failure of the sheath, followed by failure of the knot itself. This all happens well below MBS.

The big advantage of Kevlar over Dyneema is its temperature resistance and Kevlar is virtually free from creep.

Knotability of rope reduces with age. The rope becomes stiffer after prolonged outdoor use. This is mainly due to contamination between the fibers. Permanent stress reduces the knotability also.

So in real life, two ropes from the same production lot can have different knotability. It all depends of the usage history of the rope.

3.2.5. Temperature resistance

This is a measure of how it can stand high temperature. Material with highest service temperature on top.

Aramide = Aromatic Polyamide (350 ^{0}C)

PET/PES = polyethylene terephthalate (Polyester) (150 ^{0}C)

PA = Polyamide (100 ^{0}C)

PP = polypropylene (90 ^{0}C)

UHMWPE (70 ^{0}C)

Strength reduction to 50% for PA and PET is about 175 degrees C, for PP it is about 85..120 degrees C (values vary per manufacturer).

Other manufacturer says resistance to short term heat: PA: 130, PET 170, PP 80, UHMWPE (Dyneema) 70, PE 70 (all in degr. C). So there is lots of confusion. Source: https://www.beaver.com.au/

When strength at high temperature is required, no plastic that is used for rope will beat aromatic polyamides such as Kevlar/Twaron/etc.

Though the long term maximum service/operating temperature of nylon (PA) is only slightly higher then that of PP. Its short duration service temperature is well above that for PP. Therefore PA performs better under high friction conditions. This is also because of the lower friction coefficient compared to PP.

Note that PA/PP/PES/Kevlar/Dyneema are family names. Formulations within a family may vary. Formulations can be optimized for certain properties, such as strength or temperature resistance. Also additives may be used to improve certain properties.

For critical applications, consult the manufacturer.

3.2.6. Stretch, elongation

Here, this is a measure of how much the rope elongates under load due to **elastic elongation** (like rubber bands).

It is specified as a percentage of length increase at certain load (for example 10% or 20% of MBS, or at MBS). Unfortunately, elongation/stretch is not always clearly specified by manufacturers.

There are 4 types of elongation (or stretch) when you load a rope.

1. Compaction and reorientation of rope fibers
2. Elastic elongation
3. Viscoelastic elongation
4. creep

compaction and fiber reorientation (“bedding-in” elongation)

When you load a new rope, the fibers come closer to each other (the rope becomes thinner, air is squeezed out). In addition fibers reorient them self to equalize the tension in the fibers. When you remove the load, the rope is now somewhat longer. This effect is most dominant at relative low load and new disoriented rope. The fibers itself are not longer.

When you wiggle the unloaded rope over its full length, there will be more space between the fibers again, the rope becomes therefor thicker and returns to its original length.

This first elongation depends on the use history. When it was loaded and not moved after removing the load, adding the load again gives less elongation as most fibers were already oriented. To remove this uncertainty, a preload may be prescribed in test procedures. This more or less takes out the influence of use history.

Elongation as specified is mostly without the effect of compaction (so elastic component only as discussed below). Elongation due to compaction of fibers is also called bedding-in elongation.

Elastic elongation

This is the elongation mostly due to the modulus of elasticity of the fiber material and the angle of the fibers with the length direction of the rope. The fibers become longer during load, and return to its original length directly after removing the load. It has a more or less linear behavior. So the elastic elongation is proportional with the load. Elastic elongation and shrinking after removing the load is a fast process.

Viscoelastic elongation

When you maintain a constant load, you first get the immediate elongation due to compaction of fibers and the elastic stretch of the fibers itself. Though the load is constant, the rope still elongates slowly. After some time (can be hours) the viscoelastic elongation becomes stable (so no further elongation).

When removing the load, the rope becomes shorter directly, but it is a bit longer. During hours the rope keeps shrinking back to (near) its original length due to the viscoelastic elongation effect. You can repeat this process, and the rope will in the end return to its original length.

Viscoelastic elongation is also called primary creep and is a slow process. Secondary creep, also just called ‘creep”, is discussed below.

Creep

Creep is very slow elongation at steady load, but it will not stop as is the case with viscoelastic elongation. Every year the load is present, the rope slowly keeps elongating. This is due to permanent movement of molecules in the fibers.

When you remove the load, the rope will shrink over time due to viscoelastic elongation, but elongation due to creep is permanent. So the rope will no longer return to its original length. The fibers are permanently longer now.

When the elongation because of creep becomes too large over time, the rope will break due to “creep rupture” When you apply a load of 50% of MBS, a rope will fail in relative short time due to creep. When applying a load of 20% of MBS, it takes very much longer before it breaks due to creep. So a rope could look very good, but due to creep during its use history the breaking strength may be reduced significantly.

Creep, as a percentage/year, increases with the load relative to MBS and temperature. Of course it also depends on the material.

Additional information on creep

All effects are shown in figure 3.1. It is not strange to think of RC network charging/ discharging in the middle figure. Elongation is actually modeled virtually the same way as we model multi-component RC networks.

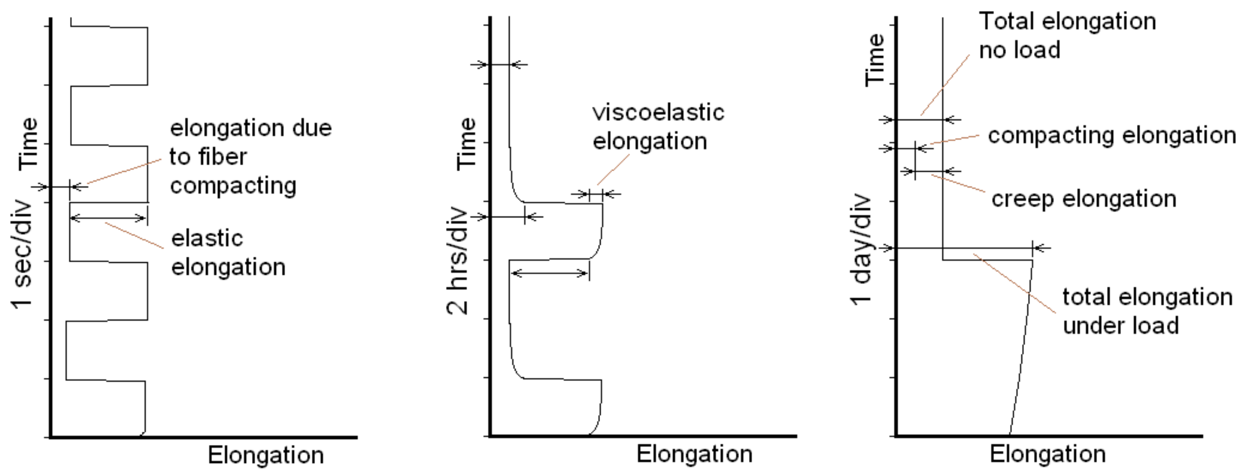


Figure 3.1: Elongation effects

Left figure

The left figure shows short term elongation effects, 1 s load, 1 s no load and this repeats. The elongation is pure elastic after compacting elongation has passed. After two cycles, the no-load elongation stabilizes due to fiber compaction and fiber orientation. The elongation due to the load is the sum of: elastic elongation, and compaction elongation.

Middle figure

The middle figure shows two cycles, 2 hours load, 4 hours no load. On top of the total elongation from the left figure, there is some viscoelastic elongation.

So the loaded elongation consists of the sum of: compaction elongation, elastic elongation and viscoelastic elongation.

The no-load elongation is first the sum of: compaction elongation and viscoelastic elongation. But after some time the elongation returns to compaction elongation only. So the fiber length doesn't change when the rope gets sufficient time to relax.

Right figure

The right figure shows a single load cycle of 3 days. You can't see the viscoelastic elongation anymore on this timescale, but the rope keeps elongating. When the load is removed the rope length doesn't return to its length of the left and middle figure (compacting elongation).

The additional elongation on top of the compacting elongation is elongation due to creep. This is permanent elongation of the fibers. When the load is present for very long time in combination with excessive load, the rope will break after some time. This can be days, weeks or years. It all depends on the rope material, temperature and load/MBS ratio.

SK75 and SK78 show creep that is near linear over time. DM20 Dyneema also shows near linear creep, but is very low compared to KS 78. Polyester shows reducing creep over time, so each month it becomes less. When you don't want to use Dyneema, Polyester is the best choice for low creep applications.

Drying line as an example

When you put a line between two points, the force will reduce over time due to viscoelastic elongation. If there were no creep, the force remains constant after days to weeks. But due to creep the tension keeps reducing because the fibers become permanently longer. You can notice this with a drying line. When your remove the cloths form the line, it will move upwards, but will not be straight. However after some days//weeks it will be straight again. When it is not straight after weeks, it is due to creep (this is permanent damage to the rope).

Elastic elongation, comparison
The stretch mentioned below is due to elastic elongation (number 2 in the list of phenomena). Material with lowest stretch is on top. The higher the number, the more the material stretches under load.

Steel (0.6)

Dyneema/Spectra (1)

Kevlar/aramide/twaron/technora (1.5)

Glass fiber (1.5)

PET/PES = polyethylene terephthalate (Polyester) (5..8)

PP = polypropylene (20)

PA = Polyamide (30)

The numbers represent the stiffness based on same diameter rope with same construction and same production process. It means that at same load, PA stretches factor 30 more then Dyneema. As a comparison glass fiber and steel are also mentioned. The gap between Dyneema/Kevlar and PET/PES is huge.

Kevlar and Dyneema stretches about 3…4% at break, PA can have 20..30% stretch before break, depending on rope construction and type of Nylon. Dyneema is similar to Kevlar. Polyester stretches about factor 3 to 4 less then Nylon.

The advantage in many applications comes from the density of Dyneema. Its weight is 8 times less compared to steel. So yes, Dyneema is a very light, very strong and very stiff fiber. Unfortunately it is hardly knotable.

When doubling the diameter of a rope, the stretch generally becomes factor 4 less at same load. There is much difference of stretch within a plastic rope family. This has 3 reasons

1. There are several chemical formulations and treatments within a plastic family. Fiber production can be optimized for impact strength, strength, low stretch, etc.
2. Geometry of the rope. Many straight fibers reduce the stretch/elongation
3. Production process. Fibers may be pre-tensioned during production. This reduces the stretch up to the working load limit (generally 10 to 20% of breaking strength). Heat treatments are also possible.

3.2.7. Electrical conductivity

All synthetic materials that are used for rope production do not conduct electricity, except carbon.

Polyamide and the aramids will absorb moisture. This can make it a not so good insulator. Dried Nylon 6 has resistivity of about 10^{14} Ohm·m, but this drops with about factor 10 for each percent of water absorption. So with 8% water absorption, resistivity drops to about 10^{6} Ohm·m.

The problem with outdoor use of rope is not the rope itself, but the water that creeps into the spaces between the fibers. New rope that becomes wet due to rain has reasonable resistance.

Pure water is a very bad conductor, it is more an insulator. Rain isn't pure water but has free ions in it. It is even somewhat acidic due to CO_2 absorption.

Rain electrical conductivity can be anything between 0.001 to 0.5 S/m. It all depends on where you live, from where the clouds arrive, and air pollution. When rain blends with salt spray during storm (coastal areas), its conductivity will be at the high end of the range.

The water absorption of rope depends on its state: no load, or loaded. Without load it can easily absorb 50% by weight. When the rope is loaded water will be squeezed out reducing the absorption to say 20..30%.

What you can expect?
Assume a 3 mm tensioned wet rope and rain conductivity of 0.02 S/m (200 uS/cm). The water fill factor is 30% (assumed). This would results in a DC resistance of 23 MOhms for 1 m of length. In real world it may be higher as water pockets can be isolated from other pockets.

The RF impedance will drop due to the dielectric constant of water (80). The capacitive conductivity of water at 20 MHz is about j0.09 S/m. This reduces the impedance to about -j5 MOhm for 1 m of rope. This is still no problem for most antenna applications.

Due to accumulation of pollution on and inside the rope, the resistance may reduce over time. I don't know how much, but it is unlikely that it will drop below 100 kOhms for 1 m of 3 mm rope. This isn't a problem for most amateur antenna installations. You may need some evaluation when using electrically short radiators, as voltage on the wire ends is significantly higher compared to half wave dipoles or quarter wave monopoles.

As a precaution, you may impregnate the first half meter of rope that connects to the antenna wire. Petrolatum and a heat gun can be used for this. This reduces water absorption significantly. Don't forget the impregnate the friction hitches also, as there the E-field is at its maximum.

As with all polymers, tracking behavior (carbon trace forming due to micro discharges) of rope is significantly worse compared to glass or porcelain. So when using electrically short antennas with high power, you may consider glass or porcelain insulators instead of impregnated friction hitches.

3.2.8. Other properties

Influence of water/moisture
Many PA/nylon formulations absorb water and become longer. When dried, the rope becomes shorter, it even shrinks.

Water attaches to Kevlar (good wetting), but its properties are hardly affect by (salt) water.

Polypropylene and Dyneema are virtually not affected by moisture and the wetting is very bad.

Epoxy bonds to Kevlar, but very bad to Dyneema, unless treated for use with epoxy (plasma treatment or chemical etching). Dyneema rope is not treated to have a good bond with epoxy and other coatings.

Density
PP and Dyneema float on water as the density is just below that of water. Nylon has density of 1.18, Polyester 1.38 and Kevlar 1.43, so they sink.

Price, availability
PP is the cheapest and is sold at DIY stores. PA/Nylon is also sold at DIY stores and is slightly more expensive.

PET/PES, if available at DIY stores (less choice), has similar price as PA rope.

The most expensive fibers for rope are Dyneema and Kevlar. Thin rope/cord is used for kiting and has good availability. Thick Dyneema rope is available for reasonable price at marine outlet stores (both new as unused excess length on spools and used). In the Netherlands Bijrinus is a good source for surplus rope (and other materials).

Creep
Aromatic polyamides have lowest creep, brand names: Kevlar, Twaron, Technora. Same is valid for liquid crystal polymers: Vectran. Exception is Dyneema DM20. This is a thermoplastic polymer with near zero creep.

When looking to the thermoplastic polymers, polyester shows lowest creep of the pre Dyneema era. Creep of Dyneema depends on what type you have. When you keep the load below 10% of MBS, the creep is negligible (SK78). PP has highest creep.

Dyneema varieties
SK75 has highest creep of the Dyneema family (and is used in cheaper ropes). SK78 has about factor 3…5 less creep elongation then SK75. DM20, introduced around 2012, has about factor 25 (twenty-five) less creep compared to SK78, but has 70% of strength of SK78. The lower strength isn't a problem for a clamping/mooring application where static loads are present during long time. Dyneema DM20 is very good for guy wires.

You should think of elongation of 0.02%/year at a load of 20% of MBS at 16 ^{0}C, compared to 0.5% for SK78. The elastic elongation for 20% of MBS is in the range of 0.7%. So given a practical product life time, 0.02%/year elongation due to creep is negligible.

Its major application is in off-shore mooring lines operating under constant static load, and then creep can be an issue.

There is also SK99. This has little more creep then SK78, but is 20% stronger.

Nylon varieties
There are many nylon varieties now and rope makers don't always mention what type of nylon they use. Nylon 4.6 shows lowest creep, followed by nylon 6.6 and nylon 6. Nylon 4.6 is about 3 times more expensive then nylon 6. There are more nylon varieties!

Flammability
All discussed materials are flammable, except the aramids (Kevlar, Nomex, Twaron, Technora).

The aromatic polyamides are inherently flame-resistant, they don't melt, or support fire. All other polymer fibers can only be made flame-retardant with a so-called flame-retardant. They can also be mixed into the fiber during production.

Over time a flame-retardant coating may wear, and then the material may become flammable. Polymer fiber rope is not flame-retardant, nor flame-resistant, unless otherwise noted by the manufacturer.

When you melt a rope end with open fire to avoid unraveling, and you make it too hot, it will burn. The flame will propagate, and may start a fire.

> When melting rope ends, check that they do not burn when you put them aside.

3.3. What material to use for your application?

High temperature applications
When the operating temperature is > 100 ^{0}C for long time, you need to use Kevlar/Technora/Twaron, or divert to metal or fiberglass cord/rope.

Large force clamping
When you use cord as a clamping means (using whippings), polyester is a good choice as it has very low creep and it adheres to epoxy. It comes second after Kevlar/Twaron/etc. For miniature things, you can use polyester yarn used for textile application. When you impregnate the whipping, do not use waxed thread.

Dyneema DM20 is of course excellent, but maybe difficult to impossible to get in small quantities and adhesion to epoxy is bad. Bad adhesion is not problematic when the epoxy is only present for protection.

Erecting wire antennas
For hoisting an antenna during a field day or summer camp, stretch is not of importance. You can just use PP braided or twisted rope from a DIY store. When you

don’t use insulators (so the rope connects to the antenna wire directly), you need to impregnate some length (say 0.5 m) with petrolatum or oil. This keeps water out of your rope. You may need a heat gun for that. When heating the rope with an unregulated heat source, you may use PET/PES or PA as you may melt PP.

Braided rope has the advantage that it doesn’t twist when running over pulleys, branches, etc.

Dyneema has poor handling with your hands, because or the low friction coefficient. You need a tool to pull hard on thin Dyneema.

Guy wires

When using rope as guy wires the choice depends on several factors:

fixed installation, steel (lattice) mast,

The first meters from the ground may need to be from metal, just in case of bush fire. Rope stretch because of creep will likely be the dominant factor, especially in case of steep guys. Such a situation requires careful design as failure may have large impact. You likely need to divert to impregnated Kevlar rope specially designed for guy line application. This is not a hobby activity.

fixed installation, glass fiber telescopic mast.

The first meters from the ground may need to be from metal, just in case of bush fire. Wind load is likely less compared to a large metal lattice mast, and some flexure of the mast is acceptable.

A safety factor of 5 is generally used for synthetic fiber rope guy wires. This is based on the breaking strength of the rope with knots, eyes, etc.

Analysis is highly recommended. You may opt for Polyester. When visibility is an issue, (sheathed) Dyneema (SK78 or DM20) may be a better choice.

3 mm polyester with braid has MBS around 2.5 kN, where 3 mm Dyneema with PES braid has MBS of around 6.5 kN. 3 mm Dyneema without sheath has MBS = 10 kN (that is 4 times stronger compared to polyester and at least 5 times less elongation/stretch).

Dyneema breaks at an elongation of 3…4 %, you can use that to calculate the stretch/elongation at the working load. Nylon breaks at an elongation of about 20..30%, depending on rope construction and type of Nylon.

When looking to the knotability of Dyneema, Polyester is first choice for most applications. See paragraph 8.9 for additional information for Dyneema and Kevlar.

When your application requires high static load and it must be Dyneema, use SK 78 as that has about factor 5 less creep compared to SK75 rope. Dyneema DM20 is even better, but availability is less, and price is higher.

When you need to re-tension your guy wires frequently, and this is not due to anchor creep, it is creep of your rope! When the creep elongation is in the range of the elastic elongation at the design load, you definitely need to replace and discard the rope. You need thicker rope and/or other rope material to reduce the failure risk.

See also paragraph 9.10.

Very long time outdoor exposure
First consider other options using metal or fiber reinforced plastic, as this will last longer. The main reason is that the contact area to the environment of solid plastic is very small compared to fibers in a rope.

When no other option is available, use sheathed rope where the load is carried by the core. Use polyester or Dyneema/Kevlar with polyester sheath/braid. Black rope has highest UV-resistance.

Use relative thick rope, as the outer layer is eaten by the environment first. More material per meter means that it takes longer to eat material before the rope fails.

There is a time consuming option: impregnation
It will generally more then double the life span. I used hot impregnation with petrolatum frequently to repel water at rope / antenna conductor transitions. After > 5 years exposure, the petrolatum impregnated part of the rope was brand new, of course except for the circumference. Non-impregnated parts showed wear, also deeper into the rope. I used hot impregnation frequently on non-sheathed rope (single braid or twisted) with >8 years outdoor exposure (Netherlands, latitude 52N).

Permanent application of rope where there is zero movement can be impregnated with Epoxy resin (not epoxy glue). When done apply a layer of UV-resistant paint. In fact you create a composite material like carbon or glass fiber reinforced plastic. Even soaking with oil helps to prolong the life of rope.

Instead of epoxy you can apply layers of impregnating woodstain or other impregnating varnish. Note that the first layer dries very slowly as the paint soaks/creeps into the spaces between the fibers, This slows the drying process significantly. So you may need to wait several weeks before applying a second layer.

4. knots, bends and hitches

4.1. *Basic knots, bends and hitches*

4.1.1. Half hitches and clove hitch

Figure 4.1.A shows a **half hitch**. When you remove the rigid piece, it falls apart, therefore it is a hitch. S = standing end, W = working end (that you use to tie the knot/hitch). The working and passes under the standing end.

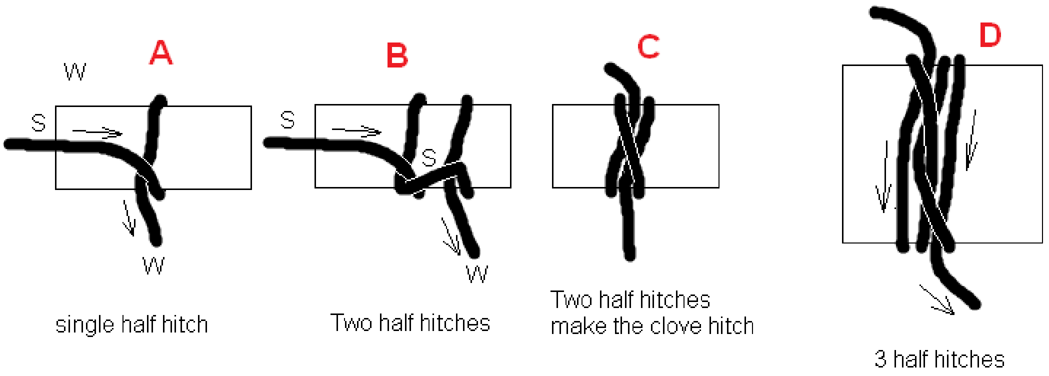


Figure 4.1, half hitches and clove hitch

The B figure shows a second half hitch added (right of the first half hitch). The working end of the first half hitch, becomes the standing end of the second (right) hitch. The half hitch must be tied in the same winding direction.

When you tighten the two half hitches and move the two turns to each other, you get the **Clove hitch**, with its typical bridge over two parallel rope turns. The D figure shows three half hitches, tight in the same direction.

Half hitches on its own have limited application. This is also valid for the clove hitch. It is an unreliable hitch to tie a rope to a rigid object. It slips in many applications. It nearly always required a securing knot.

As a midline hitch it can be useful as it can be adjusted by pulling the bridge that passes over the two rope sections below it. This is used in (rock) climbing, for example to make a belay station with three anchor points (for redundancy).

When you use a clove hitch to tie a rope to something, it is wise to add the additional half hitch as shown in figure 4.1.B., or put two half hitches around the standing end (load bearing end). There are better alternatives to this hitch.

Half hitches have applications in other knots and hitches

- As a securing means for extra protection against knot slipping
- As a termination (3 hitches) for square and diagonal lashings.
- As starting hitch for the square lashing.
- As part of the "round turn with two half hitches".
- Two half hitches (clove hitch) as the basis for the constrictor hitch
- Stowing/storing short limited amount of excess length.
- As a very efficient eye termination (clove hitch or constrictor hitch on a bight with a round former)

4.1.2. Overhand knots and barrel knots

These are real knots as you can tie them without the need of something else.

Overhand knot

Figure 4.2.A and B show how to tie an overhand knot. You make the loop with the working end (W). Of course you can tie the knot the other way around.

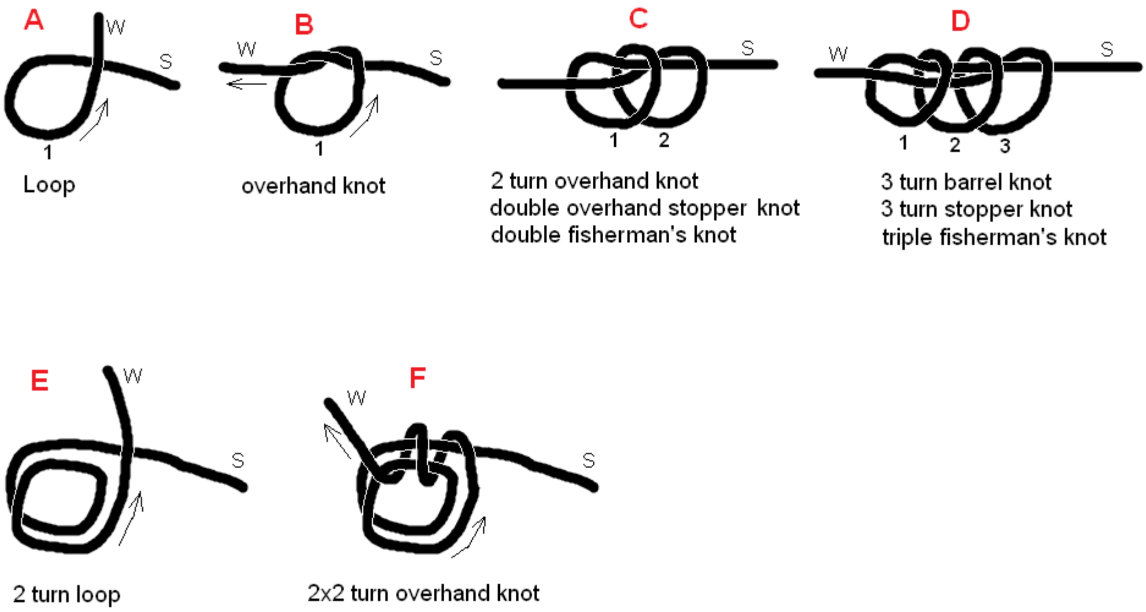


Figure 4.2, Overhand and barrel knots

As a knot alone the overhand knot has limited use. When you load W and S the knot in the B figure becomes very compact. The rope makes very tight bends (that is small bend radius). Therefore the overhand knot in a rope reduces the strength significantly. Strength reduction can be >50%. So a rope with a MBS = 1000 N, may have a breaking strength below 400 N when there is an overhand knot in the rope.

Overhand knots may accidently appear in a rope. Don't leave them in the rope, somebody else may not notice the knot. The overhand knot is the basis for the

Fisherman's bend and many other knots. It is also used as a securing knot for the tails that come out of a knot.

Barrel knots
Figure 4.2.C shows the two-turn barrel knot. You make an additional turn over the standing end and feed the working end through the two turns. This creates the **2 turn / double overhand knot**. It is also named **stopper knot** or (incorrectly?) **Fisherman's knot**.

Figure 4.2.D shows the version with three turns (**triple overhand knot**). You can add several more turns to make rope Morse code. Make sure that when you apply N turns, the working end goes back to N turns also.

The multi-turns barrel knots have lots of applications:

- It is the basis for the double/triple/quadruple fisherman's bend.
- As a sliding knot around another rope. The more turns, the higher the friction
- As a sliding loop knot (scaffold knot, double/triple overhand noose), for example to connect a rope to a carabiner.
- Quadruple fisherman's bend for Dyneema rope

Note to barrel knots

> The same tied barrel knot, can have several stable appearances when loaded. This is also valid for the simple 2 turn barrel knot / double overhand knot.
>
> So only knowing how to tie the knot is not sufficient. You also need to know how it looks like after dressing and tightening. See for example figure 4.3.

Bulky simple (stopper) knot to have good grip on
Figure 4.1 E and F show how to make an overhand knot with 2 sets of turns. The F figure is the 2x2 overhand knot. You start with a 2 turn loop, and add two turns through the loop. Of course you can also make a 3x3 overhand knot. It makes a compact but fat stopper knot that provides good grip.

This type of stopper knot is also used to make a rope/loop termination onto spear gun rubber. The stopper knot goes into the rubber, and a (double) constrictor hitch goes around the rubber. The 2x2 and 3x3 overhand knots can also be used to make non-slipping eye terminations using (sleeved) Dyneema.

Figure 4.3 shows a photo of 4 knots

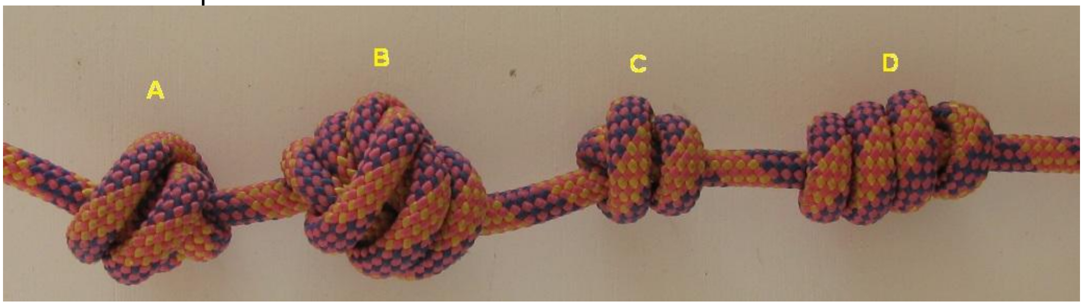


Figure 4.3, several overhand and barrel knots

A: 2x2 overhand knot
B: 3x3 overhand knot (very fat knot)
C: double overhand knot, 2 turn barrel knot
D: 4 turn overhand/barrel knot

The double overhand knot and the 4 turn barrel knot can be used as decorative knot in Morse code in rope. The 4 turn barrel knot is the 'dash', the double overhand is the 'dot'.

Note that 3x3 fat overhand knot (fig. 4.3.B) is very difficult to untie after loading. The 4 turn barrel knot (figure 4.3.C) is also near impossible to untie after loading.

The 2X2 and 3x3 stopper is especially added for making simple soft shackles. The 2x2 knot is also good for a short but strong eye termination knot for sleeved Dyneema. See Annexes 1 and 5 for more information.

4.1.3. Figure 8 and related knots

Figure 8

The figure 8 is "the" standard in climbing and rope access. Reason:

- Very simple to tie,
- doesn't "consume" much rope
- simple to recognize (the figure 8 shape),
- simple to inspect (should appear as figure 8),
- simple to dress (it dressed automatically when load is applied).
- Relatively easy to dress when "on a bight" or "retrace"

It is not the strongest, but that isn't a problem when having sufficient rope MBS. As an example, "Static" rope (Low Stretch Kernmantle, to std EN 1891) has an MBS in the 30 kN range. A figure 8 on a bight as a loop knot gives you a breaking strength of about 18 kN.

The overhand knot has same properties as mentioned for the figure 8, but has a knot efficiency of about 50% when using the "on a bight" version, where the figure 8 has about 65% efficiency. The figure 8 does not work well with Dyneema (efficiency < 45%).

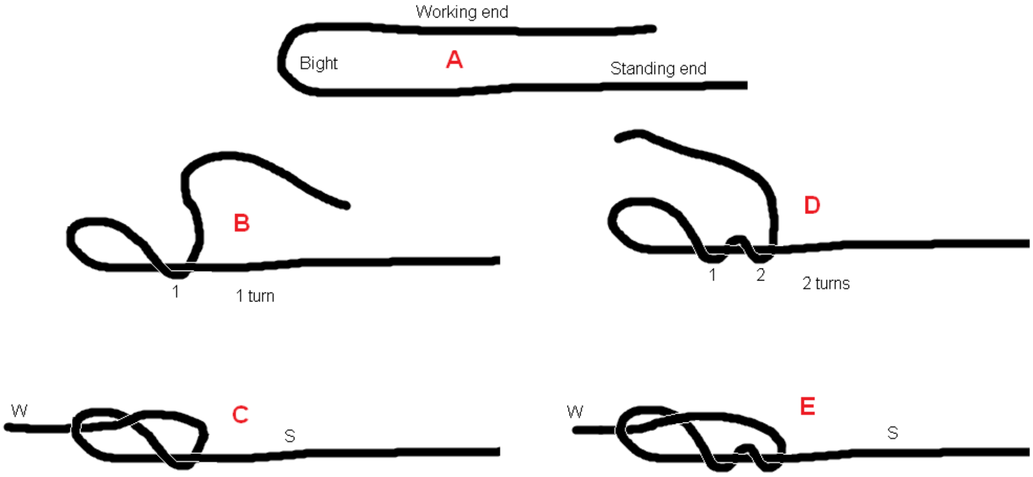


Figure 8 **Figure 10**

Figure 4.4, figure 8 vs figure 10

The figure 8 knot is used to create a stopper knot (as shown here), on a bight as an eye/loop termination, and as a bend (Flemish bend). The figure 8 follows path A, B, C in figure 4.3.

You make one turn around the standing end, or you rotate the bight over 360 degrees while fixing (with your hand) the standing and working end. Push/tuck the working end through the loop and you are done.

There is a somewhat stronger variety of the figure of 8, it is called the figure 10. Yes there is also a figure 9.

Figure 10
The figure 10 is not used frequently

- it consumes much more rope then the figure 8,
- not easy to recognize geometry.
- Requires more actions during tying
- You need to dress it well as, it can have more shapes

Where the figure 8 on a bight has 60… 65% efficiency (climbing rope), the figure 10 on a bight has about 70..80% efficiency (that is 30% stronger), when tied well. With this strength, it is the strongest of the figure 8 related knots when used on a bight.

It is said to be easier to untie then the figure 8… It is able to "give" some rope during a single shock load, reducing the peak force.

The figure 10 follows path A, D, E in figure 4.4. Instead of making one turn around the standing end, you make 2 turns around the standing end. Then push/tuck the working end through the loop. Of course you may also hold the working and standing end, and rotate the bight over 720 degrees, and then push/tuck the working end through the loop. When you tuck the working end from the "wrong" side through the loop, you make a figure 9 (stevedore knot).

When using this knot to make an eye using "on a bight", the bight is the working end. So the loop is on the left side of the knot in figure 4.4E.

Now the knot looks very asymmetric. However when tying/dressing the knot, it may become <u>somewhat</u> symmetric. See the photos below figure 4.4. To get the strength advantage you need to dress it well, and that is the uncertainty when using this knot.

Wrong figure 10
The "wrong figure 10" is shown in figure 4.4.1.

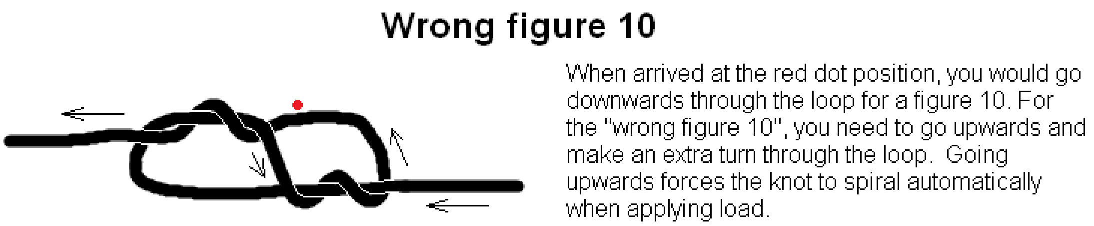


Figure 4.4.1, "wrong figure 10"

It is somewhat different from the figure 10. At the red dot position you go upwards instead of downwards, and you make an additional turn through the loop.

When applying load, this knot spirals automatically into a near symmetrical geometry (like in photo 4.4). Whether it spirals into the symmetrical shape, depends however on the flexibility and torsion stiffness of the rope. You may need to add some twist/torsion during tightening.

To be sure, it is best before tightening to grip the rope at the red dot position and pull on the left rope end. This forces the left part of the knot to have the same geometry as the right side. This helps spiraling to the most favorite symmetric appearance. It keeps this symmetry at high load. The left and right strand has same strength (compared to the real figure 10. It has a very acceptable appearance, better then the figure 10 in my opinion.

It is a symmetrical knot, so both sides have same strength.

When tied on a bight to form an eye termination it gives a rather strong termination. I used it in 1 and 2 mm Dyneema (without sheath) and it provides an efficiency of about 40..50%. When tied using cheap 3 mm braided PP rope, it has an efficiency of >55% with non-optimum dressing. To be honest, for PA, PP or PET, it is easier to use the normal figure 8 or 10 for making an eye.

As it is a rather long knot (compared to its diameter), you can bend it to remove stress. Untying is therefore possible (tested at 90% of breaking strength for 3 mm braided polypropylene).

4.2. Loop knots for eye terminations

A good splice or sewn eye is the strongest, period. But you can better use a knot with a known efficiency/strength, then a splice with unknown strength. Splices in braided rope must be very well made. This is especially valid for splices in Dyneema rope, as Dyneema has very low friction coefficient. If you are not sure about who made it, don't trust it.

> Note that a **Brummel splice** is not inherently reliable. Insufficient buried length will show failure well below the expected strength.

Rope eye terminations are to connect the rope to another (fixed) point. The loop does not constrict (become smaller) under load.

4.2.1. Bowline

The bowline is a well-known loop knot. It is easy to tie, very easy to untie after heavy load, and relatively easy to remember. There are ways to tie it wrong, so you should load it to make sure its holds. Its efficiency in nylon is about 50%, with large variations depending on type of rope.

Figure 4.5 shows how to tie the knot in two versions

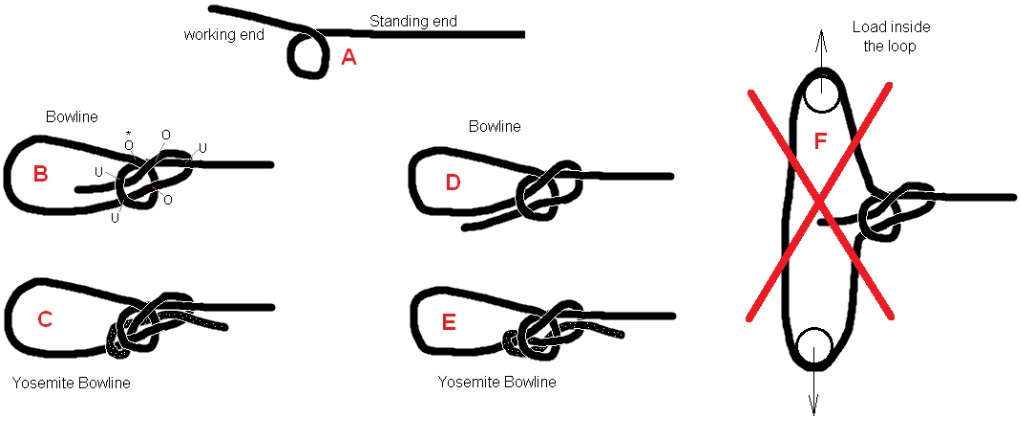


Figure 4.5, Bowline and Yosemite bowline

First start with a loop in the standing end (load bearing end, figure 4.5.A). When the working end goes over the rope of the loop, the next step is to go down with the rope.

As the working end of the loop goes over the rope (O with *), go under (U), over (O), under (U), etc to make the loop (B figure). Making the loop is like an under/over weave. You may opt for the alternative version via the D figure.

The knot may untie itself / slip under dynamic load. The Yosemite version should be a solution for that. The Yosemite is very easy to tie wrong, as adding the Yosemite finish is NOT retracing the working end. When using the Yosemite addition, you feed the wire back through the loop (not retracing) so that it appears parallel to the standing end. Then you first tighten the knot with the standing end. When done you tighten the slack (working end).

When you know exactly what to do, the Yosemite finish adds security, else you lose it. When using a bowline, leave a tail (slack) of at least 10 rope diameters.

You may not use the bowline when the forces are inside the loop as shown in figure 4.5.F. This type of load is also called “ring load” or “parallel load”. The bowline will capsize and/or you pull the knot out of its intended shape.

During normal operation, the loop of the bowline should be able to move freely around the object, so the loop should not be clamped. When clamped, the knot may turn into an undesired slipknot.

4.2.2. (Alpine) Butterfly knot, lineman’s knot, middleman loop

The (alpine) butterfly knot is a very versatile knot as it makes a loop in the line. Its efficiency is about 50…60%. It holds better under dynamic load compared to a bowline loop.

It is not the preferred choice for an eye termination loop, but it does work. It has many applications in climbing, rope access and general rigging.

Figure 4.6 shows how to tie it around your hand, fingers, etc.

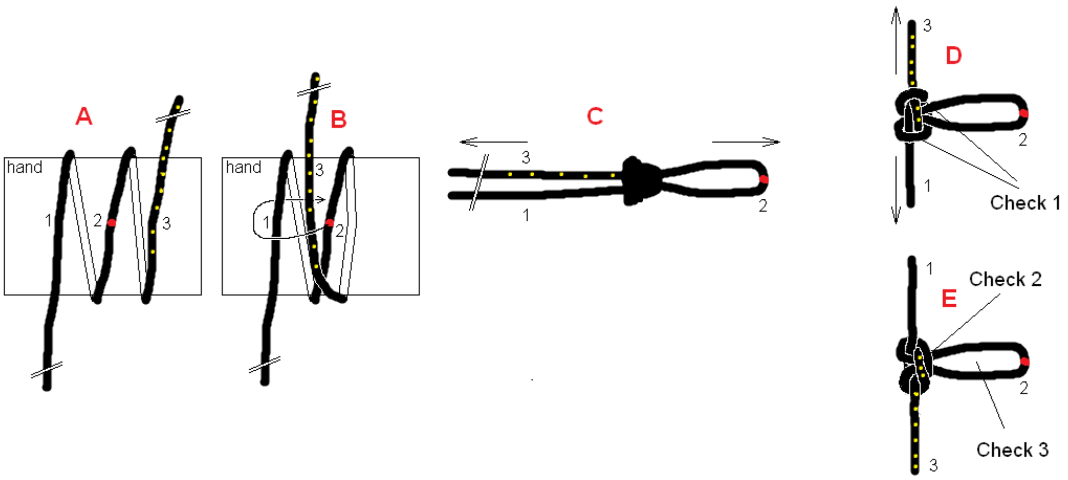


Figure 4.6, (alpine) butterfly, Lineman’s knot, middlemen loop.

When you encounter a butterfly knot, always do the checks of figure 4.6 D and E. There must be a crossing and on the other side parallel running lines. When in doubt, tie it again.

There are other ways to tie it, but this one virtually can't go wrong. Its versatility is shown in figure 4.7.

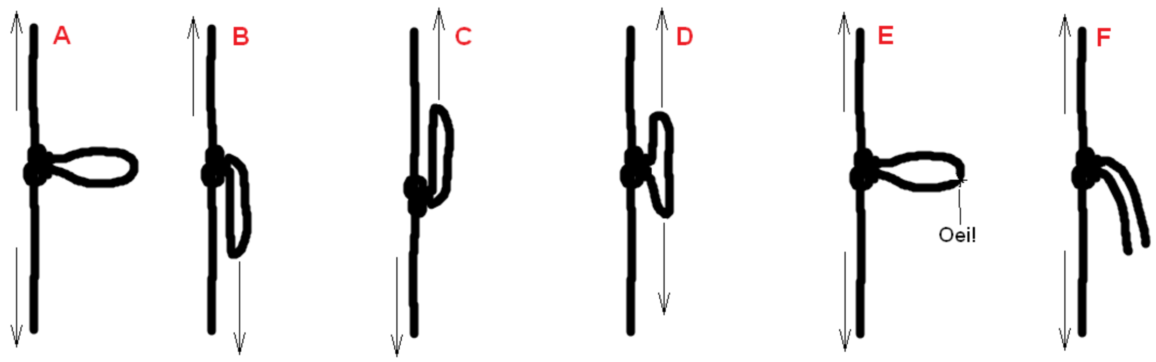


Figure 4.7, Allowed loading configurations for the (alpine) butterfly knot.

A = loop in a line that will be loaded
B, C = as eye/loop rope termination
D = as a (Prusik) loop or sling (there are better alternatives)
E = to "skip"/isolate a damaged rope part
F = as a bend to join two ropes.

Tying a loop in a line goes very fast, but creating a loop around an object is the difficult part. Yes it possible (see figure 4.8), but there are easier alternatives.

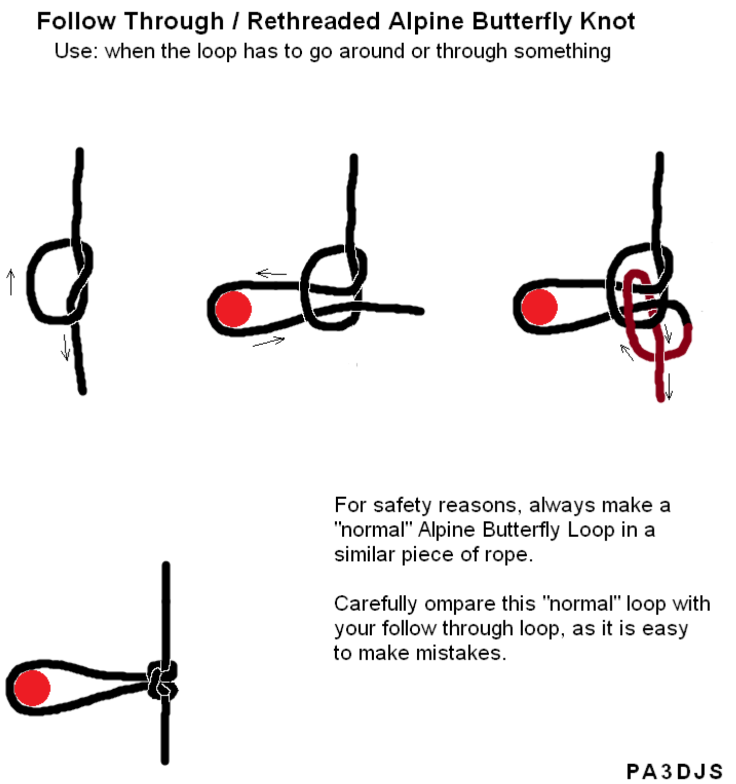


Figure 4.8, "follow" through method for (alpine) butterfly knot

As the drawing shows, it is not a real follow through, so therefore difficult to carry out.

4.2.3. Overhand, figure 8 / 10 on a bight

Figure 4.9 shows the figure 8 on a bight.

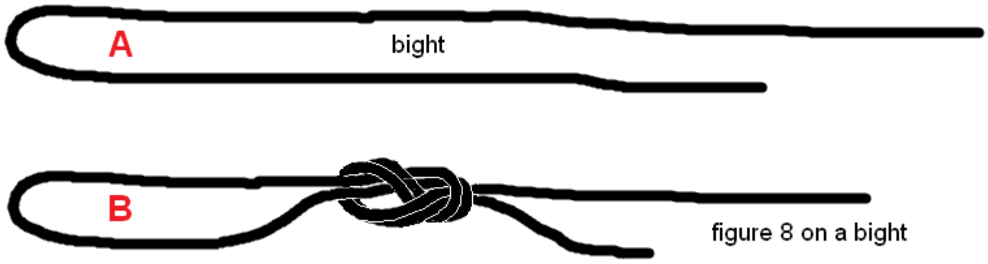


Figure 4.9, Figure 8 on a bight

Start by making a bight (figure 4.9.A), and then make a figure 8 with the ropes in parallel if it were a single rope. Best is to keep the two ropes parallel during tying the figure 8.

When you want a short knot, use the overhand or 2x2 overhand knot (figure 4.2). Use the figure 10 if you really need the strength.

The dressing is as used within Rope Access. Note that though bulky, the figure 10 unties easier then the figure 8. Figure 4.9.1 shows a photo of the overhand, figure 8, 9 and 10, all on a bight to form an eye/loop. The two ropes are always parallel, also when you look on the backside (not shown here).

Figure 4.9.1, Overhand, figure 8, 9 and 10, all on a bight

For the overhand knot on a bight (most left), there is a strength difference between loading the left or right standing end, but it depends on the type of rope and material.

Most research is done using kernmantle climbing rope and accessory cord by the big rope manufacturers (Edelrid, Mammut, Beal, Marlow, Samson, Tendon, etc) and safety institutions. You can't extrapolate these results to other rope and diameters.

Strength of the terminations in 10.5 mm static rope (Nylon, LSK rope according to standard EN 1891)

Overhand; 50%
Figure 8: 60%
Figure 10: 70%

When the knot fails, the load carrying end (standing end), breaks near/in the knot. The loop itself seldom breaks, as load onto the loop legs is only half. When the bend radius of the anchor (that is in the loop) has D < rope diameter, or is sharp, the loop may break first.

4.2.4. Overhand, figure 8 / 10 follow through / retrace method

You need the rework the working end through the knot when you can't put the loop over the object (such as a bar in a fence). See figure 4.10.

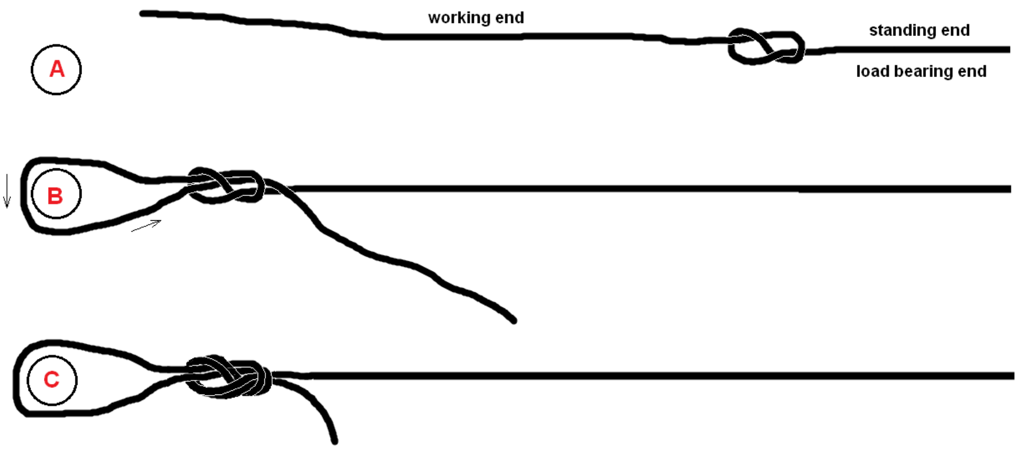


Figure 4.10, Figure 8 using retrace / follow through

A figure 8 is relatively easy to retrace, but a figure 10, is hard to retrace. The "wrong figure 10" is even more elaborate to retrace. It is easy to make a mistake during the process.

4.2.5. 2x2 overhand on a bight

It is not a very well-known knot. The knot is shown in figure 4.2 E and F. It is easy to tie, but not easy to dress. "on a bight" dressing is even more elaborate. Inspection is also elaborate as you can't follow the rope strands as in a figure 8.

The knot works very well for eye terminations using Dyneema together with a sleeve. It doesn't slip, even with a thick sleeve to increase efficiency (figure 8 and 10 slip!). Tests with thin Dyneema (for kites) show knot efficiency >70%. The reason for reasonable efficiency is that the minimum bend radius is larger compared to a figure 8 or 10.

For those who want to experiment with the 2x2 overhand on a bight, see annex 5.

4.3. Bends and endless loops

There are two classes of knots for bends

1. Bends based on Specialized knots (zeppelin, butterfly)
2. Bends based on follow through knots (Flemish bend, water knot).

4.3.1. Follow through / retraced bends

Many knots can also have their "follow through bend" version, also called "retrace bend".

Figure 8 bend / Flemish bend

See figure 4.11 for the procedure for the figure 8 knot.

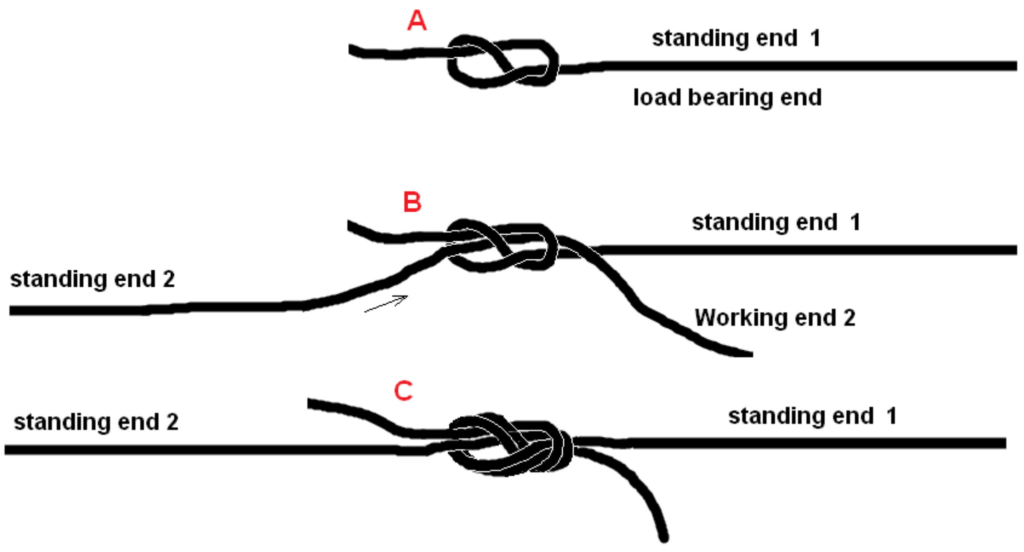


Figure 4.11, Follow through procedure for figure 8

You start with your favorite knot (here a **figure 8** as shown in the A figure). Now push the other rope into the knot where the tail of standing 1 one comes out of the knot. You really go back in. This is shown in figure 4.11B.

Now completely work rope 2 back through the knot so that working end 2 comes out of the right side of the knot parallel with standing end 1. Dress the knot and tighten all rope that leaves the knot. In this case: two standing ends and two tails. Make the tails > 10 rope diameters long.

The **figure 8 bend** is frequently called **Flemish bend**, or reversed traced figure 8
The **overhand bend** is normally used for webbing and is called **water knot**
The **figure 10 bend** is just called **figure 10 bend**, or reverse traced figure 10 (but is never used).

The knot efficiency of the bends is about equal or somewhat less then their corresponding eye/loop terminations provided it doesn't slip. So think of about 50% for the overhand, 60% for the Flemish bend.

> Note that a certain knot on a bight to form an eye termination in Dyneema rope, will very likely slip when used as a bend.

The figure 8 is thé standard knot in climbing, as it is easy to remember, easy to inspect and easy to tie. Therefore the figure 8 bend (Flemish bend) is also used (together with the Alpine Butterfly bend). When heavy loaded (hard falls), the figure 8 is difficult to untie.

The figure 10 is not used as a bend in real world.

Follow through 2x2 and 3x3 overhand bend
The **follow through 2x2 overhand bend** gives a very short bend that has at least the strength of the Flemish bend, but is also hard to untie. It is seldom used, as it is easy to make an error during retracing.

The **follow through 3x3 overhand bend** is a very fat short bend that is somewhat stronger then the 2x2 overhand bend. It is seldom used because of the elaborate retracing and dressing. You need some tools to have consistent dressing. The strength of the 3x3 overhand bend is about 25% (not percent points) higher then the double fisherman's bend (absolute about 75% of MBS for Nylon). It doesn't slip when using Dyneema, and that is the only advantage.

Double and triple follow through overhand bend
One can also retrace the double and triple overhand knot, resulting in a **follow through double or triple overhand bend.** Figure 4.11.1 shows an example of a **follow through triple overhand bend**.

Figure 4.11.1, Follow through triple overhand bend

It is a neat looking bend. The follow through overhand bends are about 10% stronger then their equivalent fisherman's bends. When using Dyneema, the slippage risk is only slightly less (for the retraced bends). Tying and dressing is difficult compared to the fisherman's bends. Therefore the use of follow through overhand bends is very limited.

4.3.2. Alpine butterfly bend

See text starting around figure 4.6. It is not the strongest, but it is easy to untie, even after heavy loading. Leave tails of about 20 rope diameters.

4.3.3. Zeppelin bend

Safest way is to use the 69 method. It is shown in figure 4.12.

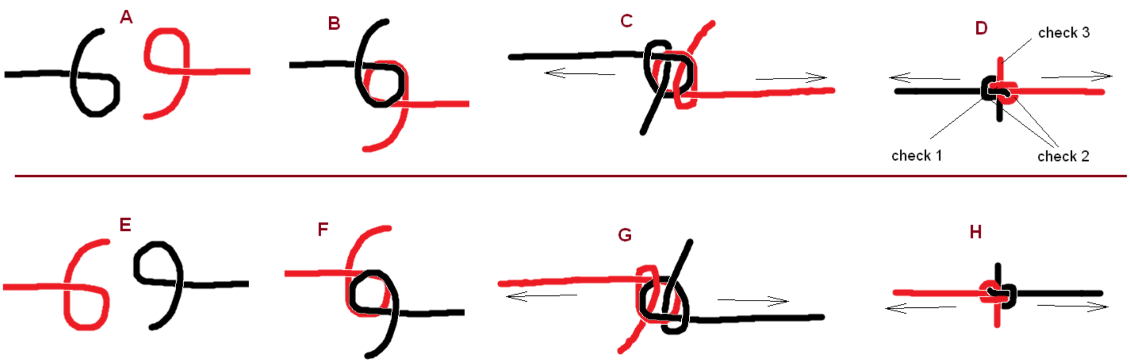


Figure 4.12, zeppelin bend

When you put the 6 on top of the 9, the working end of the 9 is below the loop and the working end of the 6 is above the loop. The working ends don't touch each other in figure B and F.

When using the 69 method, it can't go wrong, or you get something that is completely different. When you encounter a zeppelin bend, do the three checks: The tails leave at 90 degrees, one of the bridges goes under a standing end, and one goes over a standing end.

As with all easy to untie knots, they may work loose during repeated dynamic load. Leave long tails (about 30 rope diameters). You may add stopper knots (2 turn overhand knot). This stops the bend from “eating” the tails.

The problem with this bend is that it is mostly used as a bend only. When you don’t use it often, it may be difficult to remember (compared to the figure of 8 bend (Flemish bend)). This can be a safety issue. This knot slips heavily when using Dyneema. As an indication, knot efficiency <20%.

(semi) double Zeppelin bend
The standard Zeppelin bend has 1 turn in each standing end (that is the 6 or the 9). It has 1 turn in each tail / working end that goes through the turn of the 6 and 9. You may call this a 1x1 Zeppelin bend.

You can also have an additional turn in the 6 and the 9. In that case you have two turns in each standing end: a 2x1 Zeppelin bend.

One can also add the additional turn with the working ends around the 6 and 9. Then you have a 1x2 Zeppelin bend.

The versions that have an additional turn in the standing end OR the working end are **semi-double Zeppelin bends.** The semi-double bend has therefore two varieties.

When there at two turns in both a standing end, and a working end, it is a 2x2 Zeppelin bend. This is called a **double Zeppelin bend**. The double Zeppelin bend may hold when using Dyneema, but test thoroughly.

The double Zeppelin bend is easier to tie and dress then the 2x2, or 3x3 overhand bend.

4.3.4. Fisherman’s bends

These are based on 2 overhand knots with varying number of turns. The double fisherman’s bend (2, 2 turn overhand knots) is hard to untie. The triple fisherman’s bend and the version with more turns are near impossible to untie when heavy loaded. These bends are used for permanent connections. You see them mostly used in endless loops (Prusik loops).

Note that fisherman’s bends may slip when using 100% Dyneema. A triple fisherman’s bend slipped at 35% of MBS using 1.1 mm thick Dyneema kite line. This wasn’t expected.

Figure 4.13 shows the procedure for the double fisherman’s bend.

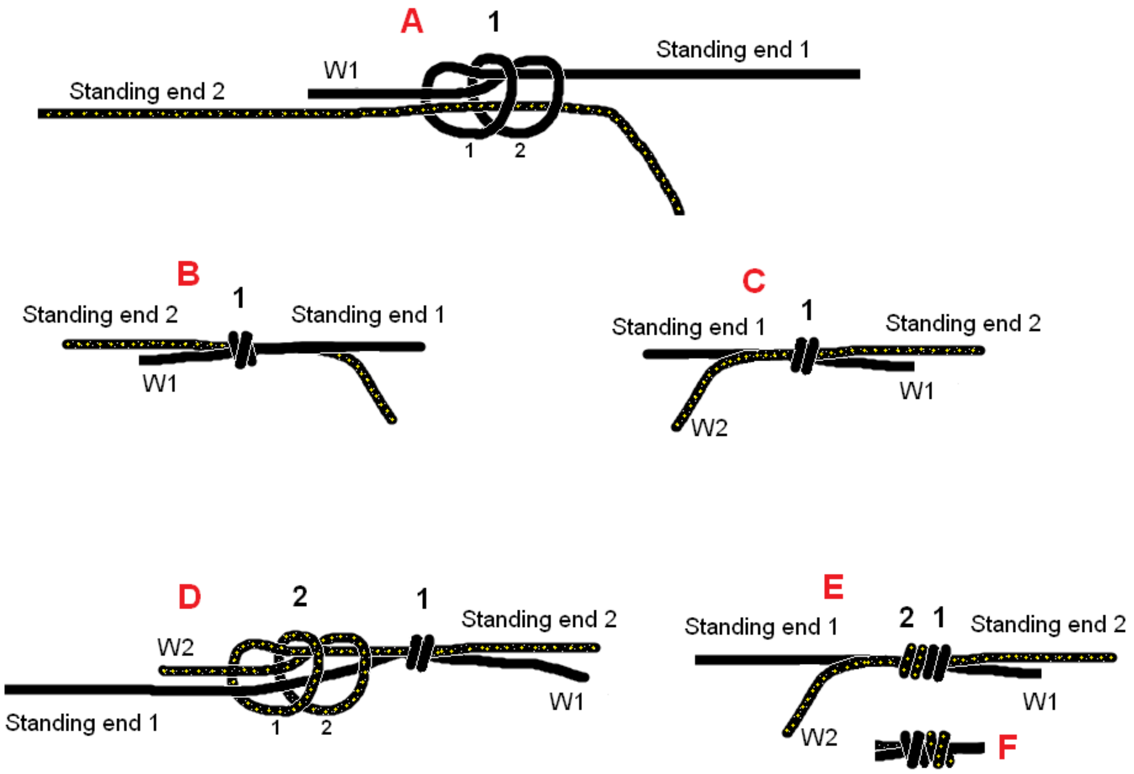


Figure 4.13, double fisherman's bend

Bring the two rope ends (standing end 1 and standing end 2) to each other. The rope with standing end 2 has markings to reduce confusion.

Figure 4.13A Make a barrel knot with 2 turns around the marked rope. Check that two turns pass over: standing end 1, standing end 2, and W1 that you pushed through the turns.

B-figure Tighten the barrel knot so that you don't lose a rope, or that barrel knot 1 comes apart.

C-figure Flip the rope ends so that standing end 1 is now on the left and standing end 2 is on the right (check the markings). Check that the rope end that you use for the second knot can move in the first knot. The first knot can slide over the marked rope.

D-figure Make a 2-turn barrel knot with W2 (marked rope end) around standing end 1 in the same way as you made the first knot.

E-figure Tighten knot 2 and pull on standing end 1 and 2 so that the knots move to each other.

You can view the knot from two sides. One side has 4 parallel "stripes" (E-figure). The other side has two crossings (F-figure). Keep the tails (W1 and W2) about 10 rope diameters long.

With 4 or more turns the fisherman's knot can be used to make a bend for Dyneema, It becomes elaborate to dress and set well. Test the bend thoroughly.

4.3.5. Sheet bend and related bends

This is very simple bend that works well when using natural fiber rope, but it is unreliable in synthetic fiber rope for both static and dynamic loads. It slips and/or comes loose.

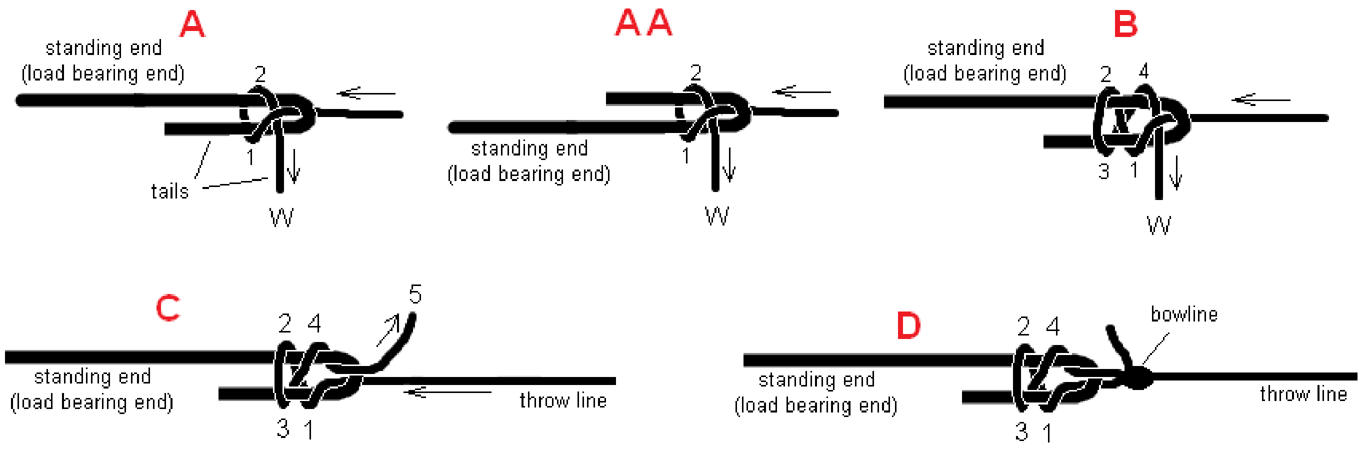


Figure 4.14, Sheet bend and variations

The **sheet bend** is shown in figure 4.14A. The drawing is such that the geometry is good to see (it is not tightened yet). The two tails are on the same side.

You make a bight from the thickest rope, with the tail closest to your body. The other line you push upwards from the underside into the bight. Finish with a half hitch where the working end (W) points towards you. The tails are on the same side now.

> Just for your curiosity: compare the knot of the sheet bend and the bowline, they are the same!

Figure 4.14AA shows the **left hand sheet bend**. Though literature says that this version is less reliable, suggesting that the A version is reliable. Both are not reliable using synthetic rope. Make sure to have long tails (much longer then in the drawings).

Modified sheet bend (not a double sheet bend)

A far better, but little more bulky version is shown in figure 4.14B. It is not the double sheet bend. The double sheet bend is hardly better then the normal sheet bend.

The modified sheet bend adds an additional turn left of the original bend. The numbers help you to understand the geometry. When the rope diameters are unequal, make the bend with the thinnest rope

The extra turn outside the original bend makes a very reasonable bend that is easy to untie and doesn't slip in PA/PET/PP rope.

Modified sheet bend for main line pulling in a tree canopy or over a roof
When you want to suspend an antenna between trees, you need an anchor point in the tree. This is mostly done by throwing/shooting a thin line over the intended branch. A thick line is then pulled over the intended branch via the throw line.

The bend in the figure 4.13D has less risk of jamming into the tree's canopy.

How to tie it?
See figure 4.14C. Start with a bight and feed the line into the bight from the underside. Follow the numbers 1 to 5. When going from 3 to 4, the throw line goes upwards through the bight.

When arrived at 5, pull it tight, so that the bight closes. Then tie a bow line at about 1..2 diameters from the rope (figure 4.13D). The main rope is now "protected" on both sides. This avoids that branches go in between the throw line and the main rope (as can happen with a (modified) sheet bend).

4.3.6. Bend using two eye rope terminations

Sometime you already have a rope with an eye termination that needs to be extended for some reason. An easy way is to see the eye as an anchor point and run a line through it and make a follow through loop (or a bowline when acceptable). This puts lots of stress onto both eyes due to the small bend radius of the rope. This simple method is not recommended.

Better option
You may feed the extension line through the black eye as shown in figure 4.15. When you load the eyes, the interconnection between the eyes look like a square knot.

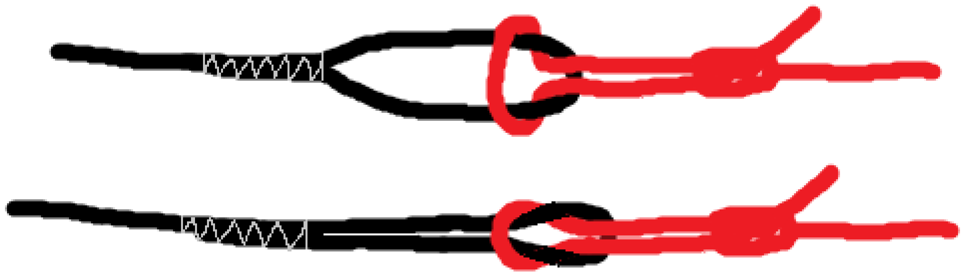


Figure 4.15, Bend using two eye terminations

The two eyes that interlace via the square knot, are stronger then a figure 8 on a bight. So when testing to destruction, the red rope right of the knot will break inside the figure 8 knot. The overall strength of this bend is therefore mostly limited by the knot that you use to make the (red) loop/eye. This method is also called "cow hitch connection". This is a bit strange as the dressing is like a square knot.

4.3.7. Endless loops (Prusik loops)

Just make a bend in a single rope, and you have a Prusik loop. The most used bend for loops out of accessory cord is the double fisherman's bend or triple fisherman's bend. Make sure to have tails of > 10 rope diameters. The water knot (retraced overhand bend, NOT an offset overhand bend) is used frequently used for slings out of webbing. Use long tails.

4.3.8. Bend using two clove hitches

When you are (very) familiar with the clove hitch, you can make a bend using two clove hitches. The concept is shown in figure 4.15.1A. It is a rather unknown bend, but easy to tie when you know the clove hitch.

Figure 4.15.1, Bend using two clove hitches

One would expect this bend to be unreliable, but it is not. The second half hitches of both clove hitches are on the inside (they "see" each other). So when pulling the standing ends (left red and right green end) the clove hitches are compressed together, as can be seen in figure 4.15.1B.

When you make one of the inside half hitches using a bight, you create a semi-releasable knot.

Though this bend is relatively easy to untie, the Zeppelin bend unties even more easily, and is slightly stronger. The clove hitch bend is easier to adjust.

4.4. Sliding loop knots / nooses

Sliding loop knots, mostly called nooses, are loop knots, but under load the loop constricts around the anchor point / object. There are sliding loop knots that slide very easy and that slight difficult (on purpose).

4.4.1. slip knot / overhand noose

The slip knot is the most simple, very simple to tie noose, but not very reliable when using synthetic fiber rope. Figure 4.16 shows the procedure.

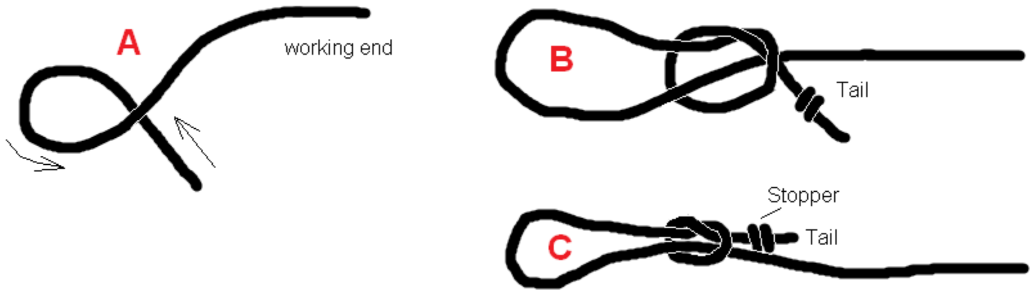


Figure 4.16, overhand slipknot

You start with a loop (A-figure) and push a bight through the loop (B figure).

Tighten the overhand knot and add a stopper knot (2 turn / double overhand knot) to avoid that the overhand knot "runs off" the tail.

Remember that you push the load bearing end through the loop. Yes this is a bit strange, you make the slip knot with the load bearing end.

> Even with the stopper, there is a change the stopper is sucked into the overhand knot resulting in failure. DON'T use it for critical applications.

The overhand loop knot / slip knot is also used as a stopper knot, but then the other end is used (**Ashley stopper knot**).

4.4.2. Running eye termination sliding loop

Figure 4.17 shows two version.

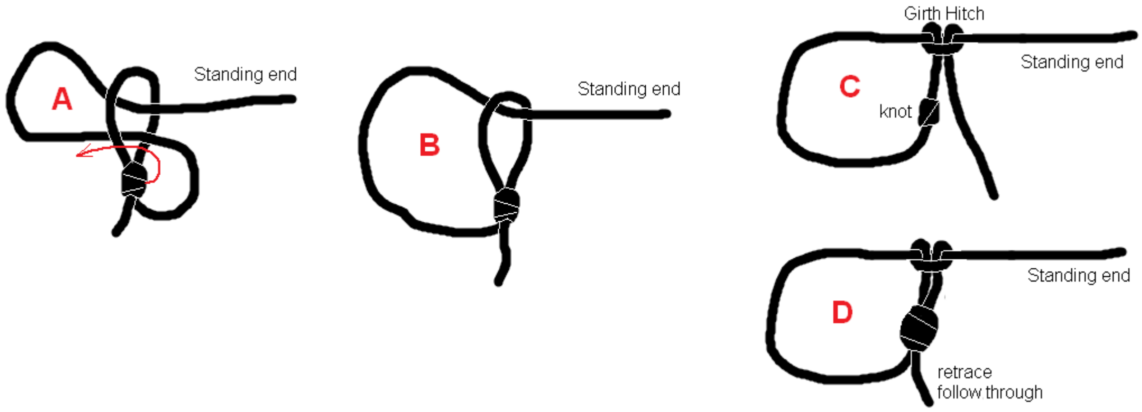


Figure 4.17, slipknots with eye terminations

First make your eye termination. The loop should be larger then the size of the knot as the knot needs to pass through the loop.

Push a Bight through the loop as shown in figure 4.17A. Now work the knot through the loop (red curved arrow) so that you arrive at the B figure. This is a slipknot that slides very easy.

When you want some more friction, use the **girth hitch** (**lark's head**) version. It is shown in figure C and D.

First make a knot in the line. You need that to make a follow through / retrace loop.

Make a girth hitch (wrong tied clove hitch) around the standing end (C-figure). Then retrace the tail through the knot to make the eye termination.

When you have access to the end of the rope, you can first make the eye termination using "on a bight" procedure. Then form a girth hitch in the air, and push the rope through it. With a 50 m long thick wet rope this may not be the best option.

4.4.3. Double overhand noose, multi turn overhand noose

High friction loops use barrel knots (multi turn overhand knots) that can slide along the standing end. The **Scaffold knot** is well-known. It uses the 3 turn barrel knot around the rope itself. The more turns used for the barrel knot, the more friction. When using 2 turns, the basic name is **double overhand noose**, also known as **poacher's knot**. The three turn version (as in figure 4.18) is the **triple overhand noose / knot**, mostly called **scaffold knot.** The basic names describe the geometry of the knot, avoiding name confusion.

It should be noted that the 2 turn overhand noose is also called (incorrectly?) scaffold knot.

More turns requires you to manually tension the turns. Just pulling on the working end or the loop itself, doesn't tighten all turns in a multi-turn barrel knot.

The scaffold knot / triple overhand noose is shown in figure 4.18.

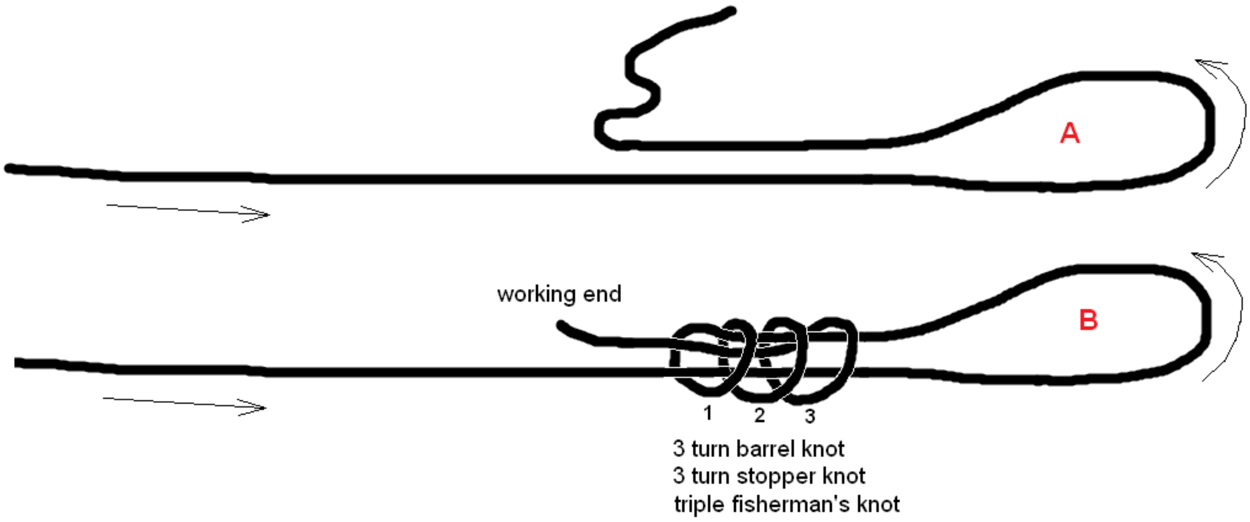


Figure 4.18, 3 turns scaffold knot

You start with a bight with sufficient excess rope as the knot “consumes” lots of rope (A-figure). Then wind the 3 turns towards the loop and feed the working end through all turns (here 3), see the B-figure.

Before tightening the knot check that the 3 turns go around the bight itself (two ropes) and the working end.

This knot/loop is frequently used to connect a rope to a carabiner, for example to make a safety lanyard. Once you have loaded the loop, it constricts around the carabiner, so you don’t lose it.

It is also very useful when you want to connect a securing rope to a tool. Instead of a single turn around the handle, you apply 2 to 3 turns around the handle (for example a hammer), and use a 3..4 turns overhand noose. When having the opportunity, make a hole in the handle, as that is of course safer.

Important note to the scaffold knot (climbing / fall protection application).

> You, or somebody else, can make it wrong. When tightened it looks the same as the correct knot, but when you load the standing end, the loop opens and the working end is pulled through though the barrel knot, resulting in full knot failure and/or loss of life.

4.4.4. Sliding loops terminated with half hitches

They also create a loop that constricts under load, but its purpose is completely different. They are tied around an object, frequently when the standing end is (partially) loaded.

Frequently you want to tie a rope to an object. You may even want some pretension. Making barrel knots or eye terminations is not the way to go in that case. Using the **single turn with 2 half hitches** or the **round turn with 2 half hitches** is a very efficient solution. The loop around an object with 2 half hitches is one of the knots I used most often, but I always add a third half hitch as backup

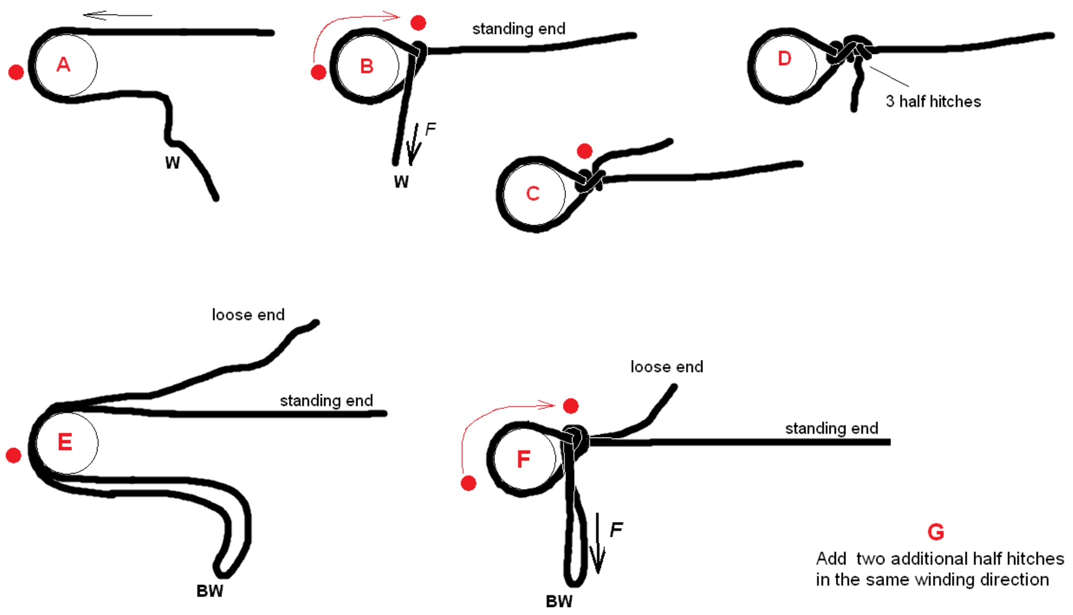


Figure 4.19, (round) turn with two half hitches

Figure 4.19 shows the procedure (single turn with two half hitches)

A-figure
Loop the rope around the pole as shown in the A-figure. Tension it and keep tension by pressing the rope onto the post with one hand (red dot position). Now you have your other hand free.

B-figure
Make a half hitch and keep tenstion (F) onto the working end (W). This redirects the standing end somewhat. While keeping tension (F) onto the working end W, move your other hand to the new red dot position and grab the half hitch so that it doesn't undo itself.

C-figure
While holding the first half hitch, tie another half hitch in the same winding direction as the first one. This makes a clove hitch. Tighten it well.

D-figure
Though the knot is now a single turn with two half hitches (clove hitch), the half hitches are not secure enough. Tie another half hitch in the same direction. You have 3 half hitches now. Pull onto the working end so that the half hitches have good grip onto the rope.

When putting two turns around the pole in the A- or E-figure instead of one, you get the **round turn with two half hitches**. The advantage of the two turns is that you can keep more tension onto the standing end and the hitch doesn't slide along the pole. As with the single turn hitch, always add an additional half hitch when making a round turn with two half hitches.

Alternative method for loops with half hitches

When having a long rope where you have a very long working end, there is an alternative method using a bight. As a bonus, this method puts less stress onto the rope as the bending radius is a bit larger. It is also easier to untie when the hitch is heavily loaded. The procedure is almost the same as for the standard (round) turn with two half hitches, except that you use a bight as working end.

E-figure

Form a large bight and wrap the bight around the pole. The bight will now be the working end (BW). When you need significant tension in the standing end, you may use two turns (instead of one as in the drawing). When you apply two turns with the bight, it becomes a round turn. Apply pressure at the red dot to keep tension in the standing end.

F-figure

Make a half hitch around the loose end and standing end.   Keep tension on the bight and move your other hand to the half hitch. Grab it firmly so it doen't slip.

G-text

Add two additional half hitches in the same winding direction.   You may wind them around both the standing end and loose end.

For both versions, you are free to wrap 3 or more turns around the pole.

Even with 3 or 4 half hitches, the hitch slips at relative low percentage of MBS when using Dyneema rope.

5. Friction hitches

5.1. *Introduction*

The friction hitch is a special type of hitch. A friction hitch is tight around an object (post, rope, leg, etc.). When the rope bearing end(s) are lightly loaded or unloaded, you can move the hitch along the object. However when it is loaded, it won't move anymore, it grabs/locks itself onto the object. The load is mostly parallel to the length axis of the object. The grabbing occurs because of constricting of several turns or braids round the rope or object.

Friction hitches are as old as rope itself, and were "reinvented" frequently. First applications were in sailing, hoisting, mining and climbing.

Though there are mechanical alternatives, friction hitches are still used in climbing (mostly the **Prusik hitch**) and tree maintenance (Distel hitch, VT hitch, Schwabisch Hitch, etc). They are very light weight and relative cheap.

People involved in Rope Access prefer mechanical devices with similar function. Mechanical devices eliminate certain human errors associated with tying friction hitches, have predictable behavior, and generally work faster in a Rope Access setting.

Friction hitches are also used during camping and other outdoor activities (think of tent guy wire tensioning, or tensioning of covers / tarps).

The rope/cord to make friction hitches in climbing is called "Prusik cord" or "hitch cord". So called "Accessory Cord" is used frequently. I prefer 7 or 8 mm for life support application. Most manufacturers specify an MBS in the range of 1200 kg for 7 mm cord out of PA or PES (PET). It can also be made out of blends (mostly with Aramid fibers).

There are tens of friction hitches. They mostly differ in small details. These details can be of major importance when your life depends on them. Why there are so many friction hitches? Good functioning of a friction hitch depends on:

1. diameter of the post or rope (where you tie the hitch onto)
2. diameter and properties of hitch cord. Flexibility and sheath material is of importance
3. Surface finish of the object in case of rigid objects (posts, bars, etc).
4. Application (rappelling, frequent loading/unloading, lifting)
5. Not directly related to good functioning, how easy is it to tie, and how easy is it to inspect?
6. Not directly related to good functioning: user's preference.

So a hitch that is perfect for a certain application showed on a YouTube video may be bad for your application. So experiment with various hitches and see what works best for you.

If you plan to put your life onto a friction hitch, you should be well trained / instructed. You must test your hitches well so that you are sure they work when they need to work. You must be your own devil's advocate. Testing means not just pulling to see whether it grabs, but you need to load them fully to check for slippage, and to readjust due to prusik cord stretch.

Friction hitches can fail, so if your life depends on it, it is really advised to have a backup system. Friction hitches should not be used when significant shock load can occur.

There are 3 types of friction hitches:

- Hitches that rely on parallel turns (like the turns of a single layer coil) around the object, such as: Prusik, Distel, Schwabisch
- Hitches that rely on a braid. These are not common in climbing as they do not work well on rope. In industry cable socks (cable pulling grip socks) are an example of braided friction hitches.
- Hybrid hitches that both contain a section with turns and a section with braid. Examples are the VT and XT hitch (arborist use).

Besides turns or braid, a hitch can have a single rope end that carries the load, or two or more rope ends.

Braided hitches using several rope ends put the lowest stress on the object. It is the second reason cable socks are used to pull cables. A hitch with one rope supporting the load puts most stress on the object. See figure 5.4 and 5.4 for the difference between single rope end and double rope end.

Cable socks for cable pulling have generally 4 or more rope ends that combine into a single point.

5.2. Rectifier hitch / diode hitch

This is a hitch that passes rope in one direction only. Most hitches slide a bit when you apply the load (backlash, sit back). See it as reverse recovery charge in slow rectifiers. That is annoying when used in combination with a loop that you use to tie things together.

The rectifier hitch is based on the basic principle of nearly all friction hitches (rope turns around the object [here the rope itself]), but it operates in the reverse direction. The hitch is shown in figure 5.1.

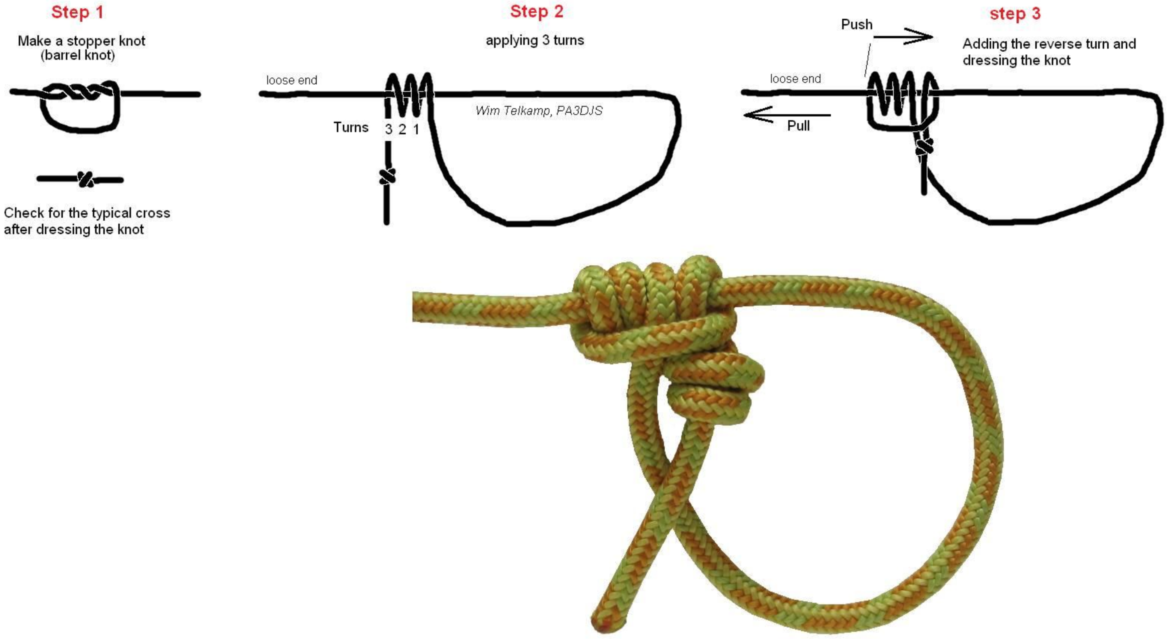


Figure 5.1. Rectifier Hitch

How to tie the hitch
First make a 2 turn overhand stopper knot as shown in step 1. Make sure to dress it well so that you see the crossing on one side, and parallel rope on the other side.

Wrap three turns around the loose end (step 2).

Pass over the loop and make a half hitch (step 3). You need to pull on the down going rope (part of the loop) to get the geometry as shown in figure 5.1. You also need to do this to make sure the hitch “bites” into the rope.

When using natural fiber rope, two instead of 3 turns may be sufficient.

How to use it:
When you want to tighten the loop around objects, you need the same procedure as with a plastic cable tie / tie wrap. You pull on the loose end, and push onto the third turn of the hitch. When you stop pulling, the loose end will not get back into the loop (zero backlash). A cable tie has less friction, therefore you need to push relatively hard onto the hitch when pulling the loose end.

Recommendations
The hitch works best with braided rope, or kernmantle rope with a loose woven braid. Rope with very tight woven braid doesn’t work (the loose end will slip into the hitch after tightening).

When you have very slippery rope, you may need 4 turns (this seldom happens). The hitch doesn’t work with Dyneema. PET/PES or PA accessory cord, or similar rope from DIY stores, works very well.

NOTE

When the hitch is not tensioned, and you wiggle with the rope, it may loosen itself. If so the stopper knot may pass under the bridge (that connects between the left and right side) resulting in failure of the hitch.

When wrong used, the hitch may more or less capsize. It retains its strength, but it will not slide anymore.

When very small backlash (about half a rope thickness) is acceptable, and the hitch has to be moved frequently a hybrid friction/barrel hitch is good alternative. See annex 6 for instructions how to tie the hitch.

Applications

Where you can use a cable tie, you can use this hitch. As rope is very flexible compared to cable ties, you can use it for more applications. By grabbing the complete hitch, you can move the rope in the other direction (the rectifier stops blocking temporary). So you can readjust it.

Think of:

- Vertical positioning of objects that you need to fix with other means
- Holding together several objects (as you would do with a cable tie)
- Tensioning of guy wires (reverse the hitch). Carefully check operation!
- Permanent fixation when you impregnate with epoxy resin (or other suitable resin).
- Adjustable foot loop (not safety related) when climbing, similar to an old school Blake’s hitch. The hybrid barrel/friction hitch has preference (see Annex 6).

5.2.1. Example, Guy wire tensioning

When you want the loop as a guy wire tensioning system, the three turns must be inside the loop and the half hitch is outside the loop. It is like horizontally mirroring the hitch (but not the loop). The loose end has tension and goes to the mast or tent pole. The loop goes around a fixed object. This can be a tent peg/stake. Carefully check correct operation!

The “mirrored” hitch is a variation of the taut line hitch.

5.2.2. Example, fixation of open wire line

Picture 5.2.1, shows a photo of a parallel wire transmission line section that is part of a wide band directional antenna for gain measurement. The spreaders are the rectangular FR4 pieces with a hole in it. The conductors were positioned with rectifier hitch loops out of 0.5 mm nylon rope, and then impregnated with epoxy resin. This shows where these simple loops can be used for. The supports are fixed to the mesh reflector using the black wire loops, with rectifier hitches.

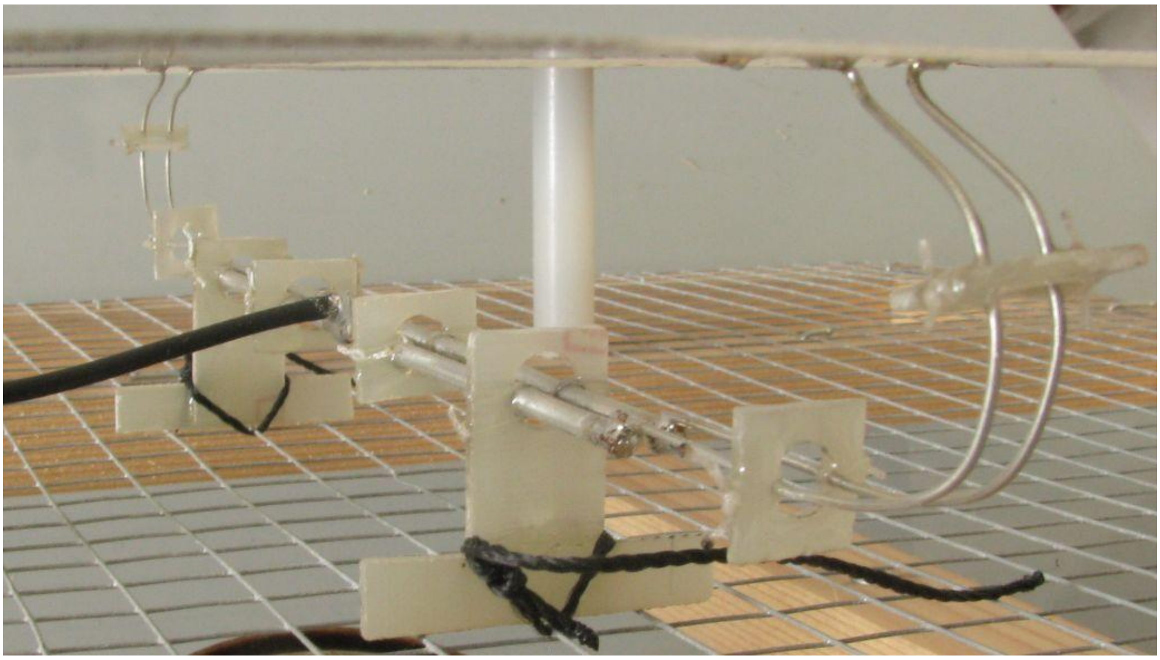


Figure 5.2.1. parallel wire transmission line

5.2.3. Example, Simple lashing with rectifier hitch

A very simple lashing is shown in figure 5.2.2A. You can use these for fixing the elements of a 70 cm or 2 m yagi onto a round or square beam, or making open wire line. The rope goes around the horizontal and vertical round staff. The rope in the A-figure makes a complete pattern. In the world of lashings this is called a “wrap”

Little off-topic, a boom for a Yagi with round cross section has higher rotational stiffness then a boom with a square cross section.

The strength and stiffness of the joint appears after impregnating the rope with epoxy resin (not epoxy glue). Thicker rope gives more strength.

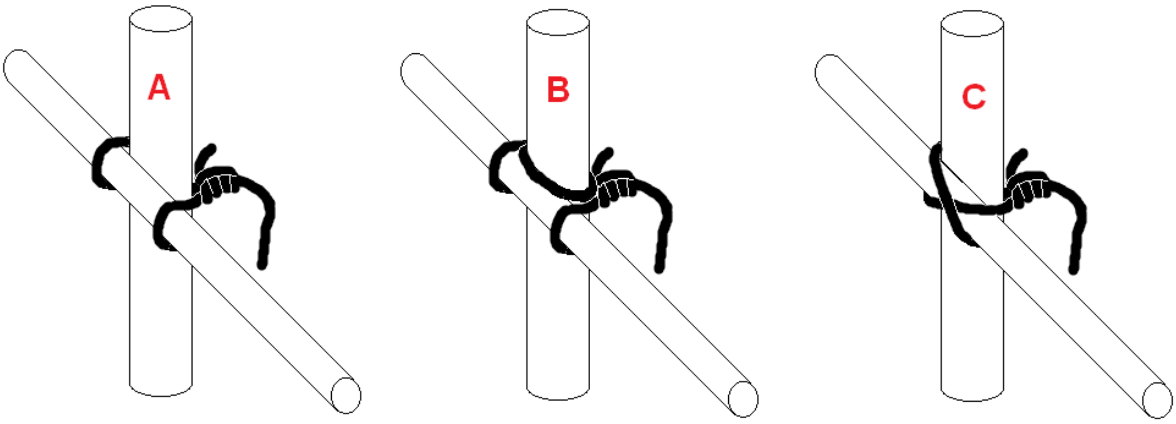


Figure 5.2.2. Simple lashings with the rectifier hitch

Adding an extra turn above and under the vertical round staff gives reinforcement (see the B-figure). These turns lean onto the horizontal round staff.

When having flexible materials (think of stranded copper wire to make an open wire transmission line), you need to make a cross as shown in the C-figure. You can combine this with an extra turn as shown in the B-figure. Make sure that the rope section at the crossing that goes through the hitch passes under. This eases tensioning of the lashing.

The extra turn also avoids unintentional movement. Of course this is only important when the construction is not yet impregnated with epoxy resin. As most epoxies have bad UV-resistance, you need to add a coating after the epoxy is fully cured (read the application instructions of your epoxy).

The strength will further increase by putting rope turns around the 4 wire sections that cross between the vertical and horizontal round staff. These turns are between the bars and are called “fraps” in the world of lashing. This works for the geometry of the A- and C-figure. The extra turn in the B-figure is no longer required when adding some fraps.

For such very simple lashings, polyester rope has preference. The rectifier hitch locks very well, creep is low, and adhesion to epoxy is good. Second choice is nylon (PA), as this is available in DIY stores.

5.3. *Distel hitch and variations*

The Distel hitch has the geometry of a clove hitch (two half hitches), but on the topside there are many turns instead of a single half hitch. The Distel hitch is used by climbers/arborists to have an adjustable lanyard, but is also suited for making termination points to antenna wires without the use of (egg) insulators.

The Distel Hitch is shown in figure 5.3

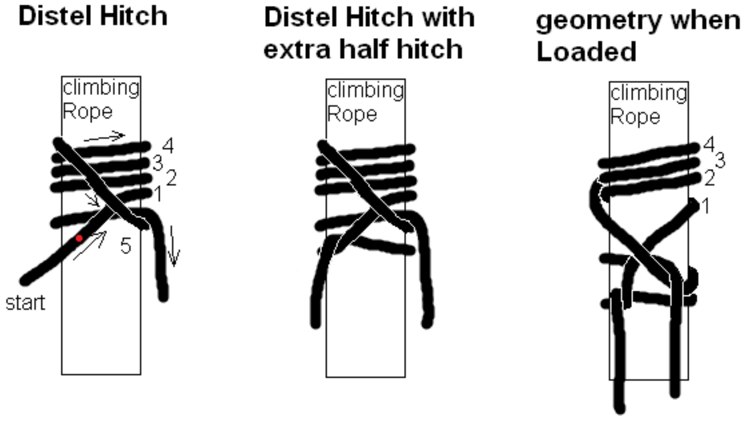


Figure 5.3 Distel Hitch

How to tie the hitch:

The left drawing of figure 5.3 shows the Distel hitch.

Wrap 4 turns around the object (here climbing rope). Then go down to 5 and tie a half hitch below the starting end, and in the same direction as you wrapped the 4 turns.

The load is shared across both rope ends and the load has to pull down. The hitch doesn't work reliable when the load pulls upwards. The hitch may untie itself a bit and then it may slide unintentionally. In a climbing situation this can be avoided by limiting the length of the load bearing rope ends.

When adding a half hitch with the starting end in the natural direction of the rope, the hitch holds better. This is shown in the middle figure. When loading the hitch, it looks like the right figure.

Depending on the object and the hitch cord to tie the hitch, more or less turns (here 4) are required.

A Distel hitch can also be tied using a loop. The two rope bearing ends are then two loops that can connect directly to a carabiner. The load is therefore shared across 4 rope sections. This enables the use of slightly thinner cord. Though locking is better when using slightly thinner cord, risk of slippage at high load increases. Test well!

Support for vertically routed cables
Figure 5.4 shows 4 options to hang a cable onto an object.

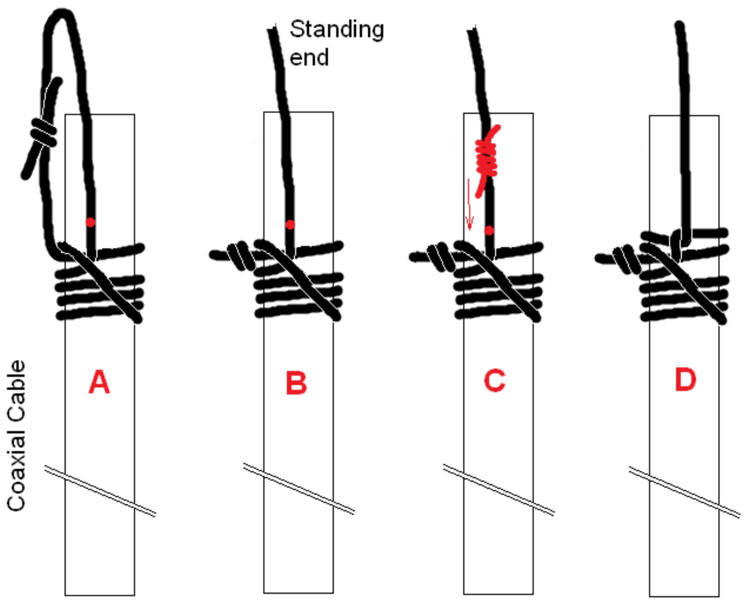


Figure 5.4 Distel Hitch, variations

The A-figure shows the standard Distel Hitch with a loop termination (here with a fisherman's bend).

When you prefer a single standing end, you can use the option shown in the B-figure. When the standing end can become loose in combination with wiggling, the hitch will untie itself and the stopper knot will slip through the Hitch resulting in complete failure. The C-figure shows a (time consuming) solution. Tie a 5 turns barrel knot around the standing end en push it down onto the knot. The D figure shows a faster option. Just tie an additional half hitch in the same direction (here to the right).

4 turns are shown, but likely you need more turns on slippery coaxial cable. Limit the distance between the supports so that the weight per support is limited to avoid damage to the cable (especially cables with foam dielectric).

One can also use a braided hitch (see paragraph 5.5). This can be a faster option when you have excess to an end of the cable.

Strain relief for cables coupled using connectors
It is not good to connect two cables with a female-female adapter and suspend the cables where forces pull onto the connectors.

An option is to tie a friction hitch on both cables behind/below (but not touching) the connectors. Tie the working ends together and move the friction hitches so that the pulling force is diverted to the standing end of the friction hitches. This nullifies the force onto the connectors.

Anchor point on a post (choking anchor)
When you tie the hitch upside down, you can use the standing end as a movable anchor point for other things.

If you plan to use a friction hitch for ascending a post / mast, you can better use a braided friction hitch as this works smoother on hard objects (easier vertical movement, with good locking onto the post). It is also recommended to use a multi-turn barrel knot to avoid loosening of the hitch (figure 5.4 C, the red colored barrel knot).

See paragraph 5.5 for braided friction hitches.

5.4. Antenna wire – Rope connection

Of course you can use egg insulators, but for a light weight construction, you can use a friction hitch. You need very flexible rope as antenna wire has diameter in the range of 2…..5 mm. Loosely braided rope or twisted rope works very well. There is a slight difference compared to the standard Distel Hitch.

Figure 5.5 shows the hitch and some termination methods.

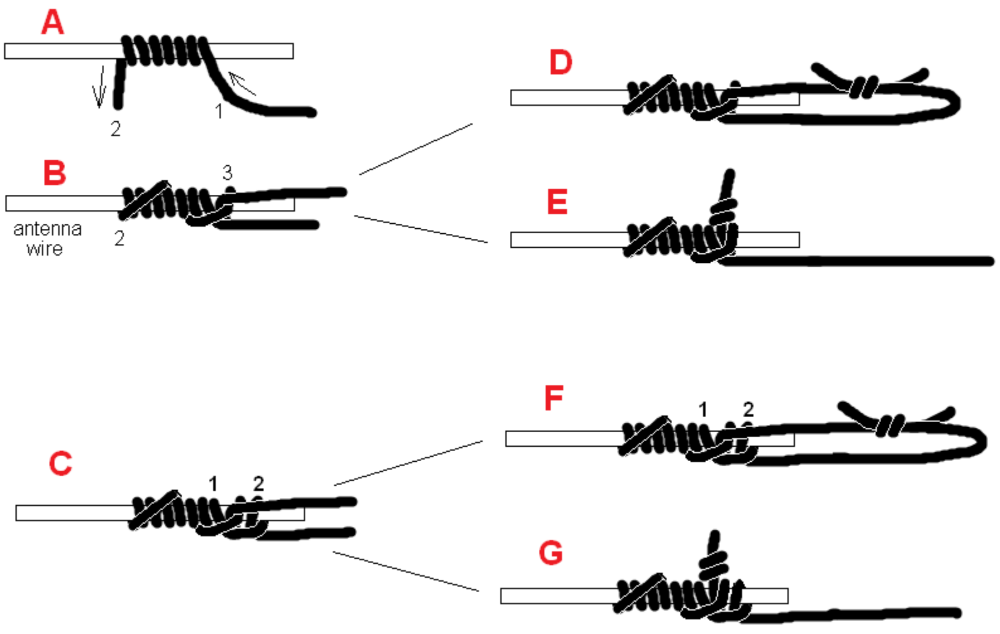


Figure 5.5 Distel Hitch, for thin (antenna) wire

How to tie the slightly modified Distel hitch

A-figure

Your start at 1 and make about 7 turns towards position 2.

B-figure

With the “normal” Distel hitch, you go to position 3 directly and make the half hitch. Now when going towards 3, you make an additional turn that goes over the existing turns (from the A-figure). Tie the half hitch.

C-figure

Adding the extra half hitch reduces the probability of undesired working loose of the hitch when there is no tension on it.

You can finish with the single rope version (E and G figure), or with the double rope loop version (D and F figure).

The double rope versions put less bend stress on the antenna wire, so they have preference.

When a wire antenna (for example a half wave dipole) is suspended, there will be always some tension on the hitches, so they will not slip.

finishing

When everything is fine, remove the tension, and put lots of petrolatum onto the hitch and the first 20..50 cm of rope that leaves the hitch. Heat the rope and hitch with a hot air gun. The petrolatum becomes fluid and soaks into the rope. Then add tension again. The petrolatum (Vaseline) avoids that water/moisture creeps into the rope, reducing wear, and it avoids detuning of certain antenna.

5.5. Autoblock Friction Hitch

The autoblock hitch is normally used as backup device in case of descending (or belaying) using a figure 8 descender. In that application it doesn't have to carry a person's weight. It is shown in figure 5.6.

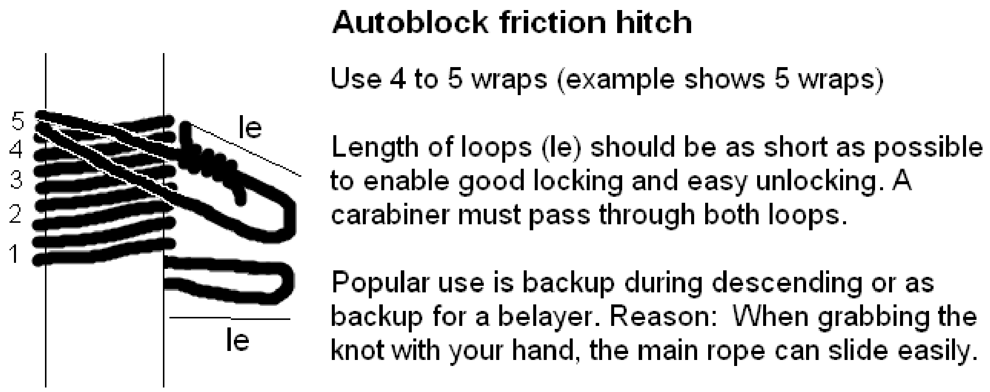


Figure 5.6. Autoblock Friction Hitch

It uses a standard Prusik loop. Some features:

- The turns have twice the advance compared to other common hitches. This reduces its locking performance, and holding power, but it releases very easy.
- It has unreliable locking power for life support situation, unless a tending device is used that keeps tension onto the hitch.
- With insufficient turns, the hitch may slide when heavy loaded. This needs to be compensated with more turns. 5 turns as shown in the figure is the minimum for reliable operation. Depending on the rope/cord combination, you may need 6 .. 8 turns.
- It is a relative long hitch. The cord “grabs” a relative long rope section (large contact area). This reduces rope wear and risk of breaking of the sheath.
- The force is divided over 4 rope sections, so you may use cord with slightly less diameter. This improves locking behavior. When using 7 mm cord, it is like having a 14 mm single rope.
- When given sufficient turns, it can support large load compared to many other hitches. This is due to the force distribution over 4 cord sections and the large contact area with the main rope (or cable).
- For good operation, the length of the loop is critical. The carabiner should sit close to the main rope.

It is very useful if you want to connect something else to a rope that you don't have to move frequently such as a pulley to make a mechanical advantage.

You need more turns then you would use for most common hitches. You may need 5 to 7 turns (so 10..14 total), otherwise the hitch will slip at high load. As with other friction hitches; test the hitch very well. You may need to shorten the loop due to rope stretch after first load tests.

5.6. 3 or 4 turn Hedden Friction Hitch

The Hedden friction hitch is a very simple hitch based on a loop. It is easy to tie, easy to remove, easy to inspect, and believe it or not, it works very well.

The Autoblock locks unreliable when using thick prusik cord, but its holding power when using 6..7 turns is very high. Relative thin cord can be used to improve its locking behavior. Thin cord is acceptable as the load is shared across 4 strands.

The Hedden hitch removes some of the disadvantages of the Autoblock hitch when looking to its features:

- Works very well with thick/stiff prusik/hitch cord, even with low number of turns. It also locks good on solid objects (poles, pipes, etc).
- Its locking behavior is better compared to a Distel hitch and way better compared to an Autoblock.
- Though it looks strange, a 3 turn Hedden hitch has better holding power compared to a 3 turn Prusik hitch. It also releases very easy compared to a Prusik hitch.
- When using 4 turns, a Hedden Friction Hitch used with climbing rated material has > 9 kN slippage/breaking strength.
- When using less turns, the hitch does work, but the sheath will break at lower load. For life support, use at least 4 turns.
- For those familiar with the Klemheist, the Hedden is a reversed/wrong tied klemheist,

The reason for its good locking behavior is because of the load first pulls on the top turn (number 4 in figure 5.6.1). When the lower bight would move down also, it may not lock. When it would move, its behavior becomes similar to that of the Autoblock hitch (that doesn't lock very well).

The Hedden hitch is shown in figure 5.6.1 with 4 turns (so 8 in total).

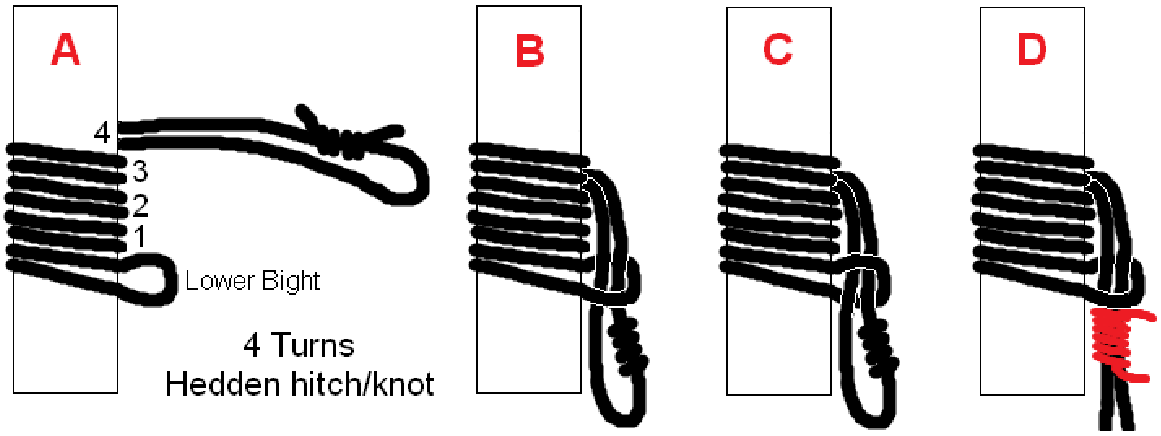


Figure 5.6.1: Hedden Friction Hitch

A-figure

You start (mostly) with an endless loop. Lay 4 turns around the rope. Before you start applying the turns, orient/turn the lower bight so that it is easy to push the bight with bend through the lower bight. The orientation depends on whether you use the version in the B or C figure.

B-, C-figure

Push the bight with the bend through the lower bight. There are two versions as shown in the B and C figure. The hitch in the C-figure is the official version. The official version (C-figure) releases a bit easier compared to the B-version.

D-figure

When left unloaded with near zero weight on a moving rope, it may loosen itself. When that is undesired, a barrel knot just below the lower bight may avoid that. That barrel knot may be useful when you use this hitch as a backup in case of main hitch failure (or user error). Other option is to add a knot. Disadvantage of a knot is that untying after heavy load may be elaborate.

You may have the double fisherman's bend (that makes the loop) above the lower bight. This enables a very small loop below the lower bight for low backlash applications. In that case the double fisherman's bend should be as high as possible. When it presses onto the lower bight when building op the load, the holding power reduces, and it even may not lock. You need at least 4 turns to have sufficient space.

Better is to use a follow through overhand bend, as that is a shorter bend compared to a double fisherman's bend (see figure 5.6.2) Do not confuse the follow through overhand bend with the offset overhand bend.

When you want the hitch to have low backlash / sit back, you may adjust the loop length so that the carabiner is very close to the hitch. This needs experimentation to find the optimum between backlash and ease of releasing. Connecting a carabiner using a girth gives overall better performance (releasing goes better).

The reason is that the load bearing strands remain parallel. This is shown in figure 5.6.2. The left side of picture is normally the top side when the hitch is used as an ascender in combination with a foot loop.

Figure 5.6.2: 4 turns Hedden Friction Hitch with low backlash

The hitch has 4 turns and grabs when pulled to the right. It is made out of 7 mm PA prusik cord formed into a loop using a follow through overhand bend. The thin white cord is used to tend the hitch to the left (when there is tension on the rope on the right side). The white cord goes around the rope and the carabiner so that it lifts the carabiner and the hitch.

When you want to connect something to a rope, and the force direction is known, the Hedden hitch is preferred over the Prusik hitch (paragraph 5.8), as it locks, ties and releases very well compared to a Prusik hitch.

As with all friction hitches, lock and release performance depends on the prusik cord / rope combination.

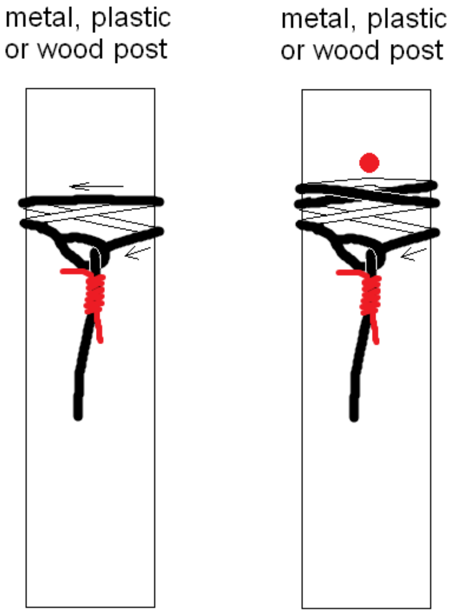
5.7. Braided Friction Hitches

A braid instead of a wrapping of several parallel turns provides the friction. A braid works unreliable on soft material such as ropes, or you need many turns and then it doesn't work fine as a movable friction hitch. A braid works very well on solid objects. A braid requires less turns around solid objects, so adjustment (moving the hitch) goes easier.

A braid also uses turns, but the turns are more or less interlaced.

Figure 5.7 shows an example of a braided hitch with a single rope carrying the load. They are also called "choking anchors".

Braid Anchor Friction Hitch for rope with eye



This hitch is for applications where it needs to be moved and/or removed frequently. For fixed anchors, use the BC-hitch as the load is shared across two rope sections.

The two turn braid hitch (left picture) is simple to tie. Just make two turns and pass the rope (through the loop). Dress the turns so that the crossing is at the backside of the post. Adjust the 6..7 turns barrel knot so that it doesn't slide down when unloaded.

The three turn hitch (right picture) needs some attention as the rope crossings change. The red dot is at 1.5 turns from the loop/eye. You start with the 1.5 turns marking at the back of the post. The rope that arrives from left crosses over the rope that arrives from the right side. On the backside the rope that crossed over, now crosses under. When the loop and long end is on the frontside again, loop the rope through the eye and adjust the barrel knot.

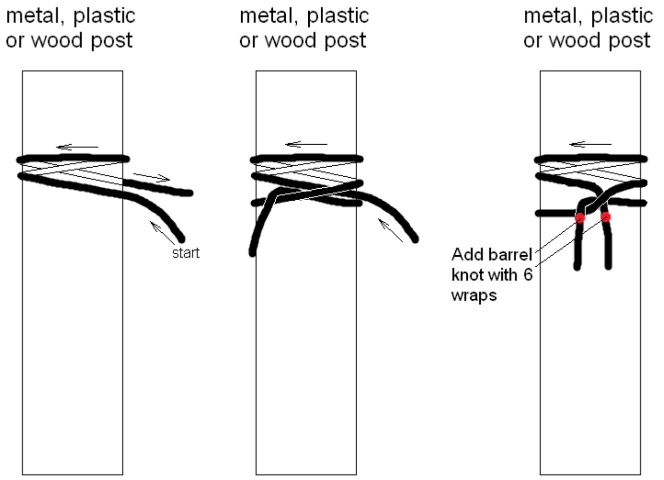
Check the positions of the crossings for reliable operation! You may form the eye into a cow hitch when you don't have the barrel knot.

Figure 5.7, braided hitch with 2 and 3 turns and single rope end

When you look to the right hitch (figure 5.7), there are three full turns. The left hitch has 2 turns. They are arranged completely different compared to a Distel hitch. The turns cross each other, and the crossing changes from under to over and vice versa. The over/under crossings are important to help maintaining the geometry/appearance.

Figure 5.8 shows a version using a top braid and a clove hitch finish (similar to the Distel Hitch clove hitch finish). It has two top turns formed as a braid.

Braid-Clove Hitch (BC hitch) for round rigid objects



This hitch looks like a Distel hitch, but the top turns form a braid instead of a wrap. A braid grips better on a solid object with less turns compared to a wrap.

you start with the top turns (here two turns), and finish with a half hitch below. This creates the clove hitch.

On thin posts/masts with a smooth finish, you may need another top turn. Make sure the rope that crosses on top, passes below at the next crossing (braid property).

As the hitch may loosen itself when moved unloaded, it is highly recommended to add two sliding barrel knots at the legs. Use 6 turns. When dressed, move the sliding knots at the red dot positions. This avoids loosening of the BC friction hitch.

Figure 5.8, 2 turns Braided hitch with double rope end.

The underside of the hitch is equal to the Distel hitch, the difference is in how the top turns are arranged. How do they look like in real world?

Figure 5.9, Braided Hitches with two turns braid

The left photo of figure 5.9 shows the single rope end braided hitch with 2 turns. Note that also the barrel knot is present to avoid loosening of the hitch. Both hitches are used for vertical work positioning (zero slack) and need to be repositioned frequently.

The left 2 turns hitch out of semi static climbing rope also shows a Distel hitch with carabiner and tending ring. This is for work positioning without the need to move the braided hitch around the pole frequently. The loop (left photo) is large enough to pass the carabiner.

The right photo shows the two rope ends version made around a scaffold tube. It is amazing that even with a braid of two turns it grips well on a scaffold tube. Note that now two barrel knots are present.

The ultimate strength of the two rope end version is higher compared to the single rope end version. That may be important in case of hoisting or belaying. These operations give a double load onto the anchor because of two load carrying ropes go down (via a pulley or carabiner).

You may add a third turn in case of a more permanent anchor (for hoisting or belaying). It adds more friction when moving the hitch, but it reduces the likelihood of slowly moving down or up with dynamic loading.

Figure 5.10 shows several variations of single rope end braided hitches as used during Scouting activities.

Figure 5.10: variations of single rope end braided Hitches

The first one (from left) uses the barrel hitch for avoiding loosening. The rope is 10.5 mm LSK “static” climbing rope (to std EN 1891).

The second one uses standard synthetic 8 mm lashing rope with classic look. It has three half hitches. In fact it is a “round turn with two half hitches with extra securing hitch” with the crossing on the back side.

The third one uses also three hitches, but they are made “on a bight” this reduces wear on the rope as the bend radius is larger.

The right version shows a three turn braided hitch using a loop that is formed into a girth hitch to add friction to avoid loosening.

So there are several variations that you can use to create an anchor around a vertical object.

When the braided hitch is for long time on the same place (so moving is not required), one can use the rectifier hitch instead of half hitches or a barrel knot. With the rectifier hitch, it will never ever move as you can add lots of pretension on the 2 or 3 braided turns. This is useful when securing a set of guy wires onto a fiberglass mast.

IMPORTANT NOTE:

> Do not use 8 mm lashing rope in a life supporting application, even if there is zero slack.
>
> 8 mm polypropylene lashing rope has strength of about 10 kN (1000 kg) when new. Natural fiber rope has lower strength. With a knot the strength will drop to 500 kg or less. This gives you (with equipment 100 kg) insufficient margin. In addition the stretch/elongation is significantly less compared to dynamic climbing rope, so with certain slack the shock load will quickly exceed the breaking strength of the rope/knot combination.
>
> A shock absorber will not help you, as it limits a fall to maximum 6 kN (600 kg), so the lashing rope may/will break.

The white rope in the left figure of figure 5.9 is SLK 10.5 mm rope, to std EN 1891, and has MBS > 30 kN. In the application shown, the breaking strength will be > 15 kN (1500 kg). The hitch may slip below that load, but well above the working load.

Alternative
When you are familiar with the Hedden hitch, you may experiment with it. The Hedden hitch holds pretty well on solid objects, and is very easy to tie when having a loop with you.

5.8. *Prusik Hitch*

Virtually everyone who is into climbing knows the Prusik hitch. It is a girth hitch, but then with more turns. Where a girth hitch has only one turn made with a loop, the Prusik hitch can have 4 turns made with the loop. It is shown in figure 5.11A.

The Prusik is fully bidirectional. It works in both directions as it is symmetrical. This may be a safety feature for climbing and fall protection in some situations. The Distel Hitch, and many others, work only well in one direction.

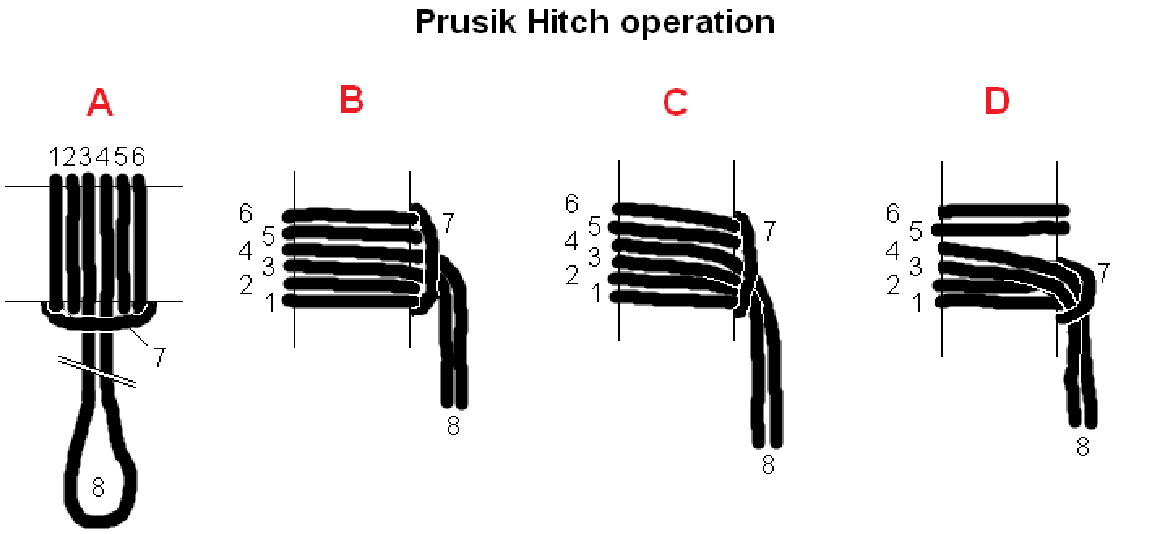


Figure 5.11: Prusik Hitch

To make the hitch as shown in figure 5.11, you need to wrap the loop three times around the rope/pole/etc., and tuck the loop under the bridge (7 in the A-figure). This gives two sets of three turns (total 6).

When increasing the load, it becomes more asymmetrical, as shown in the B-, C- and D figure. When further increasing the load, it will deform much more then in the D-figure. This is normal.

Disadvantage of the Prusik hitch is that when it is heavy loaded, it may jam. You need some effort to unlock the hitch in order to move it. When you frequently have to load and move the hitch, there are better alternatives, such as the Distel or Hedden Hitch.

The Prusik hitch is also frequently used outside climbing. Think of an adjustable anchor point on a rope, or as movable eyes in a suspension line for an overhead cable race. This application is discussed in chapter 8.

5.9. Test your friction hitches!

Good functioning of friction hitches depends of many factors:

- Type of friction hitch and number of turns
- Type and diameter of rope
- Type and diameter of hitch cord (or accessory cord)
- Wet, dry, frozen rope or solid object
- How the friction hitch is dressed and set

Therefore, you MUST test your hitches well using real conditions and check for margin. Don't just check whether it grabs, but load it fully and beyond that so that you have margin. Add a foot loop and jump on it to simulate some shock load. Note that a loaded rope has slightly less diameter and that may impact locking behavior of the hitch. When you move your hitch upwards, it may not lock again because of the slightly smaller rope diameter. This can be an issue when having more friction hitches on a single line/rope.

Even when every test gives good results, your life should not depend on a single friction hitch. You need a backup.

6. Other knots

6.1. Common Whipping knot

Whippings are normally used to whip the end of rope to avoid unraveling of the strands. Now many people melt the end of synthetic rope to avoid unraveling of the strands. I still use whippings on rope ends as it keeps the ends soft.

How to make the whipping is shown in figure 6.1. The procedure is a bit different from the standard procedure.

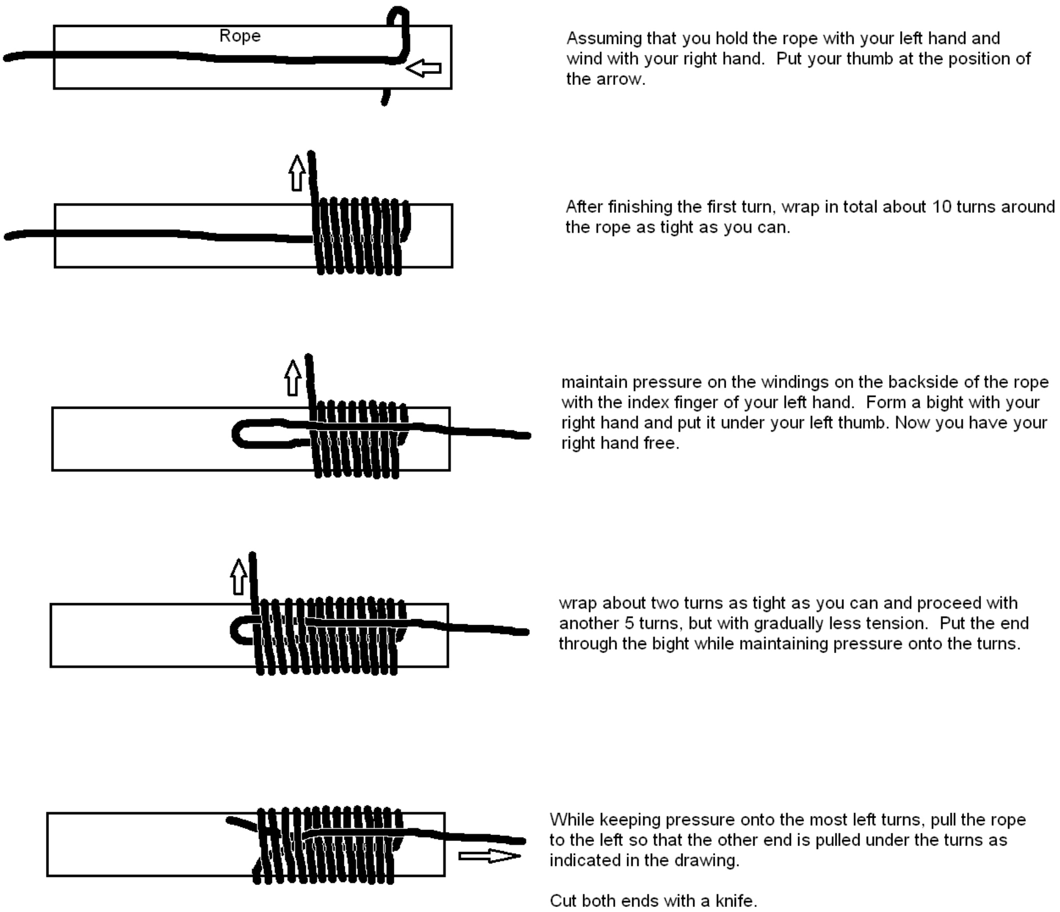


Figure 6.1 Common Whipping Procedure

The reason for first wrapping about 10 turns and then making the bight, is to avoid that you break the right end when pulling the left end under the turns.

The reason for having less tension on the most left turns is to make sure you can pull the left end under the turns. If the left end doesn't go under turns, the whipping will fail over time.

The number of turns depends on the thickness of the whipping cord and the rope.

Repairing fiberglass masts and rods

The common whipping has a nice application. If you have a fishing rod or fiberglass antenna mast, you may get a longitudinal crack starting at the top of a section. When you do nothing, the crack will work itself down, leaving your rod no longer usable.

When you see it in time, apply a common whipping with thin Polyester or Kevlar cord/rope and impregnate with epoxy resin. Heat the repair with a heat gun so that all moisture is gone and the slow curing laminating epoxy resin penetrates well.

Epoxy glue is the second choice as it penetrates not very well. This will result in a weaker repair. Do not thin epoxy glue with acetone or other solvent. The glue cures faster then the solvent evaporates. This stops the curing process resulting in a very weak repair.

When having good fine motor skills you may wrap the turns with very small spacing between them. This helps penetrating the rope, and avoids air pockets.

When not having epoxy, you may use paint (impregnating wood stain preferred). Disadvantage is the very long curing time (think of weeks). After the first application of the paint, you can apply a second layer after several weeks.

When using epoxy it is good to add a protective paint layer as most Epoxy isn't UV-resistant.

Copper to aluminum compression joint

Soldering aluminum is difficult to impossible for many people. Sometimes you can drill a hole and use a screw to connect an eye or some other means to connect copper wire.

You can use a whipping to directly connect copper to aluminum. Clean the parts and sand them with fresh sanding paper. Now join them using a whipping with thin polyester/Kelvar or Nylon rope/cord. You need thin cord so that you can have many turns resulting in high clamping force. Heat the whipping and impregnate with laminating epoxy. You may apply another layer before the first layer is fully cured. Read the instruction of your epoxy resin as the resin may form a fatty layer that needs to be removed before applying a second layer.

When you don't have epoxy, paint (wood stain preferred) works well, but takes long to cure (depending on the thickness of the whipping rope). When thinning the paint for the first layer, use a low boiling point petroleum distillate (cleaning spirit) that evaporates quickly after impregnating the whipping. These products are highly flammable!

There are many other applications for whippings, for example to make a thicker grip on a handle. When you put some glue onto the handle, the whipping will not move. You need glue that doesn't penetrate the rope, otherwise the rope becomes unpleasant to grip. When using thin glue, let it sit for a moment so that it thickens, then you can add the whippings.

6.2. *Simple soft shackle*

Musketon hooks, carabiners and D-shackles are frequently used to connect things to other objects. There is very light weight alternative: the Soft Shackle. They are very popular in sailing as they don't damage the deck compared to metal shackles.

Fixed length soft shackle
Figure 6.2 shows a very simple version that can be made out of every small piece of rope.

Figure 6.2 simple soft shackle

It uses a 2×2 overhand stopper knot (figure 4.2) and a figure 8 on a bight for the loop. The 2×2 overhand stopper knot is more bulky then the double overhand stopper. Adjusting the figure 8 takes some time as the stopper knot should just pass through the loop.

When making it from thin rope, you can better use the 3×3 overhand stopper as it is even more bulky and still easy to tie. Instead of the figure 8 on a bight, you can also use a simple overhand on a bight. So there are lots of variations.

Disadvantage compared to a carabiner is that you mostly need 2 hands to use the soft shackle.

Advantage compared to a carabiner (or D shackle) is its weight. When it falls down when working at height, nothing will break. You can put several onto your harness as they weigh near nothing.

Strength
The strength is about 80% of rope strength when using nylon or polyester rope. The stopper in its application has a strength of about 40% of rope MBS and that is the weakest link. As the load is shared across 2 rope sections, the overall strength is about 80% of MBS.

One may use the **Ashley stopper knot**. This is also a bulky compact stopper, but its strength is significantly below that of a 2x2 or 3x3 overhand stopper knot. It is the knot that fails (instead of the rope that bends near the eye).

Adjustable length soft shackle
This combines the above soft shackle with a friction hitch (the rectifier hitch). You can now open the loop without untying the friction hitch.

The adjustable shackle is shown in figure 6.3.

It consists of: the “rectifier” friction hitch, a figure 8 on a bight to make an eye, and two stopper knots (here 2×2 overhand). The rope in this example is 3 mm recycled polyester kernmantle rope. The load should be inside the loop (so called ring load).

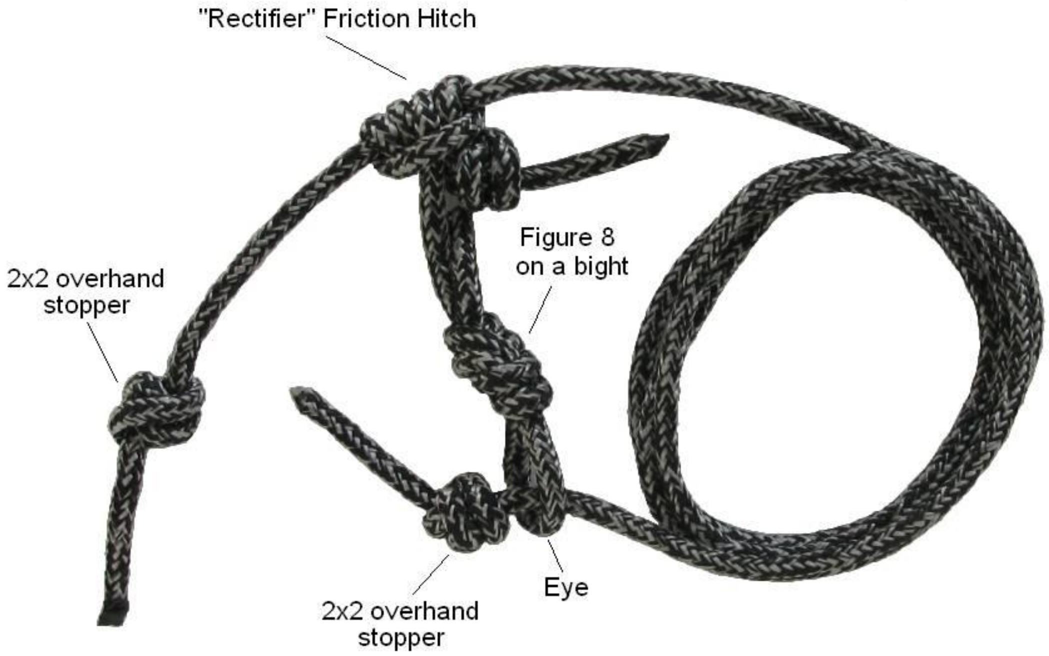


Figure 6.3 adjustable simple soft shackle

How to make it with minimum waste material?

You need a short piece of rope that has the stopper knot that you use for the soft shackle. Tie a loop with the “rectifier hitch” as shown in figure 5.1, but don’t cut the rope from the spool.

Tie very close to the hitch the figure 8 on a bight that makes the eye for the stopper knot. Adjust the figure 8 so that it is close to the friction hitch and that the stopper knot on the small piece of rope just passes through the eye.

Cut the rope close to the figure of 8, but leave sufficient tail. You need to cut the rope that goes through the friction hitch towards the spool! The figure 8 remains connected to the friction hitch. I did it wrong of course.

Make the stopper knot and pass it through the eye so that you get a closed loop again. Now adjust the loop to its maximum required size. Cut the rope from the spool including excess length to make a stopper knot (most left in figure 6.3). That stopper knot is to avoid that you pull the rope through the hitch. Instead of a stopper knot, you may also tie a loop.

When you need to make more adjustable soft shackles, you can use the same short piece of rope with stopper knot that you used for the first one. You therefore have near zero waste when finished.

6.3. Stronger secure soft shackle

When using soft shackles in application where failure should be minimal, you need a secure shackle. Though unlikely, the stopper knot (figure 6.2) may come through the eye/loop when the shackle has no load. I never had it happen, but theoretically it can.

There are soft shackles that use splices. They are the strongest as rope radius under load is largest. There is an alternative that doesn't require splicing. It is shown in figure 6.4. It uses double rope, so the strength doubles compared to the simple shackle. The strength increases even more as the bend radius of the rope inside the big stopper increases.

You can use a 2×2 or 3×3 overhand stopper. When using Dyneema the 3×3 overhand stopper may be the better choice. The securing part is created using the barrel knot that you can move towards the bight. The rope that you use for the barrel knot, should have the same or better UV resistance then the main rope. When the barrel knot fails, the soft shackle will fail also.

Operation
You pass the thick stopper knot through the bight, and move the barrel knot towards the stopper. This impedes that during no load the stopper slips through the bight/eye.

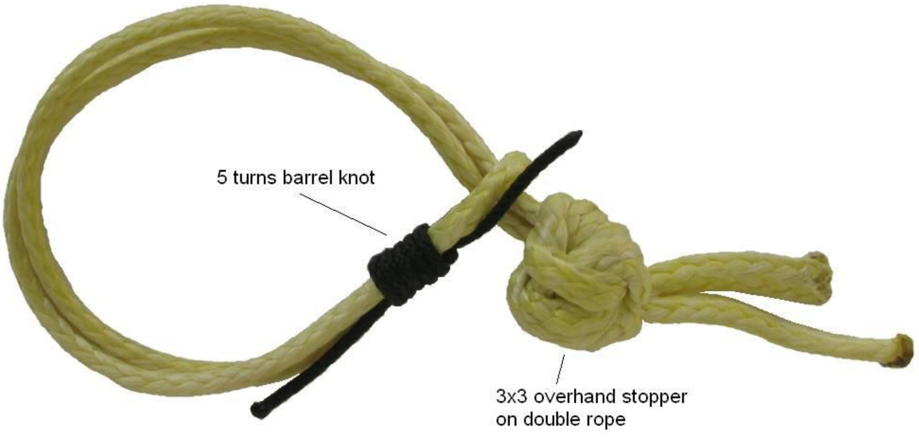


Figure 6.4 secure soft shackle using 6 mm Dyneema

This shackle is easy to make, without the button knot and without feeding the rope through itself to form a self-closing loop. You need to know the multi turn barrel knot, and a fat stopper.

When the rope you use opens easy, you may (cross) feed the rope through itself to form a self-closing loop. You no longer need the barrel knot in that case.

Once the shackle with a 2×2 or 3×3 overhand stopper is loaded, the stopper will not slip through the eye, even when the eye is very large. It only goes wrong when the load is removed and the eye opens a bit. Then the stopper will slip through the eye.

Using a small enough eye is useful for most applications. Using the barrel knot to close the eye is the safest method if you don't have a means to splice.

Strength
The breaking strength of this type of shackle is in the range of twice the breaking strength of the rope itself. The reason is that the load is shared across 4 rope sections. The big stopper knot on double rope has an efficiency of about 50%. When loading to destruction, it is mostly the stopper knot that is pulled off the rope at the stopper/eye transition, but the loop itself may also break at the smallest bend radius. Dyneema soft shackles mostly fail because the loop/noose around the double rope breaks.

Dressing the 3X3 stopper knot
The strength of this stopper knot depends on how you dress it, and how you use it. See Annex 1 for the 3x3 stopper knot.

6.4. (Double) Constrictor Hitch

The constrictor hitch is an extension to the clove hitch and is used to tie things together. The constricting force can be considerable, depending on your pull strength. It can also be used to make an efficient eye termination onto a rope, using a round former.

Constrictor hitch
Figure 6.5 shows how to make the hitch based on the clove hitch

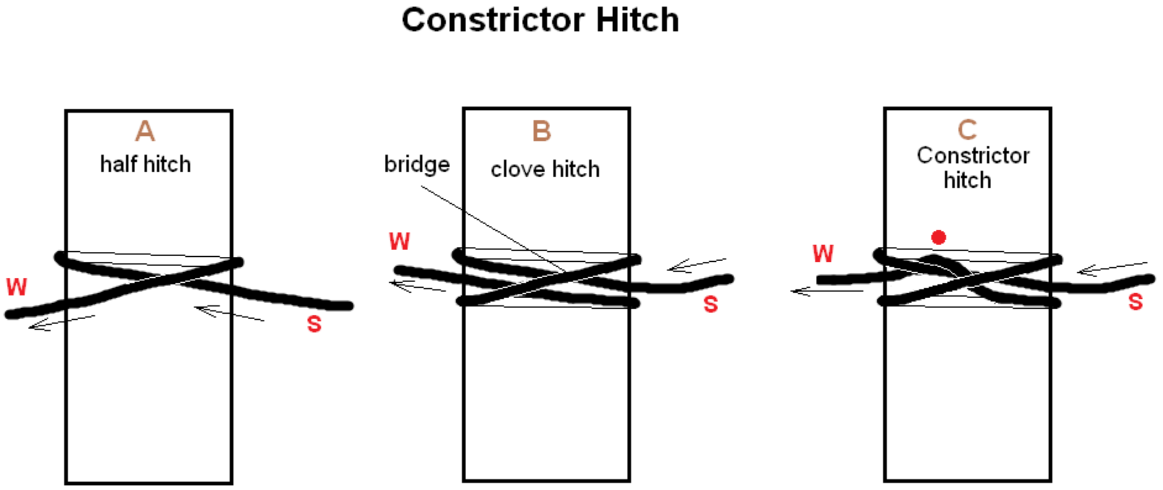


Figure 6.5 constrictor hitch

A-figure. Make single turn with the working end (W). In fact you made a half hitch now. You can see this when you move the standing end (S) upwards.

B-figure. Add another half hitch with the working end. Now you have the typical bridge crosses over two ropes. Both the standing and working end are in between the turns.

C-figure. Wrap the working end around the standing end. The working end is again in between the turns.

In the C-figure the hitch is not yet dressed. You have to wiggle with the working and standing end so that shape that is present just below the red dot is right under the bridge. So the shape has to move to the right, or the bridge has to move to the left.

Then pull hard on W and A to tighten the constrictor hitch.

Double Constrictor Hitch
The double constrictor is somewhat less known, but is less likely to loosen, and more constricting force is available.

The double constrictor hitch has a bridge of two parallel turns instead of one, as is the case for the normal constrictor hitch.

How to tie the double constrictor hitch (figure 6.6)?

When you start with a rope that is not fixed to the objects

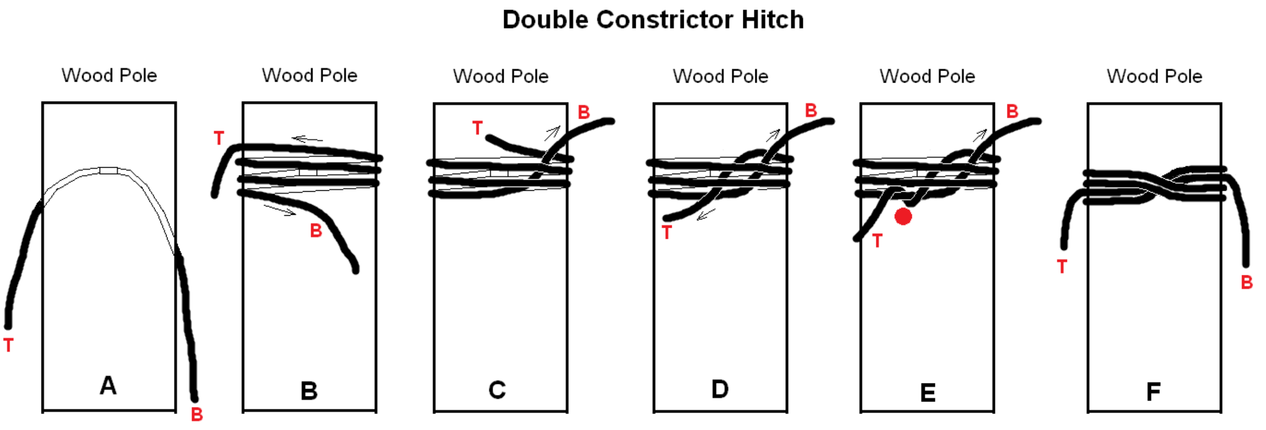


Figure 6.6 double constrictor hitch

We start with the C-figure from figure 6.6.
C-figure. Wrap with rope end T (that is your working end now) two turns around the B rope end. Make sure that the working end T remains under end B when you are ready with this step. You have now three turns, two over rope end B and one under rope end B.

D-figure. Pass the working end T under the two windings where the B end also passes under. Make sure that end T is in between the turns. Now you have a double clove hitch, as the bridge has now to turns.

E-figure. Wrap the working end T once around end B. Make sure that both end B and T are in between windings.

F-figure Wiggle with the rope ends so that the shape at the red dot position is under the bridge. When done, pull hard on both ends simultaneously. The hitch should look like as shown in the F-figure.

Adding another hitch
There are applications where you want to add another double constrictor hitch on the same object using rope ends B and T. In that case you need some additional steps as you start with a fixed rope now.

A-figure. Turn the object over 180 degrees so that the bridge of the constrictor is on the back side.

B-figure. Apply 1.5 turn with rope end T, and in the other direction 1.5 turns with rope end B. It is important that the rope follows that natural direction, otherwise the previous constrictor hitch may loosen.

Now you have three full turns around the object.

C-figure. Pass end B under the two turns. Make sure not to pass under end T too.

From here you can proceed with the steps as discussed before.

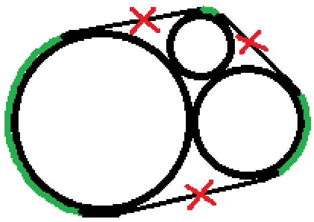
This method is not very intuitive, as you don't have reference to (for example) a normal clove hitch.

Tying the double constrictor onto an existing wrapping goes easier when using a skewer or (thin) stick. The new turns come on top of the skewer. You tie the knot and remove the skewer before final tensioning of the constrictor knot.

I use the above method to tie 5 double constrictor hitches that are part of 4 guy wire anchor points on top of wood poles that are used during instruction (climbing). That means there are 15 rope turns around the pole. By using 5 constrictor hitches, there is lots of redundancy. When a hitch or a rope turn fails, the remaining rope turns will take over the load.

To make sure that the hitch holds, there must be pressure from the object inside the constrictor hitch at the position of the bridge.

Figure 6.7 shows a cross section of several objects that are tied together with a (double) constrictor hitch.



The rope section between the two terminations of the constrictor knot has to be in the green areas.

Figure 6.7 good positions for the bridge of the constrictor hitch

The bridge should be at a position where the there is some bend radius, and the surface is rigid. Possible positions are indicated with green. The cross-out positions where the rope is not supported from the inside are “forbidden”. The hitch will not hold.

Are you instructing children?
Children may practice on each other. When a child ties a (double) constrictor hitch around another child’s arm or leg, and pulls the ends, blood flow will stop immediately. It remains stopped even with zero pulling force on the rope ends. It keeps constricting.

Make sure to have material available so that they do not tie (double) constrictors around legs, fingers or arms.

Alternatives?
Though constrictors are good knots, with good constricting force, not everyone likes them. This is especially valid for the double constrictor as you cannot make it from a clove hitch.

When large constricting force is not required, you may use the “rectifier” friction hitch using say 2 or 3 turns around the objects. Another option is the trucker’s hitch.

6.5. Constrictor lashing

When you are familiar with the constrictor hitch, the constrictor lashing is very simple, but fast way to have a (temporary) connection between two cross bars.

When you impregnate the lashing with epoxy resin, it can be a permanent connection. One could think of connecting Yagi elements to a boom for upper VHF or UHF frequency range.

It is shown in Figure 6.8.

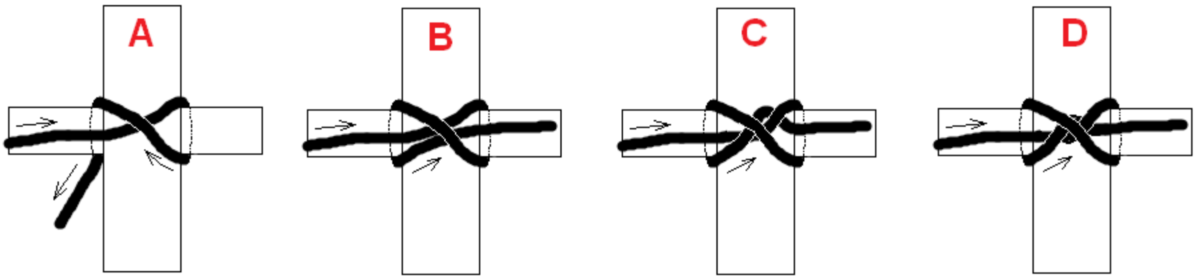


Figure 6.8 Constrictor Lashing

When you look to the B figure, you see the same geometry as a clove hitch, The rope ends are in between the loops and the bridge crosses over two rope sections.

When you wrap one rope end around the other rope end, it creates a constrictor hitch (C-figure). It should be dressed so that it looks like the D-figure. The constrictor hitch creates a full so called “wrap” with cross around the crossed bars. You can also make a double version that gives a secure hold, but you can better use this normal version as a starting point for additional wraps to create a strong connection between the crossed bars.

To be honest, I use it more for gardening then Radio Amateurism. When you are familiar with the rectifier friction hitch, you may use the simple lashing with rectifier hitch (figure 5.2.2). The rectifier hitch version is faster when you have access to one end of the crossed bars.

6.6. Near 100% strength hitches

Why are knots so weak?
The reason why knots have limited efficiency is because of the mostly small bend radius of the rope end that carries the load. The outer strands receive more stress then the inner strands. This is similar when bending a tube, the outer radius is subjected to highest stress (N/mm^2).

There is a second reason that knots have limited efficiency; dynamic load. A knot more or less may give out and take in some rope each dynamic load cycle. This causes rubbing of fibers to each other and that will cause wear. So after many cycles, the knot will fail at a load well below the static MBS of the knot.

Tension free hitches
When having round objects with large diameter (compared to the rope) one can make use of the friction between the object and the rope, so that the working end virtually doesn’t experience tension.

When putting many turns around the object, the friction between the rope and the object transfers gradually the rope force onto the object. There will be no small bend radius, so strength of such knots is near 100% of MBS. The same operation principle is used in eye splice.

Note that when using Dyneema, you need many (maybe 20) turns to transfer the rope force onto the object.

It works so good that this method is used to connect a rope to a test jig for determining the MBS of the rope itself.

Figure 6.9 shows the idea.

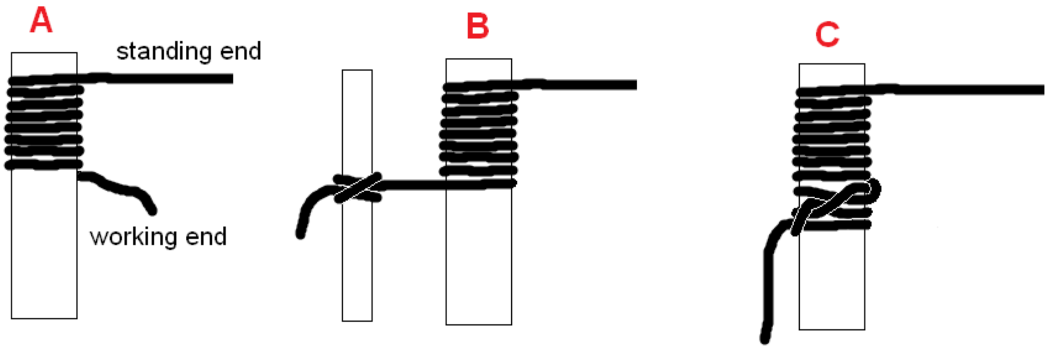


Figure 6.9, near 100% of MBS hitch

The round object can be a tree, or some other strong object. The object should not be able to rotate around it axis, as this hitch creates torque along the Z-axis (in case of a vertical bar/post/etc.

A-figure. You start with sufficient turns.   You need less turns around a tree compared to nylon rope around a shiny metal bar. You only need very low tension on the working end to have full force on the standing end. When it slips, you need more turns.

B-figure. When sure you have sufficient turns, you can use a clove hitch on another object. Add a securing half hitch (not shown in the B-figure).

C-figure. Of course you can also tie the working end around the object using half hitches or constrictors (more elaborate).

disadvantages

- The first turns (seen from the standing end) will elongate during the loading process. This isn’t a problem. However when you have **dynamic/cyclic loading**, the hitch will give out rope, and takes back rope. This constant rubbing of the rope onto the object will damage the fibers, resulting in far less then 100% strength of MBS after frequent cyclic loading.
  A splice is superior in that respect. Fibers of the working end, which go into the standing end, virtually don’t move with respect to the fibers of the standing end.
- The force is transferred to the object on one side of the object via one rope section. When the object is a tree, you may damage the bark and maybe you damage the cambium directly. The cambium is like the blood vessels in your body. When you damage the cambium, the tree will die.
  When using a loop as a sling, the load force is distributed across 4 rope section, reducing the stress onto the bark and underlying cambium.

6.6.1. Clove hitch on a bight

A (double) clove hitch is normally tied around an object with diameter larger than the rope diameter. This puts low stress onto the rope because of absence of small bend radius. Why not use a clove hitch on a bight to form an eye termination? The idea came from the use of Dyneema for kites when the internet was in its beginning. Knots that work well with Nylon and Polyester, performed really bad with Dyneema (and Kevlar).

This all has to do with the slippery nature of Dyneema, and low stretch compared to PA. E-modulus of Nylon is in the range of 1…5 Gpa (depending on type of Nylon). Dyneema has E-modulus in the range of 100 Gpa (N/m^2).

To make an eye termination using a clove hitch on a bight, you need an object (a former), as a hitch doesn't hold in air. Figure 6.10 A and B show how to tie the clove hitch on a bight.

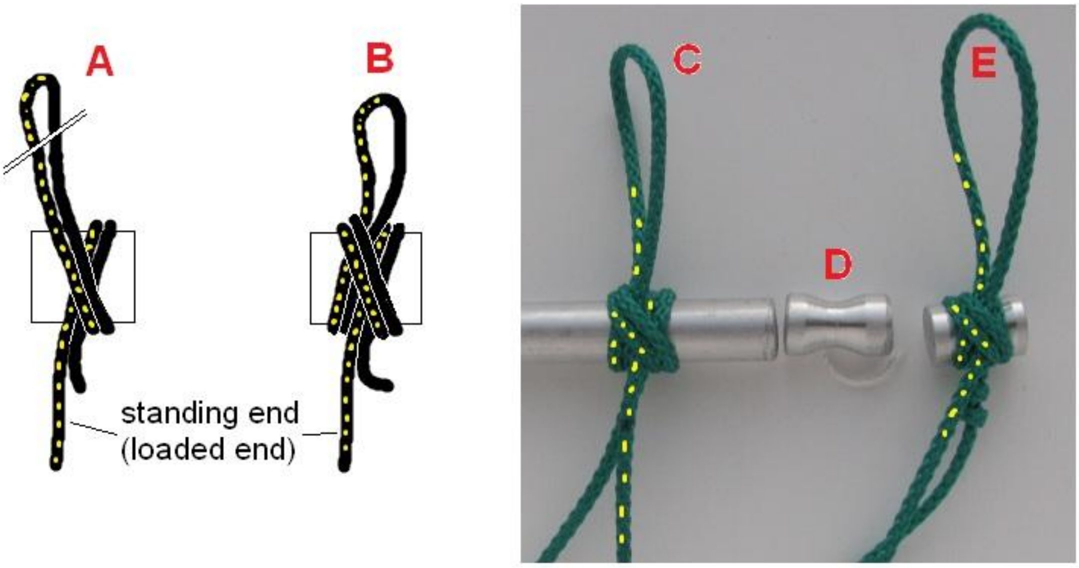


Figure 6.10, Clove Hitch on a bight

Use a round aluminum bar or tube with D_{former}/D_{rope} = 3…6 (Nylon, Polypropylene, Polyester). Try to stay on the low side, as dynamic load performance is better. This is because of higher pretension and less rope in the hitch. Tie the hitch as shown in figure 6.10 A and B. make sure that there are no twists in the bight (so the two rope sections remain parallel).

Testing the hitch

You test the eye as any other eye. Dress the hitch and make sure all rope sections remain parallel (also the non-visible side). Increase the load until it breaks. It should not show any slip when testing 3 hitches to destruction. When you are sure it doesn't slip, you may add a stopper knot as shown in the E-figure. The stopper knot is only to avoid tail eating, but not for preventing slip.

Cycling load

With a prolonged dynamic load, the tail may slowly move into the hitch. This is avoided or significantly reduced by using a former with V-cross section as shown in the D-figure. It is also important to keep D_{former}/D_{rope} in the range of 3..6 to reduce giving out and taking in rope.

How to get the hitch into the V-former?
Tie the hitch onto a tube with same or slightly larger diameter then the V-former. Then you transfer the hitch from the tube to the V-former. The V-former has about 140 degrees angle. When gradually dressing and tightening the hitch, make sure all turns remain parallel. The V-former tends to compress the turns, this makes tightening more elaborate. The compression that occurs because of the V-shape of the former assures that the hitch keeps partially tensioned after removing the load. This reduces giving out and taking in rope, and virtually eliminates tail eating.

Test with 1.5 mm nylon onto the former of figure 6.10E (D_{former}/D_{rope} = 4.5). No slipping, 1.5 mm tail eating (no stopper knot present). Load: 400 cycles from 0 to 50..60% of static rope MBS. Total test time is 4 minutes. The Sample did not break. The hitch is hard to impossible to untie.

6.6.2. Double clove hitch on a bight

Dyneema requires at least a double clove hitch to avoid slipping of the hitch. The D_{former}/D_{rope} ratio needs to be larger as the rope stretch is less compared to PP/PA/PET. Think of D_{former}/D_{rope} = 6...12. The V-angle can also be 140 degrees. Try to work with the lowest D_{former}/D_{rope} ratio, as that improves dynamic load behavior. In addition the former is smaller and less rope is required.

How to make the double clove hitch is shown in figure 6.11. It is advised to practice with a single rope, as in figure 6.11. When familiar with the hitch, you can make the hitch using a bight.

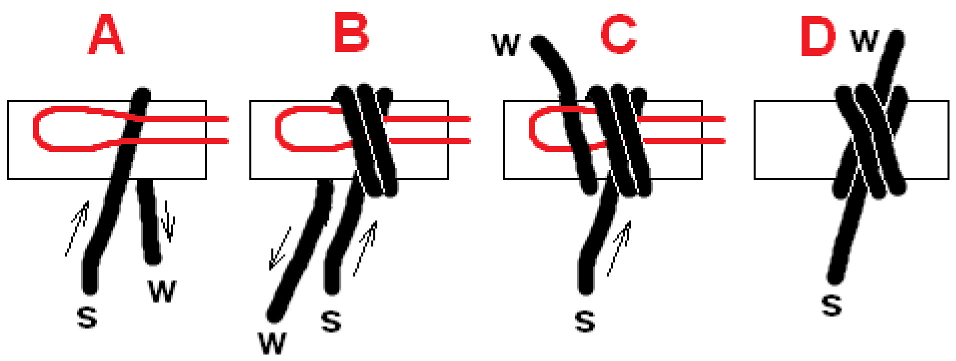


Figure 6.11, Double Clove Hitch

A-figure
Make a single turn, and apply a bight or loop over it. This loop is later required to pull the working end. You may use a small piece of tape to fix the loop onto the tube.

B-figure
Apply an additional two turns.

C-figure

Tuck the working end through the loop and pull the loop out of the two turns. The working end goes under the bridge now. The working end is right of the two turns (the bridge) now.

D-figure

Check that both the working end, and the standing end is between turns (similar to the clove hitch). The double clove hitch has a bridge consisting of two parallel rope sections. The clove hitch has only one rope section.

The working end will be the bight when tying a **double clove hitch on a bight**.

Especially with thin rope, dressing is elaborate as you have 6 strands now. It is acceptable that some turns go over other turns, but make sure that during tying the bight remains parallel (that is no twists).

Test your hitch so that you are 100% sure it doesn't slip. It will eat the tail slowly with dynamic load, especially with large D_{former}/D_{rope} ratio. Therefore you need a stopper knot. A 2x2 overhand stopper is recommended (figure 4.2F).

6.6.3. Constrictor hitch on a bight

Why not use a constrictor hitch? The constrictor hitch adds a spiral/twist that may weaken the rope a bit. That spiral/twist also provides the additional friction that gives the constrictor hitch its constricting properties.

When D_{former}/D_{rope} ratio is relatively large, you can use a constrictor on a bight to avoid slipping as the spiral turn has large advance (or pitch). Loss of strength will be negligible. When D_{former}/D_{rope} ratio is small (say < 5), the spiral/twist advance reduces. This reduces the breaking strength, but also reduces tail eating with cyclic loading. A constrictor uses less rope then a double clove hitch. Therefore considering a constrictor can be a good solution.

When you just have round bar (without the V), using the constrictor on a bight provides sufficient grip to avoid slipping (PA, PP, PET and Dyneema) and tail eating. The constrictor is more compact then the double clove hitch, so the former can be shorter (saving weight/material). Disadvantage: It is hard to impossible to untie.

Test with constrictor with $D_{former}/D_{rope} = 5$, aluminum, no V, and 2 mm PP braided cord, no tail eating, It outperforms both figure 8, 9 and 10 on a bight and on a double bight.

Test with constrictor with $D_{former}/D_{rope} = 6.7$, aluminum no V, and 1.5 mm PA twisted rope. No slipping, zero tail eating after 250 load cycles of 0 to 50..60% of rope MBS. Total test time 2 minutes.

Test with constrictor with $D_{former}/D_{rope} = 12$, aluminum no V, and 0.8 mm 100% Dyneema (SK75, no sheath). No slipping up to breaking load, < 1mm tail eating after 250 load cycles of 0 to 40% of rope MBS. Total test time 2.5 minutes. The hitch could be untied. Note that the test load is above the breaking strength for eyes based on figure 10 on a bight.

These test show that the constrictor may be an alternative for the double clove hitch as many people are familiar with the clove hitch. When you know the clove hitch, the step towards the constrictor is simple. Dressing is also easier as you have 4 strands instead of 6.

6.6.4. How critical is D_{former}/D_{rope} ratio?

It is not very critical, but you need to think about it, as it is a trade-off between static strength and dynamic load performance.

Making it very large may give you a static strength of >95% that can be useful for measuring the rope's MBS. However the former is bulky and the hitch will give and take more rope as there is more rope in the hitch. This is bad for the dynamic behavior. Except for very static loads or MBS testing, you can better lose some strength and gain dynamic load performance.

A smaller D_{former}/D_{rope} ratio uses less rope in the hitch, and the bridge gives more pretension, reducing giving out and taking in rope (so better dynamic performance).

When using PA, PP or PET with $D_{former}/D_{rope} = 3$, you don't need a constrictor. A clove hitch, with a stopper to block tail eating, gives significant pretension in the hitch. 4 measurements on a 1 mm 8 strand braided rope showed a lowest breaking strength of 40 kg and 44 kg maximum. Rope MBS = 42 kg. When you can lose some strength, you may even go down to factor 2.5.

Using a constrictor (with $D_{former}/D_{rope} = 3$) gives breaking strength of 37 kg. That is 88% of MBS. The lower breaking strength is because of the spiraling of the rope under the bridge.

For UHMWPE (Dyneema) you need the double clove hitch, or the constrictor. These hitches will introduce larger bends on small D_{former}/D_{rope} ratios. The minimum ratio depends on the rope construction. Small pitch ropes (less strength, but more elongation) can handle $D_{former}/D_{rope} = 4$, with strength >80% of MBS. Most Dyneema ropes are optimized for strength and low stretch. This may require a bit larger D_{former}/D_{rope} ratio. Best option is to test to destruction, using at least 3 samples.

For Aramids (like Kevlar) you can use same D_{former}/D_{rope} ratio as for Dyneema. A normal clove hitch will work as Kevlar has high friction coefficient. Only for very large ratios, you may use a double clove hitch. See also paragraph 8.8.

Former surface finish

The former must be very well finished (glossy, no scratches). From experience, scratches reduce the breaking strength, especially with thin ropes (1 mm or less). It is not recommended to use plastic formers as they can't dissipate heat well, or may deform when using Dyneema.

6.7. Daisy chaining

When you have a short piece of thick excess rope, you can wind it, but daisy chaining is also an option. It is shown in figure 6.12. Daisy chaining goes fast, and it unties easy with near zero risk of making spaghetti.

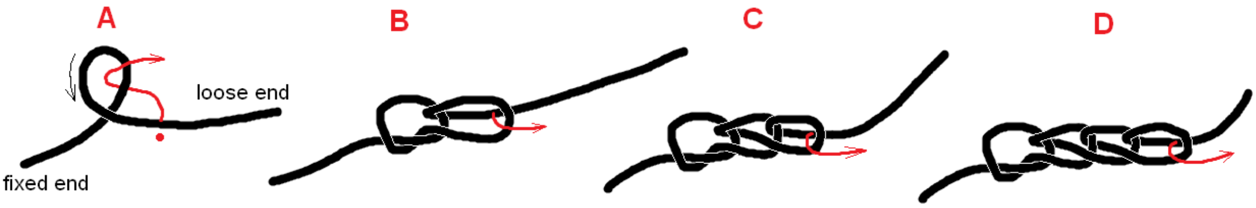


Figure 6.12, Daisy Chaining a rope

How to daisy chain?

A-figure

You start with an overhand noose (slip knot). Make a loop as shown in the A-figure. Push the loose end down and under the loop starting from the red dot position. Push two fingers through the loop and grab the loose end an pull a bight upwards and move it to the right. The result is in the B-figure. You have an overhand noose now (slip knot).

B-figure

Push two fingers through the new loop and grab the loose end, and pull a bight upwards and move it to the right. This creates the C-figure. You have a new loop now.

C-figure

Repeat the procedure from the B-figure. When the loops become too large, you push your fingers through the loop and grab the loose end very close to the previous loop (so more to the left). When you pull the loose end upward through the loop, the loop tensions (becomes smaller).

D-figure

This shows an additional loop. When the loose end is too short to form a complete new loop, just pull the complete loose end upwards through the loop. Tighten the last loop so that the loose end doesn't slip out of the loop. When you don't do the last step, the daisy chain will untie itself.

Daisy chaining "shrinks" rope about 5 times. When you need to use the rope, pull the short loose end out of the loop, and firmly pull the loose end. This unties all cascaded slip knots.

Daisy chaining is also useful when you need to wash your rope. It avoids making spaghetti. When you have a very long rope, first double the rope, then daisy chain.

6.8. *Releasable knots (quick-release knots)*

Releasable knot are knots that can be released by pulling a rope section (frequently the working end used to tie the knot). A shoe lace is an example of releasable knot.

Many knots can be converted into a releasable knot by forming a bight in the working end, and use the bight to tie the last part of the knot. Adding a bight may reduce the holding power. The knot may slip, or capsize. Do your own testing when converting an existing knot into a releasable knot. For example when tying the second half hitch of a clove hitch with a bight, it becomes even more unreliable. Same is valid for the constrictor hitch (the holding power reduces).

There are two categories:

1. Knots that cannot, or very difficult, be released under tension.
2. Knots that can be released under full tension.

You can also divide them also in

1. Knots where you need access to a rope end.
2. Knots that don't required access to a rope end.

But also

1. Knots that constrict when loaded (such as the slipknot or scaffold knot)
2. Knots that do not constrict when loaded (such as a figure 8 on a bight).

Non-releasable under load example

Figure 6.13 shows an easy to tie releasable non-constricting loop knot based on a clove hitch around a bight. The loop cannot be released when loaded. This can be a safety feature. The knot keeps its shape when unloaded (it doesn't fall apart).

A-figure

Wrap the rope around the object

B-figure

Form a bight in the rope section that will carry the load (that is the standing end).

C-figure

Tie two half hitches around the bight to create a clove hitch.

D-figure

Form a bight with the working end (WE) and push it through the bight in the standing end (indicated with C).

Tighten the clove hitch. Grab rope sections A and B. With your other hand grab the clove hitch. Pull them apart so that bight C constricts. Pull Bight D so that the bend at positions E below the clove hitch has no slack.

Repeat the above process so that the knot is tightened well.

E-figure

As the tail of the working is not pushed through loops, this knot can be tighten halfway a rope. You don't need access to the rope end. The working and can be on the same side as the standing end. But be careful to avoid confusion.

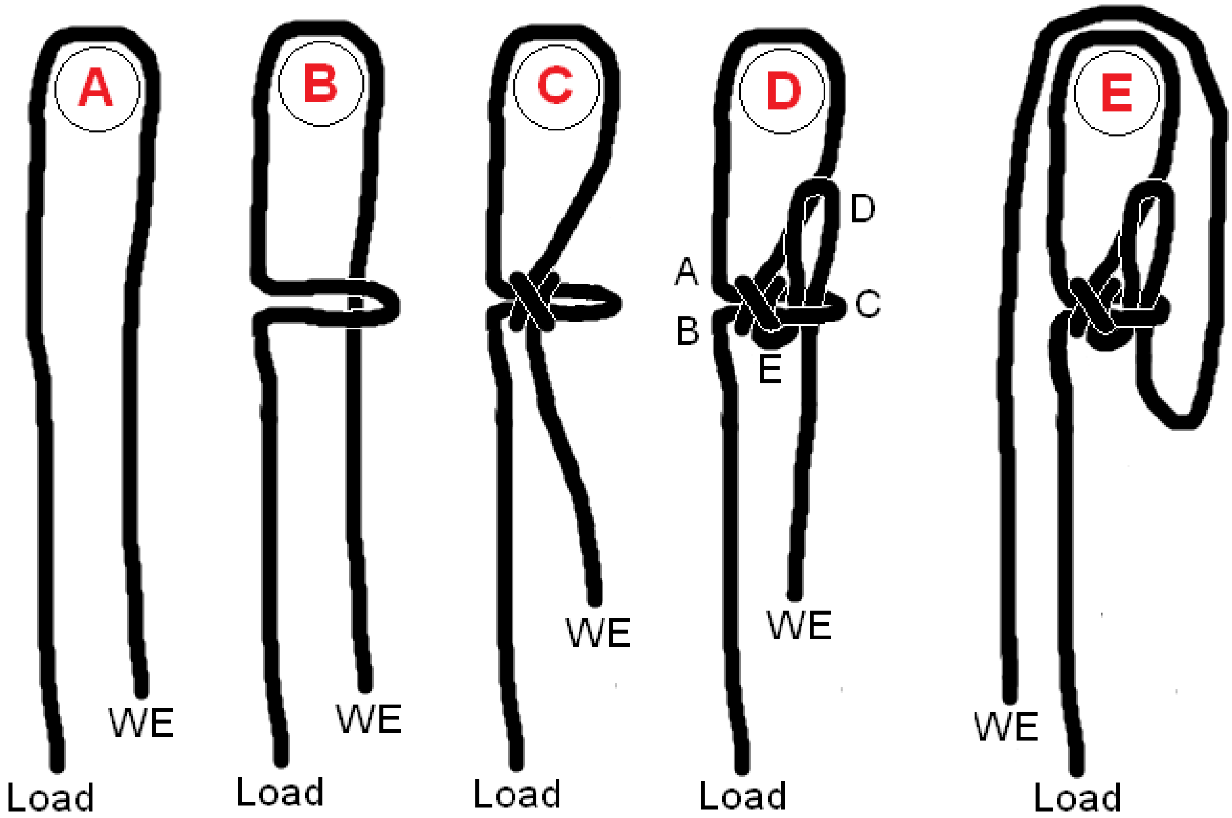


Figure 6.13, releasable loop knot first example

To release the loop knot (D-figure), remove the load and pull the working end so that bight D is pulled out of bight C. Pull the load end again to pull bight C out of the clove hitch. This completely removed the knot.

Releasable under load example using daisy chaining

Figure 6.14 shows a quick release constricting loop knot that can be released under full load. It is based on daisy chaining the working end about 4 times around the standing end. Each time a bight is added, the force reduces and jamming is avoided, even with loads that would break the rope. See the previous paragraph for how to daisy chain.

Important note

The very small release force can introduce serious risks. When using a long release line/rope, the knot may release itself due to the weight of the rope in case of relative small load.

The holding power relies solely on a well tighten daisy chain <u>around</u> the standing end. When that goes wrong, the knot may look fine, but may untie itself under full load. The daisy chain trick can be used to make many types of releasable knots and hitches, as long as you have a bight or loop to start with.

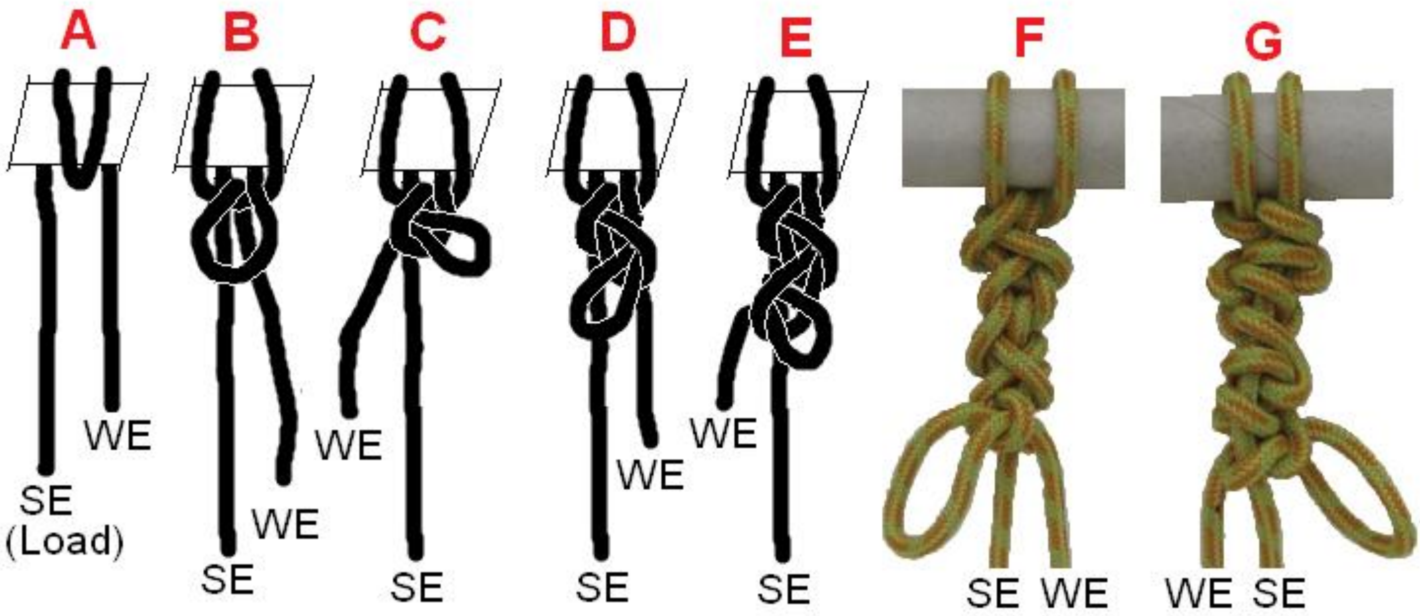


Figure 6.14, releasable loop knot 2nd example

A-figure

Start with a bight that you wrap once around a pipe or other structure. The load bearing rope end is on the left indicated with SE (Load).

Tip: you may wrap the bight several times around the object to enable pretension in the standing end, as with a round turn with two half hitches.

B-figure

Form a bight with the working end, and push it through the bight that goes around the object.

C-figure

Move the working end down and to the left so that it passes under the standing end. Form a bight with the working end again, and push it through the previous bight. Tighten the previous bight well. It helps to pull down the rope section that goes under the standing end (not visible). This tightens the previous bight. Then remove the slack by pulling the newly formed bight. .

D-figure

Move the working end down and to the right so that it passes under the standing end. Form a bight with the working end again, and push it through the previous bight. Tighten the previous bight well as described before.

E-figure

Move the working end down and to the left so that it passes under the standing end. Form a bight with the working end again, and push it through the previous bight. Tighten the previous bight well.

You should repeat this process an additional two times.

F-figure

This figure shows a photo of the finished knot. The bights are well tighten. In a real knot, you don't need to chain that many bights. 4 bights are mostly sufficient.

G-figure

This figure shows the underside where you can see the more or less zigzag pattern. This shows that the daisy chain is really around the standing end.

The left and right (zigzag) movement of the working end makes this knot easy to tie as a midline knot. You don't need access to a rope end.

When you release the knot, the daisy chain is eaten, bight for bight. When the last bight is freed, the rope falls, or shoots, off the object.

You may use this knot to release very heavy loads. The load is temporary transferred to the release line (the working end) when it comes of the object. Long lines can store lots of energy (especially Nylon/PA). So do not stand in the line of the rope.

When the loaded line (standing end) runs to the right, and you are say about some meters away from the loaded rope, make sure there are no people right of the release line. They should be well behind you. The release line may violently move to the right. Make sure that slack (of the release line) is right of you, so that the release line doesn't catch you.

Of course when the load is on the left, the slack should be on you left side.

Variations

When the rope diameter is very large compared to the object diameter, you can start with a round turn with one half hitch using a bight. Use the bight and the working end to daisy chain around the standing end.

There are also variations that reduce the load onto the bight that you use to start daisy chaining.

7. Pulleys and mechanical advantage

7.1. Introduction and pulley efficiency

7.1.1. What is a Pulley (or block)

Pulleys are very useful when you need to change the direction of a force and/or you want to transform a small force into a large force. Transforming a force to a larger force is called: “**mechanical advantage**”.

Figure 7.1 shows a simple pulley application.

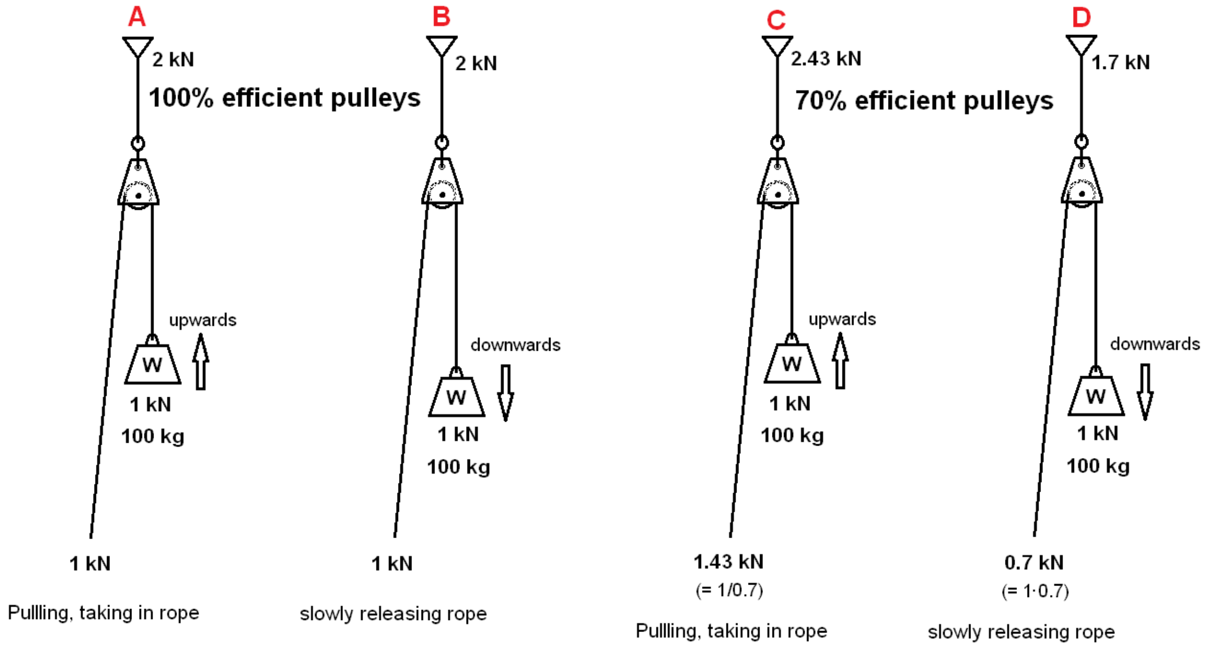


Figure 7.1 Simple pulley application and efficiency

The simplest pulley is a single wheel with groove (called a “sheave”) that can rotate around an axle. The wheel is between cheek plates, so that the rope cannot run of the wheel. A pulley is also called a **block**.

The bearing can be a plain/bush bearing. The wheel just rotates around the axle with nothing in between. This gives friction. Pulleys can also have ball or roller bearings to reduce friction. Even the friction between the wheel and the cheek plates can be reduced using ball bearings between the wheel and the cheek plates. This comes with a high price...

The cheapest pulleys have just a plain/bush bearing, and of course introduce friction and wear out quickly.

Pulleys/blocks can have several wheels (sheaves) that can rotate independently. This is useful to make **mechanical advantage**. See it as the mechanical equivalent of the electrical transformer. You can transform current and voltage. With a pulley system you can transform displacement and force.

A **block** is a pulley where you have to push the rope through the block. So you need access to one end of the rope.

A **snatch block** is a pulley where you can rotate the cheek plates so that it opens. When it is open, you can put the pulley onto the rope without access to a rope end.

7.1.2. Pulley efficiency

Pulley efficiency is the ratio between the output energy and input energy. It is frequently expressed as a percentage.

When you use a pulley as in figure 7.1A, the input energy is $F_{lift} \cdot s$ and the output energy is $F_{load} \cdot s$. s is the distance that the load moves upwards. That is the same as the amount of rope you have to take in.

$$Pulley\ Efficiency\ \ (\eta) = \frac{E_{out}}{E_{in}} = \frac{F_{load} \cdot s}{F_{lift} \cdot s} = \frac{F_{load}}{F_{lift}} \quad []$$

You can safely say: pulley efficiency equals F_{load}/F_{lift} ratio when lifting (so the load moves upwards).

Pulleys with bush/plain bearings have efficiency ranging from 50 to 80%. It all depends on the materials and the wheel/axle ratio. Thin axles give better efficiency, but lower load capability and higher wear. When using roller bearings, efficiency can be above 90%. The values are for the situation where the angle between the ropes leaving the block is 0^0 (as is nearly the case in figure 7.1)

Efficiency increases when the angle between the ropes increases. This is because the force on the axle/shaft reduces with increasing angle.

7.1.3. Lowering and lifting

Frictionless pulley

A frictionless pulley has η = 1 (or 100%), so you need to pull with the same force as the load pulls down due to gravity. See figure 7.1A.

$F_{lift} = F_{load}$

Figure 7.1B shows the situation where you need to lower a load, so you need to give out rope. With a frictionless pulley, you need to hold the line with the same force as the load pulls down.

$F_{lower} = F_{load}$

Pulleys with friction
Now the situation depends on whether you are lifting or lowering a load.

Load lifting
Figure 7.1C shows the lifting situation, you provide the energy to increase the potential energy of the load. Some of your energy is lost as heat in the block. Rearranging the pulley efficiency formula:

$$\text{Lifting a load}: \quad F_{lift} = \frac{F_{load}}{\eta} \quad [N]$$

So the force required to lift a load is always higher then the load.

Load lowering
The situation is shown in figure 7.1D. Now the load pulls rope through pulley, so the load tends to lift you. Input and output changed. The input is now the load that tries to lift you up, and you must provide the load by pulling, but giving out rope. The force you need to apply when lowering the load is F_{lower}.

$$\text{Lowering a load}: \quad F_{lower} = \eta \cdot F_{load} \quad [N]$$

Lowering a load requires (somewhat) less force then the load itself.

For a real pulley/block:

$F_{pull} > F_{lower}$

7.1.4. How to determine pulley efficiency

Determining efficiency is mathematically simple, but actual measurement may be elaborate.

Lift a load with constant speed and determine F_{lift}
Lower the same load with constant speed and determine F_{lower}

$$\eta = \sqrt{\frac{F_{lower}}{F_{lift}}} = \frac{F_{anchor.lower}}{F_{anchor.lift}} \quad []$$

Multiply with 100 to get the efficiency as a percentage. When you are able to measure the force on the anchor, you can use the alternative formula.

Depending on the force measurement apparatus, it can be hard to get a stable reading.

7.1.5. Forces on the anchor point

Figure 7.1A, and B frictionless lifting and lowering

Two 1 kN forces pull down on the wheel/sheave. So the wheel/sheave pushes with 2 kN onto the axle of the pulley. This force is transferred to the anchor. The anchor is therefore loaded with 2 kN (twice the load).

For the 100% efficient block, it doesn't matter whether you lift or lower the load.

With friction the situation becomes different.

Figure 7.1C, lifting with 70% efficient pulley

You need to pull with 1.43 kN for a 1 kN load, so the total force onto the anchor is the sum of these forces: 2.43 kN. That is more then twice as high.

Figure 7.1D, lowering with 70% efficient pulley

You need to give out rope while holding 0.7 kN for a 1 kN load, so the total force onto the anchor is the sum of these forces: 1.7 kN.

Force on anchor points is frequently overlooked when using pulleys.

By lifting and lowering a load, one can assess the efficiency of a pulley.

7.2. Mechanical advantage

Besides changing the direction of a force (as in figure 7.1), you can also reduce the pulling force by using more pulleys (or blocks with more then one wheel).

Mechanical advantage is F_{load}/F_{lift} ratio.
This is similar as for a transformer $n = V_{sec}/V_{prim}$, just output over input ratio.

For (cheap) bush/plain bearing pulleys it will be in the range of 0.5 to 0.8.

7.2.1. How to calculate mechanical advantage?

Figure 7.2 shows 3 scenarios:
A-figure, frictionless lifting or lowering

B-figure, lifting with 70% pulley efficiency for both pulleys.

C-figure, lowering with 70% pulley efficiency for both pulleys.

There are several ways to calculate the forces. There is a lazy one.

1. Assume a rope tension at a convenient place in the pulley system.
2. Calculate the rope tension/force in the other rope section using the pulley efficiency.
3. Add the rope tensions for each pulley to find F_{load} and F_{anchor}.

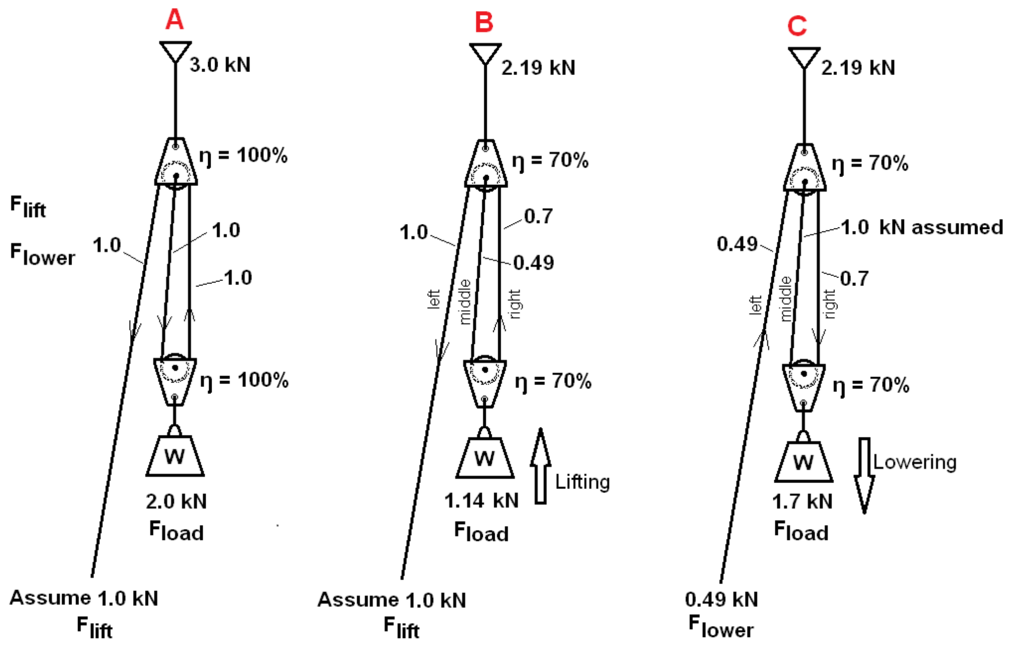


Figure 7.2 Calculating mechanical advantage

7.2.2. Mechanical advantage without friction

A-figure. It doesn't matter where you assume a certain tension, as the tension is the same for all three rope sections.

Assume F_{lift} =1 kN in the left rope (that you hold in your hand). All three rope sections have a rope tension of 1.0 kN.

Two ropes leave the lower pulley, so the load must be 1.0+1.0 =2 kN = F_{load}.
Three ropes leave the upper pulley, so the anchor must experience 3 kN = F_{anchor}.

A lift force of 1 kN gives F_{load}=2 kN, so the mechanical advantage is factor 2.
F_{anchor}/F_{load} ratio is 1.5.

> For a frictionless system, the mechanical advantage equals the number of ropes that leave the pulley(s) that carry the load.

Here 2 ropes leave the lower block, so the mechanical advance is factor 2.

7.2.3. Mechanical advantage, Lifting with friction

B-figure. Most convenient positions for assuming rope tension is the left rope section (that you have in your hand). Then follow the rope through the pulleys and calculate the tensions using the efficiency.

It is good to remember/check that the tension on rope the comes out of a pulley is always higher then the tension of the rope that moves into the pulley.

Assume F_{lift} = 1 kN
The rope comes out of the left side of the upper pulley, so

$F_{right} = eff \cdot F_{lift} = 0.7 \cdot 1 = 0.7$ kN

As we are lifting, the right rope section comes out of the lower pulley, so the middle rope sections has tension

$F_{mid} = eff \cdot F_{right} = 0.7 \cdot 0.7 = 0.49$ kN

Now we have all forces

$F_{load} = 0.7+0.49 = 1.19$ kN

$F_{anchor} = 1.0 + 0.7 + 0.49 = 2.19$ kN

$F_{lift} = 1$ kN

We have very poor mechanical advantage: factor 1.19. But don't forget that a single 70% efficient pulley has a real mechanical advantage of 0.7. So you win factor 1.19/0.7 = 1.7.

7.2.4. Mechanical advantage, lowering with friction

C-figure. Most convenient positions for assuming rope tension is the middle rope section. When the load moves down, the middle rope comes out of the lower pulley, so the right rope section carries less tension. Then follow the rope through the pulleys and calculate the tensions using the efficiency.

$F_{middle} = 1$ kN assumed

$F_{right} = 0.7 \cdot 1 = 0.7$ kN

$F_{left} = F_{lower} = 0.7 \cdot 0.7 = 0.49$ kN

$F_{load} = 1+0.7 = 1.7$ kN

$F_{anchor} = 2.19$ kN

We have very good mechanical advantage for lowering: 1.7/0.49 = 3.5

Though lifting may be a heavy task due to the small mechanical advantage, lowering will go very easy.

7.2.5. Mechanical advantage for a 3 pulley system

Figure 7.3 shows a schematic of a 3 pulley system that would give a mechanical advantage of 3 when there would be no friction.

The mechanical advantage of factor 3 can be seen quickly as there are three ropes going to the load.

The upper pulleys are normally on a single axle and can rotate independently. Rope section D is normally in line with the axle of the lower pulley.

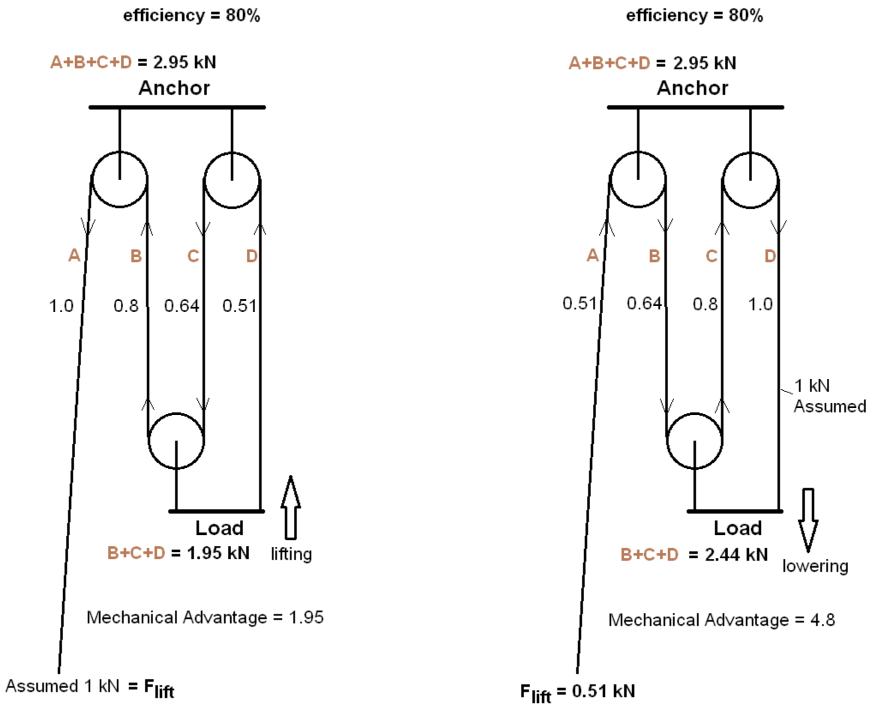


Figure 7.3 three pulley system

The rope sections are indicated with A, B, C and D. Rope run directions are indicated with the arrows.

Rope tension is mentioned below the letter indicators for the lifting and lowering case.

For the lifting case the mechanical advantage is 1.95, compared to 3 for the frictionless case. F_{anchor}/F_{load} = 1.5, compared to 1.33 for the frictionless case.

The gain compared to a single pulley is factor 1.95/0.8 = 2.44, so that isn't bad.

The lowering case has a mechanical advantage of 4.8, compared to 3 for the frictionless case. F_{anchor}/F_{load} = 1.21, compared to 1.33 for the frictionless case

When there would be no friction the mechanical advantage would be 3, but it is 1.95. The overall efficiency for this pulley system is 1.95 kN/3 kN = 0.65 (65%).

This example also shows that when you want large mechanical advantage ratios, you need high efficient blocks, otherwise you gain near to nothing. The higher the required mechanical advantage, the higher the block efficiency must be to benefit from the higher number of pulleys.

When you would do the math for using carabiners instead of pulleys, you may use an efficiency of 40%. You will see that your gain is marginal for a 2 “carabiner pulley” system. It is near to nothing when going from a 2 to 3 “carabiner pulley” system. For lowering you have lots of gain of course, as the friction of the rope through the carabiners will help you.

7.3. On-rope pulley systems

With friction hitches you can put a pulley (or more pulleys) on rope to make a mechanical advantage and/or redirection of force.

You can also use a friction hitch to block unintended lowering of the load, or to block unintended force reduction.

Figure 7.4 shows three systems with increasing functionality.

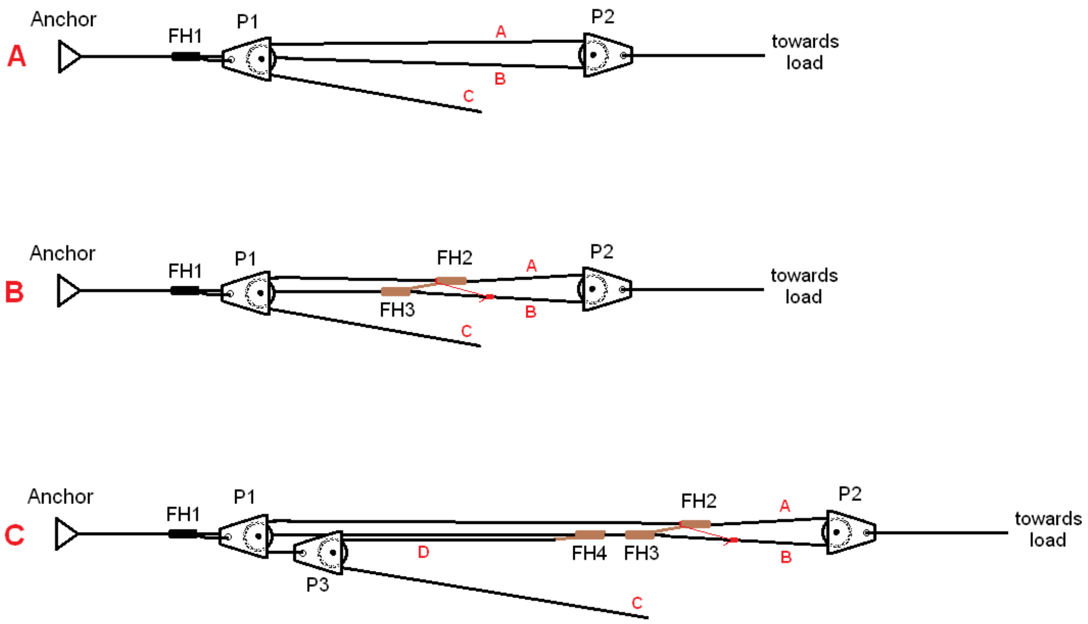


Figure 7.4, on rope pulley systems

A-figure

The rope that is connected to the anchor, goes behind pulley 1 towards pulley 2. There is a friction hitch (black, FH1) on the rope that connects to pulley 1. Of course one could use a midline loop knot (such as alpine butterfly), but a suitable hitch does virtually not weaken the rope.

For this situation a long **Autoblock hitch** (figure 5.6) works very well as the rope section right of the hitch also has tension. Think of 6 or more turns, so in total 12 or more as you use a loop to tie this hitch.

The system has factor 2 mechanical advantage (lossless) like figure 7.2.A.

In case of no friction, rope section A, B and C carry same tension. Rope tension is half F_{load}. Force on the anchor is $1.5 \cdot F_{load}$. Force on FH1 is F_{load}.

B-figure

The pulley system is the same as shown in the A-figure, but two friction hitches are added and a red piece of elastic (shock) cord.

The shock cord keeps tension on the connection between friction hitches 2 and 3 via a tending ring or miniature tending pulley. As long as rope section A runs to the left, rope will pass through it. This is the normal situation for pulley system A when lifting. As FH2 and 3 experiences less then half the load of FH1 it can be a hitch that releases easy (such as Distel Hitch).

Once you let go rope section C, rope section A would run to the right. This will not happen as friction hitch 2 will now lock onto the rope. Adding the hitches makes an auto blocking system with near zero slack (because of the piece of elastic cord / shock cord).

As there is now zero force on pulley 1, you may reposition friction hitch 1. This is the main advantage of using a friction hitch instead of a midline loop knot. After repositioning of the hitch, you can continue pulling on C. The hitch will automatically open itself en will pass rope section A that goes to left.

If you want to lower, you need a second person, or hitch 2 must be within reach. First you need to pull C so that the load is of the hitch. Then you need to grab friction hitch 2 and move it a bit to the left so that there is no tension on the rope sections that leave the hitch. Now you can lower the load, or in this case, reduce the tension in the system. When you let go hitch 2, hitch FH2 will lock itself again, so you can release rope section C.

Figure C

Figure C adds another pulley (P3) and another friction hitch (FH4).

Pulley 3 has a mechanical advantage of factor two for the rope section that goes to pulley 1. You have a series system of two pulley systems with factor 2 mechanical advantage. The overall mechanical advantage is factor 4 (referenced to rope section C) Disadvantage is that the travel is limited as there is no continuous rope.

To enable larger travel, you need the FH2 and FH3 system. Once you stop pulling, pulley 1 and 3 are tension free. Now you can reposition FH1 and FH4. Pull again on C and now somebody else can reposition the FH2//FH3 blocking system.

Due to the fact that the pulling force at section C directly goes to pulley 1, this system has better efficiency then a system with 4 pulleys to make a factor 4 mechanical advantage.

You can use the whole system in reverse (anchor becomes load and vice versa), to get better mechanical advantage. Figure 7.4A gives 3:1`mechanical advantage when used in reverse.

Controlled lowering
For all pulley figures (figure 7.1 to 7.4), you may add a friction hitch around the rope that connects to an anchor on the ground. In case of letting go (think of a wasp sting), the friction hitch will take over. Of course it is important that the hitch gets some pretension as in figure 7.4.C to avoid shock load due to slack.

The friction hitches discussed here are designed for good locking with low slack. The disadvantage is that you need to unload the hitch to unlock it.

There are two popular hitches (the VT and XT) that can be gradually unlocked by pushing onto the top of the hitch. This enables controlled lowering without using your own weight. It is like using a mechanical descender for climbing.

These hitches are not the easiest ones to use. Before using them in a real application, you need to experiment rigorously on the actual rope, using the actual Prusik cord, or break things.

You can make a factor 4 mechanical advantage with only 2 pulleys (and friction hitches). You don't have the inverted pull direction that you need to lift something when standing on de ground. It can be useful for horizontal tensioning.

7.4. Safety Factors for pulleys

A pulley is considered a rigid object like a carabiner, shackle, turnbuckle or anchor. Safety factors are therefore somewhat less compared to rope.

> Do not use: pulleys from DIY stores, small industrial pulleys or marine (sailing) pulleys for life critical purpose. They may mention a Working Load Limit (WLL), but they are not manufactured with lifting/carrying persons in mind, unless otherwise noted.

Most pulleys for Arborist work, Climbing, Rescue and Rope Access have MBS values printed on the cheeks. A Safety factor <u>must</u> be applied based on the use.
Working load < MBS/SF

Activity	**SF**
Horizontal pulling	3
Lifting of goods	6
Life critical	10

Safety Factors are based on the static load. Higher values may apply in case of significant shock load.

Note that when lifting a 100 kg load with a pulley, the force on the anchor may exceed 2 kN (200 kg). So check the anchors.

7.5. *Sling forces in rigging*

Forces can “multiply” under certain conditions, without pulleys. It all has to do with angles. See figure 7.5A (basket hitch).

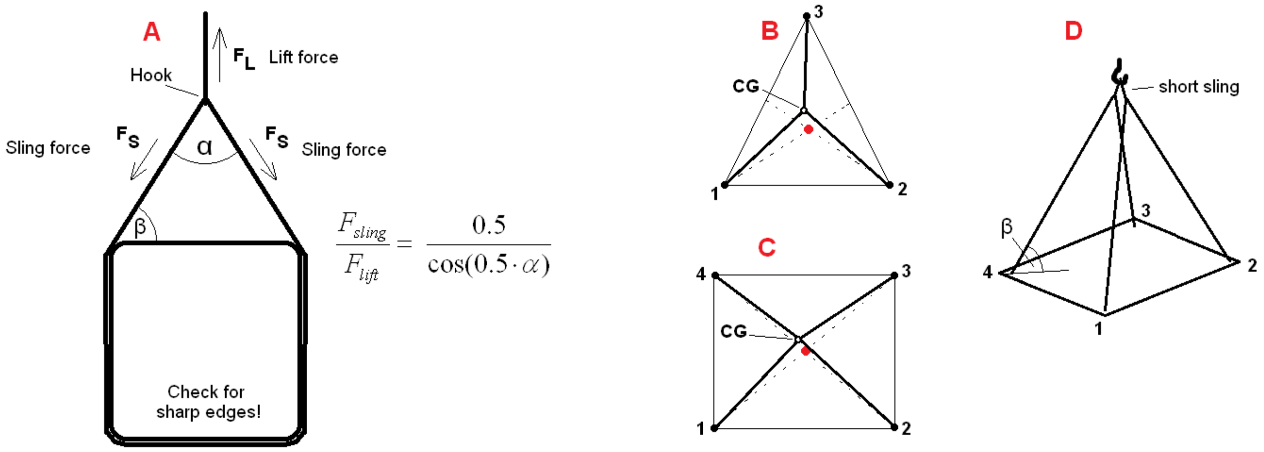


Figure 7.5, Forces in rope slings

7.5.1. Two legs (sling)

Two legs can be “made” using a rope with eyes that goes around the load as in figure 7.5A. The eyes connect to the hook. Other option uses two fixed length slings. They eyes connect directly to attachment points at the load and the hook. The slings can also connect to the load using a choker hitch.

Force in the sling (F_{sling}) can be calculated with the formula below:

$$\frac{F_{sling}}{F_{lift}} = \frac{0.5}{\cos(0.5 \cdot \alpha)} = \frac{0.5}{\sin(\beta)} \quad []$$

For α > 120^0 (β < 30^0), the sling force (F_{sling}) is greater then the lift force (F_{lift}).
For α = 90^0 (β = 45^0), F_{sling} is 71% of F_{lift}.

In case of a tight sling (that is alpha much larger then 120^0), you should do the math as sling force can be significantly above the lift force. This is similar to a very tight/straight slackline. In case of a fragile load, the sling may crush or damage the load. Large α (small β) may reduce the rated load of attachment points on the load.

When the angle (α) is small, the friction may be low and the load may fall out of the sling (when using one sling). You may need balancing legs.

When the load’s center of gravity is not exactly under the hook, the load will tilt when lifting. One of the sling legs will become more vertically. That one will carry greater load than based on the simple calculation.

A choker hitch around an object (using a girth hitch or an eye) tries to settle at alpha = 120^0, when there would be no friction. Strength is about 80% of the rope or sling strength. Of course due to friction the angle can be somewhat smaller or larger. When the load bearing section that goes to the hook makes an angle < 150^0 with itself, the strength reduce (depending on type of sling and material). Check the data of the manufacturer.

7.5.2. Three legs (triple leg bridle)

Figure 7.5B shows the three legs situation, seen from above. This situation is statically determinate. When the Center of Gravity of the load (CG) is in the center of the triangle (red dot) and the triangle have all equal legs, the load shares equally over all three legs. However, when lifting, the hook (or just the intersection of the three slings/legs) moves towards leg 3, leg 3 will experience some more force.

Load sharing is only uniform when the triangle has all equal length legs. When the distance between tie point 1 and 2 reduces (maintaining CG close to the center of the triangle), leg 3 will get more load.

7.5.3. Four legs (quad leg bridle)

This is the tricky one as the system is statically indeterminate.

Figure 7.5C shows the four legs situation, seen from above. When the Center of Gravity of the load (CG) is in the center of the rectangle (red dot) the load may not share equally over all four legs. Load sharing depends on (elastic) deformation of the structure (the load, or the legs). Large stiffness gives bad load sharing. Nylon slings give better load sharing due to the higher elongation (more stretch).

When the load is somewhat flexible (think of a large sand bag with four eyes) load sharing goes well. When the load is non-flexible (for example a thick steel plate with 4 eyes) the length of the legs must be matched for load sharing. When leg 2 is just a bit longer, or the attachment point is a bit closer to the center, the load is shared across leg 1 and 3. Small force goes to leg 4.

When the Center of Gravity (CG) would be exactly at the red dot, the load is only carried by leg 1 and 3.

> When you don’t do the math or can’t be sure that load sharing is fine, and you have a 4 legs sling, assume that only 2 legs take the load. The other legs are for balancing only.

7.5.4. Equalizing techniques for 4 legs sling/bridle

A solution is having two legs combined to a single rope with two eyes that can slide over the hook. For example (figure 7.5C) legs 1 and 2 have fix length and have their own connection to the hook. Legs 3 and 4 are a single piece of rope sling that can slide over the hook, This will equalize the forces, provided that CG is under the hook before lifting. The load cannot capsize as legs 1 and 2 have fixed length.

One may use 2 slings that can move over the hook. There is a risk that the load may capsize. Think of a rigid not to heavy load that is subjected to wind (parabolic dish).

Another option is shown in figure 7.5D. It uses a short intermediate sling. You can actually see when load sharing goes wrong, as symmetry is lost. When the connection between the short sling and the two main slings can be adjusted (using a girth hitch), forces can be equalized very well, even when the load is very rigid, and capsize risk is near zero. The short sling may make an extra turn around the hook to reduce capsize risk.

When forces are well equalized (figure 7.5D)

$$\frac{F_{sling}}{F_{lift}} = \frac{0.25}{\sin(\beta)} \quad []$$

When not equalized, sling force doubles due to load is carried by two legs.

7.5.5. Unequal leg length in case of “strange” loads.

For equal load sharing, the angles are of importance. This is shown in figure 7.6.

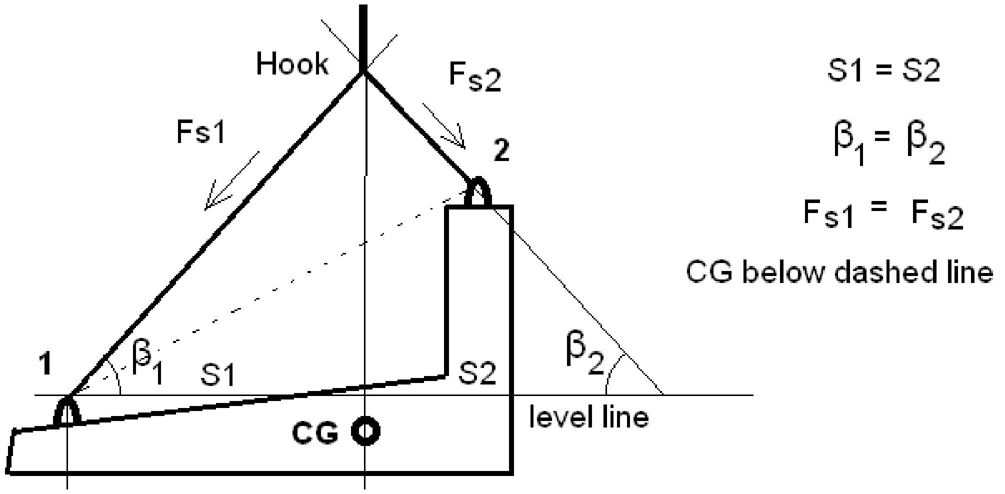


Figure 7.6, Forces in rope slings, unequal length

When CG is known, one can construct the bridle for optimum load sharing.

You start with a level line and construct a triangle with 2 same length sides. S1=S2, then β1= β2. This forces Fs1 = Fs2, as it is now a symmetrical structure, except that the eye for attachment point 2 is displaced.

To be stable, CG must be below the dashed line between the two attachment points.

In real world CG may not be known. Then just make a guess and start lifting. When the right side of the object goes up first, the hook moves a bit to the left. Then CG is more to the left instead of below the hook. When using rope, you may use a clove hitch around the hook, as that is easy adjustable but provides sufficient friction to avoid capsizing of the load when the load doesn't share equally across leg1 and leg2 (that means β1 differs much from β2).

Using unequal lengths, you may lift an antenna in its most favorite position for mounting in the mast.

Don't forget that when you use a pulley in the top of your mast and somebody at the ground does the lifting, the force on the pulley is (somewhat) more then twice the load.

Lifting things is a dangerous activity. The information in this document is not a replacement for training.

8. Advanced applications

8.1. *Getting a pulley into a tree without climbing*

Trees are very nice natural anchor points for suspending wire antenna.

For short operation with good whether the suspension line may run over a branch. However when the operation is more permanent and/or the branch moves due to wind, you need a pulley with a weight.

When the suspension line runs over a branch, constant rubbing of the line onto the branch:

- Damages the line
- Damages the bark and/or the cambium

Food and water supply to the tree goes via the layer directly under the bark and is called “cambium”. When you damage the cambium, you block the food transport to that branch, so that will die.

You can get a pulley in tree. See figure 8.1.

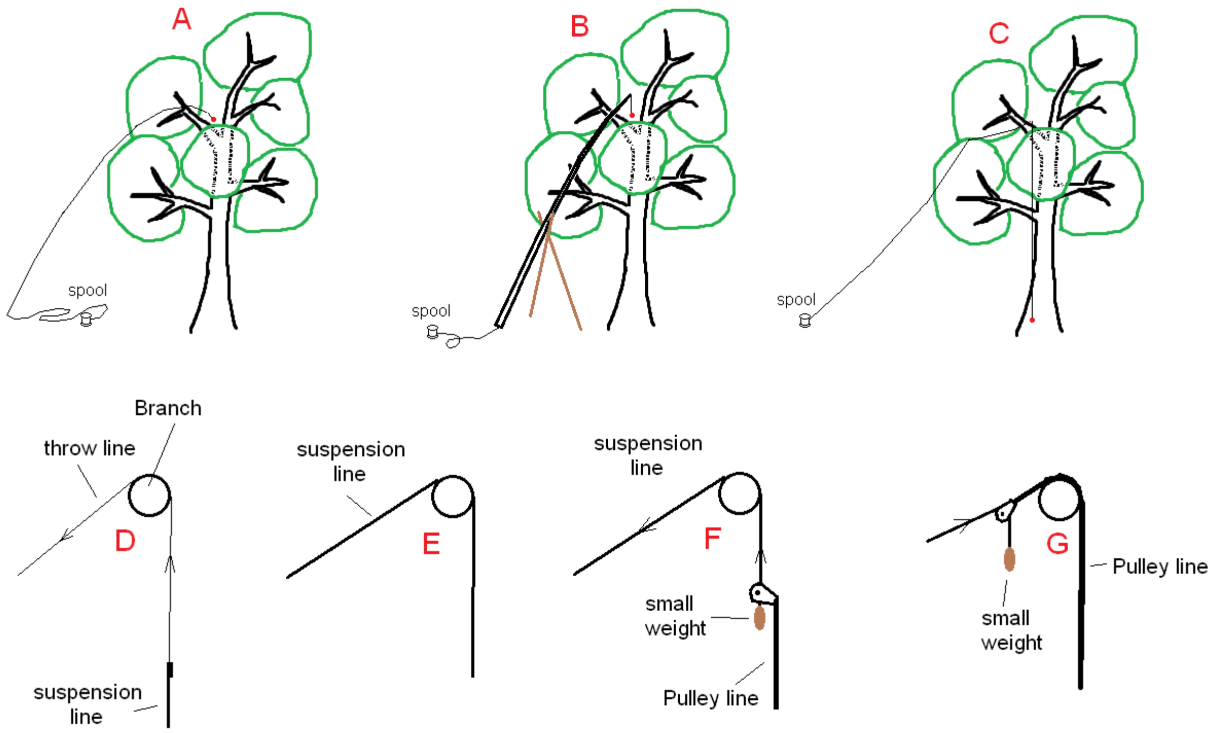


Figure 8.1, Getting a pulley into a tree

Most people use a thin throw line with a weight (A-figure, the weight is the red dot). After several tries you may get your line over the intended branch without the throw line being trapped in the foliage (figure C).

Antenna pole option
It can be done with an antenna pole. I used an 18 m Spiderbeam pole to get a line over a branch (figure B). You may need a support (such an A-frame) when there are no branches that can serve as a support. My 18 m mast has a fixture that holds all sections just above the ground, so that I can feed in a coaxial cable inside the mast during assembly. This is for wire antennas that are inside the pole.

Now I use a thin rope that goes through the pole. A tiny weight is at the top end of the rope.

During erecting of the telescopic post, the throw line is tensioned so that the weight remains on top of the top section. Once the top section is above the intended branch the weight is lowered. You may need to introduce some oscillation in the pole when the weight won't lower due to gravity alone.

When the weight is at the ground near the tree trunk, the pole is lowered. This must be done carefully to avoid that the throw line goes into the foliage. When done you arrive at figure C.

Figure D

Connect the antenna suspension line at the throw line near the trunk (using the bend from figure 4.14.D, a modified sheet bend). Pull the throw line so that the suspension line passes over the branch and comes down at the spool. The throw line can now be removed.

It is good to keep some tension on the suspension line to avoid that the line traps itself in the foliage.

Figure E

There is now only the suspension in the tree.

Figure F

Putt a pulley onto the suspension line and connect a moderate weight at the suspension line. The weight must be large enough so that it doesn't go through the pulley. The pulley has to "sit" onto the weight. Connect the pulley line to the pulley.

Pull the suspension line so that the pulley, weight and pulley line goes upwards and just passes over the branch. Now you get the situation as in figure G.

Figure G

Tie the pulley line to a temporary anchor point and release the suspension line so that the weight lowers. Tie the suspension line to a temporary anchor point near the spool.

Tie the pulley line to a high point in the tree. This reduces the risk of vandalism and reduces movement of the pulley line with respect to the branch carrying the pulley line.

A pulley on one side of the suspension is mostly sufficient. Now you can suspend your wire antenna (dipole, fan dipole, etc) into the trees.

When everything is fine, you need to untie the suspension line below the pulley and add the counter balancing weight to keep sufficient tension on the suspension wire. To avoid vandalism it is wise to have it out of reach of most people.

When done the tree can bend with the wind and the weight goes up and down. Instead of a weight, one can also use a long length of shock cord (elastic cord).

Alternative

When there are no branches interfering with the suspension line (or throw line), one can first pull the pulley line over the branch and then down towards the spool.

You can connect the pulley onto the pulley line (at the location of the spool). Feed the suspension line through the pulley and connect the weight.

The person near the tree trunk now pulls the pulley line and another person keeps some tension on the suspension line so that the weight remains close to the pulley and doesn’t get trapped into the foliage below.

When the pulley is close to the branch, the pulley line is tied temporary and the suspension line is slowly released so that the weight goes down and lands near the tree trunk.

8.2. Mounting fiberglass masts onto a (wood) pole

Fiberglass masts/poles and fishing rods/poles are used for antennas. To get more height the pole can be mounted onto a wood pole, or for example a scaffold tube.

Within Scouting a round lashing is used to connect two wood poles to each other to make a longer one. When you use this lashing to put a fiberglass pole/rod onto a wood pole, you will crush the fiberglass pole, 100% sure.   If nothing else at hand, two well-spaced figure 8 lashings may do the job, but be prepared that your pole will be crushed. This may happen during the frapping process.

The above methods use the friction force between the rope and the wood to keep the poles aligned. ‘To have sufficient friction, you need high tension in the rope and that crushes the fiberglass tubes when using the round lashing.

When using the figure 8 lashing, the radial force is over 360 degrees around the tube, so that will not crush the tube. Crushing may occur during the frapping phase where rope is tightened between the fiberglass rod and the wood pole.

When you have a wood plank, you can make a very good connection with low force onto the fiberglass (fishing) pole. The alignment depends on the wood plank and no longer onto rope friction forces.

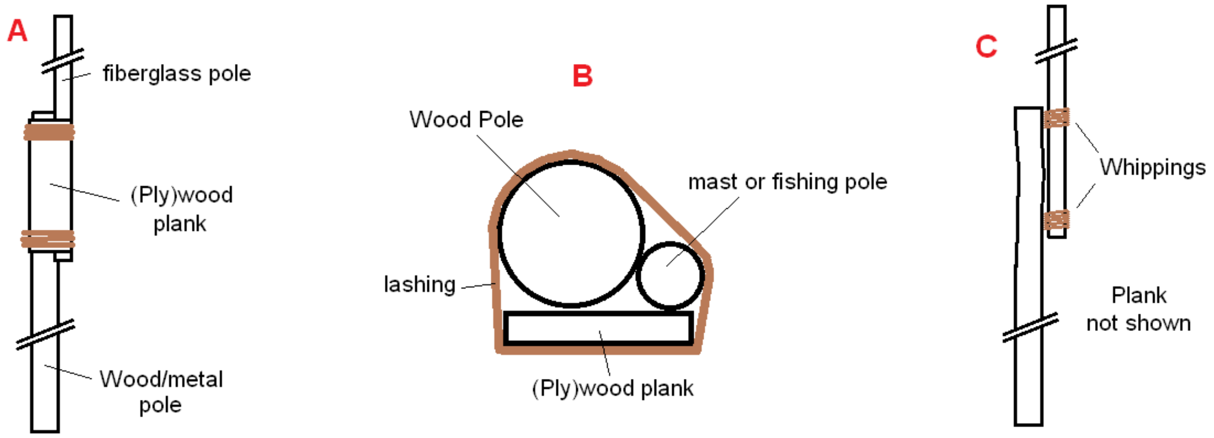


Figure 8.2, mounting fiberglass pole onto other pole

The (ply)wood plank (A-figure) assures that the fiberglass pole and wood/metal pole keep aligned (in parallel). The lashing only needs to keep everything together (B-figure).

When there is a risk that the wood pole bends the fiberglass pole (C-figure), you may apply whippings around the fiberglass pole so that there is some clearance. This also provides a kind of soft interface avoiding point loading. Then assemble everything together using the plank and two lashings.

When using a multi turn lashing, there is a risk that you apply unnecessary large force, and that may crush the fiberglass pole. I never used a lashing, but just the rectifier hitch forming a loop (figure 5.1). Two or three turns around the plank and poles are sufficient. When you experience some movement between the parts, just apply some extra tension. PP or PET rope is preferred as this doesn't elongate when wet. Of course PA is also possible if that is the only choice. Though not recommended, I once used cloth reinforced tape (gaffer's tape).

It is good to bevel/break the edge of the wood plank where the rope runs to avoid failure and/or damage to the rope.

Note:

> When you do some activities with Scouts, be very careful. They are familiar with wood poles and mostly do their best to pull as hard as they can to get a firm reliable connection between wood poles. They need good connections, as they make towers and other structures from just wood poles and lashing rope.
>
> When you let them fix a fiberglass pole onto a wood pole, near 100% sure they will break it (from experience).
>
> It is not their intention to break a pole. It is just because they are not familiar with fiberglass or carbon poles.

8.3. *Guy wires onto fiberglass antenna poles*

Many Radio Amateurs use fiber glass antenna poles. 20+ m long telescopic poles are available. In most cases guy wires are required. There are special metal assemblies available to mount guy wires onto fiberglass masts/posts. Regular assemblies for metallic masts will damage your pole.

When not having the special fiberglass mast compatible assembly, you can use a rope version using a braided friction hitch. Connecting guy wires directly onto the load bearing rope ends of a friction hitch is not recommended. This results in a highly dynamic load with varying angle towards the post. Dynamic load on friction hitches is allowed off course, but an angle that changes is not a good idea.

You can have two options:

1. The mast is fixed and doesn't rotate
2. The mast has to rotate to facilitate directional antenna without using a rotator.

In the first case the eyes (or loops) are fixed to the pole so that the rope will not move with respect to the pole. There will be no wear due to abrasion.

In the second case the 3 or 4 eyes cannot be fixed. This will lead to wear (abrasion) as the eyes should be able to move around the mast to enable rotation of the mast.

For now only the fixed version is discussed here.

8.3.1. Rope assembly for a non-rotating mast.

The concept is shown in picture 8.3.

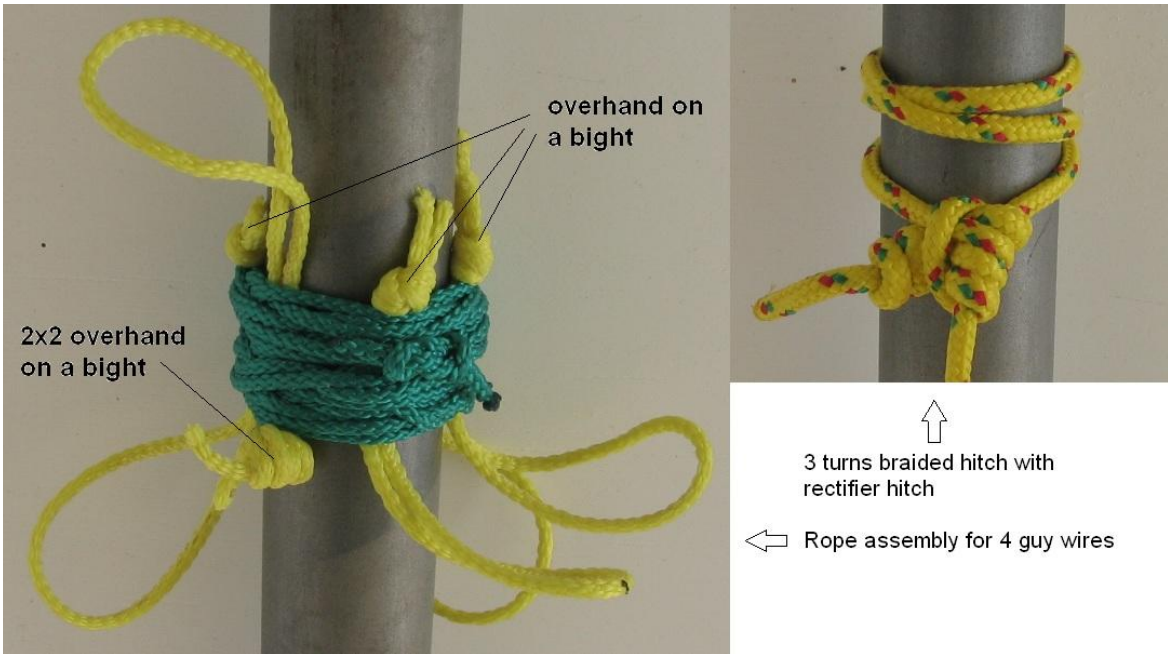


Figure 8.3, Rope only guy wire assembly for fiberglass pole

The guy wire rope assembly consists of:

- 5 stopper knots on a bight, forming 5 loops. 4 are facing down, one facing up as shown in figure 8.3, left side
- A wrapping of rope around the pole that compresses the loops onto the pole
- A braided friction hitch, shown on the right figure.

The loops that point downwards connect to the guy wires. The one that points upwards is connected to a braided friction hitch around the same pole, and that avoids that the wrapping with the loops is pulled down.

Suggestion for the stopper knot on a bight

The loops should have length of about 1.5…2 times the diameter of the pole.

On purpose just overhand knots on a bight are used for the 4 downwards pointing loops. The overhand knots are on top of the wrapping. For clarity the tails are very (too) short. Is it wise to do? No. When the green turns are not that tight, you may pull the overhand knot under the turns.

The upper loop uses a 2x2 overhand knot, clearly visible in the picture. This knot will not slip under the turns. So use fat/bulky knots for all loops. Do not use figure 8, as it does not perform better then an overhand knot on a bight.

The wrapping

The wrapping should be made from rope preferably somewhat thinner then the rope used for the 5 loops. The wrapping should be relatively tight, but don't apply too much force. When you use 2x2 overhand stoppers, the wrapping will not fail. The reason for the good tightening is that the wrapping doesn't move under the dynamic load onto the loops. This reduces/avoids abrasion.

Length of the wrapping is about the diameter of the pole. Do not make a single wrapping so that as one strand breaks, the whole wrapping fails. So a single whipping is not a good idea.

My preference is a wrapping of about 5….10 cascaded double constrictor hitches. Procedure is in figure 6.6. When you use relative thick rope for the wrapping, 5 hitches are sufficient giving 15 turns in total.

Not recommended alternative

When you have a third hand free, you can make a redundant wrapping using square knots. Start halfway your rope length and make about three turns and use a square knot. You need a finger from a third hand to make sure the tension remains in the turns. You can repeat this process to get a redundant wrapping,

The friction hitch

As you don't have to move the hitch when the pole is erected, a 3 turns braided hitch with a rectifier hitch has my preference (right photo in figure 8.3). You can give the hitch permanent pretention with the rectifier hitch so that it will never ever move. You can also use a girth hitch as shown in the right photo of figure 5.10.

Choice of rope
For semi-permanent installations, use relative thick rope, as that has less stretch, so less wear due to abrasion. Polyester rope is preferred due to the good outdoor performance and low stretch compared to Nylon.

Of course when nothing else is available PP or Nylon is also possible, but maintenance/inspection interval will be shorter. Consider impregnating the assembly with oil or petrolatum. Petrolatum requires a heat source and you have to be very careful when using PP rope (low melting temperature).

How to make the guy wire rope assembly
Take 5 pieces of rope and form a bite. Tie double overhand or 2x2 overhand knots to make the 5 loops. It is not recommended to use overhand knots on a bight.

Make an adjustable loop from thin rope to temporary fix the 5 loops onto the pole. A rubber band works better. You may use very small pieces of tape.

Apply the wrapping over a length of about the diameter of the pole. You start from the top (just below the 4 stopper knots. Continue downwards, but don't spend all your rope (here green). Continue going back upwards over the existing turns to about halfway. This is to reduce the stress on the wrapping as the guy wires tend to pull the loops away from the pole.

When done pull the loops so that the wrapping compacts a bit.

Tie the friction hitch and check whether (or not) the number of braided turns is sufficient. 3 turns work in most cases. Dress the hitch well so that the crossings are over/under and 180 degrees angle between the crossings.

Connect the hitch with the upwards pointing loop. Push hard on the complete assembly (except the friction hitch) so that you get some tension in the connection between the friction hitch and the wrapping with loops.

8.4. Overhead cable suspension

Sometimes you may want your cables elevated from the ground. Hanging your cables without a supporting line is a very bad idea. It is even worse when the total length is made using several sections with connectors. You need a suspension line with many connecting points like a suspension bridge. The cable tension is then transferred to the rope.

When the span is near horizontal and the sag is small, you can make a line with several butterfly knots in it. The butterfly knot is shown in figure 8.4 (back and front side). Tying instructions are in figure 4.6.

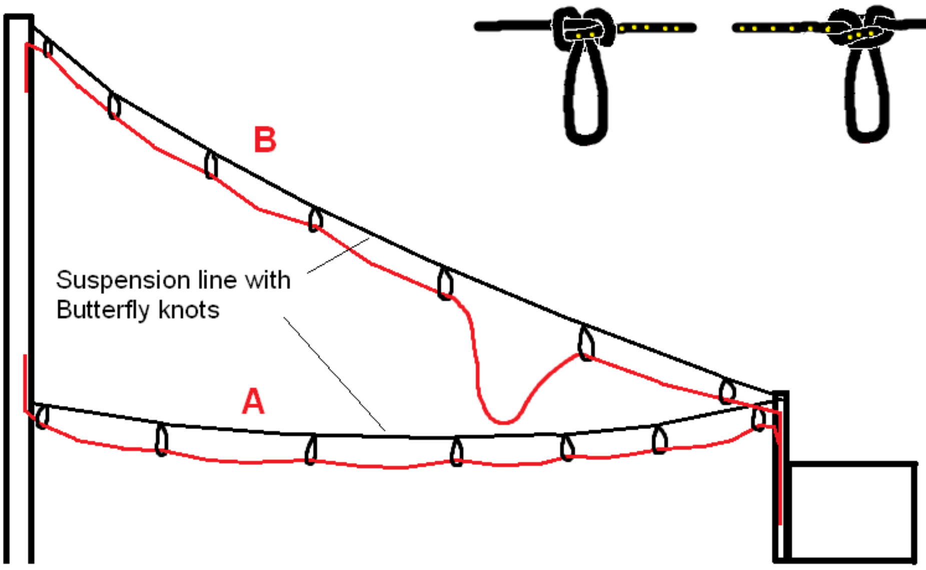


Figure 8.4, hanging a cable using a suspension line.

You pass the cables through the eyes (when on the ground) without fixing the cable to the eyes. When done you can raise the suspension line with cables. This is shown in figure 8.4A. Distance between eyes should be relative small to avoid the problem shown in the B figure.

When the span is long, with large sag, and/or inclined, the cables may move through the eyes and bulge/falls out of the suspension line. This is shown in figure 8.4B.

When the friction between the cable and the eyes isn't sufficient, you need to fix the cables to the eyes of the suspension rope/line. This can be done using a simple soft shackle and wrapping the soft shackle 3…5 times around the cable. This is shown in figure 8.5 A and B. Of course you can use more cables at the same time, or add cables afterwards, as long as the soft shackles are long enough.

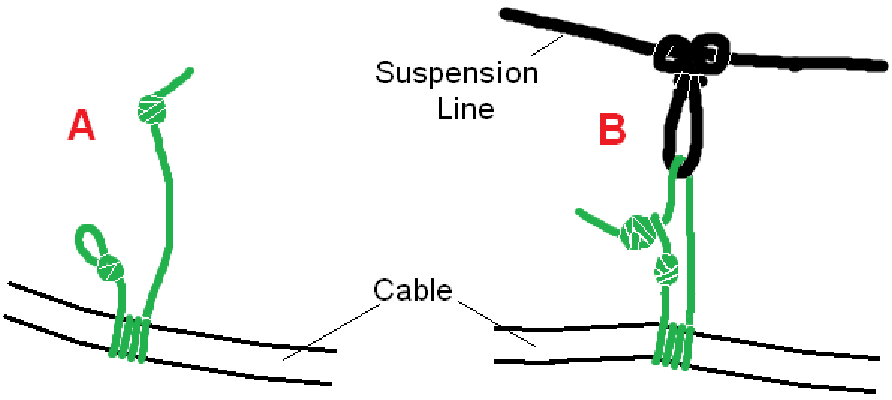


Figure 8.5, Simple soft shackle connection to the suspension line.

The loop/eye knot is a figure 8 (figure 4.9) and the stopper can be a 2x2 overhand stopper (figure 4.2E and F), or double overhand stopper (figure 4.2C). I prefer the 2x2 overhand stopper.

When the inclination of the suspension line is large, you may use a real friction hitch (Prusik, Distel, etc). To avoid losing your soft shackles, you may girth hitch them onto the eye. The girth/cow hitch is in figure 2.2.

When you want adjustable tie points for cables, or just don't like the bulky butterfly knots, a Prusik hitch using a loop or a soft shackle is an option. This is shown in figure 8.6A and B.

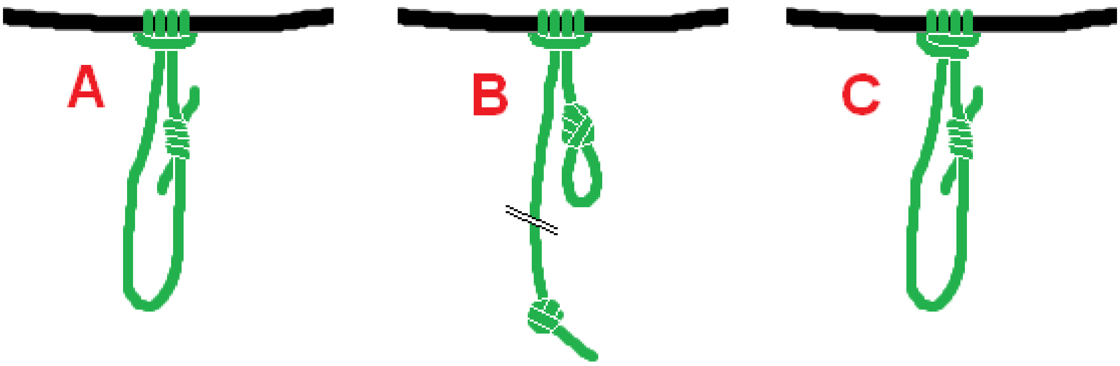


Figure 8.6, Adjustable anchor points on a suspension line.

The B-figure is the most versatile as you can choose between the loop (soft shackle closed) and the open loop. The Prusik hitch has 2 wraps in figure 8.6. When the suspension line has large inclination, you may need 3 or even 4 wraps.

Figure 8.6C shows an additional turn around the vertical standing ends (similar to the Bull Hitch). This is sometimes done with the girth/cow hitch, but also works on a Prusik. It reduces the chance that when there is nothing in the loop the Prusik loosens itself so that it moves. The extra turn is useful when you store the rope when the Prusiks are still on the suspension rope. The extra turn option is not tested for life support applications.

Suspension lines, especially those with the soft shackles are also very useful for suspending your Christmas decorations. The sag of the LED string lights between the anchor points is very pleasant to the eyes. As the stress is taken off the string, its useful lifetime may also increase.

8.5. Erecting an antenna mast using a tripod

8.5.1. Introduction

Erecting an antenna mast with the help of a tripod is frequently carried out to get a mast from horizontal to vertical position. The reasons for adding this topic are near accidents when using mechanical advantage.

The basic principle is shown in figure 8.7. When the mast is vertically (B-figure), it is fixed to the tripod. Wood poles as used during Scouting activities (pioneering) are used frequently. They are relatively heavy and can have length of about 8 m / 26 ft.

The situation just before raising the mast is shown in the A-figure. The mast is fixed to a (rope) hinge so that it can rotate. By pulling the rope (Fp, rope section on the right side) and some help from people that push the mast upwards it arrives at its final position (B-figure). Mostly the mast is fixed with a lashing onto the tripod when fully vertical.

Forces can be considerable when the mast is made from say an 8 m wood pole and a 6 m wood pole with an antenna on top. The required pulling force (Fp) can be in the kN range.

Things can go very wrong when using mechanical advantage.

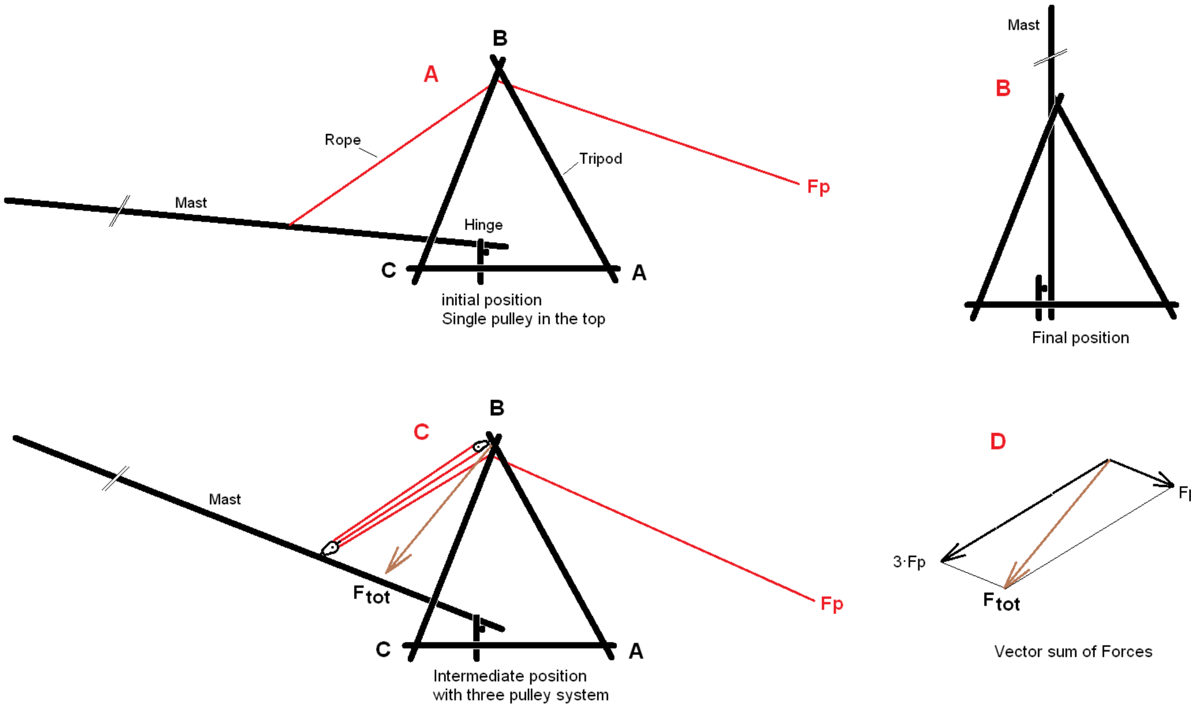


Figure 8.7, Erecting a mast using tripod and pulleys

8.5.2. Forces in the tripod system

The problem is not in the tripod itself. Good wood poles can have forces above 10 kN before buckling. This is also valid for side loading as happens when using lashings to other poles. The lashings itself can also have forces in the 10 kN range.

The problem is in the rope forces onto the B vertex of the tripod. When using a single pulley in the top as in the A-figure, the force onto the pulley acts down, or at least between the wood poles seen from vertex B. Only when the mast is near vertical, the left rope section is near horizontal and there will be some component pointing to the left. But when the mast is near vertical, the rope force (Fp) has reduced significantly.

The C-figure is completely different. Here people decided to use a 3 pulley system to reduce the work load for the people. When going from figure A to C people can help pushing the mast upwards, but at some point the mast has to be pulled vertically by the people pulling the rope on the right side (F_p). This can go very wrong.

There are three rope sections on the left side, and one on the right side. The total force on the left side is therefore 3 times Fp. A vector summation of the rope forces that act on the B vertex is shown in the D-figure.

The total force (F_{tot}) is also shown in the C-figure. F_{tot} is now outside vertex B. F_{tot} generates a moment around vertex C that tends to tip over the tripod. When the own weight of the tripod is not sufficient to compensate for the moment, the tripod will tip over to the left. This is an unstable situation as when vertex B moves to the left, the mast will become more horizontal, increasing the rope force. The people that are pulling onto the rope can't reverse this situation without causing damage. When they let go the rope, the mast will fall onto the people on the left side of the tripod.

This unstable situation may/will result in danger to the people near the mast and the tripod. I witnessed this about 3 times, luckily the operation was halted just in time as I was aware of what could go wrong.

8.5.3. How to avoid accidental tilting?

When erecting heavy masts using a tripod, especially using mechanical advantage, an evaluation is required. Very likely vertex A should be fixed to ground, or a guy should be connected to vertex B and fixed to the ground right of the tripod. It is advised to use horizontal poles between the three legs of the tripod. It gives rigidity and avoids collapsing of the tripod.

It is not recommended to use human weight at vertex A, just in case a wood pole or a lashing fails.

Though not relevant for Radio Amateurs, accidental tipping over can happen when setting up a slack line or zip line using a single pulley in the top of a tripod.

8.6. Poor man's mechanical advantage

With just rope, and maybe a carabiner or ring, one can make a mechanical advantage with the so-called **trucker's hitch**. There are many varieties of the trucker's hitch. The basic principle is treated here.

When you are not familiar with mechanical advantage, you may read chapter 7 first.

Basic operation
The basic principle is shown in figure 8.8A.

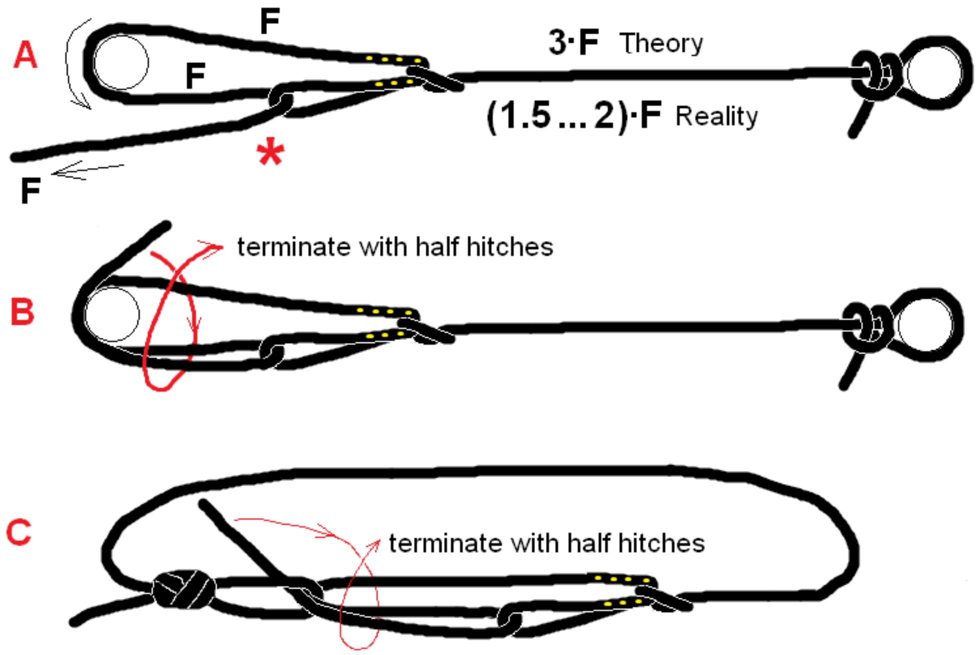


Figure 8.8, Trucker's hitch

The loop (here a slip knot (overhand noose knot), see figure 4.16) and the left anchor point serve as poor man's pulleys. The forces in the yellow marked rope sections are equal, so the slip knot loop size doesn't change.

When there would be no friction, the tension in the three left rope sections would be F, resulting in 3F tension in the right rope section that goes to the right side anchor point

However there will be friction. Depending on the surface of the left anchor point and the rope, the real mechanical advantage will be in the range of 1.5....2. When you put a ring or carabiner in the loop, the friction will be less increasing the mechanical advantage more towards 2.

Instead of an overhand noose, a butterfly knot can be used. Advantage of the overhand noose is the easy adjustment.

Termination of the knot

When F is not that large, you may grip the tensioned rope at the red star position, and tie some half hitches. You can tie them around one or both rope sections that go to the left anchor. Using half hitches on a bight eases untying. This way of termination will reduce the tension in the load bearing rope.

When you want more tension, you can use the option as shown in figure 8.8B. When you go around the left anchor point with full tension, you virtually don't lose tension. Finish with half hitches. When using half hitches on a bight, they are easier to untie.

Loop version
You can also use it to bind things together (as an alternative for the constrictor, or loop with rectifier friction hitch), see figure 8.8C. The loop at the left side is a non-sliding loop (just an eye termination).

I virtually don't use it for HAM activities. My main application (for the loop version) is binding together thin branches with natural fiber rope for transport. It uses less rope than the constrictor, and you only have to make a single loop around the branches (works faster). I also use it for securing cargo onto the roof rack of the car.

8.7. Assessing rope tension

You can "measure" the rope tension without changing the construction. So you don't have to add things in series with the rope.

Figure 8.9 shows the basic operation.

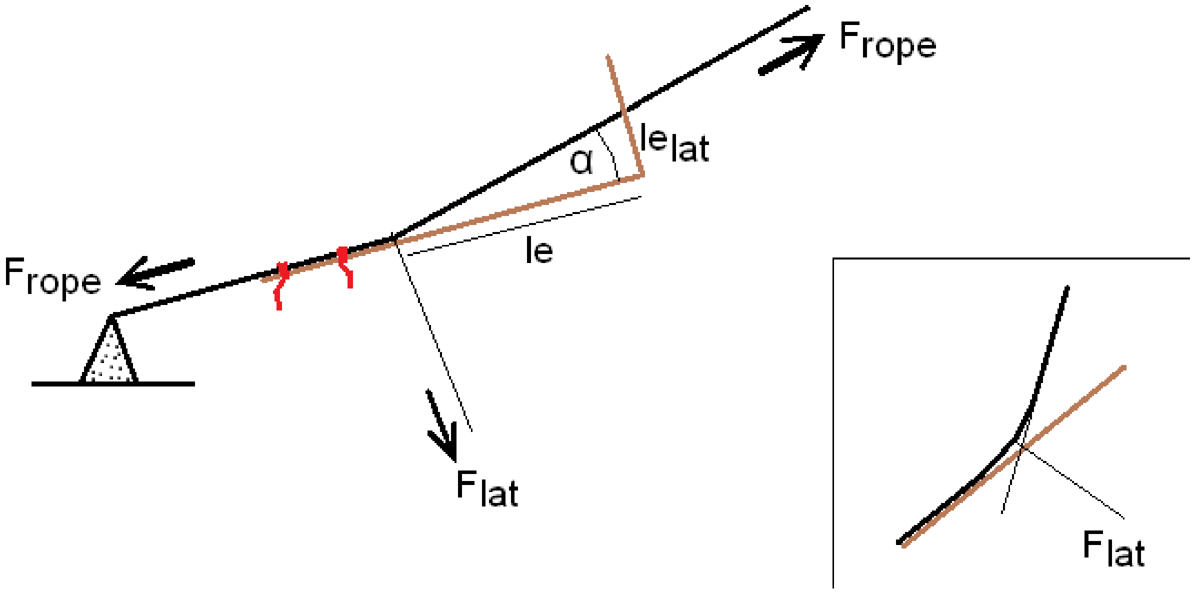


Figure 8.9, Rope tension measurement

The trick is to add a lateral force (Flat) onto the rope. This creates a small V. To assess the force, you need to know F_{lat} and the deviation angle α.

$$F_{rope} = \frac{F_{lat}}{\sin(\alpha)} \approx F_{lat} \cdot \frac{le}{le_{lat}} \quad [N]$$

R_{rope} = rope tension, in N, F_{lat} = lateral force applied to the rope, in N,
α = the deviation because of F_{lat}, in degrees,
le = length of stick that is beyond the V-vertex,
le_{lat} = deviation due to F_{lat}, use same unit as for le.

The brown stick you can connect to the rope using rope loops or clips. The angle between F_{lat} and the two rope section should be equal. Keep in mind that 10 degrees off optimum introduces an error of just +1.5 percent, as cos(10) = 0.985.

When applying F_{lat}, the rope tension may increase somewhat, especially when having steel, Kevlar or Dyneema lines. The error due to increase of tension is lowest when you measure close to an anchor. Best is to measure at two angles, and note the difference.

The formula is only valid for small α. For α < 10 degrees, error is < 0.5%.

As sin(α) ≈ tan(α) = le_{lat}/le for small α, one can skip the angle measurement and just determine le_{lat}/le ratio. For le_{lat}/le <0.15, error < 1.4%.

Example

Le = 120 mm, le_{lat} = 6 mm, F_{lat} = 20N
Check le_{lat}/le <0.15. It is 0.05, so accuracy of formula is fine.

F_{rope} = 20·120/6 = 400 N (40 kgf).

Thick lines
When having thick lines, you need to increase and decrease F_{lat} somewhat to notice rope friction and correct for that. You also may need to correct for the curvature in the rope. Luckily this is very easy. It is shown in the inset of figure 8.9. The extrapolated crossing of the ropes is at the position where the rope for F_{lat} crosses the brown stick.

When using le_{lat}/le ratio (preferred), the numbering for “le” goes from right to left, so zero is at the 90 degrees vertex. Why le_{lat}/le ratio is preferred? You can do the math even on a sand bed. You don’t need a sinus table (or calculator with sin function).

If you have a smartphone you can make a photo. When you have horizontally one of the rope sections, you can determine le_{lat}/le ratio just by pixel counting (using image processing software).

You may also copy the angle from a distance (optically) using a sliding bevel.

Warning

When the tension is so high that there is a risk of line break, you should not be near the line. Especially Nylon (PA) can store significant energy due to the high rope stretch. A line that releases its energy after breaking can hurt or even kill you.

Lowest energy is stored in Kevlar and Dyneema. But that can still be dangerous when a metal shackle fails and the shackle is accelerated by the rope towards you.

8.8. *Increasing rope bend radius in knots*

Increasing the bend radius, increases the strength of the knot.

When tying knots on a bight (to make an eye termination, see figure 4.9), or using the retrace / follow through method, you have two rope sections in parallel. See for example figure 4.9, 4.91, 4.10 and 4.11.

A bight halves a rope section in length. Again forming a bight quarters the original rope section and you have 4 rope sections in parallel now. There are two eyes on top of each other. When you put a knot onto this double bight, it becomes larger, resulting in larger bend radius. This increases the efficiency of the knot. You may gain 20..30% (not 20 percent point) for Dyneema or Kevlar. A figure 8 on 4 rope sections outperforms a figure 10 (PA/PP/PET).

Then disadvantage is the dressing as you have 4 rope sections know. This reduces the reproducibility of the dressing process.

Figure 8.10 shows a figure 8 on a bight (A-figure) and a figure 8 on a double bight. The load carrying section (standing end) now encircles 4 instead of two rope sections.

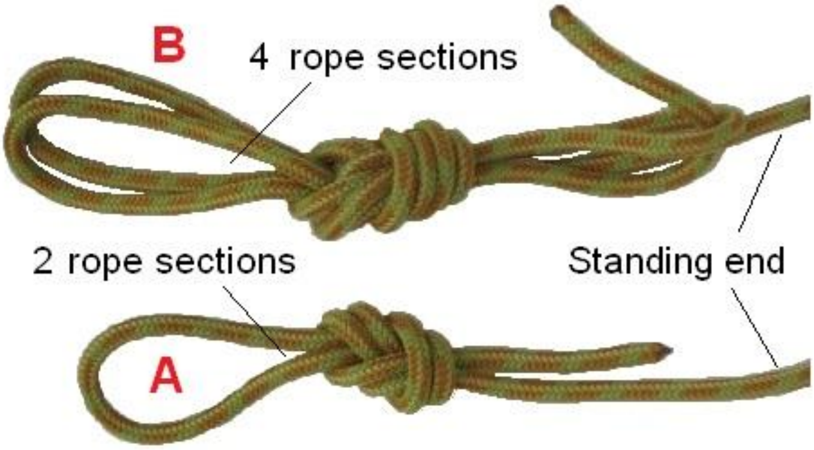


Figure 8.10, figure 8 on a bight and on a double bight.

This also works for Dyneema, but you need to start with a knot with lots of bends. A figure 8 on a bight with four strands to form an eye may slip when using Dyneema. You need to test for slippage and tail eating with dynamic load. You may use a 2x2 overhand on a bight, or figure 10 on a bight.

Knots with lots of bends are (near) impossible to dress well when using a double bight. One may retrace a separate piece of rope (or the tail) through the knot. Reproducibility will be a challenge, as how do you retrace (in between existing sections, below, on top, etc.)? A sleeve can be a very good option.

Sleeves
Putting a sleeve around the rope before tying the knot makes the knot bulky. The sleeve “thickens” the rope, thereby increasing the bend radius of the rope that is inside the sleeve. It works easier and with far better reproducibility compared to a double bight. You can use a braided rope, or sheath of an existing core-braid rope to make a sleeve. Preferred sleeve material is Polyester or Polyamide.

Tensioning of sleeves
The sleeve needs to be tensioned very well. That means gradually tensioning all 4 rope sections leaving a knot on a bight. Putting the eye around an object and tensioning the sleeve of the standing end, and tail, doesn’t tension the sleeve sections that form the eye. The reason is that the tension is taken over by the Dyneema that is inside the sleeve. You need to grab them individually.

Dyneema and Kevlar rope virtually need a sleeve to get reasonable knot efficiency. Due to the low friction of Dyneema, you also need to use a knot with lots of bends so that it doesn’t slip out of the sleeve. Don’t forget to test for slippage and tail eating.

Figure 8.11 shows the figure 8 on a bight, the figure 8 on a bight with sleeve and the splicing tool.

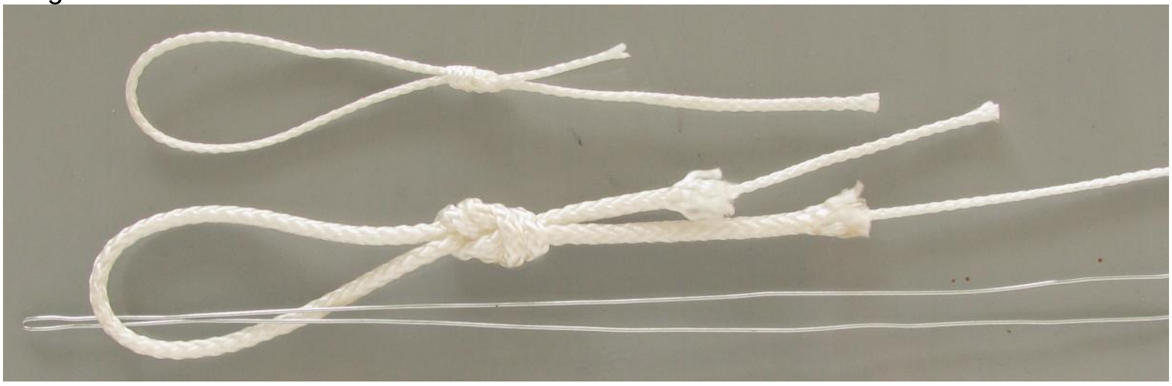


Figure 8.11, figure 8 on a bight using sleeved rope

The rope is a >15 years old never-used kite line, 1.8 mm thick, braided **Dyneema-Polyester blend**, with a strength as written on the label of 75 kg. Given the strength and diameter, the percentage of Dyneema is very low.

The sleeve is just 3 mm (2.5 mm, 5 kg load) thick braided nylon rope,. The splicing tool is a bight out of 0.75 mm steel wire.

Measurement results, breaking strength:
- figure 8 on a bight: 33 kg (44%)
- figure 8 on double bight: 42.5 (57%)
- figure 8 on bight using the rope sleeve: 63 kg (84%)
- Rope only = 75 kg (assumed 100%)

Rope strength is based on a single measurement using a rope section that is on both sides terminated with a double clove hitch on a bight. D_{former}/D_{rope} = 12, and assumed efficiency = 0.95. The weakest hitch breaks first.

The 63 kg for the sleeved figure 8 on a bight is the lowest of two measurements.

We can conclude that the sleeve makes a real difference.

Note

That the rope inside the sleeve doesn't slip, is because of the rope is a Dyneema-Polyester blend. It has more Polyester then Dyneema. In case of 100% Dyneema, the figure 8 on a bight with sleeve will slip. See also next chapter.

8.9. Dyneema and Kevlar

8.9.1. Introduction

First we had the aromatic polyamides, also known as aramids, later came UHMWPE (HMPE).

The Aramids can have brand names such as Kevlar, Twaron, Technora, Nomex and others. They are stronger then steel (by weight) and can handle temperatures where other polymer ropes melt.

In the early nineties another super strong fiber appeared on the market, officially known as UHMWPE, or HMPE. Most famous brand name is Dyneema from Dutch based DSM, and Spectra from Honeywell (USA).

It has similar strength and elongation as Kevlar, but it is lighter. Disadvantage is its low temperature resistance. The E-modulus of Dyneema and Kevlar is in the range of 100 Gpa and that is about 30 times higher compared to PA (Nylon).

The low stretch comes with another disadvantage: bad knot efficiency for both materials. Dyneema will slip, Kevlar will cut itself.

Most knots and bends that work very well using Polyamide or Polyester rope, do NOT work well when using Dyneema, even when it has a sheath.

Mixed or Blended Dyneema rope

The slippery behavior of Dyneema can be reduced by blending/mixing it with another fiber (Polyester, Polypropylene). This construction improves grip onto the rope, and the knotability. Do not confuse blending/mixing with a Dyneema core with Polyester braid/sheath.

Dyneema-Polyester mixed ropes are popular in sailing. The have low elongation, good grip and good UV resistance.

Kevlar-Polyester, Kevlar-Technora rope
Kevlar is generally not blended with other fibers. It frequently has a protective sheath (single or double) when used outdoors. Due to the high friction of Kevlar to other materials, the Kevlar core doesn't slip within the sheath.

Kevlar-Technora rope has a Kevlar core and Technora sheath. It is specialist rope used where heat is expected or light weight with low stretch is of importance. It is used in climbing, rescue and tree maintenance. It is designed to have very reasonable knot efficiency using popular climbing knots.

Dyneema-Polyester, Dyneema-Dyneema rope
Dyneema rope with a Polyester sheath, may suggest you that is has good knotability. Unless noted by the manufacturer, the knotability isn't good. The strength improvement is small. When using commonly known knots, the sheath will break and the Dyneema core is pulled out of the sheath/knot, or the core breaks.

Long pitch versus short pitch
Single braid Dyneema is available with long pitch or short pitch. Fibers are more parallel with the rope axis in case of long pitch. Long pitch ropes have lowest elongation and highest strength.

Short pitch rope is more tightly woven so that the fibers make a larger angle with respect to the length direction. It is like course thread vs fine thread in case of bolts.

Short pitch has lower strength, more elongation, but better abrasion resistance, better knot efficiency and accepts smaller bend radius. Long pitch is easy to splice, short pitch is hard to impossible to splice.

SK75 vs SK78 and DM20
These are Dyneema grades. For general rope work requiring Dyneema, SK75 is fine.

When the rope is static loaded for long time (think of antenna guy wires), or where long term elongation (that is creep) is not desired, SK78 is a better alternative, as its creep is factor 3..5 less then SK75.

When budget allows, use DM20. When used below 20% of MBS, creep elongation over 20 years is less then the elastic elongation. Several manufacturers of rope for guy wires switched to DM20 because of its superior static load performance.

There is also SK99. It is 20% stronger then SK78, but creep is similar to that of SK78.

Impregnation
You may want to impregnate a rope construction with epoxy to get a strong rigid construction. In that case Kevlar has preference over Dyneema as adhesion to epoxy is excellent. Make sure to use Kelvar without (lubricating) coatings in case of impregnation.

All Dyneema varieties have bad adhesion to epoxy. Of course when the impregnation is for protection only, low adhesion isn't a problem.

Knots for Dyneema and Kevlar

When using Kevlar or Dyneema "Tech" rope, for a safety critical application, you need to do your homework very well.

There are some options to get reasonable knot efficiency both with Kevlar and Dyneema.

- In case of Kevlar, getting larger bend radius does the job. Options are Sleeve and/or double bight, or even more rope sections in the knot.
- In case of Dyneema, both getting larger band radius, and avoiding slippage does the job. Nevertheless, larger bend radius also increases slippage when using 100% Dyneema.

Remember that you need to take the knot efficiency into account when determining safety factor. When the rope itself has a safety factor of say 10 in your application, this drops to 2.5 when the knot has just 25% efficiency.

8.9.2. Knot strength tests, unknown aramid rope

The rope is 2 strand twisted with a final coating (like a paint layer). The individual fibers itself are not coated. Outer diameter is about 0.65 mm (inclusive coating). Due to the twisted two-strand construction, its average diameter is less. It comes from China (partial spool), technical data unknown.

The coating does burn, but the fibers carbonize without burning, so it must be an aromatic polyamide. The color without coating confirms this.

Rope MBS measurement

Using clove hitch on a bight with D_{former}/D_{wire} = 15 (10 mm former), assuming efficiency of 0.95

Average strength: 33.9 kg, (4 measurements)

standard deviation: 1.7.

MBS = 30.5 kg based on 2 sigma, and corrected for hitch efficiency

2 Sigma is used as each measurement is done using two hitches. The weakest hitch breaks first, so the still good hitch has a higher strength.

Given the two strand twisted construction; this is yarn with reasonable quality.

Efficiency of clove hitch on a bight with D_{former}/D_{wire} = 4.6

Using clove hitch on a bight with D_{former}/D_{wire} = 4.6 (3 mm former),
Average strength: 26.5 kg,
standard deviation: 2.0.
Knot efficiency: 87%, based on average hitch strength and MBS
Knot efficiency: 74% based on 2 sigma and MBS

2 Sigma is used as each measurement is done using two hitches. The weakest hitch breaks first, so the still good hitch has a higher strength. The stated values can be considered 3 sigma below average.

Efficiency for figure 8 on a bight, no sleeve
Similar method as above

Knot efficiency = 52%, based average and MBS
Knot efficiency = 44%, based on 2 sigma and MBS

Efficiency for figure 8 on a bight, with sleeve
When using a **sleeve**, with wall thickness well above that of the diameter of the Kevlar, the breaking strength increases significantly. The reason is the larger bend radius. As Kevlar has relative large friction coefficient, you can use the figure 8 on a bight after inserting the Kevlar into the sleeve. In case of doubt, use a figure 9 or 10.

Sleeve has D = 2 mm (1.7 mm, 5 kg, load) nylon single braided rope.
Strength: 26.7 kg (87% efficiency).

This is similar to the clove hitch on a bight using D_{former}/D_{wire} = 4.6.

Many Kevlar ropes have a polyester sheath for UV and weather protection. The wall thickness of that sheath is relative small compared to the diameter of the Kevlar inner core. It gives some improvement of knot efficiency, but a figure 8 on a bight will generally not have an efficiency of better then 50%. Thicker rope will have less efficiency as sheath wall thickness is less compared to core diameter.

8.9.3. Knot strength tests, Kevlar with polyester sheath

These tests are to show the small difference between the figure 8 and the 2x2 overhand. The rope is Kevlar with a Polyester sheath, breaking strength (as on the label) 60 kg, overall thickness of 1.3 mm.

Figure 8 on a bight
Tested using a rope section terminated with figure 8 on a bight at each end. So the result is for the weakest of the two knots.

Strength: 35 kg (weakest of two knots)
Efficiency 58%

2x2 overhand on a bight
Tested using a rope section terminated with figure 2x2 overhand on a bight at each end. So the result is for the weakest of the two knots.

Strength: 38 kg (weakest of two tests),

Efficiency 63%

Two measurements gave exactly same result, so the 38 kg is the weakest of 4 knots.

Conclusion for Kevlar
A figure 8 on a bight has an efficiency of 44% (99% confidence, for use in strength calculations). Depending on the rope construction, this may be less. You should test! The efficiency is low compared to the same knot into Nylon or Polyester. A figure 8 in climbing rope has efficiency >60% (for strength calculations).

Even a clove hitch on a bight with small D_{former}/D_{wire} ratio of 4.6 gives 74% efficiency (99% confidence), that is well above the 44% for the figure 8.

Kevlar with polyester sheath shows higher efficiency, as the bend radius increases. Adding an additional sleeve works very well. The figure 8 on bight with sleeve has high efficiency of 87%.

For Kevlar the 2x2 overhand has practically no advantage. The strength advantage is just 9% (not percent points). A figure 8 on a bight with a sleeve has good efficiency without slipping.

8.9.4. Knot strength tests, 100% Dyneema kite line

The white unused line (Cousin Trestec, Topline) has no sheath, short pitch weave (0.8 mm), Diameter = 1.1 mm (5 kg load), strength (on the label): 200 Lb. It has a very tight weave, making spliced eyes hard to impossible. It is likely >15 years old.

Due the short pitch, this rope is not designed for maximum strength and lowest elongation, but reasonable handling and knotability.

Rope strength testing (using double clove hitch on a bight)
Normally 1.1 mm thick Dyneema has well over 91 kg of strength. Of course this is short pitch rope and that reduces the strength.
The former is 10 mm aluminum, so $D_{former}/D_{wire} = 9$. It is not recommended to use a plastic former as that gives more friction and heat is dissipated badly. For strength testing of Dyneema the ratio is little low, so efficiency will not be 95%. 92% is assumed.

Hitch Strength = 102 kg (single measurement)

Rope strength = 111 kg, after correction for efficiency

It is likely that the line strength is 100 kg instead of 91 kg (200 Lb). MBS is assumed to be 100 kg.

Single turn with 4 half hitches

Post diameter = 10 mm, each rope end has a turn with 4 half hitches

strength: knot slipped at 40 kg (40% of MBS).

It wasn't expected that 4 half hitches didn't stop slipping.

Constrictor hitch on a bight

Tested using a rope section terminated with a constrictor hitch on a bight, on both ends. D_{former}/D_{wire} = 2.7 (that is well below the recommendation). The strength is the strength of the weakest hitch.

Strength: 71 kg (71%),

Despite the Former to wire ratio is well below recommendation when using a constrictor with Dyneema, its strength is very acceptable. This shows that the former to wire ratio isn't critical.

Figure 8 on a bight

Tested using a rope section terminated with figure 8 on a bight at each end.

Average strength: 58 kg (3 measurements, no slippage),

standard deviation: 4 Kg

Strength (>99%) 50 kg (50% of MBS)

Figure 8 on a bight with 2 mm sleeve

Sleeve has D = 2 mm (1.7 mm, 5 kg load) nylon single braided rope.

Strength: knot slipped at 60 kg (60% of MBS).

2x2 overhand on a bight

A piece of rope is terminated with 2, 2x2 overhand knots on both sides, so the weakest fails first.

Strength: 62 kg (62% of MBS).

Note that with thin rope dressing (keeping the turns parallel) is demanding.

2x2 overhand on a bight with 2 mm sleeve

Sleeve has D = 2 mm (1.7 mm, 5 kg load) nylon single braided rope.

Strength: 84 kg (84% of MBS).

Dressing is now much easier

2x2 overhand on a bight with 3 mm sleeve
This test is added to check whether the knot slips when using a thicker sleeve.
Sleeve has D = 3 mm (2.5 mm, 5 kg load) nylon single braided rope.

Strength: 90 kg (90% of MBS).

Figure 8.12 shows the 2x2 overhand on a bight with 3 mm sleeve. The double clove hitch on a bight is also shown. This sample is actually tested to destruction and showed the 90 kg breaking strength, without slipping.

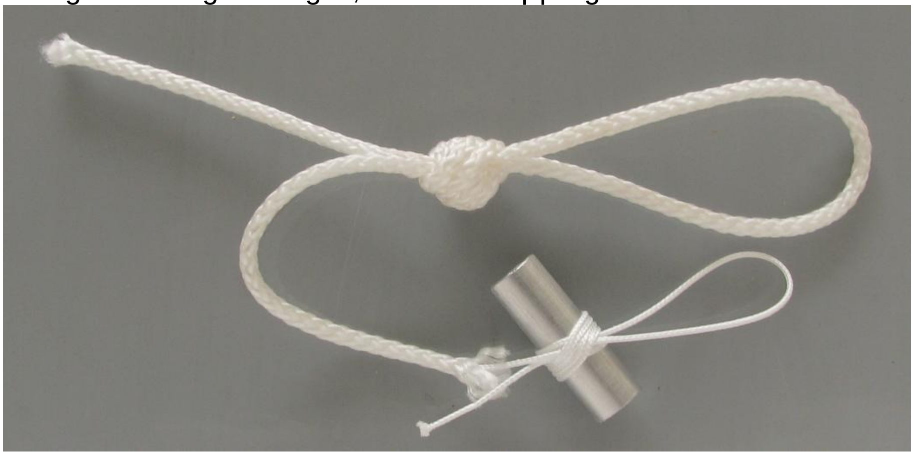


Figure 8.12, 2x2 overhand knot on a bight using 3 mm sleeve

Figure 10 with 2 mm sleeve
Sleeve is 2 mm (1.7 mm, 5 kg, load) nylon single braided rope.

Strength: 62 kg (single measurement) (62% of MBS).

A higher results was expected, based on the measurements with Kevlar and Dyneema using the 2x2 overhand using a 2 mm sleeve. Reason can be slight slipping that melted the Dyneema.

Figure 10 with 3 mm sleeve
Sleeve is 3 mm (2.5 mm, 5 kg, load) nylon single braided rope.

Strength: knot slipped at 69 kg (69% of MBS)

Zeppelin, Flemish and triple fisherman's bend
In case of a sleeve, a 2.5 mm diameter (2.1 mm, 5 kg load) green braided PP rope is used as sleeve.
The Flemish band is a follow through figure 8 (not an offset figure 8). Same is valid for the 2x2 and 3x3 overhand bend.

Zeppelin bend (1x1 Zeppelin bend)

Strength: knot slipped at 18 kg (18% of MBS)

Semi double Zeppelin bend (1x2 Zeppelin bend)

Strength: knot slipped at 23 kg (23% of MBS)

double Zeppelin bend (2x2 Zeppelin bend)
Strength: knot broke at 44 kg (44% of MBS)

double Zeppelin bend (2x2 Zeppelin bend) with 2.5 mm sleeve
Strength: knot slipped at 64 kg (64% of MBS)

Flemish bend (follow through figure 8)
Strength: knot slipped at 20 kg (20% of MBS)

Triple Fisherman's bend
Strength: knot slipped at 35 kg (35% of MBS)

Follow through Triple overhand bend
Strength: knot slipped 10 mm at 26 kg (26% of MBS)
Broke at 38 kg (38% of MBS)

Follow through 2x2 overhand bend (not an offset bend) with 2.5 mm sleeve
Strength: knot slipped at 50 kg (50% of MBS)

Follow through 3x3 overhand bend (not an offset bend) with 2.5 mm sleeve
Strength: broke at 81 kg (81% of MBS)

Figure 8.13 shows the 3x3 overhand bend, and the rope terminations for testing (double clove hitch on a bight). This sample is used to measure the 81 kg.

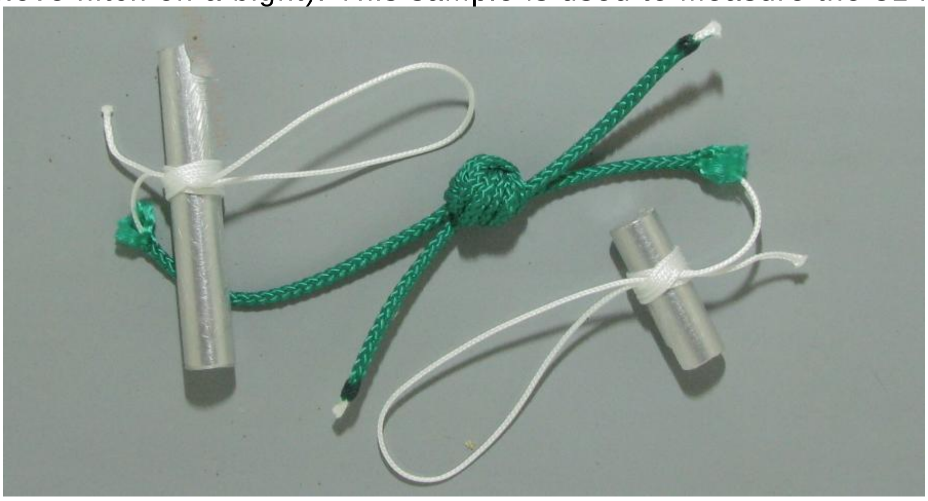


Figure 8.13, 3x3 overhand bend using 2.1 mm sleeve

Conclusion for Dyneema

1. A single turn (or round turn) with even 4 half hitches, still slips. This wasn't expected.
2. A **constrictor hitch on a former** below recommended values (ratio of 2.7 was used) shows > 70% efficiency.
3. A **figure 8 on a bight** doesn't benefit from a sleeve, as it slips.
4. A **figure 10 on a bight** is marginally stronger then a figure 8 on a bight. When adding a sleeve, operation is not reliable. It slipped with a thicker sleeve.
5. **The 2x2 overhand on a bight** with sleeve gives best performance, A thicker sleeve increased efficiency without slipping. It should be noted that beyond a certain D_{sleeve}/D_{rope} ratio, increasing the ratio is not worth the investment.
6. The bends perform bad, even a **triple fisherman's bend** slipped at 35% of MBS. **The 2x2 overhand bend** slips, though the 2x2 overhand on a bight performs well. The difficult to dress, very bulky **follow through 3x3 overhand bend** performed well with 81% efficiency, without slipping.

8.9.5. Overview of indicative break test results (Dyneema)

The table below is for the Cousin Trestec Topline 1.1 mm unsheathed 100% **Dyneema** kite line (short pitch). Strength according to label: 200 pound, own measurement 111 kg. MBS is assumed to be 100 kg. Efficiencies are referenced to 100 kg.

Where “slipped” is mentioned, the knot keeps slipping.

Knot, bend or hitch	**Efficiency (%)**	**notes**
Single turn with 4 half hitches	40	Slipped
Constrictor hitch on a bight $D_F/D_W = 2.7$	71	weakest of 2
Figure 8 on a bight	50	>99% confidence, 58% average efficiency
Figure 8 on a bight, 2 mm sleeve	60	Slipped
Figure 10 on a bight, 2 mm sleeve	62	Single test
Figure 10 on a bight, 3 mm sleeve	69	Slipped
2x2 overhand on a bight	62	Weakest of 2
2x2 overhand on a bight, 2 mm sleeve	84	Single test
2x2 overhand on a bight, 3 mm sleeve	90	Single test
1x1 Zeppelin bend	18	Slipped
1x2 (semi-double) Zeppelin bend	23	Slipped
2x2 (double) Zeppelin bend	44	Single test
2x2 (double) Zeppelin bend using 2.5 mm sleeve	64	Slipped
Flemish bend (follow through figure 8)	20	Slipped
Triple fisherman’s bend	35	Slipped
Follow through **Triple** overhand (barrel) bend	38	Slipped 10 mm at 26%
Follow through 2x2 overhand bend with 2.1 mm sleeve	50	Slipped
Follow through 3x3 overhand bend with 2.1 mm sleeve	81	Single test

Actual efficiency of a knot or hitch depends not only on the knot, bend or hitch, but also on the type of Dyneema, rope construction and thickness. A sheath and/or sleeve mostly increases knot efficiency, but also increases slippage risk.

Use the table as guideline for knot selection only. Do your own testing. You should also test dynamic behavior. It is good to have a backup knot or hitch just in case of slow tail eating.

Knots that are used for eyes and bends, perform significantly less when used as a bend.

8.10. *Square lashing*

Those with a Scouting background know the square lashing. It is a very strong hitch to join two wood poles that are near perpendicular to each other. The rope stress is relatively low. This is because of the way you start and terminate the square lashing.

When you support a JOTA operation (Jamboree On The Air) and there is a wood pole tower, there will be many square lashings. Inclined poles (forming triangles with legs and beams) provide rigidity to the tower. These are joined using diagonal lashings.

Supporting JOTA operations (every third weekend of October) gives youth an opportunity to introduce themselves to the fascinating world of Amateur Radio.

> Be very careful when lashing hollow structures onto a rigid horizontal structure, as you may crush the hollow structure (think of a fiberglass pole or mast).

The reason for high risk of crushing is because there is a point contact between a round beam and a fiberglass pole/mast. You may use the method of paragraph 8.2 to connect the fiberglass pole onto a solid pole. When done, lash the solid pole onto the existing structure.

Other option is to use a thick metallic pipe that accepts/surrounds the fiberglass pole. The point contact is then between the thick pipe and the beam.

Use of the square lashing

When you want to join a vertical pipe onto two vertically aligned beams, two square lashings will do the job. When you have soft soil, just one horizontal log (or metallic bar) and one square lashing is sufficient.

Starting a square lashing

You start a square lashing using a clove hitch when using natural fiber rope, and a constrictor hitch when using synthetic fiber rope. This is shown in figure 8.14A. In most cases starting onto the leg is preferred.

Wrapping

Wrapping is the process of laying rope turns that join the two poles.

The beam can “sit” onto the clove hitch (or constrictor hitch) when making the first full wrap (figure 8.14B).

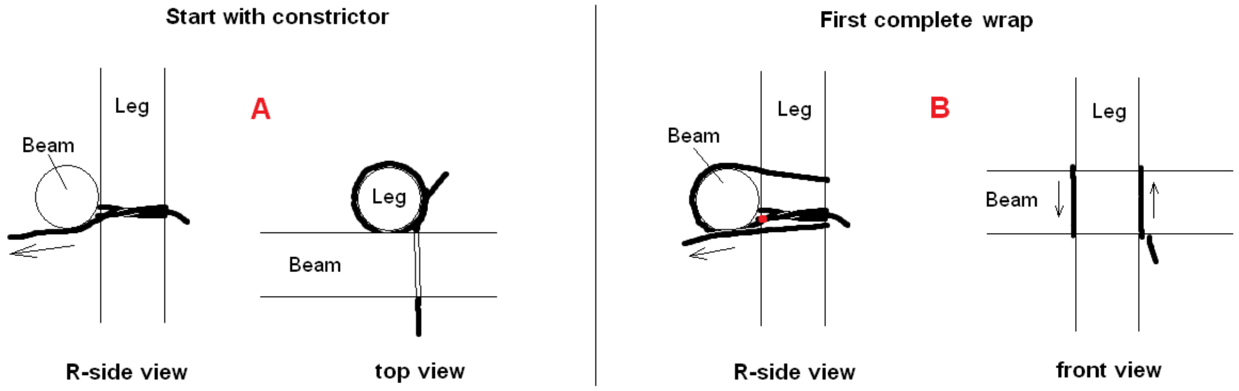


Figure 8.14, Starting a square lashing and first complete wrap

It is important that during the wrapping process the beam doesn't slide down. If so, the rope that goes around the leg gets inclined and then you will not be able to get sufficient tension in the wraps. The constrictor or clove hitch is in between the wraps. This avoids loosening of the hitch.

As you can see the rope turns that go around the leg point a bit to each other. This is because of the inside-outside principle. The next two wraps go on the outside when going around the leg, and go on the inside when going around the beam. This is shown in figure 8.15A.

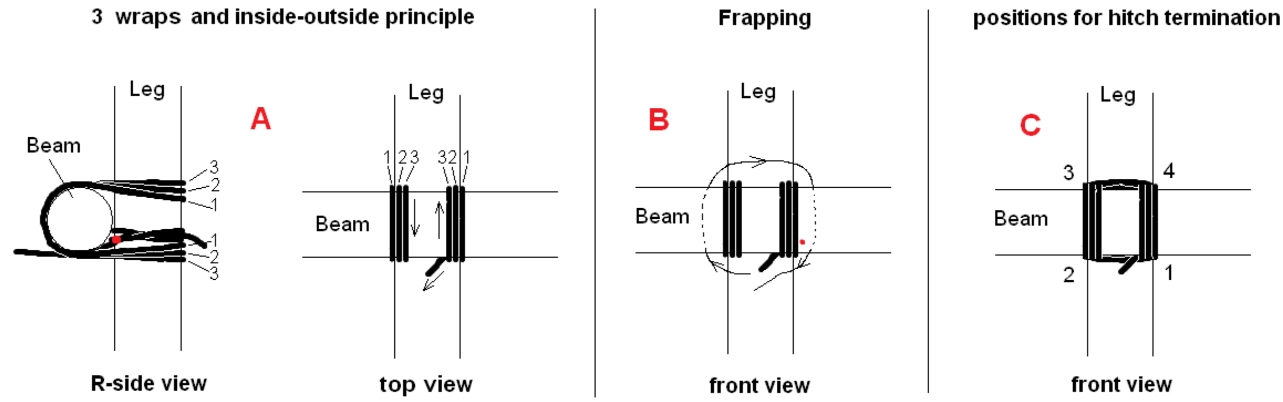


Figure 8.15, Adding additional wraps and adding fraps

The numbers correspond with the wrapping order. “1” is the first wrap, ‘3’ is the last wrap. Most square lashings use three full wraps, so 12 rope sections cross between the beam and the leg.

Frapping

Now we need to add more tension in the 12 rope sections that join the leg and beam. This is done by applying fraps around the wraps. It is shown in figure 8.15B and C. Fraps must be tighten very well, as they have to constrict the wraps increasing the tension in the wraps. Of course when you do this with a fishing pole as leg, you will crush the pole (sure).

When the beam and leg have same thickness, you start frapping closest to the leg and move to the beam. When the beam is thin compared to the leg, the first frap sits onto the beam, and the other two fraps go towards the leg.

Termination of the square lashing
You use three half hitches onto the beam or the leg to terminate the lashing.

When your rope runs horizontally, you terminate on the horizontal log/pole (the beam). When you look to figure 8.15C, the rope leaves at position 1 and it came from position 4. So the rope runs vertically. You need to terminate on the vertical log/pole (the leg), below the beam. You may have bad view at position 1 and 2. In that case it is best to continue frapping until the rope leaves at a convenient position.

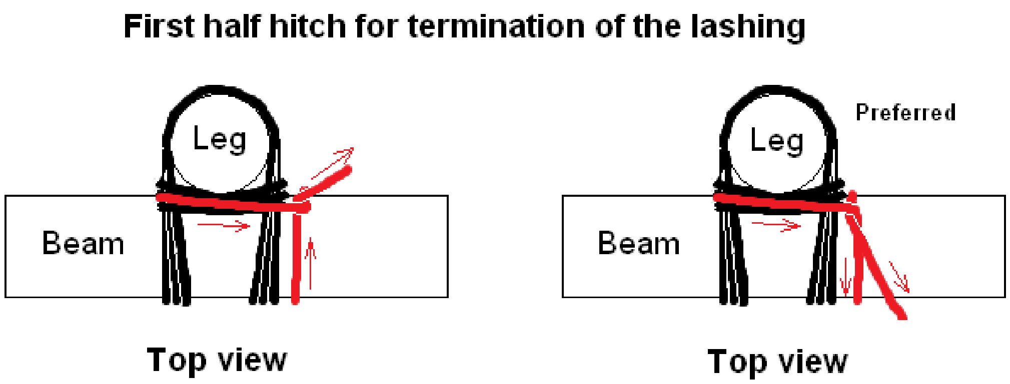


Figure 8.16, lashing termination with half hitches

When you look from above onto the beam, position 4 in figure 8.15C is most easy. You have direct view onto the last quarter section of a frap. The rope runs from 3 to 4 (horizontally), so you terminate with half hitches on the horizontal log (the beam), on the right side of the leg. This is shown in figure 8.16.

The half hitches shown in figure 8.16 can be tight away from you (left figure) or towards you (right figure). It doesn’t make much different, as long as you make sure the last part of the frap runs parallel with the beam (that is the shortest path) and the half hitch sits close to the lashing. Figure 8.16 shows space between the wraps and the half hitch. This is for clarity, but the half hitch should touch the wraps.

Rock the rope end so that the half hitch tightens. Help tighten the hitch by grabbing the half hitch and turn it so that it tightens well. Add another two half hitches in the same direction to avoid loosening of fraps. Rock the rope in between each half hitch and help by turning the hitches. You have three half hitches now. This is generally sufficient.

Figure 8.17 shows a photo of a complete lashing. This lashing is very loose to avoid crushing of the PVC beam.

Figure 8.17, photo of complete square lashing

Excess rope you wind around the beam and terminate with two half hitches.

Tips
When you may step onto the half hitches, it is best to terminate the lashing on the other side, or onto the leg. There is still debate about where to terminate a square lashing; onto the beam or onto the leg. When on the leg, the half hitches receive more rain that runs down the leg. When using PP or PET rope, you can terminate onto a leg if termination onto a beam is not convenient. PP or PET rope will not rot or shrink.

When having very thin rope, you may add 4 or 5 wraps and fraps. When the forces onto the leg are very small, two wraps and fraps are good enough.

You may use PA rope, but you need to stretch/pull the rope very well, as during rain the rope elongates. When using nylon, you can best use thin rope as you will be able to apply more elongation/stretch during lashing. 100% Dyneema is not suited for lashings.

Do not let Scouts lash your fiberglass mast onto something. Very likely they will crush your mast, as they are used to make very tight lashings using wood poles. In my opinion, a fiberglass pole should not be lashed directly onto beams with round cross section. You need some (soft) interfacing material, or a pipe that accepts the fiberglass pole. The pipe displaces the point contact to the pipe and a beam.

8.11. Guy wires

To be added

9. Climbing into your mast

Disclaimer

Climbing is a potentially dangerous activity. This chapter is informative and is not a replacement for tower climbing safety training or professional advice. Climbing a tower/mast is more than just reading some articles and buying PPE (Personal Protection Equipment). Climbing into your (lattice) mast requires the right equipment. The skills have to be in your brains, not in a PDF document on your computer.

For the recreational indoor or outdoor climbers; industrial/tower climbing is different. You have likely no belayer watching you, and there is no belayer absorbing large part of the fall energy in case of a fall.

Do your own research, so that you can assess the risks. TeTech is not liable for any direct or indirect damage resulting from the use of information provided in this chapter or other chapters.

9.1. Introduction

Though tilt-over crank-up towers are popular among Radio Amateurs (you don't have to climb), fixed (lattice) towers and masts, or crank-up only towers are used by many Radio Amateurs. Roof mounted masts (with guys) are also popular, as you gain height because of the roof elevation.

We can say that many Radio Amateurs need to climb on a ladder, or the mast/tower itself to reach the antennas.

"*You're exaggerating a little, aren't you? It is only 2 m to reach my antennas!*"

Depending on where you live and which safety requirements are applicable, fall protection may not be required in case of 2 m fall height. However fatal accidents occur during working around the house just using small stepladders! A fall from 1 m can lead to severe injuries, or even death. A wasp that stings you may send you to the ground.

The example below may use unfamiliar terminology. Terminology is described in the next paragraph (use your second opened document to search).

An example (figure 9.1)

This example was an actual situation of spring 2024, but without accidents.

You have a guyed lattice mast on the ridge of your gable roof. Everything (mast/roof/guys/anchors) has been inspected, and is in good condition. You need to exchange your 2m/70 cm vertical antenna.

You bought yourself a simple industrial fall arrest harness with an elastic Y-lanyard with a shock absorber as advised by the vendor. You also bought a rope with a rope grab to safely reach the mast, and some spare carabiners. You use an old leather belt as work positioning lanyard to flip around the mast.

You installed the safety rope with rope grab over the ridge of the roof, and tied it to a big tree trunk. The mast is far away from the edge of the roof, so the rope will not slide off the roof. You put up your ladder to the gutter and the job can be done!

The situation is shown in figure 9.1

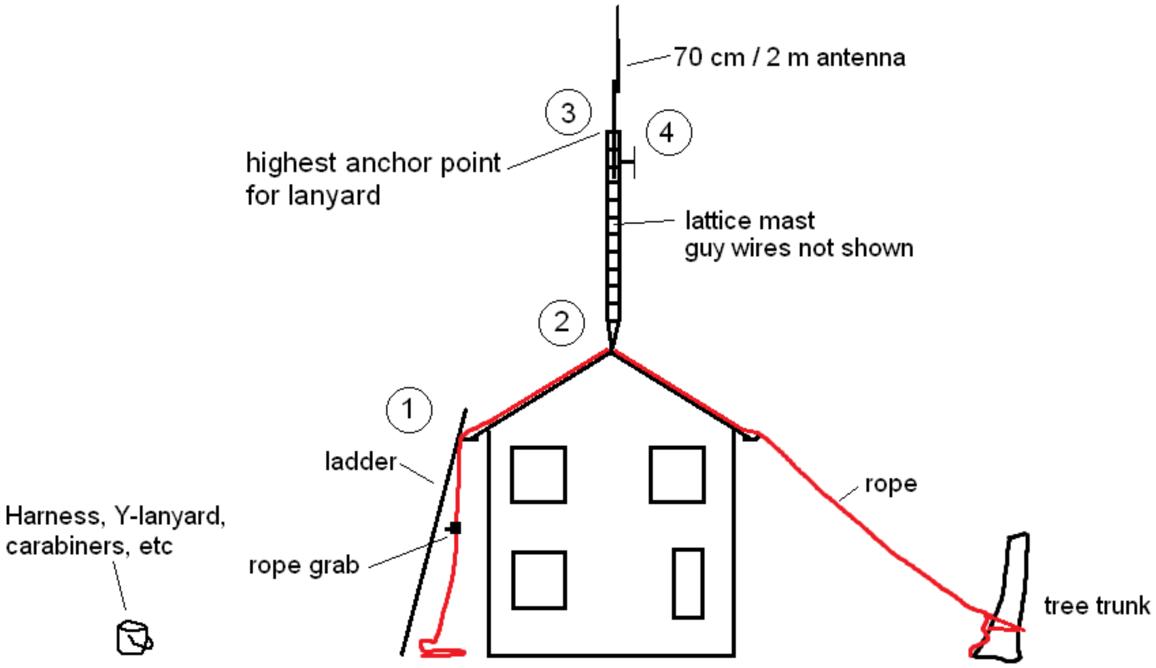


Figure 9.1, Guyed mast on gable roof

What can go wrong?

The numbers below correspond to the encircled numbers in figure 9.1

1. During the transfer from the ladder to the roof the ladder moves a bit and you lose your balance. Because of your reflex, you pushed the ladder sideways and it is now flat on the ground. The rope grab activates and catches you, so you don't fall to the ground. Due to little slack and rope stretch you hang just under the gutter, but can't get onto the roof. Who will save you now? As you have a simple fall arrest harness, you may experience harness suspension trauma in about 5 to 10 minutes.
2. You reached the ridge of the roof and looks over it to check for irregularities on the other (right) side.
   Did you attach the rope at the ladder side to an anchor too? If not (as in the figure) and you fall over the ridge, the rope will not help you.
   Do you have a bidirectional rope grab? You likely have not, as there are no bidirectional mechanical rope grabs on the market. The rope grab will not stop

your fall when falling over the ridge, even when the rope at the ladder side is connected to an anchor point.

3. You start climbing your mast and upon reaching your work position you lose balance during putting the belt around pipe that is on top of the mast. The lanyard stretches and your fall is arrested after first making a 1.7 m fall. During that fall your foot slides between two rungs and you break your ankle. Who will save you?
4. Can your mast (especially the rungs) handle a peak load of up to 6 kN (maximum arrest force for industrial shock absorbers)?

This example shows that even when using industry standard fall protection gear, things can go very wrong.

Climbing into open metallic constructions can be very dangerous, as you likely hit something before your fall protection actuates. You need PPE that is suited for the job, not the PPE that the vendor can offer you for a good price.

What could you change to reduce injuries in the example:

- Secure your ladder so that it can’t slide or fall backwards, then situation 1 can’t occur. That is the best and easiest thing you can do.
  If you still want to be prepared for hanging without any support, you need at least foot loops so that you can stand to keep blood flow through your legs. Harness suspension trauma can occur in about 5…10 minutes using a standard fall arrest harness.
  A step further is another rope grab or friction hitch with a foot loop so that you can ascent or descent on the rope.
- You can avoid sliding of the roof on the tree trunk side (situation 2) when you connect yourself to the mast before reaching the ridge.
- To reach the antenna, your chest will be well above the top of the mast (situation 3). The anchor point for the lanyard is now well below the tie point on your harness. The (free) fall height is too large to survive a fall without injury, even with a short lanyard.
  First you should use as short as possible lanyards. Accept that the work takes longer because of this. Lanyards over 1 m length are way to long for solo climbing a mast. During climbing, the lanyard should be connected onto the mast as high as you can reach (yes, this is annoying, but reduces your fall height). Even a short lanyard doesn’t solve the pipe problem.

  When the pipe that protrudes out of the mast is strong enough, you can use an adjustable work positioning lanyard that connects with a friction hitch onto the pipe. This requires a harness with at least work positioning D-rings, but a sit harness is advised. You can push the hitch around the pipe well above your head. When pushing (with your legs) yourself up, you simultaneously take the slack out of the positioning lanyard, so you can’t fall anymore. You can gradually reach the antenna by repeating the process. Use this together with a tight positioning lanyard at waist level, or somewhat above.
  Other option is temporary installing a structure parallel to the mast that reaches the antenna.
- To enable you to rest, or get rid of insects, you need an additional large carabiner so that you can connect yourself directly onto your mast once you stop climbing.

That goes much faster then using a belt. You have both hands free now to do your things. This requires a harness with additional D-rings, or work positioning belt.

- To reduce the shock load onto your mast (and yourself), you could use a complete other climbing technique using two adjustable lanyards, and a large carabiner. This enables you to climb near slack free towards the top of your mast reducing the peak force to about twice your body weight (+equipment). In case of losing grip or balance, your total fall distance is because of rope stretch only, reducing the risk of severe injury significantly. Disadvantage: it takes long and is very demanding when you are not used to that.

Hopefully this introduction shows you that having “some” Personal Protection Equipment (PPE) to arrest a fall is not sufficient to avoid severe injuries or even death. It may even give you a false sense of safety, encouraging you to take more risk. This mostly increases the risk of injury.

9.2. Terminology and definitions regarding work at height

This paragraph should make you familiar with the vocabulary used within work at height. When you see a new term or concept that you don’t understand, search into a second document. You will likely find an explanation.

9.2.1. Personal Protection Equipment (PPE)

Personal Protection Equipment contains all material that you use to reduce the risk of injury. Fall protection is part of your Personal Protection Equipment when working at height. It contains all material you use to avoid falling out of your mast. Think of: your harness, lanyards, rope, shoes, helmet, etc.

Also items that you use to work at height (work positioning lines, ascenders, descenders, seat, etc) belong to PPE, and are regulated under various international standards (ANSI, ISO, EN, GB, AS/NZS, etc).

9.2.2. Fall restraint versus fall arrest

Fall restraint systems assure that you can’t fall. The measures limit your working area so you can’t reach an edge. Work positioning where you are slack free connected to an anchor point also prevents you from falling.

Work restraint systems don’t have shock absorbers. You can’t fall. Your total fall distance is due to rope stretch. There will be virtually no shock load. When you use them wrong (for example accepting slack), they are very dangerous, as they can’t absorb a shock load.

Fall arrest systems assume that you may fall certain distance before your safety equipment arrests your fall. When you fall, the system catches you and your fall speed is decelerated in such a manner that peak forces are limited. Peak forces are limited to 6 kN in most industrial sectors. Webbing based shock absorbers (also called screamers) are used in many working areas. Fall arrest systems do save you from death, but not from (severe) injuries. Even 4 kN force on your body can seriously harm you (fractures, dislocations, ruptures, etc). Fall arrest systems require sufficient clearance below you to avoid that you hit an obstacle (floor, beam, etc) before your fall is arrested.

In many cases you need to be rescued after a fall. This must be done as soon as possible to avoid harness suspension trauma.

9.2.3. Harnesses and how to use them

The harness is an important part of your Personal Protection Equipment (PPE). A harness failure is mostly fatal when you need it. The type of harness you need, depends on the type of job and whether you use it as a tool, or just wear it for catching you in case of falling.

Figure 9.2 shows three different harnesses.

Figure 9.2, example harnesses

Simple fall arrest harnesses
The simplest harnesses you wear just to catch you in case of a fall. You don't use the harness for the work itself. An example is shown in the A figure. They are very cheap to manufacture.

It has a metal D ring on the back marked with capital A. It is the preferred connection point for a safety lanyard with shock absorber, or other fall stop device. They may have an option to connect a safety line at your chest. This can be via a D-ring that is already present, or using a carabiner and the two eyes marked with A/2.

When using the chest connection on a harness with A/2 eyes, you must always use both eyes. They are therefore marked with A/2. Check the documentation that comes with the harness!

The chest connection point is not for connection of long lanyards where you can make a fall of say 1 m before the shock absorber activates. To arrest relative long “free falls” you need to use the D-ring on your back. When using the chest connection point, you may break your neck as your head flips backwards.

The chest connection point is for connection to protection systems that have low slack. Think of rope grabs or a runner on a vertical rail or steel cable. You can also use it for very short safety lanyards (with shock absorber). There are situations where this is better then using the D-ring on your back. This will be discussed later.

Once fallen, you need to be rescued quickly to avoid suspension trauma.

Fall arrest harnesses with work positioning rings
The B figure shows a harness with 2 additional D-rings left and right at your waist. There is also a waist belt that supports your back. You have 4 connection points now: 1 at your back for long fall arrest, 1 on your chest (using a carabiner) for short falls, and 2 for work positioning.

The D-rings on your waist are not for fall protection. Never connect a fall arrest lanyard to these rings for fall protection using lanyards with shock absorbers. The waist D-rings are for connecting yourself onto an object so that you can lean back and have two hands free for work. You use the harness as part of your workplace; it is not just there for your safety.

You use the D-rings together with a work positioning lanyard, mostly adjustable. It is connected on the left ring. You flip it around an object, or tuck it through an object, and connect it to the right D-ring. The work positioning lanyard prevents you from falling. But in case of an error, you may fall, so you also need a backup. That can be the fall arrest lanyard on your back, or a short lanyard on your chest. They can have other D-rings depending on the type of work.

These types of harnesses are cheap and very useful as long as you can stand on your feet.

Once fallen, you need to be rescued quickly to avoid suspension trauma.

Full body work/sit harnesses
These harnesses have soft / wide paddings to increase comfort. An example is shown in the C-figure. You can work in such a harness with your feet in the air, hanging onto a rope. They are also called Rope Access harness.

They are used by Rope Access technicians (off-shore maintenance, high rise window cleaning, wind turbine construction/maintenance), tower construction/maintenance, tree maintenance, etc.

They have at least 5 D rings: 1 on your back for general fall protection, 1 on your chest for fall protection with low slack, 2 at your waist for work positioning, and 1 near your belly button for a fully suspended workplace.

They can have more rings for specialist applications. Equipment rings (out of plastic) are mostly present. Of course these are not for work positioning or fall arrest. There may also be provisions to install additional support (for example a seat).

Sports climbing harnesses

These are the harnesses that sit around your legs and waist only, and are used for sport climbing. Sport climbers may use them for climbing their mast slack free, but you really need to know what to do. It is not recommended as they are not compatible with several industrial climbing hardware.

Arborists use similar sit harnesses, but they are specially designed for working in trees. They are not sport climbing harnesses. Climbing and moving through the canopy is done with zero slack. So they are not used with shock absorbers.

Summary of the rings on your harness

- The ring on your back (dorsal ring) is the only connection point for a long lanyard with shock absorber (or other fall stop device). It is the only place where you can survive a long fall with limited direct injury. The ring is marked with “A”
- The ring on your chest (sternal ring) is for connection to fall stop devices using a very short lanyard so that your “free fall” height is limited (below 0.5 m recommended). The fall stop device (rope grab, runner), walks with you when you climb. It is important that the rope/line that runs to the top of the tower/mast has no slack, otherwise you still fall before the fall stop device actuates.
  It can be marked with A, or A/2. When marked with A/2, you always need to connect to both A/2 eyes/loops.
- The rings left and right of your waist (work positioning rings). These are for putting yourself in a comfortable work position so that you have your hands free to work. When using these rings, most of your body weight is on your feet.
- The ring at your belly button (ventral ring). This is for working fully suspended. It is also useful as additional tie point for work positioning, or additional tie point for a backup lanyard (zero slack!). It is not for catching you when making a long fall.
- Some harnesses can have shoulder rings or eyes, and more rings on the waist belt, but you will not need these for tower climbing.
- Equipment rings (mostly from plastic). Do never use these rings for fall protection or work positioning. They are for storing your tools and climbing hardware (rope, accessory rope, descenders, carabiners, etc).

Additional notes on the chest ring (sternal ring)

For many applications it is not recommended to use the sternal (chest) ring for fall arrest, as the risk to injure yourself is higher compared to using the D-ring on your back (dorsal ring). However, “many” does not mean “always”. We climb a mast, and then it is different:

- You may be able to self-rescue. That is difficult when you hang suspended onto the ring on your back (dorsal ring).
- It is very likely that your head slams into a structure when falling with the lanyard at your back.

In that case it is safer to use the ring on your chest provided:

1. Your harness is certified for suspension and fall arrest on the chest (sternal) ring. As far as I know, all work harnesses (figure 9.2C) are certified for that.
2. You keep the free fall distance below 0.5 m (that means very short lanyard).
3. The lanyard does not create unsafe situations during the work.

9.2.4. Harness suspension trauma

Suspension trauma is the term for all medical problems that may occur during (and after) prolonged hanging into a fall arrest harness.

What is the reason for suspension trauma?
When hanging, the straps around your legs impede/reduce blood flow resulting in more blood in your legs that will not flow back. It can happen in about 5..10 minutes after you fall. The situation is even more serious when you are unconscious because of the relaxation of your muscles. More blood will collect in your legs (without flowing back to your heart) This goes together with other medical issues (such as reduced blood pressure).

Your situation can even worsen after you are on the ground again. This is because of the “damaged” blood that is in your legs will now flow back towards your body. Medical rescue teams are prepared for this situation.

What to do after a fall?
When you are conscious after your fall and can’t rescue yourself immediately, or you don’t have people near you that can rescue you, you **immediately** call emergency. When you do nothing now, you may become unconscious and may even die. That is why you first have to call emergency when you can’t rescue yourself.

Delaying suspension trauma
Use **foot loops / foot straps**. They enable you to stand so that your leg muscles contract and the straps around your legs stop constricting your blood vessels. You could change the pressure on your feet from left to right to stimulate blood flow. You can try to get yourself in a sit position (legs up). This all goes easier when you hang onto the chest (sternal) D-ring instead of the dorsal D-ring.

If you can arrive in a hang position during your climbing activities, you should practice this before you climb. As there is a change that you are not able to call emergency, people on the ground should be instructed what to do.

With additional hardware (descender / ascender /rope grab / friction hitch and rope) you can self-rescue if you are conscious and have practiced that on the ground.

Note that hanging unconsciously in a sit harness will also worsen your medical condition. A sit harness is not a means to avoid suspension trauma, it just takes longer to occur.

9.2.5. Fall factor, fall height, slack and shock absorbers

Fall height or fall distance

This is the distance you fall before the fall stop/arrest system activates. The larger the fall height the more potential energy (from gravity) is converted into kinetic energy of your body. When your fall is stopped too fast, the shock load will result in excessive force on your body and equipment. See also figure 9.3.

Even when there is nothing in the vicinity that you may hit during a fall and you use a 6 kN shock absorber, a long fall always increases the risk of injury. This is because your body is subjected to the 6 kN for a longer time. It is wise to keep fall height to a minimum.

> For the sport climbers; you should do really stupid things to experience > 4 kN during climbing with a belayer.

Fall factor

This is the ratio between the fall height and the rope length. See also figure 9.3. It can be maximum 2, why?

Together with the type of rope, the fall factor determines the peak force that acts on your body and the anchor during the arrest of your fall. When the peak force can become excessive, a shock absorbing device has to be used.

> For the sport climbers; when climbing with a belayer, a certain fall generates significantly less force compared to the situation where the end of the rope is connected to an anchor point.

Slack

This is the general term used for excess or loose rope. For climbing it is the amount of rope that remains loose when you slightly tighten the rope. When a vertical distance between you and an anchor point is 3 m, but the rope is 5 m long, the slack is 2m and the fall factor is 0.67. So you have the take in 2 m of rope "to take out the slack".

When using a lanyard, it equals the vertical "free" fall height/distance until the lanyard catches you.

Shock load and shock absorbers

Shock load is a short transient phenomenon (in Newton-seconds) that occurs when a moving mass is stopped abruptly. The faster a falling mass is stopped, the higher the peak force.

Shock absorbers try to decelerate your fall to zero over a certain minimum distance (and time) so that a predetermined force is not exceeded. Large velocity-mass product requires large vertical distance to safely stop your fall. In addition, the peak force acts longer on your body, increasing the risk of injury. See also annex 2 and 4.

Figure 9.3 shows some situation regarding fall factor.

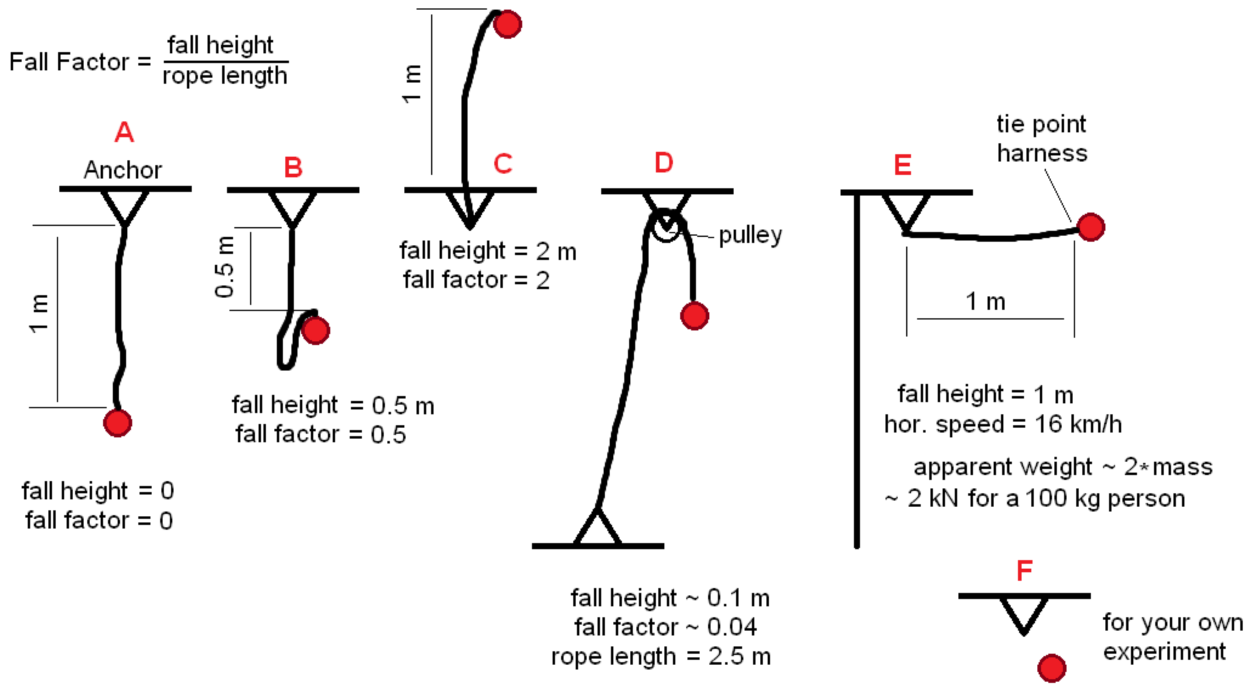


Figure 9.3, fall factor and fall height

In the A-figure there is near zero slack. When you fall you will experience the rope stretch. You bounce somewhat and you hang steady. In that case the **peak force** onto your harness and the anchor is about **twice your weight**. Only when your weight is slowly transferred to the rope, the peak force equals your weight.

The B-figure shows FF=0.5. This is fully acceptable on a dynamic climbing rope (not pleasant), but not onto semi-static climbing rope. With the semi-static rope, the peak force may exceed 6 kN and that is not acceptable in industry.

The situation in the C figure is absolutely unacceptable without a shock absorber. Even with a 6 kN shock absorber you may be injured after the event. The reason is that the 6 kN is for healthy (work) people and because of the fall height, that 6 kN is present for more then say 100 ms. What may happen if you have a “weak” lower back? Is your neck still strong, etc?

The D figure will generate a peak force on your body of twice your weight. However when the **pulley** is 100% efficient, the peak force on the anchor will be **four times your body weight**. This is frequently overlooked. When accepting significant slack and you use a 6 kN shock absorber, you get up to 12 kN onto the anchor when the shock absorber activates. This may likely set the Safety Factor for the anchor well below 2 (= unacceptable).

There are specialty shock absorbers “**screamers, load limiters**” available to be used on less strong anchors (think of ice climbing). They actuate at a well-defined reduced load. This may help you in case of anchors that doesn’t meet >12 kN, but the additional fall distance upon activation of the device is larger as the deceleration must be less compared to a 6 kN shock absorber. The fall height must be reduced significantly. To calculate the maximum slack in your lanyard, you need to know the minimum activation force and the maximum elongation of the device, see Annex 3.

Some manufacturers: Yates, Edelrid and Petzl Charlet.

> When watching professional tower climbing instruction videos using Y-lanyards, you will notice that they accept large fall height (> 1m) when something goes wrong. That is a trade-off between time and accidents (money).
>
> Time should not be a factor in a Ham radio situation, so go for small fall height with lower risk of injury.

Swing fall
The situation in the E-figure is special. There is zero slack so there will be low shock load in the rope. But your body will experience significant peak force when you slam into the vertical structure!

When you do the math, the peak rope force will be twice your body weight. But gravity will smash you into the vertical structure with 16 km/h. A swing fall is generally acceptable when the height loss (fall height) due to the swing only (exclusive rope stretch) is less then 0.3 m. Your speed upon meeting the wall will be about 7…8 km/h. This may lead to minor injury, but the risk of severe injury will be very small.

Shock absorber operation
Most shock absorbers work via ripping of stitches when the load exceeds certain value. This is shown in figure 9.4.   It consists of a piece of webbing with two eyes, folded into a bite. The bite is stitched together in such a way that the stitches tear apart when the design force is exceeded (A-figure). The webbing is folded into a small package and put into a plastic or textile envelope.

The B-figure shows the absorber after a fall with small fall height. When the fall height, and weight of the person, is larger, more stitches rip, so the elongation is also more. (C-figure). When the kinetic energy is too large, the device fully extends (D-figure) and the fall is not correctly arrested. You will experience excessive force when this happens.

Every device to limit the peak force during a fall operates via extending your fall. So you need sufficient free space (clearance) below you, to make sure your fall is stopped before hitting the ground or other object.

Read the manual to find the maximum length of the lanyard, and the distance between the ground and the anchor point (that is the minimum required clearance).

Standard industrial shock absorbers limit the force to 6 kN, but they may activate as low as 3 kN. This must be taken into the calculation of the clearance so that you don't hit obstacles below you.

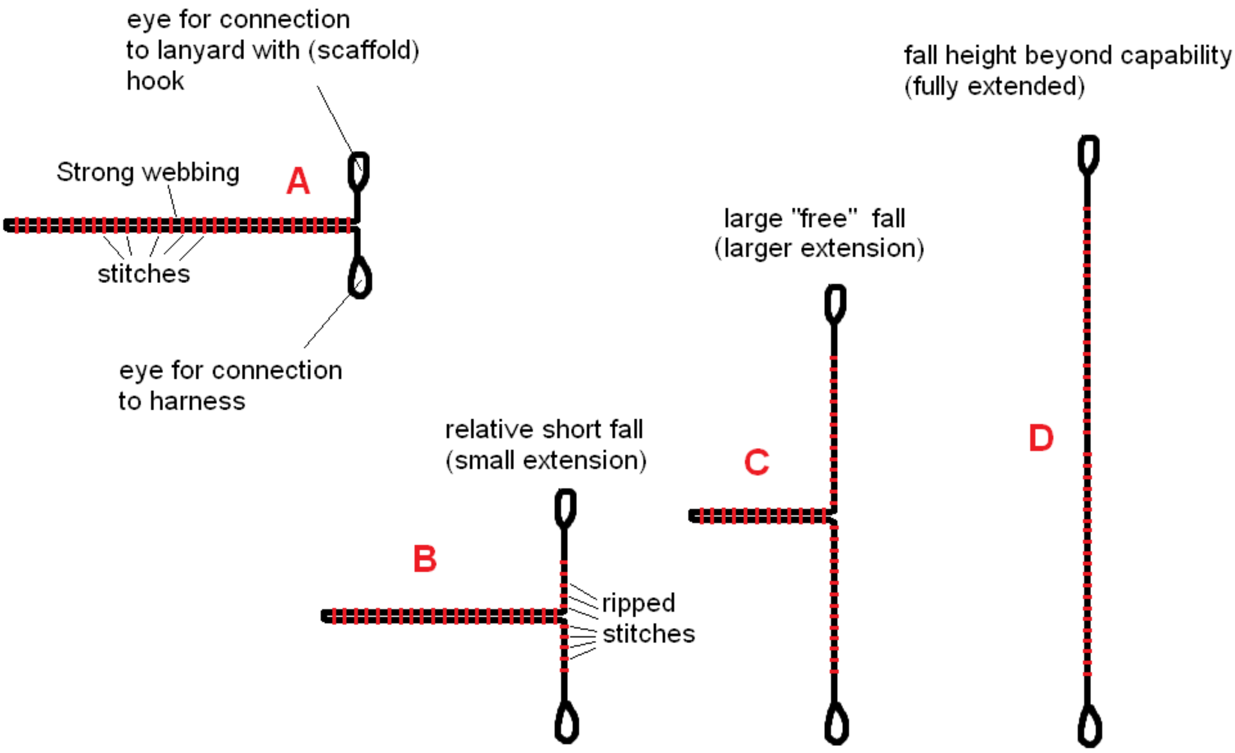


Figure 9.4, shock absorber operation

Short circuiting a shock absorber
When there is a direct or indirect (rope) connection between the underside and upper side of the shock absorber, that connection can limit the extension of the shock absorber. When this happens, your fall is stopped abruptly by that connection as the shock absorber can't further extend. This generates very high peak force. This will break your back, or hardware. It is said that the rope connection "short circuits" the shock absorber.

> When there is risk of falling, there may never be a (rope) connection between everything that is connected to the underside of the shock absorber and a fix point.

When using a Y-lanyard with shock absorber (via ferrata / klettersteig set), you may never connect one of the lanyards to your harness, as that creates a "short circuit" connection between the underside and the upper side of the shock absorber. It is also said that you "bridged" the shock absorber.

When using a work positioning lanyard that is not slack free and you fall, the shock absorber is also short circuited as the work positioning line will catch you and that may break your back, or hardware. This is the reason that when you stop climbing (when using a Y-lanyard), you first connect yourself <u>slack free</u> to the structure with a very short lanyard, and then install the work positioning line.

So when climbing using a Y-lanyard with shock absorber, check that when you fall, your fall is not stopped by some rope, work positioning line, or object below yourself.

9.2.6. Lanyards and connectors

There are several types of lanyards and many words for the same thing. Other names: life line, cow tail, tether, attachment lanyard.

Connectors are all hardware to connect your lanyard to yourself and an object. Think of carabiners, snappers, quick links, scaffold hooks, (safety) snap hooks, etc.

Fall arrest lanyard

These are lanyards that should arrest (stop) your fall in a safe manner, They are used in situations where there is slack to provide maneuverability. A complete fall arrest lanyard has a shock absorber (as a separate part, or integrated), a small safety hook for connection to the harness, and a larger hook for connection to an anchor point. There are adjustable varieties, but they can't be adjusted to very short length. Adjustable fall arrest lanyards may be used for work positioning. Note that they are supplied with 6 kN shock absorbers, unless otherwise noted.

Fall restraint lanyard

These are lanyards that have no shock absorber and you may never be in a situation where your fall is stopped by the fall restraint lanyard. You must use them slack free. When you fall in a fall restraint lanyard, it will break you, or your gear. A fall restraint lanyard avoids that you can arrive in a situation where you could fall (over an edge for example).

Work positioning lanyard

These are (mostly) adjustable lanyards for use with the left and right waist D-rings on your harness. You may only use them with zero slack. Falling into a work positioning lanyard will break you, or your gear. Even when you have no slack, you need a backup system. A single failure should not send you to the ground.

You can also use an adjustable work positioning line that you connect to one waist D-ring only. This enables you reaching a point that is say 1.5 m away from the mast.

There are also positioning lanyards that you connect between the belly button (ventral) D-ring and an anchor point. They are very useful during transfers.

I- and Y-lanyard

A single lanyard is sometimes called I lanyard. Two lanyards connected to a single point (for example a shock absorber) are called Y-lanyard (figure 9.5). When climbing a mast, you always need at least a Y-lanyard, two I-lanyards, or you need to have a (fixed) installed rope or rails to use a runner or rope grab (on your chest (sternal) ring).

Do never connect two I-lanyards to the same point when there is slack. This puts the shock absorbers in parallel. This doubles the peak force to 12 kN in case of a fall. This will break you, or your hardware.

A Y-lanyard with shock absorber is called a “via ferrata set” or “Klettersteigset” in outdoor climbing.

Fall prevention lanyards (cowtails), attachment lanyards
These are short lanyards (mostly < 0.7 m) that you connect to a point above the tie point on your harness (button belly ring) so that you have near zero slack. They prevent you from falling when changing work position or installing your work positioning line. They do not have a shock absorber. In fact they are just fall restraint lanyards.

The best ones are made from so called dynamic climbing rope with fat knots (to Std. EN 892). Reason: you can accept some slack as the rope stretches and the knots will give out some rope. Both will limit the peak force to well below 6 kN.

Discarding lanyards
Once you made a fall on a fall arrest lanyard, the inspection slip of the shock absorber will tear. That means: discard the complete product (rope/sling/hooks/etc).

When, by accident, you made a hard fall into your work positioning lanyard, discard it completely.

You may also have to discard your harness when you made a very hard fall. Your harness may have indicators that tear when making a hard fall.

> A fall arrest lanyard will only protect you from excessive force when your fall is not caught first by another lanyard without shock absorber (the “short circuit” condition).
>
> That is the reason for when you stop climbing, you secure yourself immediately with a short lanyard without slack, and then install your positioning lanyard.

Carabiners
They are also called “biners” and are a type of connector. You use them to connect things together. Minimum Breaking Strength (MBS) of standard carabiners is about 22 kN when used properly!! Specialist carabiners can have MBS of 45 kN (or more).

Do only use carabiners and hooks intended for climbing or PPE, when your life depends on them. Don’t use musketon / snap hooks from the DIY store, even if they mention a load on it (mostly a WLL value). You need good gear for your safety.

Don’t mix PPE carabiners with non PPE carabiners with similar appearance. When working into your mast you don’t want to check every carabiner to avoid using a tool carabiner for safety. Besides the manufacturer and CE mark (or other marking), the minimum breaking strength (closed, cross, open) is stamped onto the carabiner, with arrows indicating the force direction. Its MBS in the length direction is typically 25 kN with closed gate. Many carabiners have a unique serial number.

Screw lock carabiners are relatively cheap. Tri-lock carabiners are another option. They are more expensive, but when you are used to them, they work fast.

Carabiners come in steel and aluminum. When you need many of them, you may (partly) use aluminum carabiners.

Read the manual on how to use, and not to use them.

Side loading
Side loading is when the carabiner is bent over an edge. This is tested by hobbyists and institutions. Failure can occur around or below 6 kN, so this is not compatible with 6 kN shock absorbers.

Amateur radio masts may have relative weak rungs. They are not designed to handle a fall event using a 6 kN shock absorber. This is reflected into the US examination question pool regarding where to connect your lanyard. It should be connected to legs and not onto the rungs according to the question pool. You have to check whether side loading occurs when putting a carabiner onto the legs. Very likely it will experience side loading, so you need scaffold hooks.

Quick links / maillon rapide
When you don't need to (dis)connect frequently, you can use quick links. They are smaller then carabiners and they weigh less. I use one for my permanent work positioning lanyard on my left waist D-ring.

Scaffold hooks
These are the big hooks that you can use onto thick rungs, legs and scaffold tubes.

Very likely some side loading will occur when placing them on a leg. In case of a fall, the gate may open and the hook may bounce off a tower leg. Use material that is according to the latest standards. The scaffold hooks that can have some side loading are relatively heavy.

9.2.7. Rope grabs and friction hitches

Rope grabs
When you (temporary) install a rope at the highest point in your mast that goes down, you can use a rope grab. It works much faster then using a Y-lanyard, and you work slack free reducing peak forces and injury.

Its main function is to grab the rope when you fall, so your fall distance is near zero. This reduces peak forces and risk of injury.

There are functionally two main types:

1. Rope grabs that grab the rope when you fall (in Europe Type A). They are part of your fall protection. They are used frequently with a shock absorber and can handle relative large fall distances.
2. Rope grabs that you use to climb a rope (ascender application, progress capture device, in Europe Type B), or for vertical work positioning. You can hang on them, but not fall in them, as they are not strong enough to catch a fall. Use them slack free.

Fall arrest rope grabs (Type 1, Type A) can be

- Manual, when go upwards, they follow you automatically (slide along the rope), but will not follow you when moving downwards. You need to move them down manually by lifting the ring, or by pressing a button.
- Self-trailing, they follow you when going upwards and slowly downwards. Many self-trailing types can be switched to manual so that they do not slide down without intervention. Example: Petzl ASAP Lock, CAMP Goblin.

Even with zero slack, and using a self-trailing type, you may first fall certain distance before the device grabs the rope. These types must be used with a shock absorber in most cases, especially when there is little rope length above you.

Devices that do not slide down can be used without a shock absorber when connected directly onto a D-ring and zero slack in the rope above you.

An example of an automatic (not-self-trailing, no anti-panic function) fall arrest rope grab with short lanyard is shown in figure 9.4.1.

Figure 9.4.1, Manual rope grab with short lanyard

To move it down, you just lift the ring with the lanyard. You don’t need to touch the part that is around the rope. In case of short rope below you, you may need to add some weight to avoid slack in the rope above you.

As it is a unidirectional device, you need to install it in the right direction (arrow pointing upwards, or text “UP”) and on the right rope. So going over the ridge of a gable roof is bad idea, as “UP” points then down.

> When using a manual or automatic device, it mostly doesn’t protect you when you override its function with your hand. So if you panic and grab onto the device, it may likely not operate (and you fall down with the robe grab in your hand).

Friction hitches
Within the arborist and climbing community friction hitches are used for rope grab function and work positioning. If you know what you do, they are versatile, work very well, are cheap and weigh near nothing.

Many functions required in climbing and rigging can be made just using “accessory cord” or specialist “Hitch Cord”. Popular friction hitches are: Prusik, Distel, Autoblock, VT, XT, etc. I do not further treat them as the risk of human error is significantly larger compared to the mechanical equivalents.

When you want to experiment with friction hitches for climbing, you may read:
https://www.tetech.nl/divers/DO_FrictionHitchWeb.pdf
It has general sections on what rope/cord to use and how to test your Friction Hitches.

9.2.8. Rope, knots and Safety Factors

In many cases rope will be in between you and the anchor point on your mast. It is therefore pretty important to use reliable rope. Within climbing and fall protection there are five types of rope:

1. Dynamic climbing rope to std EN 892
2. Semi Static (LSK) rope to std EN 1891
3. Static rope
4. Accessory cord to std EN 564
5. Marine, utility and industrial rope

Dynamic climbing rope
Dynamic climbing rope has large elastic stretch. It is made out of PA (Nylon). It is the only rope that can be used with relative large fall factor without a shock absorber. An important property of dynamic climbing rope is the impact force. It is the peak force during the first fall test when the rope is subjected to a fall factor of 1.77 with an 80 kg mass. It is mentioned on the label.

A Fall Factor of about 0.7 will generate a peak force of about 6 kN. Note that during its use the stretch becomes less, putting more force on your body with same Fall Factor.

When you can keep the fall factor below 0.5, you can use lanyards out of dynamic climbing rope without shock absorbers. Once fallen, it is advised to discard the rope as the next fall the peak force will be higher.

Dynamic climbing rope has no MBS specification! You can expect >15 kN for 10 mm rope.

Semi-static rope (Low Stretch Kernmantle, LSK rope)
This is rope with low stretch for activities where the elastic behavior of dynamic rope is not desired. It is also made out of Nylon (PA), but you may encounter rope with a PP (Polypropylene) core and PES (Polyester) sheath. Due to the low stretch, a fall factor of 0.3 can generate 6 kN. So when making a lanyard where you may have slack just before you fall, you need a shock absorbing device.

When installing a rope from the top of your mast to use a rope grab directly connected to your chest ring, LSK rope is a good option. You have near zero Fall Factor, so peak force is about twice your body weight. When using dynamic climbing rope, the peak force is the same. However, your additional fall distance due to rope elongation will be unnecessary large. This may result in indirect injury.

The MBS of 10.5 mm type A Low Stretch Kernmantle rope is in the 30 kN range. When making an eye with a figure 8 on a bight, its strength is > 18 kN. When used with a rope grab and pre-loaded, you can expect a static elongation of <40 mm/m of rope length for a weight of 100 kg. That means that when there is 10 m above yourself, and you fall into the LSK rope (zero slack), the total fall distance is < 0.8m (because of peak force is twice your weight), and you settle at <400 mm below where you were before the fall.

Note that a fall of 0.8 m (total fall distance) along a lattice mast is large, and may result in injuries.

Static rope
This has even less stretch/elongation then Semi-Static rope. There is no harmonized standard for these ropes. They can be made out of Polyester, Dyneema, Kevlar and other fibers with very low elongation. These ropes have very poor shock load capability, but it is not used in such situations. These ropes are virtually irrelevant for radio amateur mast climbing.

Accessory cord, Cordelette
This is relative strong but flexible static cord with diameter from 2…8 mm. The common cord has a core-mantle construction and is made out of Nylon (PA) or Polyester (PES). The 7 mm variety is very useful for making friction hitches onto 10..11 mm climbing rope. You may use 8 mm onto >11 mm rope. There is an MBS spec in the standard, but most (if not all) manufacturers exceed the minimum spec. For 7 mm you can expect an MBS of 1200 kg (12 kN).

“Tech” cord using Kevlar, Technora and Dyneema may also be certified under EN 564, but behaves different compared to the common PA or PES cord. The Knotability can be poor, but flexibility is generally better compared to accessory cord. This means that you can wind a 10 mm cord around an 11 mm rope with little effort.

Marine and industrial rope

The only industrial rope that you use for safety, is the rope that is sold as PPE for use with rope grabs (mostly Nylon/PA 12 mm rope, MBS = 30 kN, to std EN ISO 1140). Though all climbing rope has core-sheath (Kernmantle) construction, the industrial EN-ISO 1140 and 1141 (polyester) rope frequently has a twisted construction. The PA rope has elongation about half that of dynamic climbing rope. It frequently has a tracer strand that loses color when it needs to be replaced.

Do not use “marine” rope, Paracord, “utility” rope, or rope from DIY stores. Of course you can use it for non-safety related things. Think of a foot loop or stirrup ladder out of woven PP (polypropylene) rope, as long as your safety doesn’t depend on it. Note that PP rope has low abrasion resistance, low melting temperature, and is not UV-resistant, unless specified. Friction hitches may melt onto PP rope due to the low melting point of PP.

When you consider using DIY store material, you really have to do the math.

Knots and their strength

Knots do “weaken” the rope. The less elongation a rope has, the more strength you lose.

For dynamic climbing rope or semi-static rope (PA, Nylon), you can expect

Knot/bend	**Efficiency [%]**
Figure 8 on a bight as eye termination or bend	60
Figure 10 on a bight as eye termination or bend	70
Overhand on a bight	50
3 turns scaffold knot	60
Offset overhand bend with backup knot	40
Follow through overhand bend	50
Butterfly knot as midline knot or bend	50
Double fisherman’s bend	60
bowline	50

Remember: a knot having 60% efficiency has 40% loss of strength.

Safety factors

When you rely on an industrial shock absorber, all textile rope materials should have a breaking strength > 15 kN. That gives you a static safety factor > 15 (15 kN / 1 kN), and dynamic safety factor >2.5 during your fall.

If you think you can't reach SF > 2.5, you may consider shock absorbers with reduced maximum peak force (Yates has 2 kN shock absorbers / load limiters). Please note that the deceleration distance increases (see Annex 3). That means you very likely need to reduce your fall height significantly as shock absorbers have limited webbing length to stop your fall.

9.2.9. Fall factor, fall height and peak force

When using fall factor to calculate the peak force, the peak force is overestimated when using very short lanyards.

When having a lanyard out of dynamic climbing rope of 0.5 m length with FF = 0.7, one may expect about 6 kN peak force when using a rigid weight. The fall distance (or slack) is then 0.35 m.

Actual peak force will be less. The reason is that:

- There will be elastic stretch in the harness. That stretch is no longer small compared to the fall distance
- There will be stretch in your body, that will also not be small compared to the fall height/distance
- The knots may give out some rope

All these factors increase the deceleration length/path, reducing the peak force compared to a dead weight directly connected to the rope.

Having a short lanyard (with same fall factor) also reduces the duration of the peak force. This puts less stress on your body (back and neck). Falling on a 2 m lanyard with FF=0.5 gives large peak force with relative long duration. Falling on a 30 cm lanyard with same FF=0.5 gives less peak force with less duration.

9.3. Climbing, think twice

When you are familiar with working in towers you can assess whether you will climb in your own mast to install and remove antennas.

When new to working at height, you need to learn a lot. This is also valid when you have experience with (indoor) climbing or rock climbing. After reading this introduction, do you still want to climb your mast to work at height? Are there other solutions:

- Knowing a fellow amateur that can do the job,
- renting/borrowing an aerial work platform (AWP),
- retiring your mast and have a tilt-over crank-up tower
- retiring your yagi antennas and change to wire antennas using fiberglass poles
- Installing pulleys at high points so that you can raise wire antennas

When you decide to climb and spend money:

- Is your physical and mental condition in good shape? Working at height is more demanding for both your body and your brains. Besides the work, you also need to constantly check your safety.
- Are you able to work at height? Freezing and/or anxiety due to fear of height when in a mast is very unpleasant. Dizziness is also not what you want when at height.
- Is your mast strong enough to climb (and attach lanyards and ropes)
- Is your mast and environment safe to create a safe work position? Sharp edges, protruding pieces of metal may seriously cause injuries when a foot slides of a rung. Also nearby power lines can create a hazard.
- Can you get instruction? As mentioned in the disclaimer: This document is not a substitute for a good training.
- Do you climb alone? When alone you should do everything possible to avoid arriving in a situation where help is needed to avoid injury or death. In my opinion, there should always be someone that can call emergency.

When you decide to climb, you have to make a plan to figure out how you do it, what gear you need (to buy), and how to acquire the skills. You should learn your skills close to the ground. That is much better when something turns out different compared to what you had in mind. Your plan should have many “what if” scenarios.

9.4. Climbing, what do you need?

9.4.1. Harness

You very likely climb into an open structure with your face towards that structure. You may have to work standing on a rung. You may also want to take a break (depending on the height of the mast and your physical condition). Best option is to secure yourself on your chest and/or waist with short lanyards.

In my opinion you need <u>at least</u> a harness with a chest (sternal) D-ring and work positioning rings (D-rings on your waist).

If you can spend the money, go for a basic full body work harness (Chest, Back, belly button and waist D-rings). You don’t need a high end ATOM or PETZL harness for occasional antenna work. Check the production date, as officially most harnesses have a 10 year lifetime, even when on a shelf. You can get a discount when buying an “old” harness.

9.4.2. Lanyards

With lanyards you connect/attach yourself to a safe anchor point (strong rung, leg, step, anchor bolt, etc). The type of lanyards you need, depend on how you climb/work. Making the wrong choice may result in fatal accidents.

Assuming that your mast doesn’t have an integrated vertical rail or cable fall protection system, you need to decide to climb near slack free, or using lanyards with shock absorbers. (near) Slack free climbing is demanding. When you mast is fine, it is easier to accept slack, but risk of injury is significantly larger in case of falling.

Fall arrest lanyards

When accepting slack, you need two I-lanyards, or a Y-lanyard, both with shock absorbers. Use as short as possible lanyards and connect them preferably to the chest (sternal) D-ring. Yes, you need to reposition the hooks frequently, every rung, but you will love it when you made a fall. I use lanyards that are just as long as my arm when reaching up. I reposition a lanyard every rung (about 0.3 m). This limits my fall height to under 0.5 m.

Is your mast strong enough to secure yourself onto the rungs (6 kN shock absorber), or do you need to use the legs? When using the legs, you likely need large scaffold hooks. You may consider shock absorbers with lower Peak Force. When you use a Yates 600 series, the slack in your lanyard upon falling should be < 0.3 m for a 100 kg person, including equipment.

You can make the lanyards yourself so that you can use the optimum (short) length. When using a shock absorber, static climbing rope is fine (to std: EN 1891). Use a scaffold knot (triple overhand noose with one or two turns around the carabiner) to connect the rope to the carabiner or scaffold hook.

When making a Y-lanyard, the shock absorber sits in the middle using a girth hitch with an extra turn around the lanyards. An example fall arrest Y-lanyard is in figure 9.5. As mentioned, depending on your mast, you may need scaffold hooks.

Figure 9.5, Y-lanyard with 6 kN shock absorber

Adjustable Positioning lanyards

It is very useful to have some adjustable work positioning lanyards that you can operate one-handed. I make them myself using Distel friction hitches and a tending ring or pulley. I use 10.5 mm semi static or dynamic rope and 7 mm accessory cord for the hitches. When not familiar with friction hitches, you can buy adjustable work positioning lanyards.

The excess length of positioning lines can be daisy chained (figure 6.12) when climbing to the antennas. Use positioning lines with zero slack. Remove any non-used positioning lanyard, as it may interfere with your fall protection.

Fixed length / attachment lanyards

These are short, fixed length lanyards that are mostly used without shock absorber, as you use them with near zero slack. When you make them yourself, use dynamic climbing rope using fat knots (scaffold knot for the carabiner and follow through figure 8 for permanent connection to your harness). You can make them to suit your job. Dynamic rope allows some slack without experiencing excessive force when falling.

You can also buy them for say 5 to10 times the price compared to DIY. Check their properties, as several are made from low stretch rope and need to be used zero slack.

Near zero length lanyard

This is nothing more then a carabiner directly connected to the belly button D-ring, or via a short piece (cm range) of climbing rope. As soon as you stop climbing, you connect yourself slack free to the mast (rung). It is just to rest or to have your hands free.

It should be connected onto a rung, or onto a leg, just above a rung, so that it contacts the rung. It should not slide down, as that is the same as having slack.

Lanyard for Climbing in pipe sections

It is assumed that you can stand with your feet on a solid object. That can be the mast itself, or a step (temporary) present onto the pipe. When you have nothing to stand on you need to climb fully suspended. That requires even more training.

When you need to be above the mast itself, you run into safety issues. You can't connect the fall arrest lanyard above you. In addition that pipe section may not be strong enough to handle a 6 kN peak force. Then a lanyard with rope grab that is connected with a braided friction hitch onto the pipe (figure 5.9, left) is an option.

You need to work slack free to avoid shock load. That means, no slack in the rope above you, and rope grab directly connected to your harness (chest or belly button D-ring).

There is some redundancy as you also use the work positioning line between the waist D-rings. When one line fails, you don't fall.

I use friction hitches, but a manual rope grab is highly recommended, as that gives the smallest peak force in case of losing your balance.

You need to practice with such equipment at the ground frequently, so that you know what to do and how your equipment behaves.

My standard lanyards:

- 1, Y-lanyard with 6 kN shock absorber for general mast climbing, not for positioning
- 1, adjustable work positioning lanyard that is on a Waist D-ring to flip around the mast, a rung or a leg.
- 2, adjustable lanyards out of climbing rope for near slack free climbing or work positioning.
- 1, zero length lanyard (large carabiner that is directly onto the belly botton D-ring)
- 2, adjustable lanyards for use on pipes with friction hitches

All adjustable lanyards can be adjusted by pulling the loose end (one-handed operation).

> When watching professional tower climbing instruction videos using Y-lanyards, you will notice that they accept large fall height (> 1m) when something goes wrong. That is a trade-off between time and accidents (money).
>
> Time should not be a factor in a Ham radio situation, so go for small fall height with less risk of injury.

9.4.3. Connectors

It is good to have some spare connectors (carabiners, quick links, soft shackles) with you.

Check that the opening of carabiners is sufficient to fit around legs/rungs and check for undesired loading. Another shape or size may work better (for example scaffold hooks or wide opening carabiner).

You may also have some soft shackles. They weigh near nothing and are flexible.

9.4.4. Rope

You may carry with you some pieces of general rope, climbing rope and rope assemblies. You can better have something with you instead of nothing. Short pieces you can girth hitch around rings for tools.

Some things to consider taking with you (of course job dependent)

- 7 or 8 mm Accessory cord with eyes (when familiar with friction hitches
- 6 mm Accessory cord loops (when familiar with friction hitches)
- A few meters of 7 mm accessory cord, just to improvise
- A few meters of dynamic climbing rope, just to improvise
- Adjustable foot loop when you may hang fully suspended, or may fall just over an edge. You need extra hardware in case of descending/ascending
- Several meters of (non-climbing) rope with varying diameter.
- Rope (with pulleys) for hoisting tools and antennas
- Rope loops (slings) for non-climbing application
- Shock cord loop to tend friction hitches.

The first time that you climb you may install a semi-static line so that you can climb using a rope grab instead of climbing hooks. When you know your mast, you can do that from the ground using a fishing rod. The reason for “when you know your mast” is that there may not be sharp edges, and the structure must be strong enough.

9.5. Securing and ladders

You may need to use a ladder as in the example (figure 9.1). The horizontal line in figure 9.6 is (for example) the gutter. Your feet are several meters above the ground. Do you secure yourself during climbing? Most people will not secure themselves when climbing a ladder. When at the work position they may use a work positioning line to maintain balance, or just use a single lanyard.

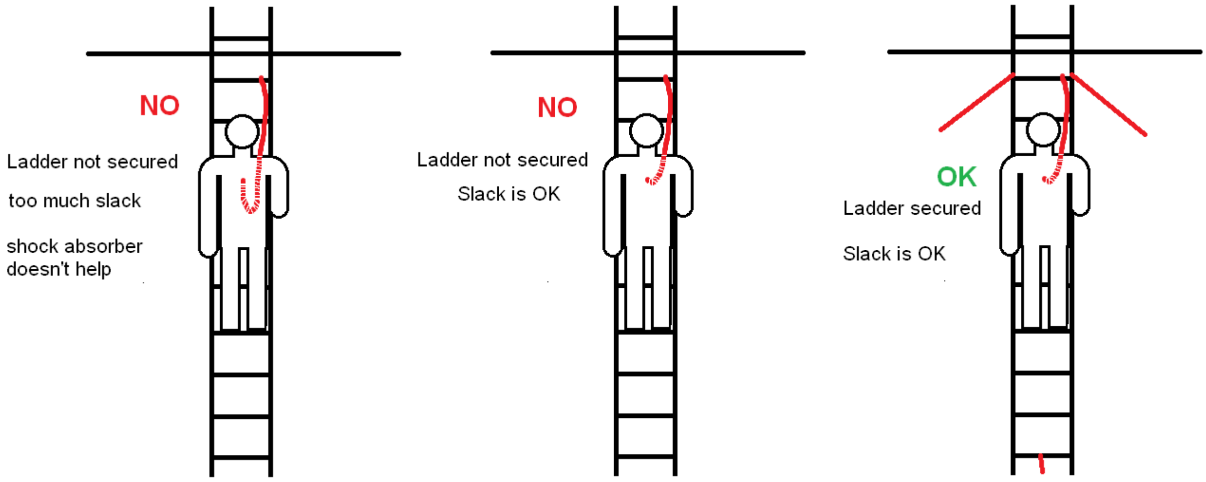


Figure 9.6, securing onto a ladder

The lanyard is connected to the chest (sternal) D-ring or belly button (ventral) ring. Assume that you are several meters above the ground with your feet.

Left figure

Your ladder is not secured, it can slide. That risk may be higher then falling from the ladder. When connected to a falling ladder, you can do nothing to put yourself in the best position to survive the fall.

Most ladders are not constructed to handle a peak force of 6 kN (1300 lb), so an industrial 6 kN shock absorber in that long lanyard doesn't help you. In addition that fall will slam your face onto a rung (or step).

Middle figure

Slack in lanyard is fine (about 15 cm), but the ladder is not secured

Right figure

The ladder is secured to avoid back falling, sliding to left or right and the ladder base can't move. Together with the negligible slack in the lanyard, this is a safe situation.

Is it safe to connect to a rung?
As long as there is negligible slack and using a lanyard out of dynamic climbing rope, you can connect to a rung. The peak force will be about twice your body weight. Ladders have a safety factor of >4 based on the maximum load stated in the documentation.

A scaffold hook may not sit right when connecting onto one of the legs.

Using a rope grab
Securing during climbing onto a ladder using a Y-lanyard is very slow, as you need to reposition the lanyards every step. So many people climb without securing. When you have a rope grab and a safety line installed, it will not slow you down. I prefer an automatic rope grab (or friction hitch) that follows upwards, but not downwards, as this generates the lowest peak force in case of falling. Disadvantage is that climbing down takes more time as you need to reposition your rope grab every step down.

Figure 9.7 shows climbing a ladder using a rope grab or other fall protection friction device. Assume that your feet are several meters above the ground, so falling from the ladder will lead to severe injury when not secured.

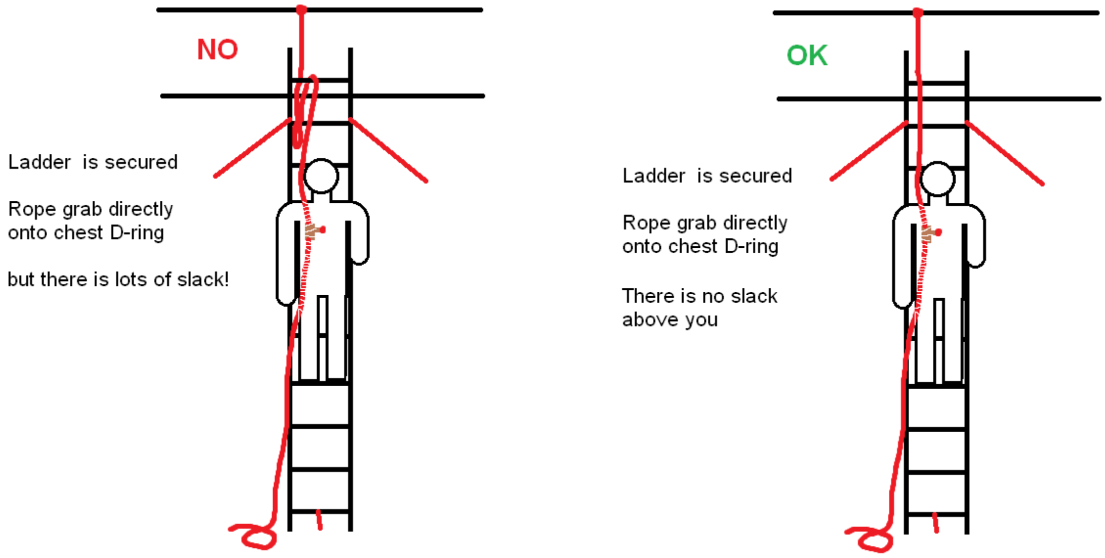


Figure 9.7, securing onto a ladder, using a robe grab

Left figure

The ladder is secured and the rope grab is directly connected with the chest D-ring. Look above you! There is at least 0.6 m of slack. Together with the rope stretch you will make a hard fall as your face will likely hit the rungs hard, and you don't use a shock absorber.

Right figure

The ladder is secured, the rope grab is directly onto the chest ring, and there is no slack above you. A fall my not be pleasant, as your face may hit a rung. Without it the damage will be significantly more.

You may even connect the securing rope to the upper rung (preferably near a leg/rail) when there is no higher point available.

Using an unsecured ladder (not recommended), descending along a rope

You would think that securing the ladder isn't necessary as when the ladder slides away you don't fall (figure 9.7).

When the ladder slides away, you will hang fully suspended, with nothing below your feet. When you are not prepared to handle this situation, you will experience suspension trauma as the straps around your legs will impede/reduce blood flow. See also **harness suspension trauma** in the introduction section.

When having slack below you (as in figure 9.7), you may wrap the rope around one of your feet so that you can stand on the rope (or tie a loop in it). This is the same technique that you use to climb a rope (when you were younger...), Then release the rope grab slowly (lifting the ring) and let it slide down. You can repeat this process until you are down. This doesn't work when the line below you is (lightly) tensioned.

Descending along a rope using a second friction device
The best option is to have another friction device. There are many: rope grab, friction hitch, (hand) ascender, descender, rope clamp, etc. You also need an (adjustable) foot loop or strap.

The second friction device you position below the rope grab at or somewhat below waist level with a foot loop so that you can stand. You may need to adjust the foot strap. Note that when you have a hand ascender, you connect that above the rope grab. You can add redundancy by having a dynamic rope lanyard between the hand ascender and you belly button D-ring.

Transfer your body weight onto the second friction device (by standing in the foot loop). Now you can move the chest rope grab down that saved your life. Transfer your body weight back onto the chest rope grab so you can move down the second friction device. By repeating this process you can descend the rope and you rescued yourself!

You can imagine that this doesn’t work when your robe grab is on your back.

> You definitely need to practice this at ground level. It is rather demanding. **Most rope grabs don’t have an anti-panic function**. When your reflex is to hold on to the rope grab in the wrong way, it may continue to slide down as it may not grab. The same is very valid when using a friction hitch.
>
> You may also carry a backup device with you, in case you drop something (for example your foot loop).

9.6. Climbing your mast

9.6.1. General rules/advice in a nutshell

- Use equipment that you know how to use.
- Wear protective clothing and protect your skin (sunburn).
- Only climb when you feel mentally and physically fit.
- Have a backup plan when something goes wrong (that includes informing others what to do)
- Be careful when changing medication (dose or type), have your medication with you in case you are allergic to insect stings and bites.
- Check your mast/tower before and during climbing (use binoculars). Every step you take, you look for irregularities (bolts, guy wires, rust, etc). Things may wear over time
- Check your harness and ropes, rodents can cause serious damage.
- Avoid climbing with bad weather (wind, (very) cold, (very) hot, etc)
- Don’t take more risk because you have fall protection. Fall protection can still cause severe injury.
- Use as much as possible three point support. That is you are always connected with 2 feet and 1 arm, or 2 arms and 1 foot during climbing. It reduces the risk of falling.
- Do not put your arms inside the mast when climbing, as you will break that arm when falling
- Reposition your lanyards frequently to minimize fall distance. You may need to adjust the length of the lanyard to climb with minimum fall height. Yes I know this slows climbing.
- Connect preferably onto a leg instead of a rung, unless you are sure the rungs are strong.
- Keep your body close to the mast. It reduces stress on your arms/hands.
- When you stop climbing, immediately connect yourself slack free to the mast.
- When using a Y- lanyard with shock absorber to limit peak force, do not “short circuit / bridge” your shock absorber
- Use work positioning so that you and your mast form a stable couple.

Most people climb in a mast using a Y lanyard with shock absorber. Your mast should be strong enough to handle a shock load of 6 kN (Europe) as the shock absorber may generate a force up to 6 kN when falling. I am sure not all amateur antenna installations can handle 6 kN.

Other option is climbing using two lanyards with rope grabs or friction hitches. This enables slack free climbing. You are always connected to your mast via a rope with rope grab with zero slack. This is demanding and takes more time, but enables climbing into structures that may not have sufficient safety factor for climbing with 6 kN shock absorbers.

9.6.2. Climbing in a lattice mast with shock absorber

Figure 9.8 shows a situation.

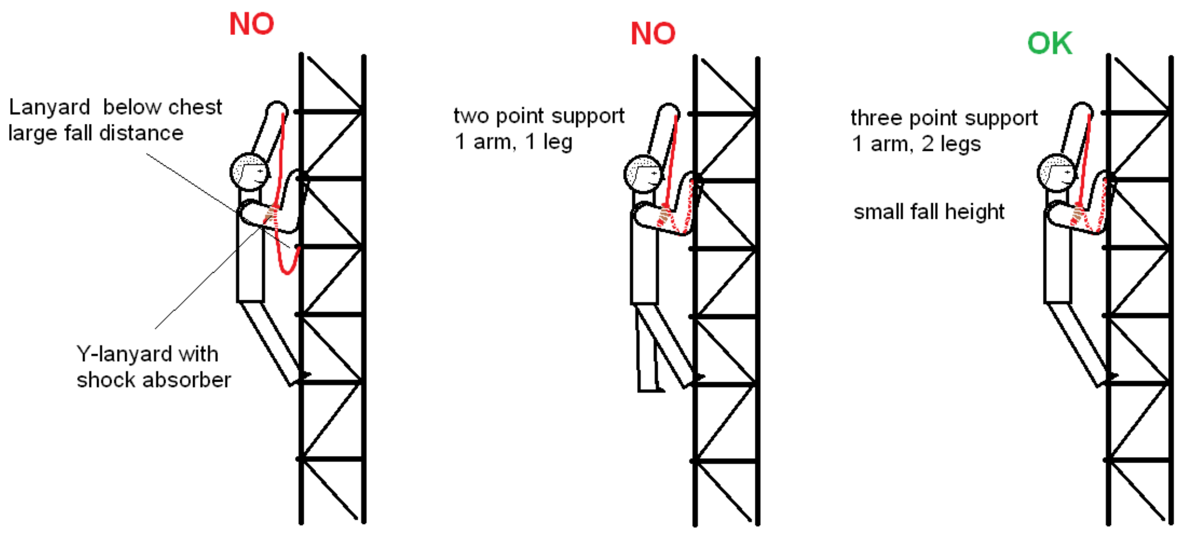


Figure 9.8, Climbing lattice mast situations

Left figure

Your lanyard that is connected to the mast is well below your chest. Your fall distance will be about 2 rung-rung distances. Reposition more frequently and your fall height nearly halves.

Middle figure

Your lanyard that is connected to the mast is at the right position. Your fall distance will be about 1 rung-rung distance.

Change your climbing technique! You stand on one foot and hold with one arm. This is an unstable situation that significantly increases risk of falling.

Right figure

Your lanyard that is connected to the mast is well above your chest. Your fall distance will be about 1 rung-rung distance.

You have 3 point support (2 legs, 1 arm).

After connecting the lanyard in your left hand to the mast, you can climb one rung. Then you reposition the lowest lanyard with your right arm above the other. This enables you to climb with the smallest fall height.

9.6.3. Interrupting your climb

You may need to interrupt your climb. Think of: checking your mast, resting, dealing with insects, etc.

Figure 9.9 shows what you can do.

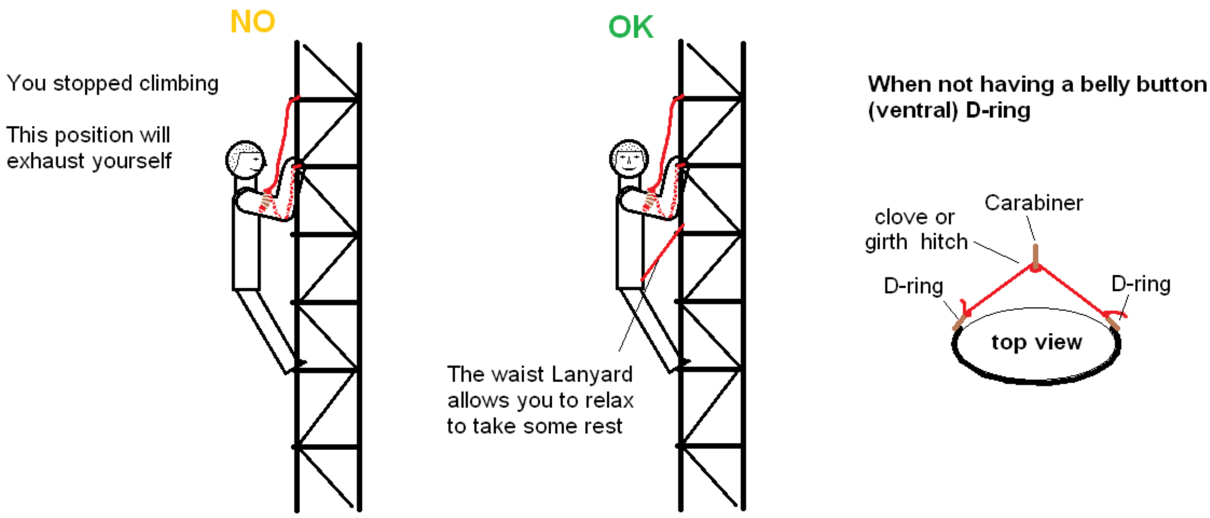


Figure 9.9, Resting during your climb

Left figure

You just connected the upper lanyard and want to stop climbing for a moment. As there is virtually no slack in the upper lanyard, you may hang onto your lanyard. This is not recommended. Fall arrest lanyards you use for arresting a fall. So hopefully you never need them.

Middle figure

Best option is to have a fixed length lanyard at your waist (without shock absorber) that you can connect directly onto a rung or leg, **slack free**. The length should be optimized for your mast depending on your height and distance between the rungs.

The fall arrest lanyard remains connected (is your backup).

Right figure

When you have waist D-rings only, you can use a short piece of climbing rope that you connect onto the D-rings. Connect a carabiner onto the rope using a girth or clove hitch. Reason for these hitches: you don't lose your carabiner, and the hitch is easy to adjust while it doesn't move/slide when loaded.

The fixed length (short) lanyard is an addition to a work positioning lanyard that you flip around the mast or through the mast.

When you continue to climb, you remove a work positioning lanyard first. Then you remove the short lanyard, as you should not fall into that lanyard (no shock absorber).

Of course when you disconnect the short lanyard after installing the positioning lanyard, you first connect the short lanyard. Then remove the work positioning lanyard. Just before starting to climb you disconnect the short lanyard.

9.6.4. Climbing a short pipe section

Many masts/towers have a pipe section that holds antennas. The pipe may be on a rotator/rotor, fixed, or adjustable in height. Figure 9.10A, B and C show an example.

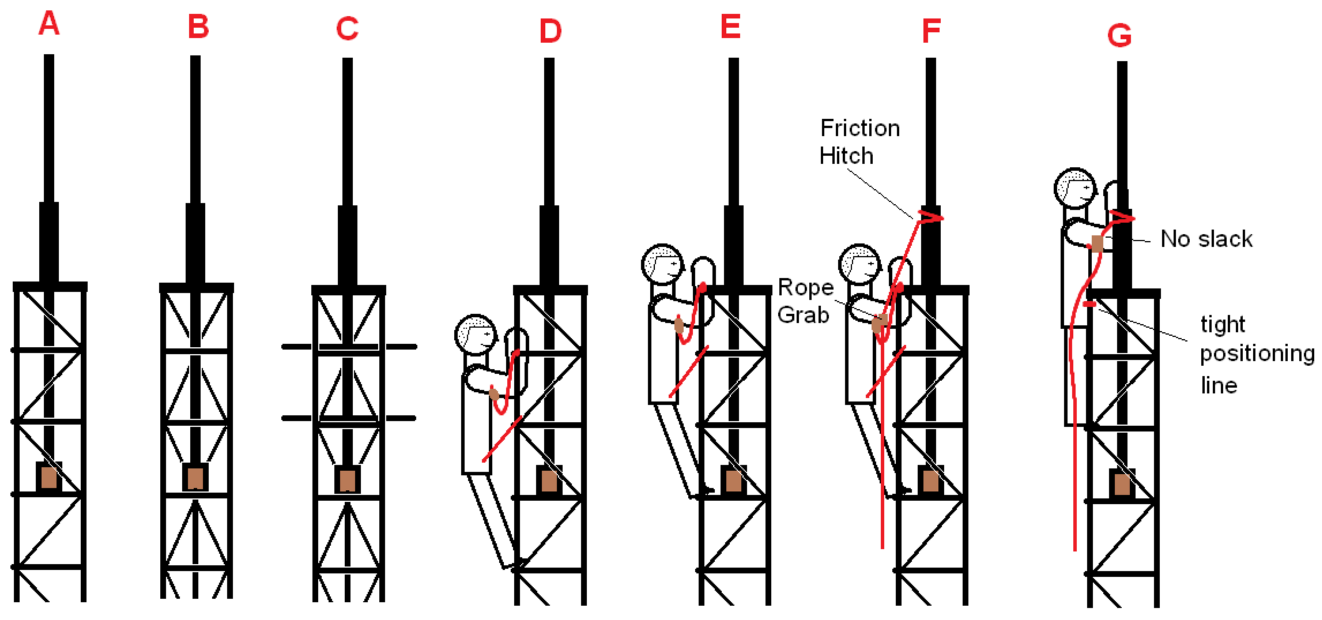


Figure 9.10, Climbing short pipe sections

The A-figure has the same orientation as in figure 9.9 where you climb the mast from the left side.

The B-figure shows left side view. This is what you see when you climb as in figure 9.9.

Skinny masts may not have sufficient space for your feet near the pipe section. In that case you should install tube sections that can be used as footsteps (C-figure). This gives you much more stability around your vertical axis.

When you need to stand on the highest foot step, or even on the platform (top of the mast), you run into safety problems. When using the Y-lanyard, you can't keep you fall height acceptable. In addition when a main part of your body is above the platform, your stability will be less as there are no legs or rungs anymore to hold on. Footsteps to spread your legs give more stability (figure 9.10C).

The solution is to use vertical fall restraint, so you can't fall. You can see it as vertical work positioning. To be honest, many people don't like this part of climbing as your balance will be less and you may experience some flexing of the structure. Your physics also need to be better. You need the pipe for the vertical fall restraint.

Pipe checking
Before you rely on the pipe:

- Check that it can safely hold twice your weight with sufficient margin.
- That it doesn't rotate unexpectedly

You may need to install additional hardware onto the pipe to divert axial force (your own weight) to the mast. You may also divert any rotation about the vertical axis to the mast. This satisfies the two checks.

How you climb depends a bit on your harness and where you can position your safety lanyard. In case of figure 9.10E you can get sufficient height as you can connect close the platform. When in that position you connect the lanyard with carabiner to a rung, and then flip your work positioning lanyard around the legs and adjust for optimum stability.

When you can connect only below the platform you arrive in the figure 9.10D. Now you can't reach the platform with your hands. You may use a sling around the pipe that can be used as an anchor for your fall arrest lanyard (check for sharp edges and sling ratings).

You could take another step and immediately connect yourself to the rung with a carabiner (figure 9.9-right, when not having a belly button D-ring). When done, install the work positioning lanyard for optimum stability. If something goes wrong during the step, you fall distance is a rung-rung distance more, so this involves more risk. .

Don't forget, when you climb, there is no other lanyard without shock absorber connected between you and the mast, as you may not fall into a lanyard with slack without shock absorber (that is you should not "short circuiting" the shock absorber).

Installing the vertical work positioning line
This is shown In figure 9.10F. A rope with rope grab or similar device is connected to the pipe using a friction hitch (chocking anchor) or other hardware. The friction hitch is preferred (will be explained later).

> You need a rope grab that advances with you, as it is better to use both hands to take the next step. It must be connected directly to your chest D-ring, or ventral D-ring (belly button ring). There should be no lanyard in between as that introduces slack. The rope grab should not follow you down ("Self-trailing" mode) as it takes some fall distance before it grabs.

As long as there is no slack above the rope grab, the fall distance is zero, so when something goes wrong, you won't make a hard fall.

When you have a harness with a belly button (ventral) D-ring, you connect the rope grab to the ventral D-ring, also without a lanyard. If you have a Croll, you don't need the rope grab. By the way, what are you doing here when you have a harness with Croll or similar device? Check the manual of the Croll as the rope above you may not be vertically.

In the drawings the rope grab is connected to the chest (sternal) D-ring.

Tending the rope grab.

You may experiment on the ground with a thin shock cord connected to the rope grab. The shock cord goes around your neck. It lifts the rope grab so that you have less slack. This works very well when the rope grab is connected to the ventral D-ring. You may need some weight at the rope below the rope grab.

Climbing further above the platform using the rope grab

Check that the work positioning line (waist) can advance when stepping onto the next rung. Grab the pipe and make the next step. The robe grab must advance so that your fall height remains near zero. When not, you have slack in the rope above you. Don't proceed, step back, and first solve the problem.

When you are on the next rung, tighten your waist work positioning line so that you are in a stable position. You are now in a situation as in figure 9.10G.

Further advancing

Figure 9.10G is shown in figure 9.11G again. First install a second work positioning line (using the waist rings) around the pipe as shown in figure 9.11A.

To further advance, the friction hitch needs to be moved higher as shown in figure 9.11A. This is gradual process so that slack above the rope grab remains small during moving the friction hitch. Add some slack via releasing the rope grab, and move the hitch.

The risk of falling is near zero because of the tightened work positioning lanyard (around the legs of the mast, figure 9.11G). However, you should not untie or loosen the friction hitch. It enables you to "survive" a single failure. When you loosen the hitch and you should fall, the hitch slides down, and that is the same as having slack, resulting in large peak force.

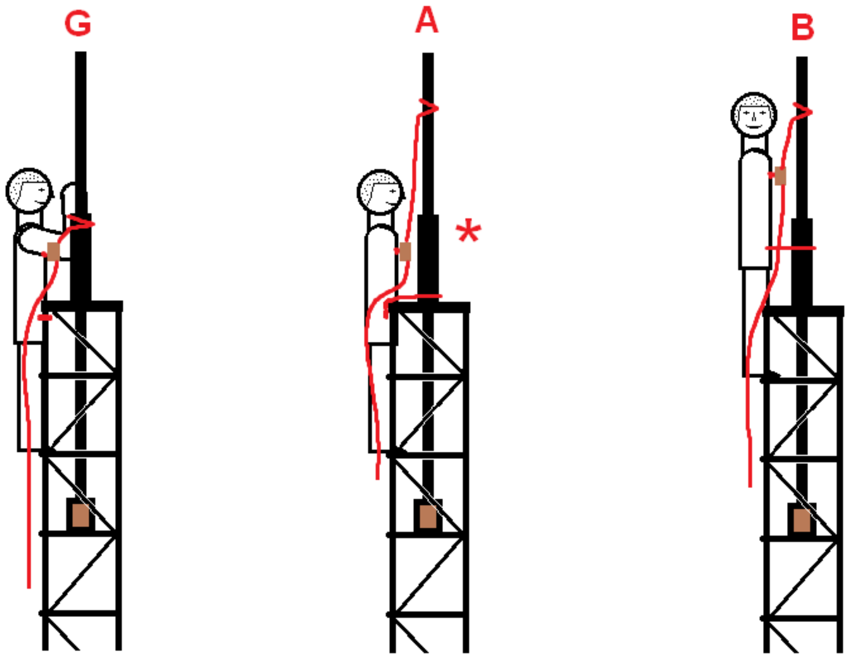


Figure 9.11, Further pipe climbing

Of course if you want to be double safe, you could tie a new hitch with another rope and another rope grab. When done remove the lower one to avoid hardware clutter.

Remove the lanyard that is around the legs of the mast, just below the platform. You should also remove the fall arrest lanyard as that limits further climbing. You are now in a situation as shown in figure 9.11A, and you are ready to go to the next rung.

Now grab the pipe and step onto the next rung. Check that the rope moves through the rope grab so there is no slack. When in the position as in figure 9.11B, adjust your work positioning line.

I prefer to have a work positioning line that doesn't slide left or right. You can avoid that by taking another line and wrap that about two times around the pipe. Other option is to create an anchor point at the position of the red star (A figure), and using a very short lanyard (probably a carabiner directly onto the ventral D-ring).

Going back down

Going down looks like doing all things the other way around. This is true, except for the rope grab. A manual or automatic rope grab will not move down. You need to do this manually. You can use a hand for that, but this may put you in a 1 hand, 1 leg support situation, as you need one hand for the rope grab.

As there is little rope above the rope grab, do not use a self-trailing rope grab. This will result in larger peak force when falling.

You may be able to lower your body with 2 feet supported and 1 hand onto the pipe. The other hand you can use for releasing the rope grab and work positioning lanyard. This goes mostly by lifting the ring that connects to you harness, so you don't need to touch the rope grab itself.

When you lowered your body, check that the rope grab locks onto the rope. Grab the pipe with two hands and step down. Don't forget to loosen your work positioning line around the pipe, otherwise you can't lower yourself enough. This procedure requires reasonable fitness.

Complete other option
When you don't like to work with only a pipe for stability, you may install an extension so that you have two legs and rungs that give similar stability as your mast. I have done that once, as the additional stability was required for installing the antenna. It took time, but worked very relaxed. You may use a ladder, but you need to climb slack free when transferring to the ladder. A ladder is not strong enough for 6 kN shock absorbers.

9.7. Working in your mast

Working at height is more demanding as you are not fully free to optimally position yourself, or the object. You also need to avoid that things fall down, or that you cut your lines, etc.

The line that runs through the rope grab may hinder your work, especially when it connects to the chest (sternal) D-ring. When you decide to remove it, you need another second means to avoid a fall when the work positioning lanyard fails. When you have a work harness the rope grab is connected to the belly button (ventral) D-ring, so you may lower the friction hitch around the pipe (but maintain zero slack).

9.7.1. General preparation

- Make a work plan, so that you know what you need.
- Use slack free work positioning. Do it in such a way that you don't have to use your balance to maintain the desired work position.
- Make or buy a good tool bag.
- You may also make a transparent small tool bag to easy find small things (bolts, nuts, washers, connectors, etc).
- Make lanyards on your tools. So that you can connect them to your harness or your wrist/arm/mast/pipe, etc
- When having people on the ground, you may use an endless hoisting line to lift and lower tools. Let the people on the ground do the lifting and lowering work to save energy.
- Use miniature carabiners/snap hooks/soft shackles/etc to easy connect tool lanyards.
- Have a means to communicate (license free portable transceivers, so that non-licensed people can communicate also). You may use VOX (voice controlled) operation.
- Know your equipment, practice at the ground (especially electric equipment)

9.7.2. Using Electric tools

Electric tools involve a risk (also valid for battery powered tools). Your work position may not be that stable compared to on the ground. When you get injured, you may not be able to climb down.

The main rule is that you can maintain your balance, even when the machine behaves unexpectedly

Removing old antennas may require the use of an angle grinder or reciprocating saw (for rusted bolts/nuts/etc). These are machines that introduce higher risk.

Angle grinder

- Wear protection (especially eyes).
- Check that the sparks don't hit your ropes or other flammable materials.
- Make sure there is sufficient clearance when the disk jams and the machine move upwards or to the left. It should definitely not hit yourself or ropes.

Reciprocating saw

- Wear protection (especially eyes).
- Avoid that sawdust lands on your rope and harness.
- Check that when you cut through you don't hit crucial things (your ropes for example)
- Make sure you can handle the machine when the saw jams
- Have spare saws and tools to change the saws with you.
- When battery power, have a spare battery (or one at the ground that can be lifted).

Electric screwdriver / drill

- Wear protection (especially eyes when drilling).
- When possible, limit the machine's torque so that you don't lose control. Jamming during drilling in metal is a serious risk.
- Avoid that chips (from drilling) lands on your rope and harness. If so removed them after drilling
- Check that when you drill through you don't hit crucial things (your ropes for example)

9.7.3. Avoiding losing objects (antennas, hardware)

Falling objects can be a hazard for people below, **and yourself**! Small objects (think of a metric M10 nut) may bounce of a part of the mast and may injure people below. An old antenna that you can't hold may fall onto yourself, or on a guy wire. When it snaps you may put yourself in serious trouble.

When you remove (old) antennas, you may need to fix them temporary before cutting/grinding the last bolt. This may require you to climb higher to attach a rope (or pulley with rope).

The same is valid when installing new antennas. You may need to install additional hardware to lift and position the antenna.

You should definitely avoid that large falling objects hit you, people below, or guy wires.

9.8. Final word on the climbing section

This is the end of the climbing section. I hope this chapter gives you some information to avoid that you do things the wrong way.

As mentioned at the top of this chapter: this is not a replacement for good training/instruction. Climbing involves risks that you need to understand well.

Your feedback to make this document better is highly appreciated.

10. Annexes

10.1. Annex 1, 3x3 and 2x2 stopper knot

Tying and dressing
The 3x3 overhand stopper knot makes a compact fat knot in a line. It is relatively easy to tie/remember. Because it is compact and fat, it also works well in soft shackles, as it will not be pulled through the loop.

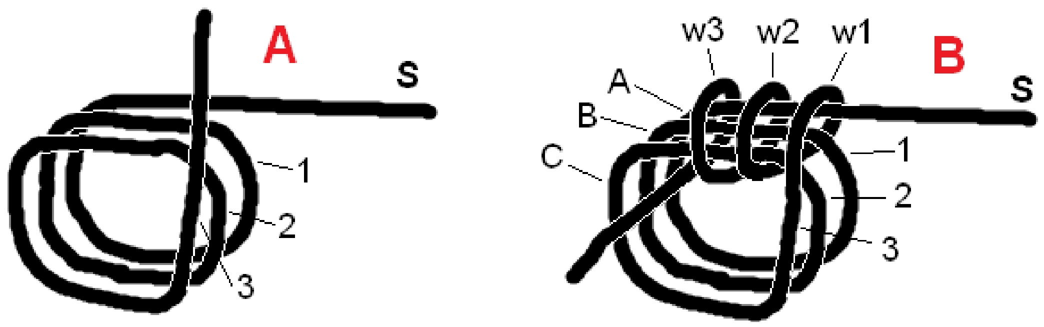


Figure A.1.1 basic geometry and tying steps for the 3x3 stopper

How to tie it?

A-figure. You start with 3 turns wound around an object (or in air). Winding 3 is closest to you.

B-figure. Wrap 3 turns (w1…w3) and put some tension on it so that turns 1….3 are pushed onto each other.

Basic dressing.

Grap turn 2 on the right side, and pull it out of the knot. This tightens turn 3. Grap turn 1 and pull it out of the knot, this tightens turn 2.

Pull w2 out of the knot, this tightens w1, pull w3 out of the knot, this tightens w2. Now pull the working end, this tightens w3.

Check that the order of turns didn't change. Now tighten the standing end, this tightens turn 1. You can repeat the process of pulling the "normal" turns and the W-turns with pliers to get a stiff bulky knot.

It should look like knot 1 in figure A.1.2.

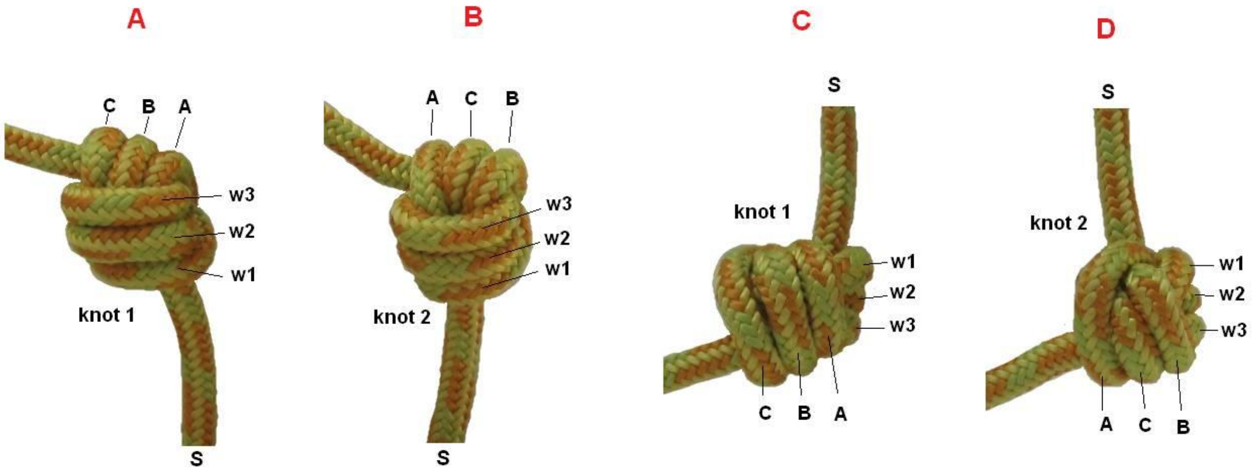


Figure A.1.2 basic geometry and tying steps for the 3x3 stopper

Version knot 1 is fully symmetric. Both standing and working end have same strength. It has the best visual appearance and sits reasonably on the center of the rope. This dressing is preferred when having (for example) more fat stoppers in a single rope.

Alternative dressing

When pulling onto the standing end, you tighten turn 1. When you manipulate turn 1 over turn 2 and 3 before pulling the standing end, the turns order changes.

This can be seen in knot 2 (figure A.1.2). A corresponds with turn 1, hence turn 1 is now on the left side (compare figure A.1.2, A and B). The D-figure shows that turn 1 crosses over turn 2 and 3 so it can reach the side of the knot where the working end leaves the knot.

Turn 1 (that leads to the standing end) has an increased radius now. This makes the knot itself stronger. The standing end that leaves knot 2 has now more strength compared to the working end. This can be useful when making soft shackles.

Also with this alternative dressing you need to repeat pulling onto the windings (with pliers) so that it becomes hard and stiff. Getting sufficient tension in a 3x3 overhand stopper is elaborate.

Another alternative is to have turn 1 in the middle, so you get CAB instead of CBA.

Usage

After many experiments with thin (1…3 mm braided rope), using the alternative stronger dressing in soft shackles, the rope just brakes outside the knot, or the figure 8 on a bight broke. With PP mostly the figure 8 on a bight broke, but with nylon (PA) the rope broke at the eye/knot transition. The knot is in the eye of the soft shackle and the working end terminates into a well-dressed figure 8 on a bight.

There was relative large variation in strength. The reason is the orientation of the stopper onto the eye.

Figure A.1.3 shows the strongest and the weakest orientation. On the left side of both photos is the eye. There is no provision for preventing that the knot slips through the eye/loop. During testing the knot never slipped through the eye. The eye never failed.

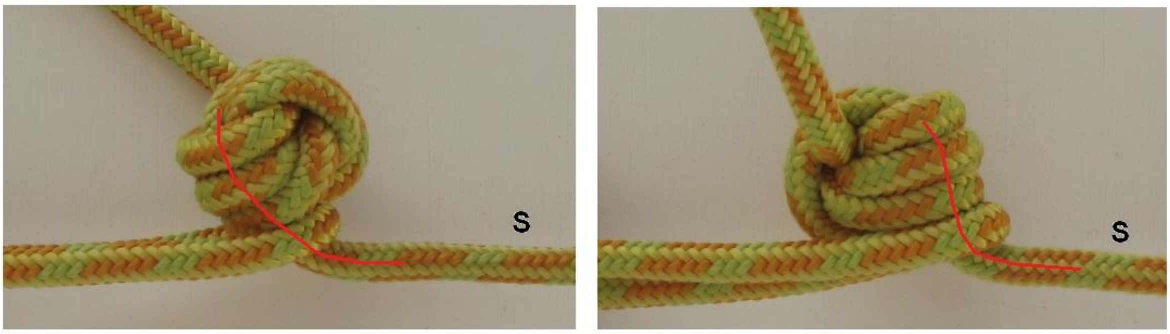


Figure A.1.3 Stopper orientation in a soft shackle.

In the left photo the working end is behind the knot (pointing away from you). The red line shows the path of the standing end. In the right photo the knot is rotated over 180 degrees. The working end points now towards you. Also here the red line shows the path of the standing end.

The path of the standing end makes difference. When testing to destruction, and using the orientation of the right photo, the standing end just breaks outside the knot where it meets the eye (noose) that goes to the left.

When testing the orientation of the left photo, the figure 8 on bight broke in most case when using PP rope, but when using PA rope, the rope broke mostly at the knot/eye transition. So with the optimum orientation the stopper/eye combination has similar strength as a well-tight figure 8 on a bight. So you can expect 60% knot efficiency for nylon. The wrong orientation is somewhat weaker.

3x3 overhand versus 2x2 overhand stopper

The 3x3 version has larger bend radius, so should be stronger under static load, but the 3x3 version also has more rope in the knot. When gradually loading both knots, the 2x2 version gives out significantly less rope.

The 3x3 with the special dressing, gives out more rope then the 3x3 with the standard dressing. This is a disadvantage with heavy shock load as the rope may melt due to the heat (Dyneema or PP).

With braided nylon the 3x3 seems not stronger then then 2x2 version, but with PP the 2x2 version seems stronger (compared to figure 8 on a bight). This likely has to do with getting sufficient tension inside the knot to reduce giving out rope.

The 3x3 is more difficult to tighten very well compared to the 2x2 stopper. So when a not so fat stopper is required, you may use the 2x2 version. This is especially the case when using double rope, as you have in fact 4 normal turns and 4 “w” turns.

I don’t have a setup to test the strength with Dyneema. 6 mm 12 braid has already about 30…40 kN breaking strength…. With Dyneema there is a knot slippage risk due to the low coefficient of friction.

Other number of turns (such as 2x3)

To reduce giving out of rope, one may make a 2x3 overhand stopper (2 normal turns, 3 “w” turns). This maintains the large bend radius as the standing end goes over three strands, but it becomes less bulky.

Using the alternative dressing (so the standing end is at the side of the working end) with a 2x3 stopper and optimum orientation, it gives out less rope and it appears stronger with braided 2 mm nylon cord. More times the figure 8 on a bight broke, so that is a sign it is stronger.

So additional experimentation is required to figure out whether a 2x2, 3x3 or other configuration stopper is best for certain application.

Note that all these stoppers are significantly stronger then the Ashley stopper knot.

10.2. Annex 2, Shock Load

10.2.1. Basic concept of shock load

Shock load occurs when a moving mass is stopped (very) fast. Think of a car that crashes into a wall, a falling load due to a failure in a hoisting operation, a person falling out of a mast that is “caught” by its lanyard.

Shock load is mostly defined as a short duration force transient due to the fast deceleration of the falling/moving mass. The peak force is significantly higher then the static force.

The duration of the transient and the peak force is determined by

- Speed and mass of moving/falling object, the larger the mass-velocity product, the larger generally the peak force and the duration.
- The distance it takes to decelerate the speed to zero. The larger the distance, the smaller the peak force, but with longer duration.
- The distance (or path length) is related to the flexibility of the structure that catches the moving/falling object. The more flexible, the smaller the peak load and the longer the duration.

The peak force and duration is physically related via the impulse of the moving mass.

$$J = \int F \cdot dt = m \cdot \Delta v \quad [Ns]$$

J = impulse in Ns, F = Force generated by the mass in N, Δv = velocity change in m/s.

So when you want to change the speed of a mass from v_0 to zero, the surface under the Force-time curve equals $m \cdot V_0$. The Force-Time product is constant. You can choose to stop the mass in short time, but that goes with large peak force and vice versa.

It is like opening a switch in series with an inductor that carries certain current. The opening of the switch tends to reduce the current through the coil in zero time, but this will result in a voltage spike that will create an arc across the contacts of the switch.

Adding a transient absorber across the contacts limits the peak voltage so that coil current doesn’t drop to zero that fast. This is similar to using a shock absorber to limit the peak force on your body.

Figure A.2.1 shows the basic principle of how the impulse of the moving mass (m·Δv) translates to a peak force.

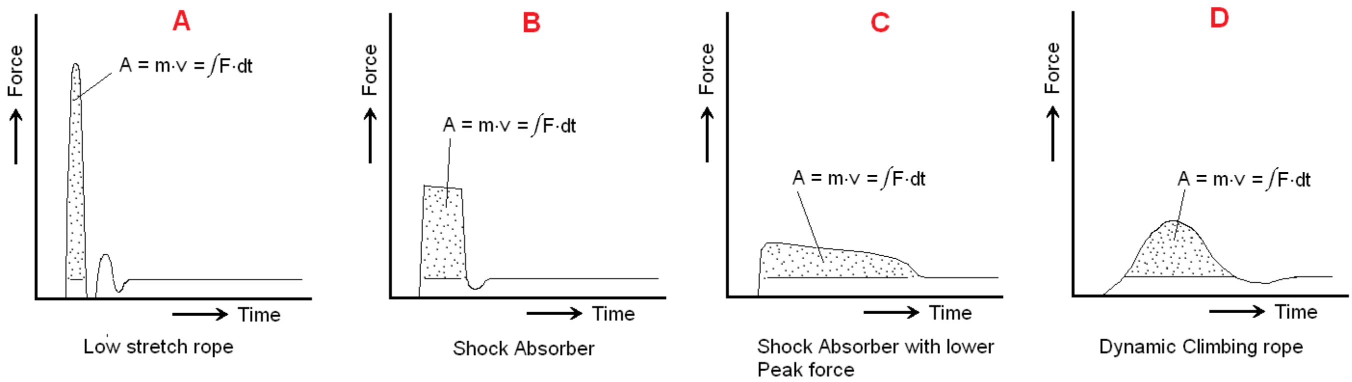


Figure A.2.1. Various shock load arresting scenarios

A-figure

Here a weight falls into a low stretch rope. You are decelerated in a very short time, resulting in a high peak force as the surface under the Force-Time curve (A) equals $m \cdot \Delta v$. In a real situation this might kill you.

B-figure

Now a shock absorber (load limiter) is put in series with the rope and the weight. The peak force is limited now, but to get the same area (A), the time it takes to decelerates to zero velocity must be longer. After the fall, you are closer to the ground compared to the A-figure, but still alive.

C-figure

This shock absorber (load limiter) has a lower peak force, so it takes even longer to decelerate to zero. When the fully extended length of the load limiter is insufficient, you may still experience a peak force, so careful evaluation is required. Low peak force shock absorbers, can handle less shock load.

D-figure

Now dynamic climbing rope is used. This rope is like stiff rubber band. The Area is the same, but the peak force is well below the peak force for the low stretch rope.

10.2.2. How to handle shock loads?

Given a mass with velocity v_0, the peak force depends on the time required to decelerate the speed of the mass to zero. This follows from the Force-Time product. When the mass is stopped in very short time, the distance travelled will be short and the peak force will be high. Therefore all systems to limit peak force tend to decelerate the mass over certain distance. This spreads out in time the transient, resulting in lower peak force.

Another approach is to avoid that a mass can gain considerable speed. In fall protection this is done via “fall restraint” instead of “fall arrest”. Fall arrest blocks area also used. They work like the seat belt in a car. The mechanism takes out slack automatically, but the mechanism blocks when you move (too) fast.

Rope Access technicians work with near zero slack. In case of something goes wrong, they will fall, but that is because of the elastic elongation of the rope only.

The peak force due to the elastic elongation of the rope is twice the weight of the technician+equipment. Shock absorbers are therefore mostly not necessary.

Some formulas (don't get nervous)

When the force is constant during the deceleration process, there is a simple relation between the mass, its velocity and the duration of the peak force transient.

$$F_{const} = \frac{m \cdot v_0^2}{2 \cdot s} \quad [N]$$

F_{const} = Force during the deceleration process, in N. Condition is that the force is constant, s = deceleration distance, in m, v_0 = initial velocity just before the beginning of the deceleration process in m/s.

When using brake systems that behave as a (lossy) spring (for example rope), the peak force is about $1.6 \cdot F_{const}$.

Example falling into a rope

Imagine you make a fall of 1 m and then a rope catches your fall via your harness. During that fall potential energy is converted into kinetic energy (velocity). Your weight is 80 kg

$$v = \sqrt{2 \cdot g \cdot h} \quad [N]$$

v = velocity after falling over h meters, in m/s, h = fall height in m,
g = gravity on earth (9.81 m/s^2).

V = 4.43 m/s (15.9 km/h) for 1 m fall

Imagine you are on a 2 m long rope, and the rope stops your fall by stretching 0.2 m. So the deceleration distance to 0 m/s is 0.2 m.

What about the peak force on your body?
Using the formula for F_{const} gives F_{const} = 3900 N. As you fall vertically we also need to add a factor m·g. So the force on the rope will be in the range of 4700 N average. The rope doesn't provide you a constant force during the deceleration phase. You can expect a peak force of about 160% of the average force.

So the peak force on your body will be in the 7.5 kN range (so you "weigh" 750 kg for a short moment). That peak force is beyond what is acceptable in European industry for fall protection (fall arrest, limit is 6 kN in most parts of the world).

Is that 7.5 kN something you can expect in real world?

When using polyester marine rope

Imagine you have a sailing background and you have some brand new 10 mm very fine polyester line sitting in your shack. You made a lanyard from that line as it has an MBS of 2500 kg (so plenty of margin) and elongation of 3.8% at 30% of MBS.

When that line is loaded with 7.5 kN, it stretches 3.8 cm/m. The actual elongation would be 76 mm instead of 200 mm. So the deceleration goes much faster, resulting in a much higher peak load as the impulse remains the same.

My rope calculation spreadsheet says 13.3 kN with 130 mm peak elongation for a fall distance of 1 m and a rope length of 2 m.

Though your weight is 80 kg, the shock load due to the fall into the rope is over 1300 kg!! There will be a knot in your rope (for example a figure 8 on a bight to connect to your harness). As it is a polyester line, knot efficiency is less then that for nylon. When you have a knot efficiency of 50%, the line will break at 2500*0.5 = 1250 kg.

In real world the shock load will be somewhat less because: the knots will give out some rope and there is stretch in your harness and stretch of your own body.

We can conclude regarding the polyester sailing line:

1. The line may break and you will fall down
2. If the line holds, the force on your body will be so high that you will likely be seriously injured.
3. When you want to use that rope, you need to install a shock absorber (also called “screamer”).

When using dynamic climbing rope (to std EN 892).
When you would be so wise to buy dynamic climbing rope (8.9 kN impact force), the situation becomes completely different, as that rope is like very stiff rubber band. That rope would elongate about 30% with 750 kg load (that is 60 cm when 2 m long). The elongation is about factor 8 higher compared to the polyester sailing rope.

My rope calculation spreadsheet says: peak force of 5.2 kN and a peak elongation of 0.44 m for a 1 m fall with rope length of 2 m.

We can conclude regarding the climbing rope with 8.9 kN impact force to Std EN 892

1. The peak force is limited to 5.1 kN (yes, that is a hard fall)
2. The rope will not break when tied correctly.

The 8 times larger elasticity of the climbing rope gives you longer deceleration distance. This spreads out the impulse over longer time, resulting in a significantly reduced peak force compared to the “very fine” polyester sailing rope.

Do not use “static” LSK rope for catching your fall when climbing. These ropes are used in zero slack applications only. Think of descending and ascending or near zero slack belaying. The only exception is when there is a shock absorber (screamer, load limiter) between the line and your harness.

You can recognize them via the technical standard. Dynamic Climbing rope is certified under std. EN 892, where LSK rope is certified under std. EN 1891. Accessory cord is certified under std. EN564 and is not suited for climbing when you can make a fall (it has insufficient stretch).

10.2.3. Overall conclusion and recommendations

The impact force due to shock load does depend of course on the impulse of the shock load (Force-time product), but also on how the shock is handled by the rope (or other system).

Nylon can elongate a lot (in the 10..40% range). Therefore Nylon is able to spread out the impulse in time so that peak force is limited. Polyester has significantly less elongation resulting in larger peak force onto the rope and/or the construction.

Though Dyneema and Aramide ropes are much stronger then Nylon, they may break. This is because of their very low stretch compared to Nylon, resulting in very high peak force.

When using Dyneema or Aramide rope as guy wires, you need to make sure that there is no slack in the system. If so it will introduce significant peak forces into the guy wires and your mast. Slack can occur over time when the ground changes due to rain, draught or anchor creep. Regular inspection is required. When slack occurs due to creep of the rope fibers, you need thicker rope, or rope out of fiber with less creep!

When you cannot avoid slack in a system (think of rigging or climbing), you need to assess the effect of the impulse generated by the shock load. This is likely beyond the expertise of average Radio Amateurs, unless you can use guidelines such as there are for climbing and safe working at height.

In case of fall protection and climbing into lattice masts, you can do your math well to reduce the impact force on your body. However you can get indirect injuries. A limb can get between two rungs during your fall, your chin can hit a rung, etc.

If possible, keep your free fall height (slack) to a minimum, even when local regulations allow larger value.

10.3. Annex 3, elongation of shock absorbers (screamers)

10.3.1. Introduction

When the fall factor is such that the peak force can't be limited via rope stretch or other means, shock absorbers are frequently used (also called "screamers", or "load limiters" in climbing). They consist of a long piece of webbing that is folded into a bight, and stitched together. The folded webbing is put into a fabric bag to form a compact unit that is connected between the lanyard and the harness.

When a certain peak force is exceeded, stitches are ripped apart, so that the unit becomes longer and the load (person) is more gradually decelerated to zero. The higher the initial velocity and mass, the more stiches tear and the more the shock absorber will elongate.

Standard industrial shock absorbers limit the peak force to under 6 kN. Many start to elongate at around 3 kN. For certain applications this may be too much, so there are specialty shock absorbers that limit the peak force to say 2..3 kN (guaranteed) putting less stress onto the anchor point.

The elongation of a shock absorber is limited. When excessive energy must be absorbed, the device may reach is maximum length. Beyond the maximum length, peak forces are only limited by rope elongation. The combination of mass, fall height and peak force should be such that the shock absorber never elongates to its maximum length.

10.3.2. Elongation versus mass and fall height

One can write up a very nice differential equation to find the relation, but it can be done based on energy only!

The basic principle is shown in figure A.3.1.

When you make a free fall, you accelerate due to gravity over a height of h_{ff} (free fall height). Gravity adds energy via $E_{grav} = m \cdot g \cdot h$. When the rope with shock absorber catches your fall, the deceleration phase starts and the shock absorber converts kinetic energy into heat (E_{abs}). You keep falling for a moment so gravity still adds energy to the system during the deceleration phase. The energy due to gravity is represented by the left area (A_{grav}) in figure A.3.1.

The shock absorber must absorb more energy then is added by gravity; otherwise your fall won't be stopped. The absorbed energy ($E_{abs} = h_s \cdot F_s$) is represented by the right area with thick dots. The force (F_s) must be larger then $m \cdot g$ to stop your fall.

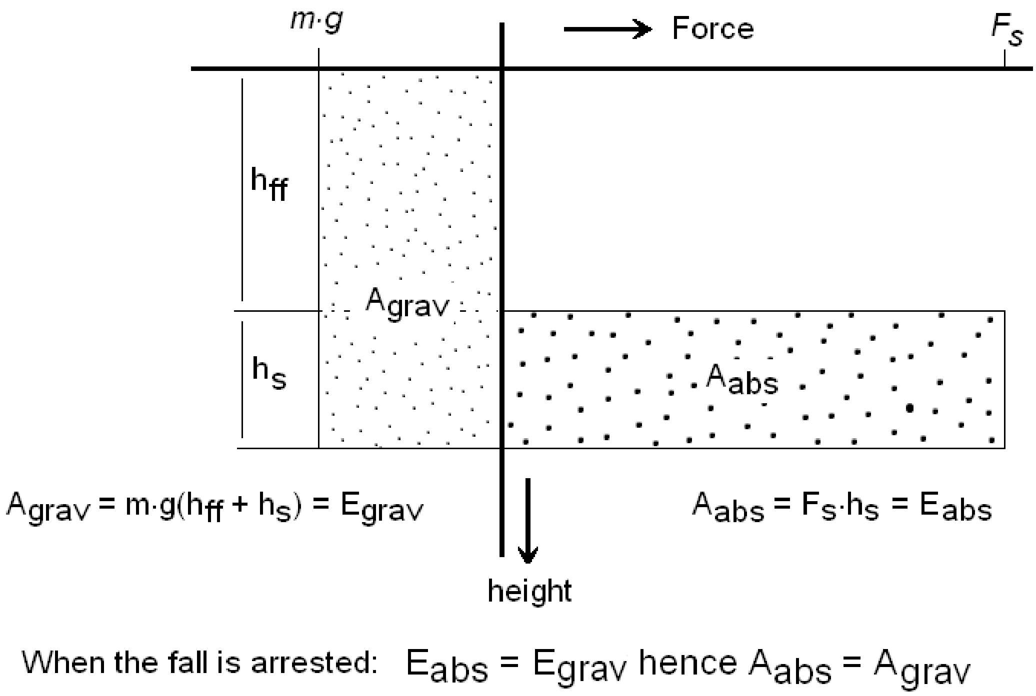


Figure A.3.1. shock absorber energy relations

The (simple?) math:

The energy that gravity puts into the system equals

$$E_{grav} = m \cdot g \cdot (h_{ff} + h_s) \quad [J]$$

The energy that is absorbed (converted into heat) equals:

$$E_{abs} = F_s \cdot h_s \quad [J]$$

In this example the shock absorber force is constant during the deceleration phase, In real world this may be different.

When the fall is arrested (steady situation):

$$E_{grav} = E_{abs}$$

$$m \cdot g \cdot (h_{ff} + h_s) = F_s \cdot h_s \quad [J]$$

Rearranging the equation for h_s gives:

$$h_s = \frac{h_{ff}}{\frac{F_s}{m \cdot g} - 1} \quad [m]$$

Assuming constant peak force F_s during the deceleration process.

g = gravity constant = 9.81 m/s^2

h_s = elongation of shock absorber, in m,

h_{ff} = free fall height to zero slack in the system, in m,

m = mass of the falling object (mostly a person with equipment), in kg,

F_s = the peak force during the deceleration phase, in N

$F_s > m \cdot g$, otherwise formula is no longer valid.

So when your weight plus equipment is 95 kg and you make a free fall of 1 m just before actuation of the shock absorber with F_s = 3 kN, the shock absorber elongates 0.45 m.

When calculating elongation, you need to use the minimum value of Fs, not the maximum. An industrial 6 kN shock absorber may start to elongate (tear apart) around 3 kN. For calculating the Safety Factor, you need the maximum value for F_s (generally 6 kN for industrial absorbers).

When using a Yates 2 kN screamer, you need an elongation of 0.87 m (for 1 m free fall, 95 kg). This exceeds the maximum elongation of a 600 type Yates shock absorber by far (max elongation = 0.3 m), When the screamer in this example is at its full length, there is still kinetic energy in the mass. You (and your hardware) will therefore experience a peak force well above 2 kN.

As F_s may not be constant during the deceleration phase, actual deceleration distance (h_s) will be larger, so more clearance below you is required.

10.3.3. What you should check when using shock absorbers

1. As shown above, you need to use a shock absorber that limits the peak force (Fs) to a value that leaves sufficient safety margin in the system. Industrial Personal Protection Equipment hardware is designed to be used with a 6 kN max shock absorber. The MBS of textile products (lanyard, harness) is generally > 15 kN, giving Safety Fac tor > 2.5 during the peak force event. Hardware for anchor points is rated with a MBS > 12 kN within many standards.
   Some constructions may not have sufficient margin based on 6 kN, and then a 2 to 3 kN shock absorber may give you sufficient margin.
2. The elongation should be below the maximum elongation of the shock absorber. This needs evaluation using the formula, or according to procedures provided by the manufacturer of the shock absorber (preferred). You definitely need to have some margin.
3. You need sufficient clearance below the anchor point. When not, you hit the ground before your fall is arrested to 0 m/s
   Clearance needs to be greater then the sum of: lanyard length (with length of shock absorber, carabiners, etc), elongation of shock absorber, elastic elongation of harness, length from tie point to your feet, elastic elongation in lanyard rope and shock absorber. Add some margin.
4. Limit your free fall distance to the minimum acceptable. Falling along a lattice mast can results in severe injuries. Your knees, head, chin can hit a rung. An arm or leg may enter between two rungs, etc.

Shock absorbers are very useful devices to limit the peak force onto your body and other system parts (rope, anchor, harness, etc), but the total fall distance to 0 m/s does increase. This is especially true when using low peak force shock absorbers. Without careful evaluation you create a false sense of security.

10.4. *Annex 4, Units related to yarn and rope technology*

When reading research papers on rope/yarn technology, you may encounter units that you don't see in mechanical engineering.

In mechanical engineering material strength is mostly related to the cross section, think of stress in N/mm^2, or pa (Pascal for pressure). In Fiber material engineering strength is mostly related to weight/length ratio. Weight/length ratio, or length/weight ratio is used to specify the thickness of yarns.

When you go to your local textile hobby shop and ask for a polyester yarn with diameter of 0.2 mm (to make a miniature whipping to connect copper wire onto an aluminum element), they likely can't help you. It is not the way thin yarn is specified.

There are many (old) units, but "tex", "dtex", and derived quantities, are the most used units in research papers on rope/yarn. In the USA and UK you may find the "den" (from denier).

When you are using yarn intended for sewing, you can use the "count" and material to get an idea of the breaking strength of the yarn.

This paragraph also shows how to convert yarn technology units to mechanical engineering units.

10.4.1. tex, dtex and denier

the unit "tex" is the weight in gram of 1000 m of yarn/rope. Weight/length ratio represents linear density. tex (or dtex) is the most used yarn/thread size unit used in research papers to express linear density. So I convert all other definitions to tex, or engineering quantities (such as Mpa).

$$tex = \frac{weight\,[g]}{length\,[km]} \qquad [g/km,\;\; mg/m]$$

The thicker the rope, the larger the tex number. A rope with a weight of 9 g/m (=9000 mg/m) equals 9000 tex. So when you convert the weight/m ratio to mg/m, you have the tex value.

The unit dtex (or decitex) has the d from "deci" (factor 1/10).
Therefore: 1 tex = 10 dtex.
This is similar to 1 m = 10 dm, or 1 Bel = 10 dB (decibel).

You may encounter "ktex". 1 ktex = 1000 tex, similar to 1 kg = 1000 g.

Denier (or **Den**) is also used. This is the weight in g for 9000 m of yarn. Conversion goes via

$$tex = 0.11 \cdot denier \qquad [g/km,\;\; mg/m]$$

10.4.2. New Metric (Nm) and Wt counts

This is a measure to express the length/weight ratio of a yarn. You may find it on spools or labels. Thick yarns have a small Nm number (or count).

Nm is the length in multiples of 1 km that you get out of 1 kg of yarn, or the length in meters that you get out of 1 g of yarn.

$$New\ Metric\ (Nm) = \frac{length\,[km]}{weight\,[kg]} = \frac{length\,[m]}{weight\,[g]} \qquad [km/kg,\ m/g]$$

Nm is the inverse of the weight of yarn in g/m.

“Wt” or “#” has same definition as Nm. Conversion formula to tex

$$tex = \frac{1000}{Nm} = \frac{1000}{Wt} \quad [g/km,\ mg/m]$$

When you convert wt counts to tex, and know the tenacity (paragraph 2.6.4) of the fiber, you can calculate the breaking strength. Example

> A 40 wt yarn equals a yarn of 1000/40 = 25 tex. It has a diameter of roughly 0.18 mm (when stretched and depending on yarn material). In case of polyester, with a tenacity of >30 cN/tex, it has a breaking strength of 750 cN (>0.75 kg on earth).

10.4.3. No.Tkt

When you encounter “**No.Tkt**”, you have Gütermann yarn. You can convert that to tex

$$tex = \frac{3000}{No.Tkt} \qquad [g/km,\ mg/m]$$

Example

> When you see in a textile hobby shop Gutermann polyester yarn with thickness = 120, it is 25 tex. Polyester has a tenacity of >30 cN/tex (centi-Newton per tex).
>
> The 25 tex polyester yarn will have breaking strength of > 25*30 = 750 cN. This is equal to >0.75 kg on earth.

10.4.4. Tenacity

Tenacity is the ratio of breaking strength in gram-force (equal to cN) and the weight in tex. So it relates the breaking strength to the weight per unit of length (linear density). It is also known as the “specific breaking stress”

$$Tenacity = \sigma_s = \frac{breaking\ strength\,[gf]}{linear\ density\,[tex]} \qquad [gf/tex]$$

Research papers express tenacity mostly in cN/tex instead of gf/tex. A mass of 1 g (=0.001 kg) on earth experiences a force due to gravity of 0.01 N = 1 cN. (“c” equals

0.01). Therefore “gf” equals “cN” So the result of the formula does not change when changing from gf to cN:

$$Tenacity = \sigma_s = \frac{breaking\ strength\,[cN]}{linear\ density\,[tex]} \qquad [cN/tex]$$

examples

What is the tenacity of a polyester rope with a breaking strength of 280 kg with a weight of 9 g/m? 9 g/m equals 9000 mg/m = 9000 tex. 280 kg equals 2800 N, and that equals 2800·100 = 280e3 cN.

“e3” is a short way to write “$\cdot 10^3$”, or multiply with 1000.

So the polyester rope has

tenacity = 280e3/9e3 = **31 cN/tex** (gf/tex)

What is the tenacity of a Dyneema rope with a breaking strength of 4300 kg with a weight of 20 g/m? 20 g/m equals 20e3 tex. 4300 kg equals 43 kN, and that equals 4300e3 cN

So the dyneema rope has

tenacity = 4300e3/20e3 = **215 cN/tex** (gf/tex)

The Dyneema rope is almost factor 7 stronger compared to the polyester rope when you relate the strength to the weight/meter.

The table below shows some properties of other fibers. “Stainless” is stainless steel. Abacá is same as Manila hemp

fiber	Tenacity [cN/tex]	Rel. density []	Elongation at break [%]
Cotton	17…40	1.5	8
Silk	25…45	1.3	15
Abacá	45…85	1.5	7
Nylon	30…90	1.1	40
Polyester	30…90	1.4	30
polyprop	20…50	0.91	30
Dyneema	250…400	0.97	4
aramide	180…250	1.4	4
Stainless	25	7.9	1.5

Variation of tenacity is large, so don’t take the highest values. This is because of the variation of chemistry, production process within a fiber family, and whether you look to a single fiber, or a bunch of fibers that are part of a yarn.

You can use the formula below to convert yarn units to mechanical engineering units. But remember that the rel. density of a yarn is less than the values in the table due to air between the fibers. As a rough guide, use 85% of the relative density from the table.

$$\sigma_{ult}[N/m^2] = 10 \cdot 10^6 \cdot \frac{\sigma_s[cN/tex]}{rel.density}$$

σ_{ult} = ultimate stress obtained during stress vs strain (elongation) measurement.

10.4.5. Conversion of tex to diameter

You need to know the relative density (specific gravity) of the yarn. This is not equal to the base material (fiber) relative density, as there will be air in between the fibers. So the relative density of the rope is less than the fiber density.

$$d = 0.036 \cdot \sqrt{\frac{tex}{rel.density}} \qquad [mm]$$

D = diameter, in mm,

tex = weight in g per 1000 m of rope, or in mg/m,

rel. density = density of the rope/yarn relative to 1000 kg/m^3.

The example polyester rope (core-sheath construction) has a diameter of 3 mm. So the density of the rope should be 1.3 (1300 kg/m3). The density of the polyester base material varies between 1.38 to 1.5. So there is not so much air between the fibers.

To have some rough indication of diameter of a loaded yarn, just set density to 1, then the formula simplifies to

$$d \approx 0.036 \cdot \sqrt{tex} \qquad [mm]$$

The formula overestimates the diameter for “heavy” fibers such as polyester and Kevlar. For nylon the estimate is rather good. It underestimates for polypropylene and Dyneema.

10.4.6. Conversion of tenacity (cN/tex) to N/mm^2

This also requires the relative density, so this is a bit problematic. Mechanical engineers are familiar with this stress definition. Fiber technologists may call this the “engineering stress”.

$$\sigma_{ult} = \frac{ultimate\ strength}{0.25 \cdot \pi \cdot d^2} = 10 \cdot tenacity \cdot rel.density \qquad [N/mm^2]$$

σ_{ult} = ultimate tensile strength, in N/mm^2

Ultimate strength = breaking strength, in N (this is not MBS, as that I lower)

d = diameter, in mm

tenacity = strength, in cN/tex

tex = weight, in g/1000m, or mg/m

rel.density = density relative to 1000 kg/m^3

The ultimate tensile strength is also called tenacity, so check the units to avoid confusion.

Due to air in between the fibers, the rel. density is less than the material rel. density. Therefore the calculated stress based on the yarn/rope rel. density is less than the actual stress inside the fibers. The fiber stress is also a bit higher due to spiraling of the yarn.

You may also use:

$$\sigma[N/m^2] = 10 \cdot 10^6 \cdot \frac{\sigma_s[cN/tex]}{rel.density}$$

σ [N/m^2] has equal unit as pressure, so you frequently see “pa”. Example:
σ = $10 \cdot 10^6$ N/m^2 equals σ = 10 Mpa.

10.4.7. Specific modulus of elasticity

In mechanical engineering, we know

$$\sigma = E \cdot \varepsilon \qquad [pa,\ N/m^2] \qquad \varepsilon = \frac{\Delta le}{le} \quad []$$

σ = stress in the material, in N/m^2, or pa (Pascal)

E = modulus of elasticity, or short E-modulus, in N/m^2

ε = relative elastic elongation.

F = σ·A, in N

The E-modulus is based on the cross section of the material, therefore it has unit N/m^2. Materials with low elastic stretch (such as Dyneema) have large E. Materials with large elastic elongation (such as rubber) have low E-modulus.

One can also base the E-modulus on the linear mass density. This is not common in mechanical engineering. Then it is called specific E-modulus.

$$\sigma_s = E_s \cdot \varepsilon \qquad [cN/tex] \qquad \varepsilon = \frac{\Delta le}{le} \quad []$$

σ_s = stress in the material, in cN/tex

E_s = specific modulus of elasticity, or short E-modulus, in cN/tex

ε = relative elastic elongation

F = σ_s·tex, in cN

10.4.8. Conversion from E_s to E

You need to know the density of the material to enable accurate conversion.

$$E[N/m^2] = 10 \cdot 10^6 \cdot \frac{E_s[cN/tex]}{rel.density}$$

Finally, we related al units that are frequently used in textile production and research to mechanical engineering units. So you can use whatever system you prefer.

10.5. Annex 5, 2x2 overhand on a bight

10.5.1. Introduction

The 2x2 overhand knot is normally used as a compact bulky relative strong stopper knot. It can therefore be used for soft shackles as an alternative for the button knot (see also Annex 1 for the even bigger 3x3 overhand stopper).

When used to form an eye termination (2x2 overhand on a bight) it is marginally stronger (< 10%, not percent points) then the figure 8 on a bight.

The advantage appears when using Dyneema rope with a thick sleeve. A thick sleeve increases the bend radius of the rope, increasing its strength. When using a figure 8 on a bight with a thick sleeve around Dyneema rope, the knot slips. It wasn't expected that the figure 10 on a bight also slips. The Dyneema is pulled out of the sleeve. The failure of the figure 10 is the reason for adding this Annex.

The 2x2 overhand on a bight with thick sleeve doesn't slip and shows efficiency >70%.

Its disadvantage is the elaborate dressing compared to a figure 8, and with a sleeve around the rope it is very bulky.

10.5.2. Tying and dressing the 2x2 overhand knot

Figure A.5.1 shows how to tie the knot and its real appearance when dressed.

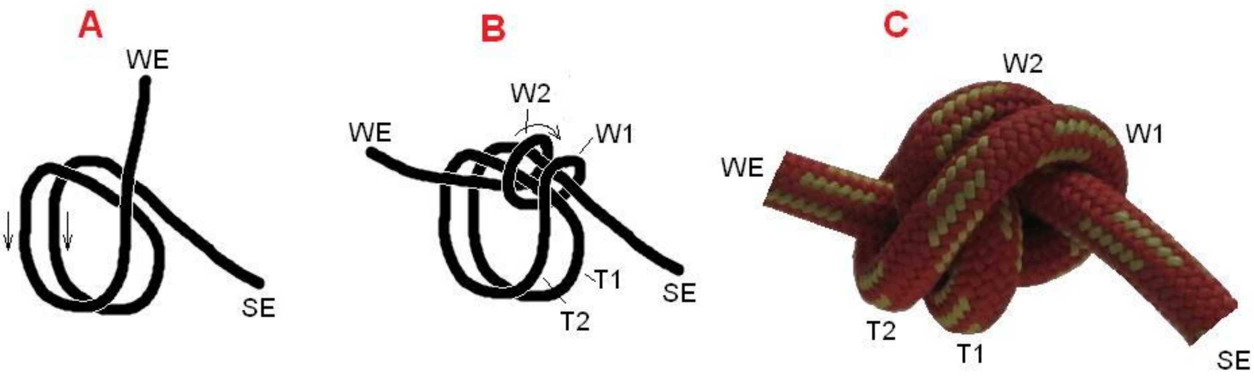


Figure A.5.1 2x2 knot tying and appearance

Start with two turns as shown in the A-figure. Then add the W turns as shown in the B-figure.

Dressing

You grab with your fingers T1 and T2, and pull the working end (WE). This tightens W1 and W2.

Grab W1 and W2 with your fingers so that it doesn't untie. Pull T1 further through the wrapping of W1 and W2. This tightens T2. You may tighten W1 and W2 again after tightening T2.

Pull the standing end (SE) while grabbing the complete knot with a hand. This tightens T1.

Setting the knot
Further tightening can be done by pulling onto SE and WE while grabbing the knot. Do not pull simultaneously onto SE and WE.

Better tightening is possible by holding the knot and pulling T1 (with pliers) further through the wrapping W1, W2. Then pull onto SE.

Pulling onto W2 in the right direction (with pliers) tightens W1. Then pull on the working end (WE) to tighten W2.

10.5.3. Tying and dressing the 2x2 overhand on a bight

Instead of a single rope section, a bight (double rope section) is used when tying the knot. This is the difficult one, as you have 4 T-turns and 4 W-turns now. The same turns definitions are used as for the 2x2 overhand knot. So T1 consists of a red and green rope section (see figure A.5.2).

Tying and dressing the Eye termination
For clarity the load bearing end (standing end, SE) is the red rope. In real world the rope has same color. The bight, consisting of a red and green rope section is the working end for tying the knot.

Form a bight and make two turns around your fingers or some former, as shown left in figure A.5.2.

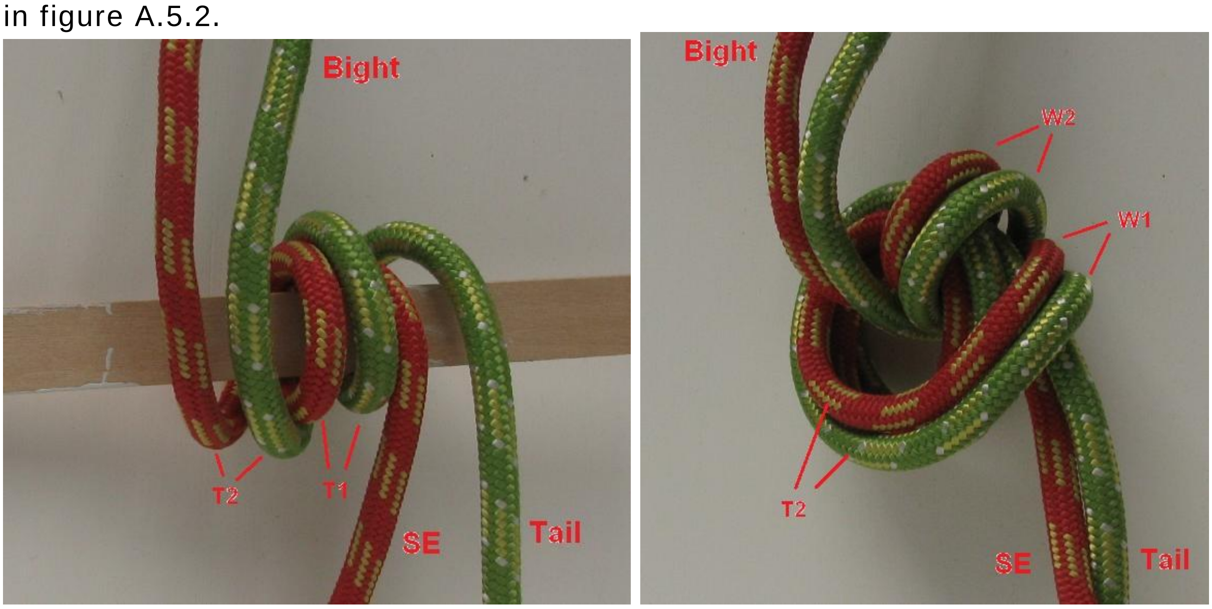


Figure A.5.2 Tying and dressing the 2x2 overhand on a bight

Tie two W-turns around the T turns with the bight, as shown in figure A.5.2 right. The T1 turns are not visible now (are behind the T2 turn).

Grab all T-turns and pull the bight so that the W-turns tighten a bit. Grab the W-turns so that they don't untie.

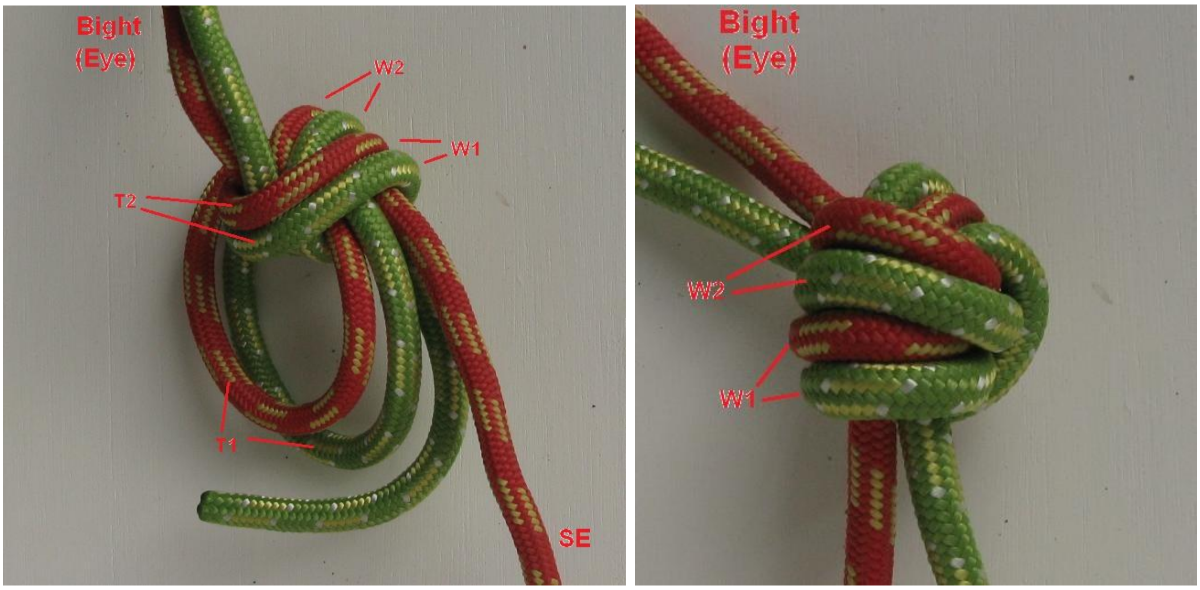


Figure A.5.3 Tying and dressing the 2x2 overhand on a bight

While you have the W-turns in hour hand, pull onto the red and green T1 turns so that the T2 turns tighten. This is shown in the left photo of figure A.5.3. Check that the order of the T- and W-turns remains as in the figure. The short green tail leaves the knot most right.

Now pull the tail and SE so that the T1-turns tighten. Make sure that the Standing end (Red rope with SE). is second from the right. When done, the knot should look like in the right photo of figure A.5.3.

Figure A.5.4 shows the knot seen from the underside.

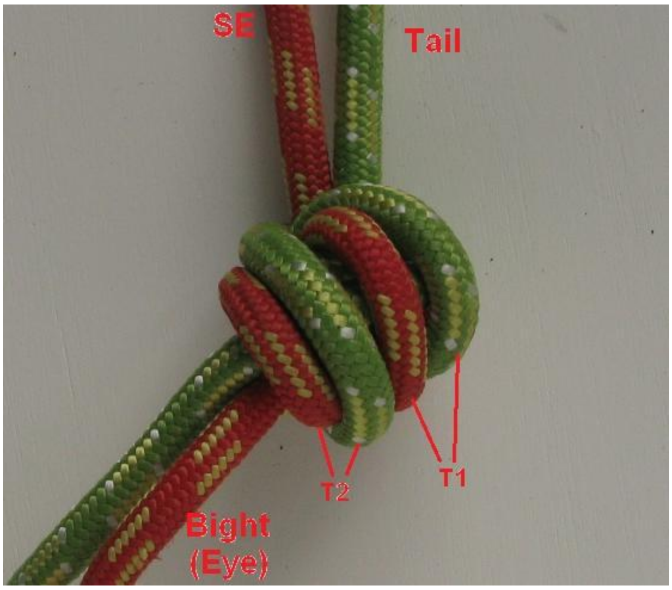


Figure A.5.4 Tying and dressing the 2x2 overhand on a bight

Further tightening can be done by grabbing the T1-turns and pull them further through the wrapping (W-turns). This tightens the T2-turns. Pull SE and Tail to tighten the T1-turns.

10.5.4. Using sleeves

The 2x2 overhand on a bight is only useful when you add a sleeve around the rope before tying the knot, as that gives the high knot efficiency with Dyneema. It doesn't slip when using Dyneema rope.

You will only get better efficiency when the wall thickness of the sleeve is >0.5·(rope diameter). You may need to use a second sleeve on top of the first one to get sufficient wall thickness. Recommended material is Dyneema or Polyester. You can use single braided rope, or remove the core from kernmantle rope and use the mantle (braid) as sleeve.

Setting the knot

Setting/tightening the knot goes different compared to no sleeves. One may put the eye onto an object and just tighten the standing end (SE) and the Tail. This doesn't tighten the sleeve around the two rope sections that form the eye, as the Dyneema eye is inside the sleeve.

You need to grab the knot with your hand, and tighten all four sleeve sections individually. This is especially true for the two rope sections that form the eye.

10.6. Annex 6, Adjustable loop hitches

10.6.1. Introduction

Adjustable loops are used frequently to (temporary) position things, or (permanently) hold things together. They don't use other cord to make a friction hitch. It uses the rope itself as with a Blake's hitch.

For permanent clamping applications, the Rectifier Hitch works fast without any backlash. One of the rope sections leaves at 90^0 and that eases application around thin objects.

For low load applications multi-turn overhand knots (barrel knots) work very well. They can provide safety when worn around the neck or a limb. Above certain force, the rope is pulled out of the barrel hitch. It is important to make sure that the rope end is well finished to avoid jamming.

For loops that need to be adjusted not that much, should not untie, should not move when unloaded, and are relatively heavy loaded, there are more choices. The rectifier/diode hitch does work very well, but may not be the best choice. It may work loose when unloaded in combination with wiggling, and may capsize when used incorrectly.

The hitches to be discussed work like the Hedden hitch. The load bearing rope section is on top of the hitch (when used vertically with the load bearing rope section down). The lower turns experience less tension.

When the risk of working loose when unloaded, and moving when unloaded is not acceptable, a hybrid hitch can be a good solution The hitch that is described first, uses a friction hitch that is terminated with a 2 turn / double overhand knot (or generally a barrel knot). The friction hitch part provides the holding power and the barrel knot part protects against loosening or moving when unloaded. The barrel knot also maintains pretension on the rope turns (friction hitch part), assuring reliable grabbing. The friction part works generally well with 3 turns to 4 turns.

Instead of a double overhand knot as termination, one may use: half hitches, one or two overhand knots, triple overhand knot, etc. They all behave a bit different.

10.6.2. Tying instructions

These instructions are for a hybrid hitch with 3 turns that make the friction hitch part and a double overhand knot as termination. Versions with other terminations are described further down this Annex. The turn that connects to the load bearing rope section is on the left (so on top of the hitch, similar to a Hedden hitch).

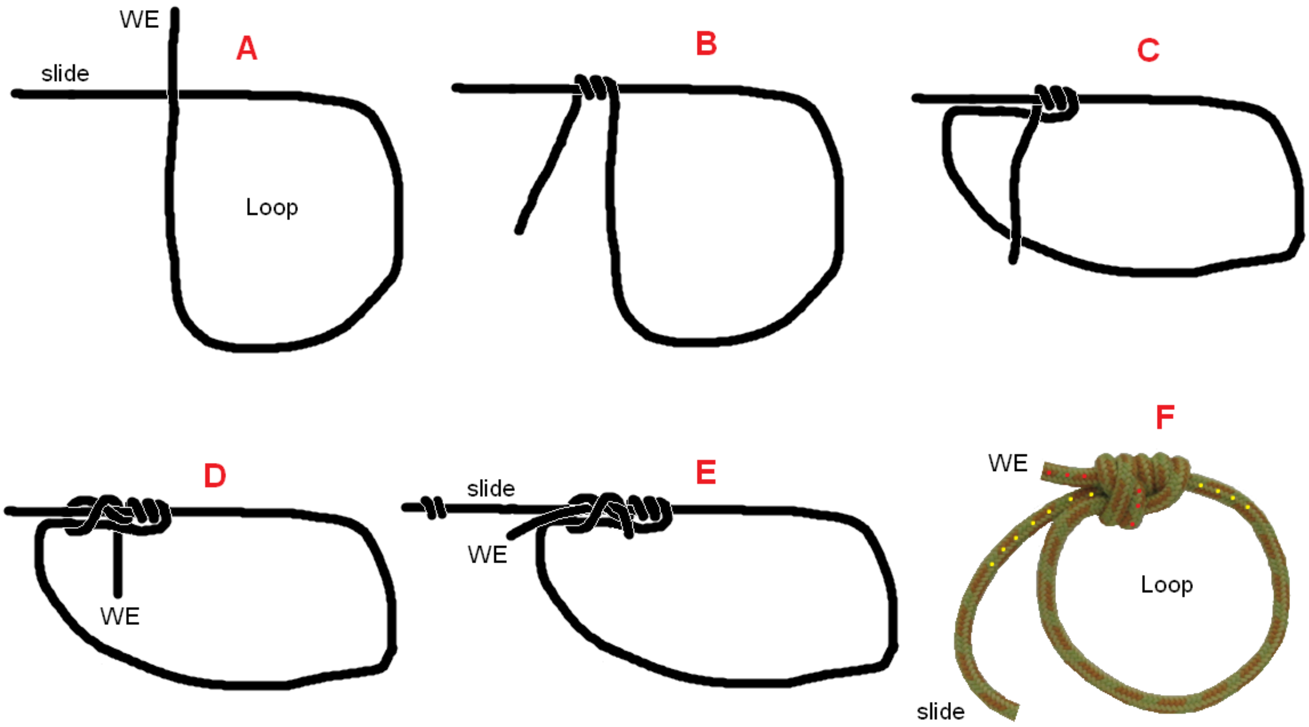


Figure A.6.1: Tying instructions, double overhand knot termination

Figure A

Start with a loop. WE is the working end, and is used to tie the hybrid hitch. The section indicated with “slide” will slide through the loop when finished.

Figure B, C

Apply three turns. These three turns will make the friction hitch part.

Figure D

Apply two turns when you want to make a double overhand knot. Make sure the typical X is present. You may also change to the alternative two overhand knots version (figure A.6.2).

Figure E

Push/tuck the working end through the <u>two</u> turns (under the X) to make a (near) double overhand knot. There are three rope sections that leave the left side of the double overhand knot.

Figure F
Dress it so that it looks like as on the photo.

To increase the loop size, grab with your left hand the three turns of the knot and pull to the right the yellow marked rope part. This is similar to virtually all friction hitches. To reduce the size, grab the knot with your right hand, and pull to the left the yellow marked rope part.

After adjusting the loop you need to set the knot so that it 100% sure locks (grabs). You set the knot by grabbing the complete knot with your right hand, and pull with your left hand the non-marked rope section that leaves the knot on the left side. This tightens the 3 turns and eases releasing/unlocking the knot/hitch after use.

When the load inside the loop tries to enlarge the loop size, the 3 turn friction hitch grabs the rope and will block enlargement of the loop.

As shown in the photo (figure A.6.1), the force should be inside the loop (loop load, parallel load). You can't release the hitch under heavy tension.

When you want to loosen/release the hitch, pull some rope (that is part of the turns) out of the double overhand knot. It is mostly sufficient to grab the turns and push the double overhand knot to the left with you thumb. You may need pliers in case of very heavy load. When this is annoying, use a version with other termination (see further down this annex).

You need flexible rope. Very tight woven double braid doesn't work. Rope that may not work with a rectifier hitch may work well with this hybrid hitch. Dyneema doesn't work.

Check correct operation under real (environmental) circumstances.

10.6.3. Other varieties

Termination with a barrel knot reduces the risk of loosening to zero, but also makes releasing the knot more difficult. Instead of a double overhand knot, two overhand knots can be used. The second overhand knot is just to secure the first, and adds to the pretension. It eases releasing of the knot compared to a double overhand knot. It doesn't untie and doesn't move when unloaded.

Version with two overhand knots

Tying instruction for the two overhand knots version is shown in figure A.6.2.

Figure A, B and C
Procedure is the same as for the double overhand version.

Figure D
Starting from the C-figure, move the working end upwards (same winding direction), and tie an overhand knot around the two rope sections.

Figure E
Add another overhand knot in the same winding direction. It should sit against the first one. It makes it more secure, but therefore also less easy to untie/adjust when heavy loaded. Add a stopper knot in the sliding end if required.

Its use is the same as for the double overhand version, except that it releases easier.

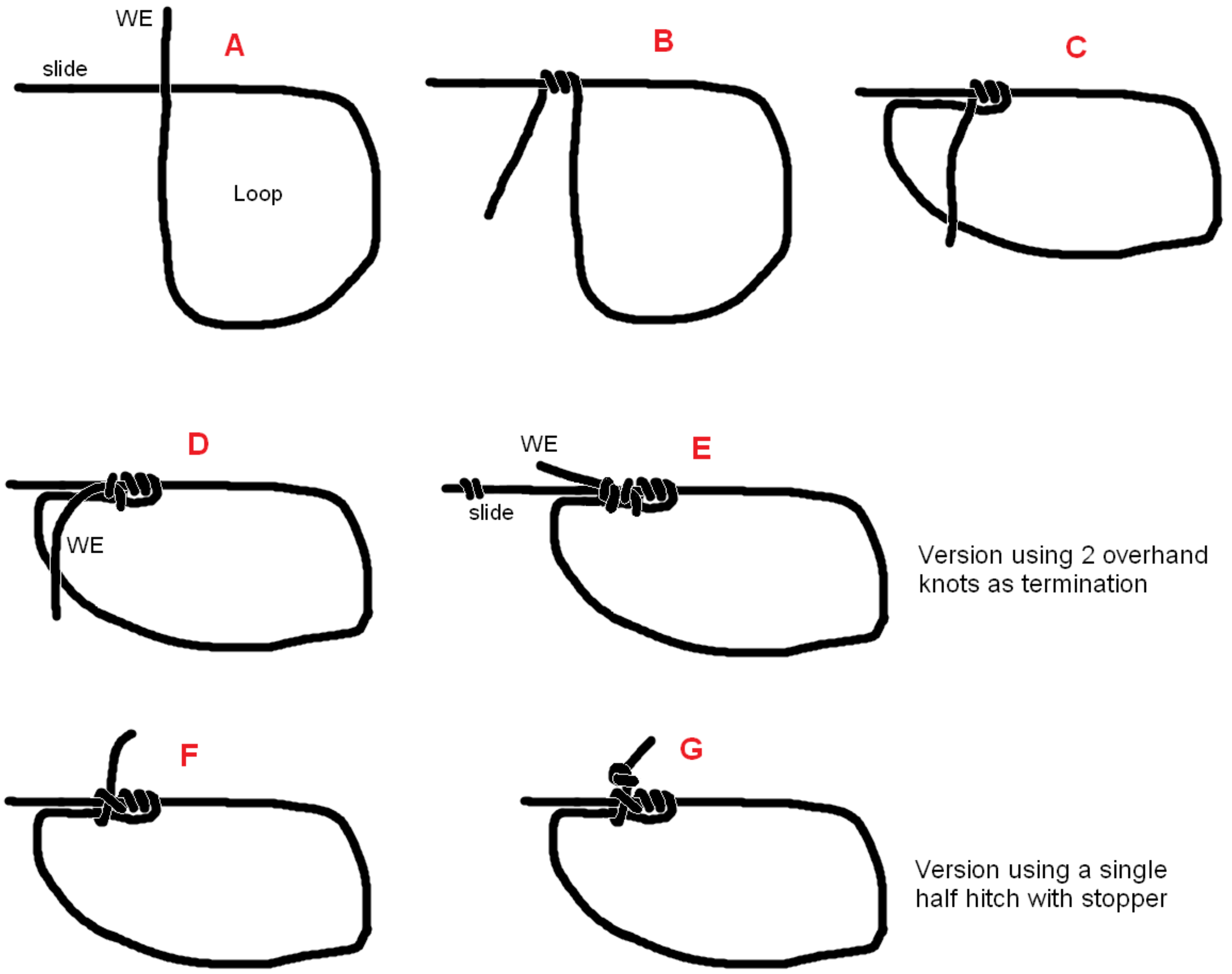


Figure A.6.2: Tying instructions for other versions

Version with single overhand knot and stopper knot
Tying instruction for the single overhand knot version is shown in figure A.6.2.

Figure D (of A.6.2)
When you tied the hitch with a single overhand knot, tie an overhand stopper knot in the working end that sits directly adjacent to the hitch.

This version release easier than the two overhand knot version.

Version with a single half hitch and stopper knot
When some movement after unloading (due to wiggling) is allowed, you may terminate with just a single half hitch with a stopper knot.

When you tied the turns as in figure A.6.2C, go to figure F. Apply the half hitch and add a stopper knot as shown in the G-figure. As the stopper knot experiences very low load, every knot is fine. Here a simple overhand knot is used. It should contact the hitch.

Version with “Blake’s hitch finish”
When you are familiar with the Blake’s hitch, you can also use a sort of Blake’s hitch finish. Even after loading with 200 kg using static rope, it releases with just two fingers. It is shown in figure A.6.3.

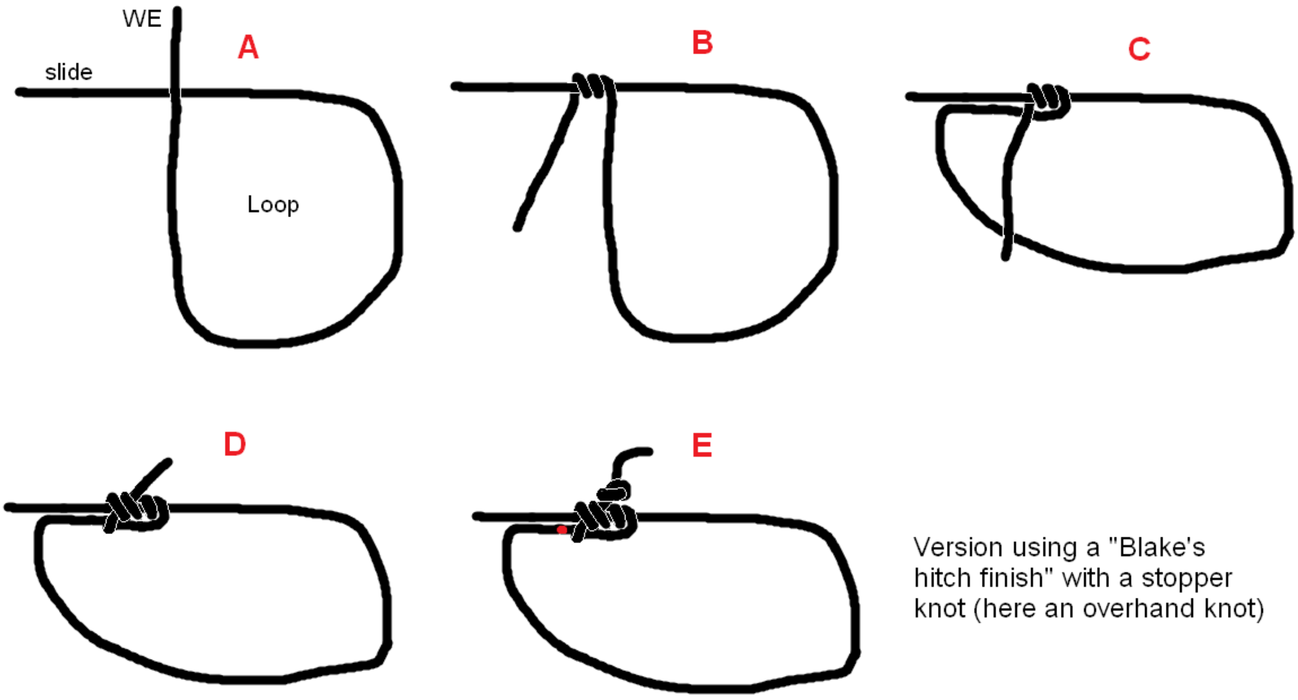


Figure A.6.3: Tying instructions for version with “Blake’s hitch” finish

At step D, an additional turn is made and the rope is pushed through the two lower (left) turns. In the E-figure an overhand stopper knot is added to avoid tail eating. This version releases very easy when pushing the red marked rope end towards the knot. To avoid loosening of the knot, one may apply 4..5 turns barrel knot at the red marked position. Adjust it so that the knot releases to a level that is acceptable for your application.

10.6.4. Application of the loop hitches

General application of adjustable loops is positioning of objects, or binding things together. The more difficult to release versions can also be used as an adjustable foot loop. The holding power is virtually the same for all versions. The difference is in the remaining friction when unloaded and ease of releasing the knot.

Recommended use for the loop hitches

Loop with Rectifier hitch

Its main purpose is permanently tying things together in applications where you would use a tie wrap. So it is always under tension. Its zero backlash sets it apart from most other friction hitches.

Loop hitch with double overhand knot termination

Its main purpose is positioning things a few times, where the knot should never untie or move when not loaded. When heavily loaded it is very difficult to untie, release or move.

Loop hitch with two overhand knots termination

Its main purpose is positioning things a few times, where the knot should never untie itself or move when not loaded. When heavily loaded it is easier to untie and to release compared to the double overhand knot termination.

Loop hitch with single overhand knot termination with a stopper knot

Its main purpose is positioning things many times, so it needs to be easy releasable. This hitch releases easy , similar to the half hitch termination with stopper. The hitch may move when unloaded in combination with severe wiggling. It may move slowly under dynamic load where the load minimum is near zero.

Loop hitch with single half hitch termination

Its main purpose is positioning things many times, so it needs to be easy releasable. This hitch releases very easy. The hitch may move when unloaded in combination with severe wiggling. It may move slowly under dynamic load where the load minimum is near zero. It is not recommended for life support (risk of loosening).

Loop hitch with “Blake’s hitch” termination

The hitch is similar to the hitch with half hitch termination, but releases extremely easy (easier then a Blake’s). It is therefore suited for frequent tensioning and releasing, This comes with the high risk of unintentional moving along the rope, as when released, it moves with near zero friction. A thin cord barrel knot can be used to maintain certain friction when unloaded.

Blake’s hitch

Though not treated here, when you know the good old Blake’s hitch, it behaves nearly as the loop hitch with half hitch termination, but releases somewhat easier.

When you need a loop that has to be opened without untying the hitch, cut the loop and add a simple soft shackle. A stopper knot and figure 8 on a bight, as shown in figure 6.3 (in the main document), works well. Use of a 2x2 or 3x3 overhand knot is preferred, as it is more bulky compared to the frequently used double overhand stopper.

Why so much varieties?
Adjustable loops are used for many applications. Some applications heed a hitch that is very easy to release, but some may require that the hitch doesn't move unintentionally when unloaded. In addition the behavior of a hitch depends on the rope material and rope construction.

When you have very tight woven bouncy rope, the version that releases very easy, may not work well. You may select the version with two overhand knots.

When having very soft flexible rope, in combination with heavy load, the version with two overhand knots may be too difficult to untie. The version with the half hitch or single overhand knot finish may work better in that case.

There can also be user preference. It is better to know some knots very well, then many knots only half.

10.7. Annex 7, Discussion of safety factors

10.7.1. Introduction

When searching for “safety factor” you will find various definitions and factors. Industry sectors have their own history and developed materials, working methods and tests. Safety factors for rope related materials may be different across geographical areas and between industry sectors.

The general formula for **safety factor (SF)** relates Minimum Breaking Strength of a component or assembly to the working load. You may also encounter “**design factor (DF)**”, or “**Factor of Safety**”.

$$Safety\ \ factor\ (SF) = \frac{MBS}{working\ load} \qquad []$$

A component or assembly can be: carabiner, shackle, rope, rope section with eyes, slings (rope or webbing), attachment point (anchor), harness, lanyards, etc.

The **Working Load Limit (WLL)** is what a manufacturer believes to be an acceptable maximum load. Without knowing the applied **Safety Factor (SF)** or **Design factor (DF)**, it is of little to no value.

$$Working\ Load\ Limit\ (WLL) = \frac{MBS}{SF} \qquad []$$

NEVER exceed the Working Load Limit. One may think that a high SF may allow you to exceed the WLL. No, it is not. A component may weaken when loaded above the WLL. When you see a component with even the smallest permanent deformation, replace it, as it has been overloaded.

10.7.2. Safety Factor (SF) vs Design Factor (DF)

There can be a difference between the **Safety Factor** and the **Design factor**. The DF is used by the manufacturer in combination with the intended use in mind. SF is used by the user community, and may vary between industry sectors and economic zones.

A turnbuckle for fencing application has, for example, a WLL of 10 kN. The manufacturer’s documentation says that a 3:1 safety factor is applied. In that case it should have MBS > 30 kN. When you would use this turnbuckle in a climbing situation, its WLL will be lower, as a higher level of safety is required.

Based on the static load (weight of climber + gear) the safety factor may be 10, so the WLL for climbing would be 3 kN (300 kg). It is better to buy hardware that is made for the job. So don’t use hardware from a DIY store for climbing or fall protection, unless intended for climbing.

Carabiners for climbing or personal protection should typically be used with SF = 10 based on the static load. So a 22 kN carabiner may hold 220 kg.

Despite safety factors, when you see permanent deformation, or you notice changes during use, discard the component.

10.7.3. MBS of a component

The Minimum Breaking Strength of a component should preferably be determined under most unfavorite practical circumstances. When this is not possible additional margin (higher safety factor) should be added/used. MBS is never used in strength calculations. A Safety Factor (Design Factor) is always applied. So a Carabiner that states 22 kN, should never ever experience a load of 2200 kg during its service life.

Though the acronyms MBL or MBS are used in industry, it does not mean that a component breaks at its maximum force it can withstand. Material may plastically deform well before breaking. In that case the material is loaded above the yield stress (σ_y). Same is valid for a component. It may deform so much, that it is no longer functional or safe. The strength of a component may therefore be based on the maximum load it can have before permanent deformation occurs.

The breaking strength of a component may reduce over time due to wear or type of usage (dynamic versus static). The reduction in strength has to be incorporated into the safety factor, so that at the end of a component's useful life, sufficient safety margin is present.

When regular meaningful inspection is possible, lower safety factor can be used. This is done in the aircraft industry. They work with relative low safety factors (can be as low as 1.5 based on peak force), but components are produced and tested under strict conditions. Heavy loaded parts are inspected regularly (X-ray, ultrasonic, eddy current, etc), and are replaced if necessary, or after a predetermined time (service life).

Structural applications can also have some lower safety factor as such situation can be analyzed well.

MBS of synthetic rope

The MBS of rope is measured relatively fast. The strain is built up quickly. Plastic behaves different when subjected to a transient load compared to a steady load. The MBS specification of synthetic rope therefore does not include the weakening due to creep elongation. Rope is therefore always used well below its MBS, even in non-critical applications.

10.7.4. Static Load and Dynamic Load

In many cases the SF is based on the static load, and is called Static Safety Factor. In case of lifting, this is a useful concept as objects are moved and accelerated slowly, so the peak force is not large compared to the static force.

Many applications involve high peak forces due to acceleration and deceleration of objects. These are dynamic forces that produce shock loads. You may encounter **Dynamic (Load) Factor**. It relates the peak force (due to dynamics) to the static force.

$$Dynamic\ \ Load\ Factor\ (DLF)\ =\ \frac{Peak\ Force}{Static\ Force}\qquad []$$

The static force is mostly based on the weight of an object or person. To make it easy for the user, peak forces are mostly included in the safety factor. This is typically done in sectors where there is lots of experience. That means DLF is known. Industrial climbing and sport/recreational climbing are well investigated, as life is at stake. SF is calculated with the static weight as reference, but DLF is included. The large SF in climbing is to account for relative large DLF, and of course to account for wear.

Generally spoken, one would use 2 safety factors to calculate the required MBS (static case and dynamic case), and use the highest of the two.

This is especially useful for synthetic fiber rope.

- The static load capability of synthetic fiber rope is not large, due to creep. This requires SF > 10 for rope that is used in climbing and rigging.
- The dynamic load capability is much closer to MBS, especially when that dynamic load occurs not frequently. SF varies in the range or 2 to 5, depending on how frequent the dynamic load occurs.

Below are some examples of forces and safety factors for some industry sectors

Fall arrest equipment. When the safety lanyard catches you, peak forces can be very high when deceleration isn't limited. Shock absorbers are used in industry/construction to limit the force due to shock load. When used properly, they limit the peak (dynamic) force to 6 kN (600 kg) maximum for a single person (European Union). That means that for a 100 kg person with gear,
DLF = 6 kN/1 kN = 6.

When someone makes a fall, the equipment involved (rope, harness, etc) is replaced. So the peak load is only applied about one time.   A dynamic safety factor of >2.5 based on the peak load is generally used for safety equipment. This translates to a Static Safety Factor (SSF) > 15.   MBS of safety equipment is therefore generally > 15 kN.   A standard carabiner has MBS > 22 kN (printed onto the carabiner), but you may encounter carabiners with MBS > 45 kN for special applications (two persons rescue, or when using pulleys [see chapter 7]).

(Recreational) climbing also has lots of dynamics, but the peak force is generally limited to 4 kN, unless you do stupid things (allowing very large Fall Factors when climbing solo). The limitation of the peak force is due to rope stretch of dynamic climbing rope. Using the wrong type of climbing rope may kill you. DLF is in the range of 5 for an 80 kg climber.

There is one difference with fall arrest; that <4 kN can occur frequently. Think of indoor (wall) climbing. A Dynamic safety factor of 2.5 is assumed to be insufficient (or barely enough). There is some harmonization between fall protection, industrial climbing and recreational/sport climbing (they learned from each other). When using fall arrest hardware for climbing, the dynamic safety factor will be 15 kN/4 kN > 3.7, and that is assumed to be fine.

Professional aerial acrobats and gymnastics

Aerial acrobatics have the largest dynamic forces compared to body weight. Aerial acrobats are very well trained people that can exert forces on equipment 5...8 times their body weight (yes, actually measured), and this may happen frequently. So DLF can be 8.

Such Dynamic Load Factors will injure even intermediate level athletes. That means that a 22 kN carabiner provides a dynamic SF = 3.4 for a 80 kg person performing an act with a dynamic load factor of 8. In contrast to fall protection, that dynamic load can occur frequently.

A static safety factor of 10 (including loss due to knots) based on body weight that is used in several sectors is not sufficient. DLF can be 8, resulting in a Dynamic Safety Factor = 1.25, where a factor > 3 is generally expected for frequently occurring dynamic load events.

The construction itself can also “amplify” forces (like current or voltage transformation in a transformer). Think of slack lines. The force in a slack line can be significantly larger then the static load onto the line.

There is no harmonized standard for aerial acrobats rigging.

Entertainment sector

The Entertainment sector has its own European Safety standard. Std EN 17206 (Entertainment technology, Machinery for stages and other production areas, Safety) covers the safety of equipment used in entertainment (theatre, production, concerts, etc).

For safety factors for rope and hardware, they follow the European Machinery Directive. Safety factors double when people can get hurt (lifting over people, lifting people), or the system is single fault proof (that requires a backup system). They define a “characteristic load” that also includes the Dynamic forces based on the so called “Use Case”. They also define an “Entertainment Load Limit (ELL)” to avoid confusion with the generally used WLL. The ELL is linked to the Use Case. Equipment can therefore have more ELL ratings as it can be used in more Use Cases.

Dynamic Load Factor is generally limited as all movements go slowly (except for fast “flying” people using fast winches). DLF is generally < 2.

Guy wires supporting (antenna) masts Though the nice weather static force is relatively low, peak force due to storm (gusts) are generally significant. As antenna masts are used for many years, the peak force occurs frequently during the life time of the mast. This requires larger SF based on the peak load. The SF should also add margin to allow (some) wear (corrosion, UV damage, frost damage, etc).

The upper guy wires mostly receive highest stress, when guy wires are attached at equidistant height. This is mostly because of the elevation angle
(there is a 1/(cos(elev)) factor in the equation).

Use of Load Cells
In the past, peak loads had to be calculated (difficult differential equations…) or guessed as measurement was hard to impossible. This may result in very high safety factors (better safe then sorry).

Nowadays we have high sampling rate Load Cells to accurately measure peak/transient forces. This enables us to establish useful safety factor (large enough to avoid injury, but not that large that hardware becomes too heavy to use). Load Cells and Acquisition Equipment is relatively affordable now. This lowers the threshold for measuring peak forces, and that enables to set relevant Safety Factors.

10.7.5. Material and usage

The type of material, shape and usage also has effect on the safety factor. A thick single structure may show cracks that propagate (become larger) during use. A multi-fiber construction (think of rope) will not propagate a failure of a single strand, but the relative surface is much larger and fibers may rub each other. This may result in certain types of wear (corrosion, oxidation, UV damage, etc).

Therefore safety factors for the same application are different for different materials. Metal hardware is used with lower Safety Factor compared to synthetic fiber rope (aka textile rope), or other things that move. As already mentioned, good production and regular inspection may reduce the minimum safety factor for a certain application and material.

When life is at stake, SF is always higher. Therefore the safety factor for hoisting people, or hoisting objects over people is higher (generally factor 2 higher). A hoisting operation that is designed for lifting materials only, may not be used for lifting persons, or lifting objects above persons, without new safety evaluation.

Plastic vs metallic components
Most plastics show **creep** when statically loaded. Permanent creep starts well below the MBS as specified by manufacturers. When after long time the **creep elongation** becomes too large, the component fails due to what is called **creep rupture**. Therefore safety factors for plastic components (so also our synthetic rope) are generally higher compared to metallic components, especially when the application involves long duration static loads (such as mooring lines). Plastic may also become brittle (UV-rays, oxidation).

10.7.6. Safety factors, examples

This section is added to give you some idea of safety factor that are used throughout several sectors of industry and recreational climbing.

Lifting/hoisting/pulling
"Level of Safety", "Design Factor or "working coefficient" is used to indicate the safety factor. Some values are from the **EU Machinery directive.**

Component	**SF**
Metallic rope	5
Synthetic fiber robe	7
Solid metal components (shackles, carabiners pulleys)	4..6
Solid metal components (shackles, carabiners, pulleys), **life critical**	10
Solid metal components (shackles, carabiners, pulleys), **horizontal pull**	3
Spreader/equalizing beams	3 (1)
Attachments (eyes) to spreader/equalizing beams	5
Fixed anchor points	3…5
Lifting machinery (think of a crane)	2…3 (1)

Notes
1: SF is based on the yield strength, so when the construction is overloaded with the safety factor, and the load is removed, there should be no visible deformation.

When lifting people, or lifting above people, the safety factor doubles (so becomes SF>14 for synthetic fiber rope). Same is valid in the entertainment sector (Std EN 17206) when a backup system isn't present.

Platforms where you stand on, and are suspended using cables/rope/etc, need to be redundant (valid for the rope/cable and anchors). This is also the reason that when you work at height and hang onto your rope (Rope Access Technicians), you need an independent backup. Tree maintenance also switched to redundant systems in parts of the world.

Do not confuse safety factor with rated load test factor (generally factor 1.25 for a new hoisting operation/installation). This test is carried out on the complete installation and is to prove in the field that the installation is able to lift the rated load. It is not to prove that safety factors are fine.

Permanent structural use (not rigging/lifting/climbing)
For permanent structural use, where forces are well known, the Safety Factor is somewhat less compared to rigging use. A turnbuckle that is used for rigging mostly has SF = 4…6. The same turnbuckle used in a permanent structure may be used with SF = 3. Of course this needs good analysis. When in doubt, use larger SF.

Ladders
Ladders are divided into use categories, varying from occasional use around the house to heavy industrial use. The manual should state its rated load. Industrial ladders can have a rated load in the 150 kg range where hobby ladders are mostly rated at 100 kg.

Std. EN 131 isn't harmonized within the EU, so requirements for ladders vary per country. In the Netherlands a ladder must be able to withstand 350 kg without visible deformation after removing the load.

That rated load for portable ladders has a safety factor 3.3....4 under OSHA rules. It should be noted that the ladder will permanently deform before an overload of factor 4 is reached. Once deformed, the ladder should be repaired or discarded.

Synthetic Rope
Rope can be used in a permanent application, but is mostly used in temporary applications. Synthetic rope is generally not used above 20% of its breaking strength (including knots, eyes etc). That equals SF > 5, or better DF > 5. This is also valid for permanent static structures. Prolonged static loads may require even larger Design Factor because of creep rupture. Creep increases with increasing temperature, so fiber stress should be reduced by increasing the Design Factor.

When life is at stake SF > 10 (including eyes/knots/etc) based on the static load and strength loss due to knots. In case of high dynamic load, think of falling and sport climbing, SF > 15 (including loss due to knots/eyes/etc). This mostly translates to a Dynamic Safety Factor > 2.5.

When you design for factor 10 and the knots provide 50% efficiency, the rope's MBS should be 20 times the static load (SF=20). This is the reason why climbing ropes are so strong (MBS in the 30 kN range for semi-static LSK EN 1891 Type A rope).

Guy wires, synthetic rope
For antenna mast guy wires out of synthetic rope, SF > 5 is used, including knots/eyes/etc. SF is based on the peak force that occurs during the highest gust that the mast must withstand. That means when you are using Dyneema and use a knot with an efficiency of 50%, SF>10 based on the rope MBS.

For temporary low risk applications (think of field days), one may go down to SF=3 (including knots/eyes/etc).

About pretension
Several sources state a pretension of 10% of MBS. This may be fine for steel rope, but not for synthetic rope. Synthetic rope requires larger SF. This would result in higher pretension compared to steel rope, even when incorporating the eye terminations. That high pretension puts additional compressive stress onto the mast (buckling risk).

The compressive stress increases significantly when Icing occurs. This is because of the small line sag of synthetic rope (less weight/m). The same amount of icing adds additional stress proportional to 1/(line sag). Therefore pretension for synthetic rope should be less compared to that for steel rope.

There is another reason why you don't want to apply excessive pretension: creep, see chapter 3.

Fall arrest / work positioning anchors

Safety factor or minimum static load capability depends on whether the anchors are certified or not.

application	Non-certified anchor	Certified anchor
Fall arrest	22 kN	2*(peak force), generally 12 kN
Work positioning	13 kN	2*(expected peak force)
Fall restraint	4.5 kN	2*(expected peak force)
2 persons (rescue)	13 kN	5*(applied static load)

Above values are based on OSHA requirements. When these forces are applied the material stress has to be below the material yield point (so no permanent deformation).

In Europe fall arrest anchors should have a breaking strength of >12 kN (single person, to std. EN 795). This is based on the maximum 6 kN fall arrest force of European shock absorbers. New Zealand specifies >15 kN (fall arrest), >12 kN (work positioning), some conditions require > 22 kN.

Note:

> When the anchor is used to suspend a pulley, anchor load may double. They are not designed for this. When using a pulley (think of top rope belay), anchor loading force is twice the rope peak force. A 12 kN anchor may not provide sufficient safety factor.

Climbing anchors (recreational)

That is rather problematic, especially outdoors in rocks. Also weight is of importance, especially when you need to carry many of the same hardware (such as cams and nuts).

Rock is a natural material with varying properties. Mostly redundant systems are used, using at least 2 bolts with minimum 2 bolt lengths of separation. Each individual anchor has to be designed to carry the full load. If one bolt fails, the others have to take over the load from the lost bolt. Instead of bolts, cams and nuts (wedges) are used that are placed in cracks in the rock material.

You can have a 45 kN bolt, but when placed in soft rock material, the shear strength will be well below 45 kN. The bolt is just pulled out of the rock material. Outdoor bolts also wear. Redundancy really adds safety and is common practice in outdoor climbing.

Modern single bolt anchors in climbing halls can withstand 25 kN or more of shear load. When securing using top rope, the rope runs from the belayer upwards through a carabiner and then down towards the climber. So forces add.

Cams and nuts can have MBS > 15 kN, but it can also be well below this, depending on size and manufacturer. When placed wrong, they may break out of the crack at a much lower force.

Petzl and others did realistic fall tests using fast Load Cells. They did it, with real humans (both for the climber and the belayer), on a real climbing wall, with varying Fall Factor.

For FF = 1, 80 kg climber, force on the anchor did not exceed 6.1 kN on the anchor. That fall factor is definitely not pleasant for both the climber and the belayer. There are videos showing the actual testing. When using old rope (less stretch), a heavy climber, and an inexperienced belayer, the anchor load may be higher. It will likely not exceed 8 kN. So practically spoken, 25 kN anchor strength provides a safety factor of at least 3, except for some instances where people do really stupid things (and may get injured).

Note that Industrial Rope Access requires an independent backup system. You are connected to 2 lines that are generally connected to 2 independent anchor points. A rope that splits into a Y to connect to two anchors is not considered a backup system (as you have one rope only). Rope Access has different rules compared to recreational climbing, as one of the ropes is actually your workplace. Where recreational climbing accepts dynamic forces, Rope Access keep dynamic forces very low (so near zero slack in all cases).

Rappel anchors (for abseiling)

Rappelling is a zero slack, slow speed activity (except for tactical rappelling). In fact, this is comparable to industrial vertical work positioning (Rope Access). Minimum requirements for anchors are stated under **Fall arrest / work positioning anchors.**

But with Rock climbing it is different**.** Rock climbers also rappel slowly to avoid injuries and to keep rope and bolt stress low. The Dynamic Load Factor will not exceed 2. When adding SF = 3 and an 80 kg person, a rappel anchor should be able to withstand 5 kN. As rock is a material with varying properties, redundant systems are used, using at least two well separated bolts.

Of course it is a very bad idea to have a mix of both climbing rated anchors and rappel only rated anchors.