Snow and Ice Anchors, and Raising and Lowering Systems

A Manual Developed by the Mazamas Advanced Snow and Ice Committee

This manual is a distillation of key principles and techniques of snow and ice anchor building, and mechanical advantage raising and lowering systems used in high angle snow and ice rescue situations.

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INTRODUCTION

Background

In August 2011 ASI committee members were fortunate to attend a professional training seminar in current alpine rescue techniques and technical rope work conducted by Rigging for Rescue (R4R) from Ouray, Colorado. This manual constitutes a distillation of key principles and techniques of snow and ice anchor building, and mechanical advantage raising and lowering systems used in high angle snow and ice rescue situations. These materials are presented by the ASI Committee as an educational supplement to be used in the development of a working program for the Mazamas, eventually within climb committee's domain for leadership and training.

Information in this manual is drawn from first-hand Rigging for Rescue seminar information that was presented to ASI committee members, seminar handouts provided by Rigging for Rescue, and recent field test results and data.

Methodology

Central to Rigging for Rescue's training methodology is a pedagogical style that emphasizes teaching a core set of fundamental principles and encouraging students to use their own critical judgment to practically apply those principles to the situation at hand. This method is offered as an alternative to rote memorization of rules and techniques on the grounds that practical application skills are more easily comprehended and retained.

CHAPTER 1: Snow and Ice Anchors

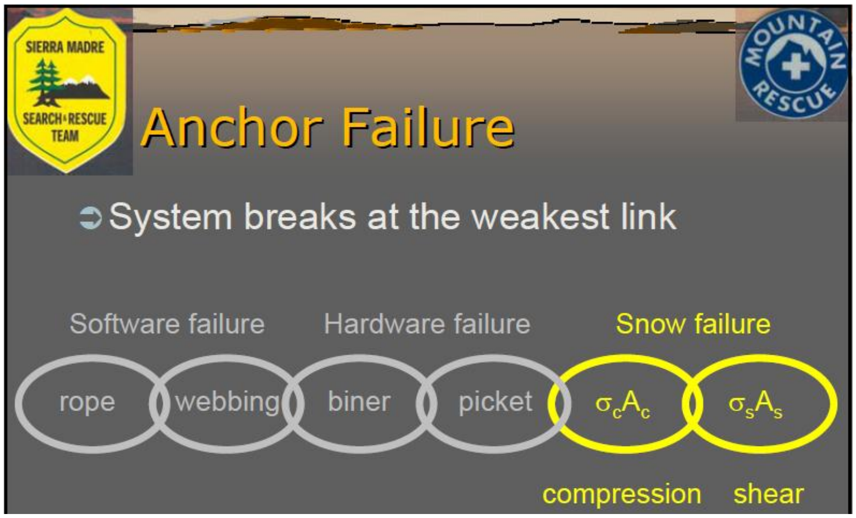
Principles and Objectives

Our objective:

Given that snow and ice are such variable, condition-dependent media, it can be difficult to determine what type of anchor is best suited to the conditions, and to determine the resulting anchor's strength. Our objective is to provide a reasonably reliable method of making these determinations. We will do so by developing a set of basic principles from the results of the most recent snow and ice anchor and anchor materials field testing data available. Applying these principles to encountered conditions will allow us to determine how to construct an anchor that is appropriate for our immediate needs. These principles can be applied to anchor building strategies for alpine climbing as well as rescue scenarios.

Some initial principles at play:

1. In order to reasonably determine the quality and strength of an anchor, one must first understand its likely methods of failure.
2. An anchor is only as strong as its weakest link.
3. 1 kN (kiloNewton) of force is about 225 pounds.



Anchor Failure

➲ System breaks at the weakest link

Software failure Hardware failure Snow failure

rope webbing biner picket $\sigma_c A_c$ $\sigma_s A_s$

compression shear

Figure 1.1[i]

Summary of Approach:

To understand an anchor's likely methods of failure, we will start in *Section I* with an examination of the properties and strength ratings of anchor building materials, from cordage and webbing to snow and ice itself. In *Section II* we will present some tricks and methods of equalizing snow and ice anchors. Finally, in *Section III* we will synthesize everything with a discussion of "The Three Ms of Anchor Assessment".

Section I: Materials and Properties

Determining the weakest link in an anchor system requires an understanding of the relative strengths and failure points of each of the materials that constitute the various links in the system. Anchor building materials will be divided into three categories:

1. Soft goods (e.g., climbing rope, cordage, webbing).
2. Hardware (e.g., carabiners, pickets, ice screws).
3. Snow (examined together with pickets) and ice (examined together with screws).

Soft Goods:

Climbing Rope: Strength and failure points, as well as cut and abrasion resistance, vary depending on rope diameter, material, and method of construction.

Static rope is not really static. It is more appropriately characterized as "low stretch" (1–5% static elongation).

Dynamic rope typically has 5–10% static elongation (lots of stretch when used as a rescue haul line) and at least 30% dynamic elongation.

Breaking (tensile) strength of a climbing rope is typically provided from the rope manufacturer *only for static ropes* (e.g., a New England 11mm static rescue rope has a breaking strength of 7,500 lbs. or 33kN). The primary UIAA standards listed for dynamic climbing ropes are *maximum number of falls* and *impact force* (the maximum amount of force a climber can expect to receive during a fall, which the UIAA limits to 12kN for single ropes, and 8kN for double ropes[ii]). Since the breaking strength is far in excess of the maximum possible force of a leader fall, it is simply not a consideration. However, breaking strength is pertinent to alpine rescue situations in which a dynamic climbing rope is used as a rescue line. It is unlikely that a large diameter single rope will be the weak link in a snow anchor. However, a single strand of thin double or twin rope may be questionable and rescuers should exercise caution.

Knots significantly reduce the strength of climbing rope or any other kind of cordage or webbing. When a rope is strained to the breaking point, it almost always fails at the knot. While the amount of strength reduction varies somewhat depending on the type and size of material being knotted, the table below provides a good general guideline.

Knot strength reduction (Source: Sterling Ropes)[iii]

Knot	Remaining Rope Strength
No knot	100%
Double Fisherman's	65-70%
Bowline	70-75%
Water Knot	60-70%
Figure 8	75-80%
Clove Hitch	60-65%
Fisherman's	60-65%
Overhand	60-65%

Cordage and Webbing:

As a general rule, the tensile strength of cordage and webbing increases with the diameter of the cord or the width of the webbing. However, material plays a large role, not only in tensile strength, but also in regard to ability to absorb a shock load (elongation) and hold a knot.

Materials Properties:[iv]

Cordage Fiber	Nylon[1]	Polyester	Polypropylene (polyolefin)	Aramid (Dupont Kevlar)	HMPE[2] (Spectra Type 900)
Strength:					
Breaking tenacity-dry (grams/denier)[3]	7.8-10.4	7.0-10.0	6.5	18.0-26.5	30.0
Wet strength compared to dry strength	85-90%	100%	100%	95%	100%
Shock force absorption ability	Excellent	Very good	Very good	Poor	Fair
Weight:					
Specific gravity	1.14	1.38	.91	1.44	.97
Ability to float	no	no	yes	no	yes
Elongation:					
Percent at failure (break)	15-28%	12-15%	18-22%	1.5-3.6%	2.7%
Moister Effects:					
Fiber water absorption	2.0-6.0%	<1.0%	0.0%	3.5-7.0%	0.0%
Rot & mildew resistance	Excellent	Excellent	Excellent	Excellent	Excellent
Degradation:					
UV resistance	Good	Excellent	Fair	Fair	Excellent
Aging resistance (properly stored)	Excellent	Excellent	Excellent	Excellent	Excellent
Abrasion Resistance:					
Surface	Very good	Very good	Good	Fair	Excellent
Internal	Very good	Excellent	Good	Good	Excellent
Thermal Properties:					
Melting point	215°C (Type 6) 250°C (Type 66)	250-260°C	165°C	427°C Begins to decompose	147°C
Chemical Resistance:					
Effect of acids	Decomposed by strong mineral acids; resistance to weak acids	Resistance to most mineral acids; disintegrate by 95% sulphuric acid	Very resistant	Resistant to most weak acids. Strong acids will attack; especially at high concentrations or high temperature	Very resistant
Effect of alkalis	Little or none	No effect cold; slowly disintegrate by strong alkalis at the boil	Very resistant	Resistant to most weak alkalis. Strong alkalis will attack; expecially at high concentrations or high temperatures	Very resistant

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[1] Of the several kinds of nylon used, type 6 and type 66 are the most common. Type 6 is more common for climbing ropes than type 66, as it has slightly better elongation (and therefore shock absorption). Type 66 has slightly higher melting and breaking point, less elongation and slightly better resistance to wear than type 6. Type 66 is more common in rescue ropes. However, how the rope is constructed may have a greater overall effect on its behavior than any differences between these two nylons.

[2] HMPE (extended chain, high modulus polyethylene); Spectra (made by Allied Signal) is one type of HMPE. It is a very slippery material and may require modified knots, bends and hitches for greater security.

[3] The strict definition of denier is the weight in grams of 9,000 meters of the yarn. For example, 9,000 meters of a 450 denier thread weighs 450 grams.

Nylon vs. HMPE (High Modulus Poly Ethylene; e.g., Spectra and Dyneema):

- HMPE has a significantly stronger tensile strength than nylon, so in static load applications it is clearly the stronger material. Pound for pound, Spectra is stronger than steel.
- HMPE exhibits much less elongation prior to failure than nylon. This means it is much less 'stretchy' than nylon. HMPE is therefore less able to absorb a shock load prior to failure in dynamic force situations. Note, however, that in applications where stretch is to be kept to a minimum (e.g., when equalizing an anchor), HMPE's low stretch properties can be advantageous.
- HMPE is much more slippery than nylon, which means it does not hold knots well. For this reason, Spectra runners tend to be sewn.
- HMPE has a much lower melting point than nylon. Consequently, applications in which friction may be encountered (e.g., an autoblock used for rappelling) should be avoided.

Sewn vs. Knotted:

- Unsewn and unknotted cordage and webbing is much more versatile than sewn runners. It can be used in full length, cut into shorter lengths, or tied into a loop with a knot.
- Knots tied in any kind of cordage or webbing significantly reduce its overall tensile strength (see *Knot Strength Reduction* table under the *Climbing Rope* section above). However, tacks sewn in runners do not compromise tensile strength. So sewn runners, while less versatile, are much stronger than tied runners.

Tensile strength of some common types of cord and webbing used in anchor building:

Material	Tensile Strength
6 mm nylon accessory cord (Blue Water)	8.4 kN[v]
7 mm nylon dynamic prusik cord (Blue Water)	10.4 kN[vi]
7 mm perlon cord (Sterling)	12 kN[vii]
5.5 mm Spectra (HMPE) (Blue Water Titan)	17 kN[viii]
1" tubular webbing (PMI)	18 kN[ix]
9/16" (15mm) tubular webbing (Blue Water)	10.2 kN[x]

Some Soft Goods Assessment Examples:

Soft goods assessment #1: 7 mm nylon cordalette used to create a two point statically equalized anchor.

- **7 mm nylon cordalette** should be reliable to **20 kN** (10 kN strength per strand x 2 strands). However, the cordalette is tied into a loop with a double fisherman's knot, effectively reducing the strength to **13–14 kN** (the double fisherman's knot reduces the strength by 30–35%).
- Tying an overhand knot to create a power point effectively reduces the strength to **12–13 kN** (overhand knot reduces the strength by 35–40%). If this is the weakest link in your anchor, your anchor is trustworthy to 12–13 kN. Note, however, that anchors built in snow typically hold less than this, so this is unlikely to be the weakest link.

Soft goods assessment #2: 5.5 mm Spectra sewn runner used to create a two point sliding-x anchor.

- **5.5 mm sewn Spectra runner** is reliable to **34 kN** (17 kN strength per strand x 2 strands).
- Tying limiter knots into the runner to add redundancy and limit the extension of the sliding-x reduces the strength of the runner to **20–22 kN** (overhand knots reduce strength by 35–40%). So if this is the weakest link in your anchor, your anchor is trustworthy to 20–22 kN. Note, however, that snow anchors typically hold much less than this, so this is unlikely to be the weakest link.

Hardware:

Carabiners: The strength rating of a carabiner is stamped on the side of the carabiner itself. Read it. Lateral forces, or forces applied when the carabiner gate is open generally reduce the carabiner's maximum strength.

Clipping a carabiner to another carabiner is an acceptable practice.

- An old mountaineering rule among American climbers stipulates that metal-on-metal connections are forbidden. However, a carabiner clipped to a picket is metal-on-metal, as is a carabiner clipped to a pulley. Clipping a carabiner to another carabiner is no different.
- What is of concern (and what should be avoided) in connecting two carabiners is any configuration that might place force on the carabiner gate, which can compromise some of the carabiner's strength. This is of little concern in the case of locking carabiners, and when carefully configured, even non-locking carabiners.

Pickets: Since the strength of a picket placement is highly dependent upon the quality of the snow it is placed in, we will examine picket strength and failure methods in the snow section below.

Types of Picket Placements (illustrations appear below in the Snow section):

- Upright top clipped (aka traditional placement).
- Horizontal mid-clipped (aka Deadman or T-Slot picket)
- Upright mid-clipped (aka Sierra picket, Kiwi picket, New Zealand picket)

Other considerations in using pickets:

- Girth hitching a runner directly to a picket compromises some of the strength of the runner (see Knot Strength Reduction under Soft Goods above). Clipping a runner to a picket with a carabiner is significantly stronger.
- The carabiner hole in a typical picket breaks at round 2000 lbs. (8.8 kN).[xi]

Ice Screws: Since the strength of an ice screw placement is highly dependent upon the quality of the ice it is placed in, we will examine screw strength and failure modes in the ice section below.

General consideration in placing ice screws:

- Historically, it was thought that the strength of an ice screw placement came from the strength of the screw's metal tube. Consequently, climbers typically placed screws at an angle away from the direction of fall to take advantage of lever strength. In recent years, testing of modern screws has demonstrated that the strength of a screw placement actually comes from the threads of the screw. Consequently, the strongest placements are angled down toward the direction of pull rather than away from the direction of pull.
- An angle of 15° from perpendicular in the direction of fall is the recommended rule of thumb for placing ice screws.[xii]
- An ice screw placement is only as strong as the ice into which it is placed (it is almost always the ice that fails in an ice screw placement failure).

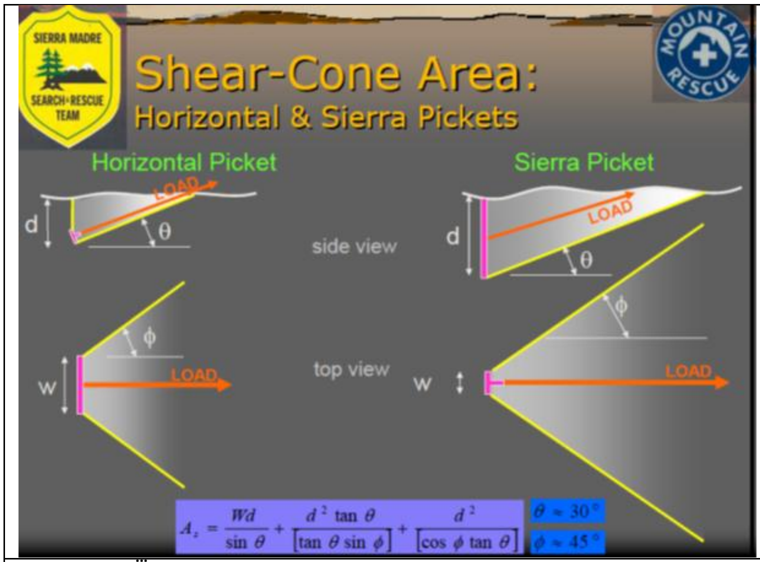
Snow and Ice

Snow Anchors:

With snow anchors the snow is usually (but not always) the weakest link in the chain; the snow is what will fail. Creating the strongest snow anchors possible is a function of determining the best gear placement for given snow conditions.

Modes of failure in snow:

- **Compression failure** is when the anchor pulls forward (cuts) through the snowpack. There is typically a lot of anchor displacement prior to failure. You can see the picket move forward until the point of failure.
- **Sheer failure** is when a large chunk of snow is ejected from the snowpack (see *Figure 1.3* below). When the anchor is loaded, a stress cone is formed in the snow in front of the anchor. It radiates out from the sides at approximately 45°, and up from the bottom at approximately 30° (see *Figure 1.2* below). Sheer failures occur when the stress cone reaches its failure point. They are usually explosive events. Typically there is very little anchor displacement prior to failure (and thus little visual warning).



SIERRA MADRE SEARCH & RESCUE TEAM

Shear-Cone Area:

Horizontal & Sierra Pickets

MOUNTAIN RESCUE

$$A_s = \frac{Wd}{\sin\theta} + \frac{d^2 \tan\theta}{[\tan\theta \sin\phi]} + \frac{d^2}{[\cos\phi \tan\theta]}$$

$\theta \approx 30°$

$\phi \approx 45°$

Figure 1.2[xiii]**:** Stress cone configuration radiates 45° from the sides and 30° from the bottom.

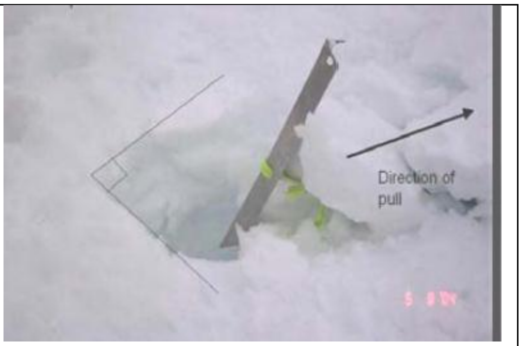


Figure 1.3[xiv]**:** Sheer failure showing ejected stress cone.

'The Snowball Test' and work hardening.

- Work hardening snow (stomping it to compress it into a denser pack) prior to building an anchor is only effective if the snow can be compressed. The best way to determine if the snow can be compressed is to try to make a snowball with it.
- **Passes the snowball test:** when you can form a solid snowball, the snow can be compressed (work hardened) to make stronger snow anchors. You should work harden the snow before building your anchor.
- **Fails the snowball test:** when you cannot form a solid snowball (e.g., the snowball crumbles or simply will not compress, which occurs when the snow is very cold and dry). You *should not* attempt to work harden the snow before building your anchor as it may destroy existing bonds and actually become weaker than undisturbed snow.

Mid-clipped pickets are much stronger than top-clipped pickets.

- In engineering terms, a top clipped picket creates a *laterally loaded pile*. Due to its slender, vertical nature, it cannot handle heavy loads that act perpendicular to its axis.
- As illustrated in figure 1.4 below, most of the force acts upon the top third of a vertically clipped picket. If you pull from the center the load is much more evenly spread.
- In knife hard snow with a force of 6 kN, a top clipped picket exerts as much as six times as much compressive pressure on the snowpack as a mid-clipped picket, making anchor failure much more likely.[xv]
- The direction of placement of a 'V' shaped picket (e.g., Yeats) may also be a factor in strength.[4]

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[4] Don Bogie's testing suggests that aiming the point of the 'V' of the picket in the direction of the load is stronger only in top-clipped pickets. In both vertical and horizontal mid-clipped anchors his testing suggests that directing

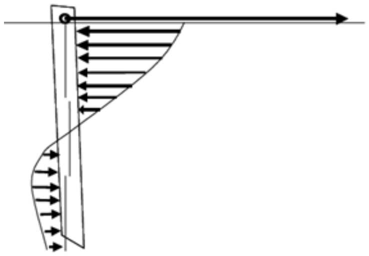

Figure 1.4

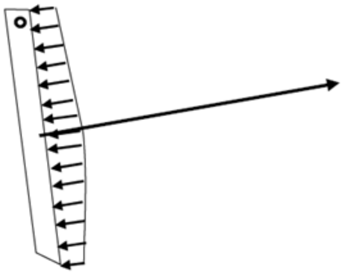

Figure 1.5

How to place upright top clipped (traditional) pickets:

- Upright top clipped pickets are optimally placed at 10-15° from perpendicular, away from the direction of pull.
- Upright top clip picket placements are reliable only in extremely hard snow (knife hard, or at least pencil hard). In such snow the picket must be driven in with a hammer, so if you can drive your finger into the snow, this placement will be ‘iffy’ at best.
- In knife hard snow (so hard that you can drive a knife blade into it, but not a pencil), an upright top clipped picket begins to fail at around **6 kN** of force. When the snow pack softens to gloved finger hardness (can drive one gloved finger into the snowpack, but not multiple fingers), the picket strength reduces to 360 lbs. (1.5 kN).[xvi]
- With forces above 500 lbs. (about 2 kN) other modes of failure begin to occur in upright top clipped pickets (e.g., picket twisting and bending, often until the picket comes out).[xvii] For this reason, Rigging for Rescue recommends that you ***never trust an upright top clipped picket to hold more than 2 kN,*** even in knife hard snow.

How to place an upright mid-clipped picket (aka Sierra picket, Kiwi picket, New Zealand picket):

- As a general rule of thumb, the picket should be placed at 15° from perpendicular, away from the direction of pull, and the attachment cable/cord should be twice the length of the picket. With this configuration the attachment will form a right angle where it attaches to the picket when the picket is driven level with the snow surface (see Figure 1.6).[xviii]

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the point of the ‘V’ *away* from the direction of pull is actually stronger. However, the jury is still out until further testing validates this claim. Yeats sells pickets with a mid-clipped cable permanently attached, and it is attached with the point of the ‘V’ aiming toward the direction of pull, suggesting that Yeats isn’t convinced yet either.

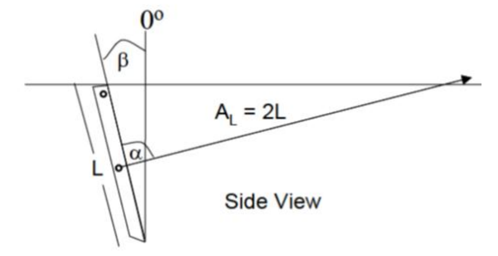

Figure 1.6

Ice and Ice Anchors

Ice screw placement and ice quality

- Ice screw placements are only as reliable as the quality of the ice.
- If the ice is aerated (usually extremely white ice has a lot of air in it), rotten, or soft it won't hold a screw well.
- When placing a screw, a continuous, solid core should extrude from the tube. If not, you've hit a hollow pocket and the strength of the placement is compromised.
- Excavate poor surface layers of ice with your ice tool to access better ice underneath.
- Watch out for melt out if the screw will be in place for a while, especially in direct sunlight.

Average ice screw failure forces, both drop test and slow pull:[xix]

Overall averages of failure forces	**kN**
Beverly/Attaway 2005-06 – Drop Tests (non-re-bored)	10.14
Beverly/Attaway 2007-08 – Drop Tests	10.58
Beverly/Attaway 2007-08 – Slow pulls Lake Ice	11.09

Angle of Placement and screw length

- Placing ice screws at a negative angle will result in less stress forces on the ice and better holding power for falls on the protection. 5–14° degrees from perpendicular in the direction of load is the sweet spot according to recent testing. See figures 1.11–1.13.
- Longer screws have tested slightly stronger in recent lake ice tests, but do not appear to be as big a factor in drop tests.[xx] Longer screws will hold better in soft or very brittle ice, whereas a shorter screw could be pulled out of the ice as the result of a fall. However, since most of the stress happens within the first third of the screw, there is not a significant loss of protection against crushing forces when using shorter screws. See figures 1.11–1.13.

Ice screw strength test imaging from JJG Engineering.[xxi]

The images below show a 22 cm screw in medium strength ice at +15°, 0° and -15° angles. The red area in the images has exceeded the crushing strength of the ice.

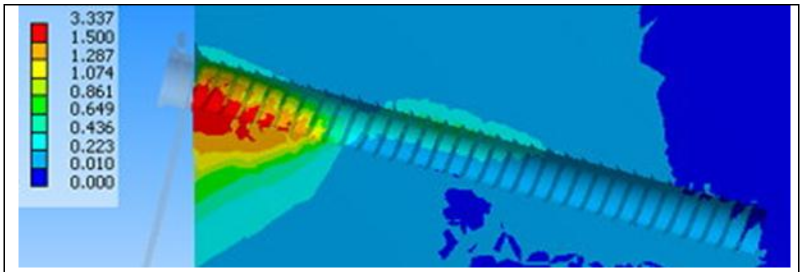

Figure 1.11: +15° placement

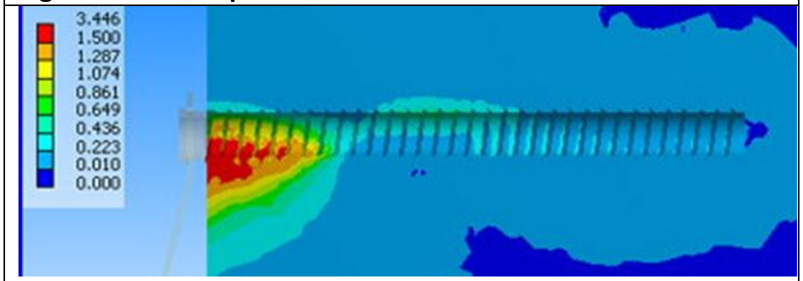

Figure 1.12: 0° placement

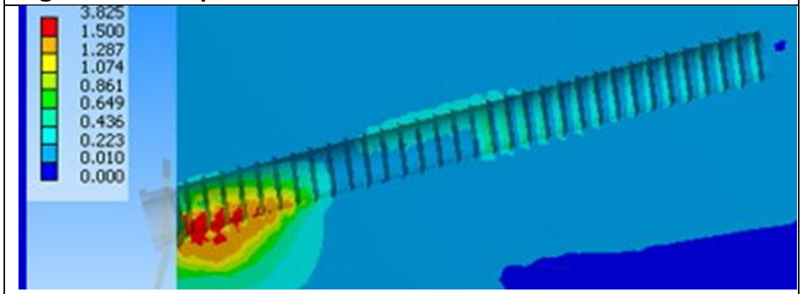

Figure 1.13: -15° placement

Ice Screw method of failure

- Recent testing shows that it is almost always the ice that fails and not the screw (i.e., the ice is the weakest link in the system).[xxii]
- Compressive forces act on the weighted side of the screw, and large portions of ice are ejected above the screw (sheer failure).[xxiii]

Ice and V-Threads (aka Abalakov Anchors)

A V-Tread anchor is created by boring two holes at an angle in the ice so the holes connect at the bottom of the 'V', then threading a piece of webbing or cord through the resulting V tunnel to create an anchor.

V-Thread Strength

- Recent testing by Petzl suggests that ice screws are typically much stronger than V-threads. [xxiv]
- Nevertheless, tests show that V-threads provide an adequate safety margin for rappelling (the primary use of V-thread anchors).
- The greater the total area enveloped by the V-thread, the stronger the anchor.
- A vertical V-Thread (A-Thread) is stronger than a horizontal (see figure 1.14 & 1.15).[xxv]
- Adequately constructed V-Thread anchors hold more than 10 kN of force and 2 V-thread anchors combined are suitable as a rescue anchor.

	
Figure 1.14: V-thread	**Figure 1.15: A-thread**

Section II: Practical Field Application

In this section we'll apply the general principles and properties of snow and anchor building materials addressed in previous sections to determine which kind of anchor is appropriate to given conditions and how to best build them. Our emphasis here is focused on snow anchors, but many of the same principles apply to ice anchors as well. This section is divided into four sections:

1. Determining which kind of picket placement is most appropriate for various kinds of snow conditions.
2. Building multipoint anchors.
3. Equalization.

Determining which kind of anchor is best for differing categories of snow.

Based upon what we've learned about snow density (e.g., knife hard) and compression (i.e., the snowball test), it is now possible to define four different categories of snow and what type of picket is best for each type.

1. Snow that can be compressed to make denser snow.

Either an upright mid-clipped picket or a horizontal mid-clipped picket. Testing indicates that both will produce an anchor with strength in excess of **10 kN** if the snow makes a good snowball. It will be less than 10 kN, however, if the snow is compressible, but wet and drippy.[xxvi]

- ***Upright mid-clipped picket (aka Sierra, Kiwi, New Zealand picket).***

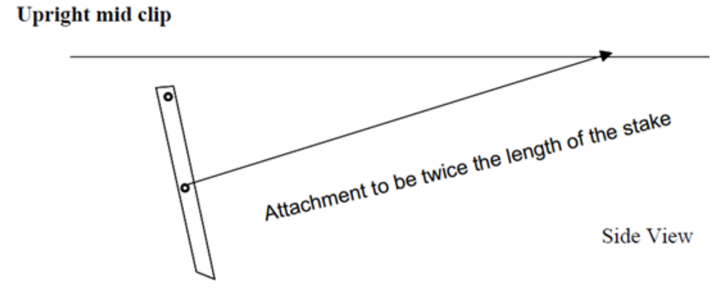

Figure 1.16

  - ○ Carve a trench as deep as the picket to the length of the attachment cable or cord.
  - ○ Work harden the snow at the base of and in front of where the picket will be placed, to an area wider than the stress cone (45° from the picket and 30° up).
  - ○ Insert the picket as described above. Placing the whole picket slightly under the surface of the snow will make it even stronger.
  - ○ Backfill the trench with snow and compress (work harden) it.

- ***Horizontal mid-clipped picket (aka 'Deadman' or T-Slot).***

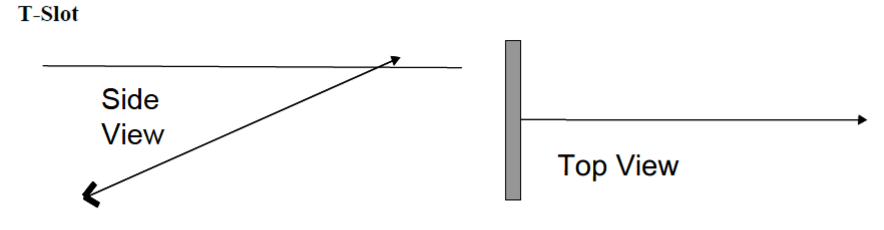

Figure 1.17

  - ○ Dig a trench at least as deep as the length of the picket or other buried object (in order to develop a stress cone big enough to match that of an upright mid-clipped picket, it needs to be buried deep). Also dig a trench for the attachment cable or cord, making a 'T'.

- Insert the picket or other object to be buried (skis, ice ax, etc.) horizontally in the trench, *at a right angle to the direction of pull*.
- Work harden the snow in front of the trench and larger than the stress cone (45° out from the picket and 30° up from the bottom).
- Backfill the trench with snow and compress it (work harden).

2. Snow that is hard, but not compressible (fails snowball test), but can have a slot cut into it.

Modified upright mid-clip picket is appropriate. This style of anchor requires a cable attachment at the midpoint (e.g., Yeats sells them this way). Testing indicates that this should produce an anchor of greater than **10 kN** in snow of knife hardness, which is stronger than a comparable upright top-clipped picket. The likely weak link in this case is the cable.[xxvii]

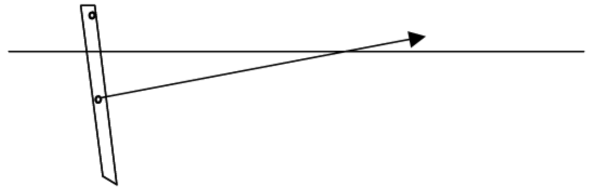

Figure 1.18

- Cut a slot with an ice ax pick (it should just be long enough) or a snow saw for the cable.
- Hammer the picket in 10-15° from perpendicular away from the direction of pull until the attachment cable reaches the bottom of the slot.

3. Snow that is hard, but not compressible (fails snowball test), and cannot have a slot cut into it.

Upright mid-clipped picket is appropriate. Testing indicates that this should produce an anchor of **6+ kN** in knife hard snow Note, however, that other failure modes often begin after 2 kN (e.g. picket twisting and bending), so it is advisable not to trust any top-clipped picket for more than 2 kN.

Figure 1.19

- Hammer the picket in 10-15° from perpendicular away from the direction of pull.
- NOTE: If belaying off of your hip from this anchor, be sure you are attached at least 1.5 meters away to minimize upward force (this is a common method of picket failure).

4. Snow that is weak (soft) and cannot be compressed to become stronger (because it is very cold or very wet).

There are really only two choices: a 'snow pig' (which has fluke like behavior) or a horizontal mid-clipped anchor (perhaps with something larger than a picket, like a ski). Testing indicates that you may get up to 7 kN of strength, but in less than pencil hard snow it will likely be **4 kN** or less. These are not very good anchors.

- **Snow Pig**

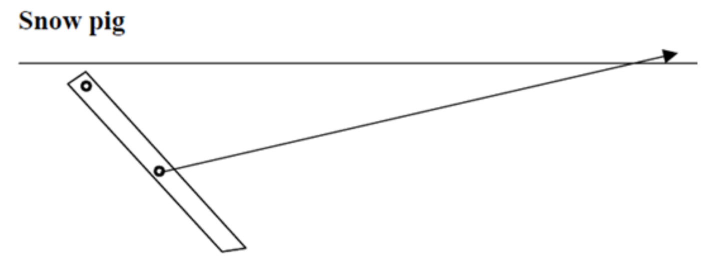

Figure 1.20

  - Do not attempt to work harden the snow (it'll only make it weaker).
  - Insert the picket at a 45° angle, in the hopes that it will dive under pressure. However, like a fluke, it could hit a hard layer and lean back further and lose strength.

- **Horizontal mid-clipped**

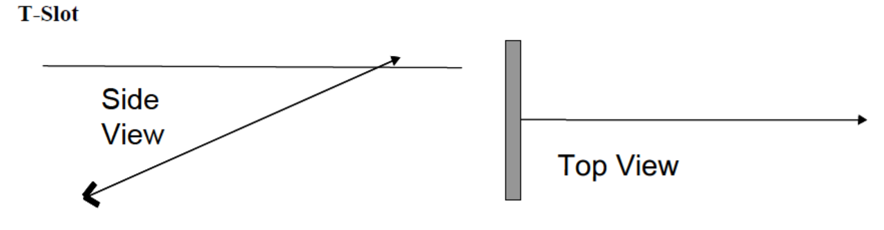

Figure 1.21

  - Dig a trench a few degrees less than perpendicular to the slope, as deep as is practically possible, but at least 15 inches.
  - Dig a trench for the attachment cord perpendicular to the other trench. The longer it is, the more material the deadman has to drag before failure.
  - Backfilling is optional, but don't try to compress it.

Multipoint Snow Anchors

When an anchor needs to be stronger than what a single piece anchor can provide (e.g., in rescue situations, or in softer snow), a multipoint anchor should be built.

Considerations in building multipoint snow anchors:

- To achieve maximum strength, separate the anchors by at least twice the distance of the deepest anchor (the idea is to avoid having overlapping stress cones).
- Pay close attention to equalizing the system (especially force distribution) to maximize the holding strength of each piece in the system.

Equalization

Like rock climbing anchors, snow and ice anchors should pass the ERNEST test (**Equalized, Redundant, No Extension, Strong, and Timely**). However, given that snow (or ice) is typically the weakest link in a snow (or ice) anchor system, particular emphasis needs to be placed on equalizing these anchors to ensure that each placement is sharing an appropriate proportion of the load. This is particularly important with rescue anchors, which must hold a heavy load while maintaining a very wide margin of error. As a general rule, Search and Rescue teams overbuild rescue anchors in order to maintain a safety margin of 10:1 (this is addressed in greater detail in the raising and lowering systems chapters).

We will assume the reader understands the principles behind the ERNEST mnemonic and will delve deeper into anchor equalization and distribution strategies and tricks.

Equalization and the Three Ds

With snow anchors, it is helpful to go beyond simply thinking about equalizing the points of a multipoint anchor to thinking about how forces are distributed throughout the anchor system. To this end, we want to focus carefully on the Three Ds: **direction**, **distribution**, and **displacement**.

The Three Ds

Direction: Be careful to build your anchor in the direction of intended pull. This is often more difficult than it seems. Manipulating the length of the leg(s) of your anchor (e.g., in an effort to equalize them) can substantially alter the anchor’s orientation in relation to the intended direction of pull. This can have a significant effect on the overall strength of your anchor, especially, for instance, in the case of a deadman (horizontal mid-clipped) anchor, which must be exactly perpendicular to the direction of pull for maximal strength.

Distribution: How the load is spread across the anchor points. In most case you’ll want to aim for an equal distribution across all points. However, in some cases it may be advantageous to focus more of the load on a particularly ‘bomber’ anchor piece, or avoid excessively loading the middle piece of a three point anchor.

Displacement: The effect of the load on the anchor materials in terms of how far they move—particularly in terms of elongation of soft goods. One can, for example, stiffen the leg of an anchor (i.e., reduce its displacement) by doubling the strands of cordage, or by pre-loading the leg to place it under greater tension.

Distribution and Focus Tricks

Longer lengths of cord stretch more than shorter lengths. This is especially true with nylon, which has fairly significant elongation properties. This means the longest leg of your anchor (e.g., the leg on the right in *Figure 1.22* below) carries a smaller portion of the load distribution because it will stretch more readily than the shorter leg(s).

There are several ways to address this:

Making legs of the anchor of equal length: Spectra (HMPE) has relatively low elongation properties (i.e., it doesn't stretch very much). This property can be exploited to equalize the legs of a multipoint anchor that otherwise has unequal legs. Simply use a spectra runner to shorten the longest leg to the same length as the shorter leg(s). Complete the anchor with cordage that possesses more dynamic elongation properties (e.g., 7 mm nylon cordalette).

Figure 1.22: Because the legs of this anchor are of unequal length, the left picket will bear a larger portion of the load due to the elongation properties of the nylon cordalette.

Figure 1.23: Equalizing legs of the cordalette by extending the right picket's attachment point with a long Spectra runner.

Double versus single strand of cord: a double strand of cord requires much more force (theoretically twice as much) to elongate than the same length of a single strand. One can take advantage of this property by strategically connecting the anchor points with an untied cordalette. A single strand of the cordalette goes to short leg(s) and a double strand goes to the longest leg(s). If the longest leg is roughly double the length of the shortest leg, the relative displacement between the longest and shortest legs will roughly equalize (e.g, see *Figures 1.23).* Similarly, in a three point anchor in which the direction of pull is aligned with the middle leg of the anchor, that middle leg will take a greater portion of the load.

The same single versus double strand strategy can be employed to compensate for this (see *Figure 1.25* below).

Figure 1.24: Equalizing unequal length anchor legs by doubling the cordage on the long leg.

Figure 1.25: Because it is aligned with the direction of pull, the middle picket in this three point anchor receives most of the load. Doubling the cordage on the other two legs helps compensate for this. The long Spectra sling also helps.

Pre-tensioning: One can also remove some of the elongation potential of a particularly stretchy leg of an anchor by pre-tensioning it. This can be accomplished by pulling the stretchy leg slightly short when tying off the power point (so some cordage elongation occurs before the other anchor points come into play), or by shortening the cord with a ***carabiner spine wrap*** (see *Figure 1.26* below) or (in the case of a double strand) twisting the cord with an ice ax. These techniques can also be used to focus force on a particular anchor point, which may be desirable if one or more of the anchor points is weaker than the others.

Figure 1:26: Carabiner Spine Wrap.

Section III: The Three Ms of Anchor Assessment

In this final section on anchor building we'll start to put the principles and information we've learned together by practically applying them to assessing anchor strength. The general idea is to perform a 'pre-mortem' on your anchor to determine its weaknesses and what might go wrong with it. If your anchor were tested to the point of failure, how would it fail and why? The three Ms of anchor assessment provide us with a method for doing this. The three Ms are:

Method of Failure

Micro-Analysis

Macro-Analysis

Method of failure:

As noted at the beginning of the chapter, without understanding the likely methods of failure, you cannot adequately judge the quality and strength of an anchor. In assessing your anchor, you should consider the following:

What is the weakest link in my anchor? One of the first principles of anchor building is that an anchor is only as strong as its weakest link.

- Armed with the information you now have regarding the strength properties of soft goods, hardware, snow, and ice, you should be able to determine the weakest link, as well as a reasonable estimate of the strength of the weakest link.

How might this anchor fail? Below is a list of things to ask yourself (this list is by no means comprehensive):

- Is the strength of your anchor adequate for holding the intended load?
- What is the weakest link in the system, and how strong is that link?
- Are there objective hazards in the area (e.g., rock fall potential)?
- Is there a sharp edge transition that could cut or abrade your climbing rope?
- What is the slope angle? Pulling a load up a 30° slope requires much less force than pulling the same load up a 60° slope.
- Is there potential for a significant shock load to the anchor (e.g., a leader fall)?
- Are conditions changing over time (e.g., is it warming, so snow and ice might begin to melt or soften; could direct sunlight melt out picket or ice screw placements)?

Micro-Analysis:

Micro-analysis is a means of concentrating your focus in assessing the tiny details of your anchor and consider the following (again, this is by no means a comprehensive list):

Follow load through each individual component of the anchor.

- Is the climbing rope free of tangles? Are there nicks or frays in the sheath?
- Are the carabiners placed correctly? No side loading? Locking gates are locked? No burrs in the metal that might cut soft goods?
- Is each knot tied correctly and dressed properly? How much do the knots compromise the rated strength of the cordage or webbing?
- Is the load focused and distributed well?

Macro-Analysis:

This is the inverse of micro-analysis. It is a means of broadening your focus to take in the bigger picture of your anchor's strength and integrity. Consider the following (again, this is by no means a comprehensive list):

Examine the larger surrounds within which your anchor is built.

- Are your anchor points solidly attached to terra firma?
    - A well placed cam is useless if the crack it is set in is created by a detached slab.
    - A secure bowline knot tied to a stout tree branch is useless if the tree branch isn't attached to a tree well rooted into the ground.
    - A well placed ice screw is useless if it's screwed into a thin slab of ice detached from a rock face.
- What is the safety of the broader environment?
    - Are you below a cliff or steep slope where rock or ice fall might occur?
    - Could you be standing on a snow bridge over a crevasse?
    - What are the avalanche conditions in the general area?

CHAPTER 2: Lowering Systems

Principles and Objectives

The objectives (what we are trying to accomplish):

1. Build a system strong enough to bear the load (e.g., 1 injured climber + 1 attending climber).
2. Build a system that affords a safe and controlled means of lowering the load.

Some of the principles at play (note: these aren't necessarily the only principles at play):

1. 1 kN of force is about 225 pounds.
2. Since human lives are at stake, SAR teams always try to work with a 10:1 safety margin (i.e., they want their system to be 10 times stronger than necessary to do the job).
3. Whether raising or lowering a load, a rope catch mechanism can be used to keep a load from out-of-control falling.

Strategy given our objectives and principles:

1. Given our example of lowering two climbers, we want to build a system capable of withstanding 20 kN of force, or:
    - [2 climbers @ 225 pounds each (conservative estimate) = 450 pounds or 2 kN] x 10:1 safety margin = 4,500 pounds or 20 kN
2. Given our example of lowering 2 climbers, we want substantial enough friction on the rope to smoothly lower without losing control of the load (e.g., a simple münter hitch or an ATC in autoblock mode probably will not suffice).

Building the Anchor

All of the principles at play from the anchor section apply here.

Building the Lowering System

In this system we will employ several ATC devices to provide additional friction sufficient to safely lower two people in a controlled manner. The system will also employ a prusik attached to the person doing the lowering, both as a rope catch mechanism to protect the load from descending out of control and to protect the person controlling the lowering.

Building the system is broken into steps below:

1. Build the anchor with a single power point capable of holding 20 kN (see *Figure 2.1*)
2. Extend the powerpoint with another section of cordage or webbing and another locking carabiner (see *Figure 2.2*).

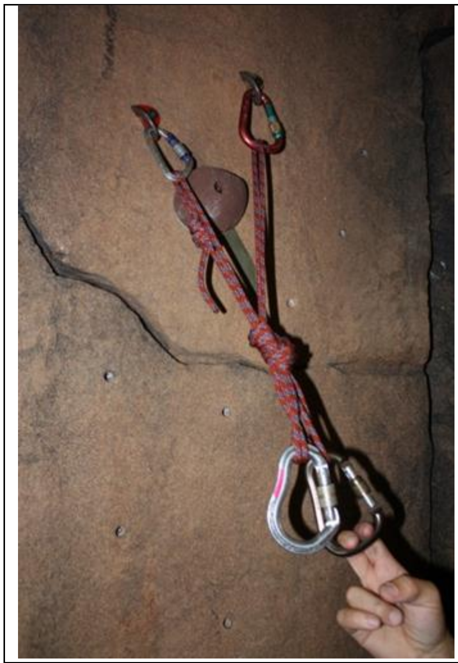	
Figure 2.1: Building the anchor	**Figure 2.2: Extending the power point**

3. Add two ATC devices (see *Figure 2.3*).
4. Add a redirect carabiner to the shelf or power point (see *Figure 2.4*).

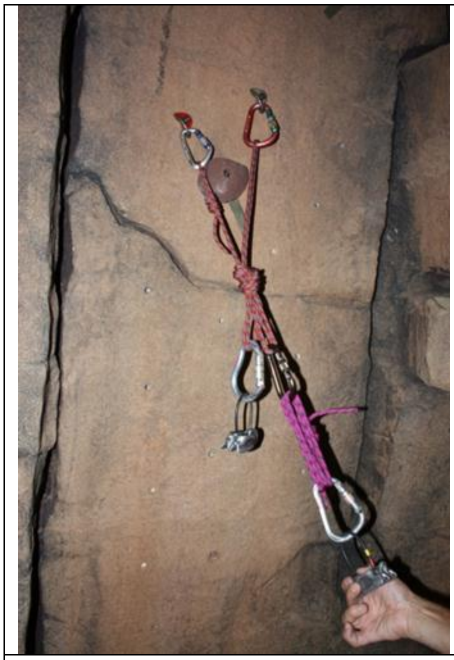	
Figure 2.3: Adding ATCs	**Figure 2.4: Adding the redirect**

5. Thread the rope through the ATCs and the redirect carabiner (see figure 2.5).
6. Add a prusik to the rope where it exits the redirect, connecting the other end to the lowerer's harness for control and protection (see *Figure 2.6*).

	
Figure 2.5	Figure 2.6

NOTE: When working in less than vertical space, it's helpful to place a backpack under the lowering system to keep it off of the ground.

CHAPTER 3: Raising Systems

Principles and Objectives

Rather than using rote memorization to learn—and then quickly forget—how to build a 'Z' or a 'C' system, we will develop a small set of fundamental guiding principles applicable to raising systems. By then examining our objectives and applying the fundamental principles we've learned, we will use good judgment and critical reasoning skills to build a raising system appropriate to the situation.

NOTE: We'll also dispense with the terms 'Z' system and 'C' system at this point, since they're at best vague, and at worst inaccurate (for example, a classic 'Z' system is a 3:1 mechanical advantage, but it is also possible to construct a 'Z' system that is a 0.5:1 mechanical advantage). Instead we will refer to the actual mechanical advantage ratios (e.g. 2:1, 3:1, 5:1, 12:1, etc.), which we will also learn how to calculate.

Fundamental Principles of Mechanical Advantage Systems (MAS)

Principles that apply to all MAS

1. **Travelling vs. Fixed Pulleys:** Mechanical advantage systems are typically comprised of travelling pulleys (at least one) and fixed pulleys. Fixed pulleys are fixed to the anchor and do not move. Travelling pulleys move (travel).
2. If the final pulley (closest to the hauler(s)) is a travelling pulley, it increases the mechanical advantage of the system.
3. If the final pulley (closes to the hauler(s)) is fixed, it simply provides a change of direction and adds no mechanical advantage.
4. When the construction of the MAS starts by having the hauling rope fixed to the anchor, the resulting MAS will be an even ratio (2:1, 4:1, etc.).
5. When the construction of the MAS starts by having the hauling rope fixed to the load, the resulting MAS will be an odd ratio (3:1, 5:1, etc.).
6. MAS ratios can be validated my measuring the amount of rope pulled relative to the distance the load moves.
   - For example, if you pull the haul strand 6 feet to move the load 1 foot, the system is a 6:1.
   - Note that rope stretch and friction are factors here, so measurements will not be very exact.

Three kinds of MAS:

1. Simple MAS
2. Compound MAS
3. Complex MAS

Simple MAS

1. All travelling pulleys travel towards the anchor at the same rate of speed *(this is the defining characteristic of the Simple MAS).*
2. The mechanical advantage of a simple MAS can be calculated by counting the number of pulleys used (minus any change of direction pulley) and adding 1 (e.g., a 2:1 MAS uses 1 pulley, a 3:1 used 2 pulleys).
3. The mechanical advantage of a simple MAS can also be calculated by counting the number of ropes under tension on the load side (i.e., not including the redirect strand if a redirect pulley is being used).
    - A 3:1 MAS has 3 strands under tension.
    - A 5:1 MAS has 5 strands under tension.

Figure 3.1: *A simple 2:1. Note the hauling strand is fixed to the anchor. Count the pulleys (1) and add 1 = 2:1. Count the strands under load (2) = 2:1.*

Figure 3.2: *A simple 2:1 with a redirect. Note that adding a fixed pulley to the hauling end adds no mechanical advantage, so you don't count that pulley, or the resulting redirect strand.*

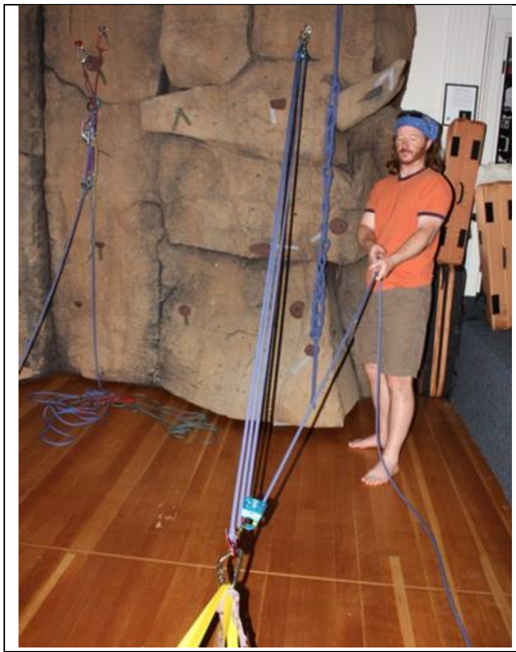

Figure 3.3: *A simple 4:1. Count the pulleys (3) and add 1 = 4:1. Count the strands under load (4) = 4:1.*

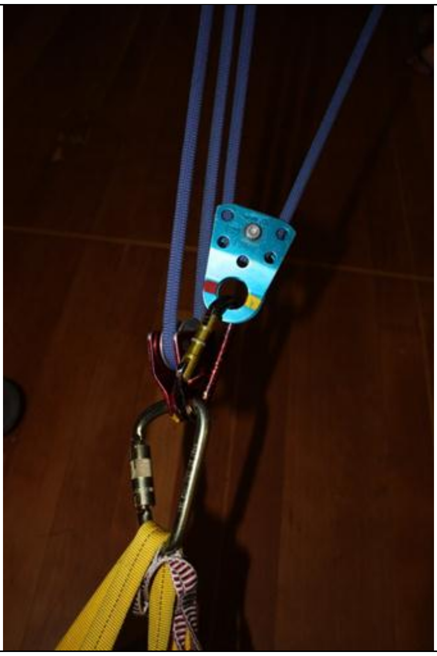

Figure 3.4: *4:1 travelling pulley detail. Both are attached to the load and travel towards the anchor at the same rate (the hallmark of a Simple MAS).*

Figure 3.5: *This is a detail of the same MAS shown in Figures 3.3 & 3.4. The third pulley has been moved from the load to a prusik chord on the second strand of the original 2:1 MAS. Pulleys no longer move to the anchor at the same rate*

Figure 3.6: *Full view of the anchor detailed in Figure 3.5. The strand above the prusik goes to a pulley at the anchor, down to a pulley at the prusik, and back to the hauler, making a 3:1 on a 2:1. This is a 6:1.*

	
Figure 3.7: *5 pulleys and 6 loaded haul strands. All travelling pulleys travel toward the anchor at the same rate. This is a Simple 6:1 MAS.*	***Figure 3.8:*** *Simple 6:1 MAS into a Compound 18:1 MAS ((3:1 on a 2:1 = 6:1) x 3:1 = 18:1). By moving two pulleys from the load to prusiks we increased the mechanical advantage from 6:1 to 18:1*

Compound MAS

1. A compound MAS results from adding one or more additional simple MAS onto an initial simple MAS.
2. Travelling pulleys do not travel towards the anchor at the same rate of speed *(this is a dead giveaway that you are not dealing with a simple MAS anymore).*
3. Compound MAS *multiply* (as opposed to adding) force.
   - Putting a 2:1 MAS on a 3:1 MAS results in a 6:1 MAS (2 x 3 = 6).
   - Putting a 3:1 MAS on the MAS described directly above results in an 18:1 (3 x 6 = 18).
4. The mechanical advantage of a compound MAS can be calculated by multiplying the mechanical advantage of the simple pulley systems it is comprised of.
5. To minimize the number of resets required when pulling, it is better to place a larger simple MAS on a smaller MAS (e.g., a 3:1 on a 2:1 requires fewer resets than a 2:1 on a 3:1, even though both compound systems are 6:1).
6. To minimize the number of resets required when pulling, you can also build an anchor for the secondary simple MAS further back than that of the primary simple MAS so each pulley system will 'collapse' or max out at the same time.
   - For a 3:1 on a 3:1, the last 3:1 will require 3 times the reset distance as the first. If you build a second anchor 3 times the distance as the first anchor is to the load, they'll max out at roughly the same time. But even if you aren't this exacting, building an anchor for the second simple MAS further back will always reduce the frequency of resets.

Complex MAS

1. A Complex MAS is a MAS that is neither Simple or Compound, which is obviously a nebulous and very non-descriptive definition. It doesn't offer much in the way of definitive characteristics.
2. Most Complex MAS require memorization to construct, and can be difficult to recognize or describe, so we won't spend much time on them.
3. Calculating the mechanical advantage of a Complex MAS is also complex (and will not be addressed here).

Constructing a Raising System

Example objectives (what we are trying to accomplish):

1. A climber on your team has fallen into a deep crevasse and needs to be safely extracted without causing (additional) injury to that climber.
2. You need a hauling system with enough mechanical advantage to allow the available hauler(s) to raise the load.
3. You need to build an anchor for the raising system that is strong enough to withstand the forces placed on it by the load and the haulers.

Some of the principles at play (note: these aren't necessarily the only principles at play):

1. Since we'll be building an anchor, all of the principles related to anchor building apply here.
2. Since we'll be building an MAS, all of the principles related to MAS building apply here.
3. 1 kN of force is about 225 pounds.
4. Since human lives are at stake, SAR teams always try to work with a 10:1 safety margin (i.e., they want their system to be 10 times stronger than necessary to do the job).
5. Whether raising or lowering a load, a rope catch mechanism can be used to keep a load from out-of-control falling.
6. The average person requires a 15:1–20:1 MAS ratio to comfortably haul a single climber out of a crevasse (which should tell you how practical a classic 'Z' (3:1) system alone is for crevasse rescue). When a single person is rescuing two climbers, the required MAS ratio increases to 25:1 – 30:1. This rule of thumb can be used to calculate the required MAS ratio based on the number of haulers available and the number of climbers needing to be rescued. For example:
    - If two people are available to haul a single climber, the required MAS ration can be cut in half (15:1 – 20:1 divided by 2 = 8:1—10:1); if three people can haul, the required ratio can be divided by 3 (15:1 – 20:1 divided by 3 = 5:1 – 7:1); and so on.
    - The classic 'Z' (3:1) system alone requires at least 5 haulers to comfortably rescue a single climber (3:1 x 5 = 15:1).

Strategy given our objectives and principles:

1. Given our example of raising 1 fallen climber, to create an appropriate safety margin we want to build a mechanical advantage system (MAS) capable of withstanding 10 kN of force, or
    - 1 climber = 225 pounds or 1 kN.
    - Adding 10:1 safety margin = 2,250 pounds or 10 kN

3. Consider an example of a three person climbing team, with one climber in the crevasse and two climbers to haul. Given the hauler strength rule of thumb, we will need to construct an MAS between 8:1 and 10:1.

4. Since each pulley in a simple MAS adds force rather than multiplying force, it would take a lot of pulleys (at least 7) to make an 8:1 to 10:1 MAS. So in this scenario it makes sense to construct a Compound MAS.
    - A 3:1 on a 3:1 may suffice (3 x 3 = 9:1); or a 2:1 on a 3:1 on a 2:1 ((3 x 2 = 6) x 2 = 12:1); or a 2:1 on a 2:1 on a 2:1 ((2 x 2 = 4) x 2 = 8:1); etc.

5. Regardless of which MAS we use, we'll set up a prusik rope catch on one of the pulleys to protect against an out-of-control drop and to hold our progress when we reset pulleys.

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