

Snow Anchors



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Background

The Coroners court finding for the four fatalities that occurred on Mt Tasman in December 2003 asked the New Zealand Mountain Guides Association and the New Zealand Mountain Safety Council to look into whether current practices with snow anchors in New Zealand are adequate. This document is a look at what is currently known about snow anchors in New Zealand. Over the past 12 months I have been involved in snow anchor testing with Ruapehu Alpine lifts, NZMGA and the DOC Aoraki mountain rescue team. That testing looked at ideas from the Fortini presentation “On the Use of Pickets and Flukes as Snow Anchors” given by Art Fortini of the Sierra Madre Search & Rescue Team to the International Technical Rescue Symposium, Denver, CO, November 2002 and at current snow anchor techniques in New Zealand. Fifty-one tests were carried out at these three sites in a variety of snow conditions. Tests were carried out in fresh soft moist snow, wet spring snow, hard cold snow and low to moderate strength cold dry snow. All testing was done with gradually increasing steady pulls, none were done with dynamic loads. While the number of tests carried out can not be considered high enough to give good statistically valid results for individual pieces of equipment, they did show the phenomena described in this document and give us an idea of the likely performance of different styles of anchors. It also highlighted a number of issues with the material strength of some anchor and attachment materials and with the orientation of V profile stakes.

Introduction

The strength of snow anchors is dependent on a combination of

- The strength of the snow in compression and shear
- The strength of the materials the anchor is made of
- The strength and placement of the attachment system
- The mode of use, angles and orientation of the anchor and its attachment system

We need to look at each of these and at their effect on each other when looking at anchor systems. We also need to examine how strong anchors need to be for different mountaineering and rescue tasks so that we can build appropriate anchors for those tasks.

Definitions

The following terms used in this document are defined as:-

Standard sized stake:- This is 60 cm long and is made of right angle section aluminium (referred to as V throughout the document) with 5 cm wide sides which gives it an overall width of 7 cm. Its area is 0.04 m^2 . The area is calculated by length times overall width less the area of the points. The surface area of the sides is not taken into account.

Top clip:- Any anchor attached at its top.

Mid Clip:- Any anchor attached at or near its middle

Upright:- Any anchor put in perpendicular to, or at an angle back from perpendicular to the snow surface.

Horizontal:- Any anchor that is put in horizontally at right angles to the direction of load.

How strong does an anchor need to be?

For rescue this is relatively simple. The anchor should meet the NZ LandSAR standard of being 10 times the rescue load. For a rescue sized load of 2 kN this means an anchor should be at least 20 kN. This means that 2 by 10 kN anchors or 3 by 7 kN would satisfy these requirements if they were tied together with an equalised system.

For climbing things are more complex as we are dealing with dynamic loads. The UIAA standard for a climbing rope is that no more than 12 kN of force can go onto an anchor for a fall of 4.8 m with 2.6 m of rope with a weight of 80 kg. This is based on the maximum short-term load a human body can handle with out damage. Most modern climbing ropes out perform the standard by a significant amount with some claiming figures of between 7 and 8 kN. In real life the actual load on an anchor is affected by a range of things some of which lower the load and others that make it worse. They include friction, age of rope, number of previous falls it has held, how wet the rope is, what the actual weight of the load is, slope angle, type of belay and fall factor.

Fall factor, which is the distance of the fall divided by the amount of rope that is between the belayer and the falling climber is the key predictor of load. With falls of the following fall factors the likely maximum loads are; ff 0.5 -- 6 kN, ff 1.0 -- 9 kN, ff 2.0 --12 kN. (Information comes from the Petzel web site) The figures are for a vertical fall for the standard UIAA 80 kg mass. There is no reduction for friction between the falling climber and the ground. If friction and the effects of slope are taken off then loads can be 30% less for a 45° slope. That means the range of maximum loads on a snow anchor is likely to be between 4 kN and 8kN. If used as a runner, force is 1.6 times the maximum that is expected on the belay anchor.

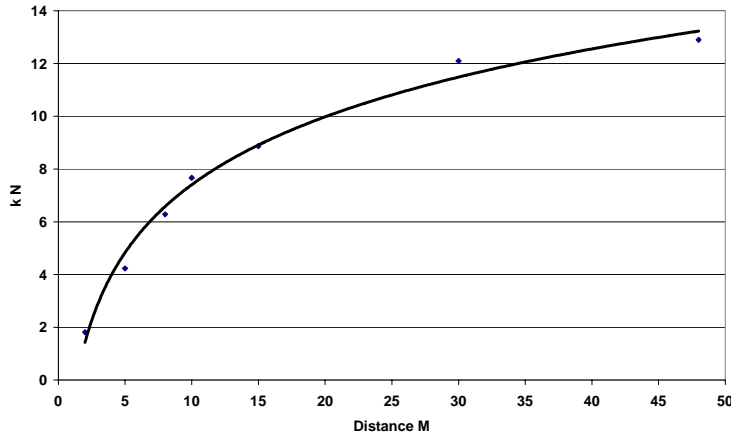
The sort of uses that snow anchors get make it unlikely that one would receive the maximum sized loads. They are mainly used for belaying on moderate angled slopes, belaying over crevasses and abseil anchors. It would be unusual for a snow anchor to be used as the only anchor for a situation where a lead climber could take a fall factor 2 fall on steep terrain. The uses snow anchors are put to would give us the likely following loads for these situations.

- Leading on 45° slopes and belaying over crevasses- 4 kN to 8 kN
- Runners - 8 kN to 12 kN
- Top roping 1 person or abseiling- 2 kN to 3 kN
- Top roping 2 people- 3 kN to 4 kN

Ideally anchors should be able to handle 12 kN. However there are material strength issues with cables and stakes themselves which make this hard to achieve. It would therefore seem that although there are some circumstances when snow anchors could receive over 10 kN that this is unlikely for the type of use they normally receive so a target of 10 kN for the strength of the components in a snow anchor would be a more realistic target to set. Some snow conditions will limit anchor strength to less than 4 kN when using conventional sized anchors.

Force on a person in an Avalanche

- 40 cm thick slab on a 45° slope
- Assumes a person goes into a arched backwards position hanging from a waist harness that gives an area 0.4 m² and debris density starts at 350 kg m² and drops to 200 kg m² as the snow accelerates



A particular circumstance when a snow anchor could be subjected to loads of greater than 10 kN is if an avalanche hits the person being belayed or tied to an anchor. For large paths forces are likely to be higher than in the diagram to the left but most climbing avalanche accidents typically occur when the climbers set off an avalanche themselves. These avalanches are usually not particularly large and the climbers are normally high in the start zone. If someone is less than a rope length from the top of where an avalanche started this is probably a

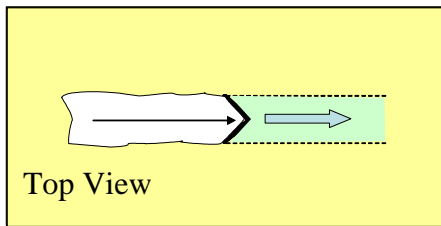
reasonable representation of likely loads. Therefore a 10 kN anchor is likely to hold someone if they are being careful with how they are traveling and belaying in avalanche paths.

Key point – Be aware of the maximum load your anchor could be subjected to and build them strong enough to cope with that.

Snow Strength

Snow fails either in shear or compression with snow anchors.

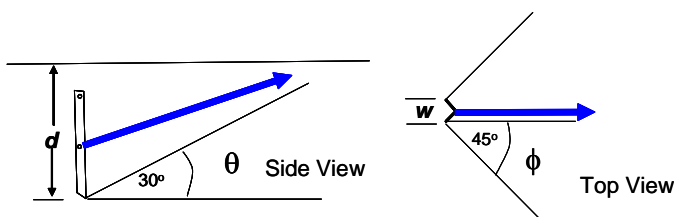
Compression Failure



In compression failure the anchor pulls forward through the snow. Under a steady load this can be a fairly slow movement. The compression strength of a snow anchor is dependent on the compression strength of the snow, the size of the buried object and whether the load is evenly spread over the buried object.

The Anchor pulls forward through the snow

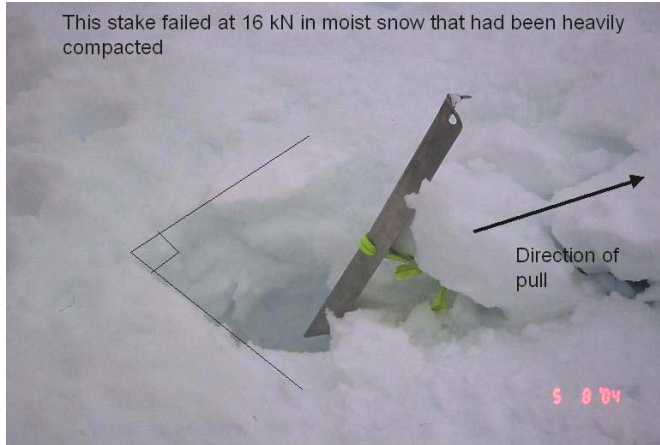
In a shear failure, a stress cone in the snow is formed around the buried object. It goes out from the sides of the object at approximately 45° and up from the bottom of it at approximately 30°. The stress cone phenomenon was described by Fortini in his presentation.



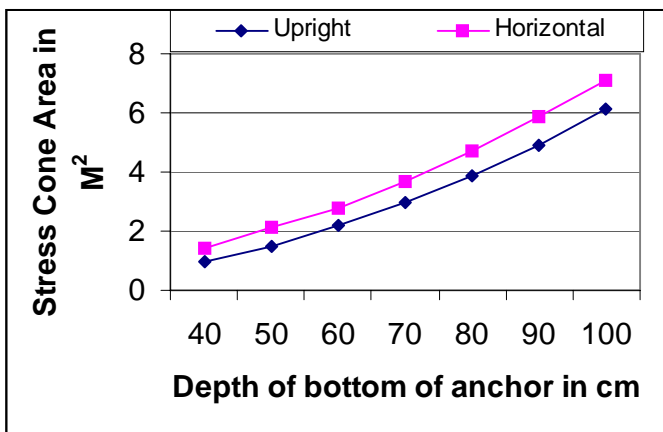
When it fails it does so fast and the snow cone and anchor come out of the snow in an explosive manner. The shear strength of a snow anchor is dependent on the shear strength of the snow and the surface area of the stress cone. The size of the shear cone is a lot larger than

the buried object. It can be over 50 times the size of the buried object depending on its depth and width. The size of the stress cone can be calculated by working out the surface area of the three surfaces that make it up by using the following formula from Fortini's presentation.

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



Observations of stress cone failures such as the photograph to the left in snow that has been manually compressed do not show clean shears of the entire cone. Weaknesses obviously exist inside the compacted snow, which mean that the actual shear surface is less than the theoretical area and therefore the strength will also be weaker than the maximum theoretical strength. However failures under shear are still relatively strong when compared to anchors failing under compression.



An important feature of this is that increasing the depth of an anchor has a far larger effect on the size of the stress cone than increasing its width. The graph to the left shows the theoretical stress cone size for a standard sized snow stake. When used as an upright anchor it is 7 cm wide. When used as a horizontal anchor it is 60 cm wide. A T-slot using a 60 cm stake would need to be 52 cm deep to have a bigger stress cone than the stake in as an upright mid clip.

If we look at the compression strength of snow as described in the Avalanche Handbook we can see that it varies hugely from < 1kPa for fist hardness to >1,000 kPa for knife hardness snow. Each step in the snow hardness scale is an increase by an order of magnitude. Snow is generally about ten times stronger in compression than in shear. As the shear cone provides a greater surface area for the force to work on this can in certain conditions make for a strong anchor even though shear strength is only about 10% of compression strength.

Compression strength				Theoretical Compression strength, if load evenly spread for 60 cm x 7 cm stake with area of 0.04 m ²	
Hardness	Pa	k Pa Range		k N Range	
fist	0 - 10 ³	-	1	-	0.04
4 finger	10 ³ - 10 ⁴	1	10	0.04	0.4
1 finger	10 ⁴ - 10 ⁵	10	100	0.4	4
pencil	10 ⁵ - 10 ⁶	100	1,000	4	40
knife	> 10 ⁶	1,000	> 1000	40	>40

Average of Strength	Snow Water				
	Snow Hardness when tested	Dry	Moist	Moist to Wet	Average
4 finger to 1 finger				4.7	4.7
1finger to pencil		3.5			3.5
pencil			12.1	7.7	9.5
knife		12.1			12.1

The test results to date of mid clip similar sized anchors shown above are in line with the table above them although the wetter, less hard snow gave a higher average than the strength table indicated it would. The failures above 10 kN were mainly the stakes attachments breaking or shear failures.

Snow will fail when compressive stress exceeds compressive strength or when shear stresses exceed shear strength. In weak snow compression failure is the predominant failure mechanism. In strong snow shear failure is the predominant failure mechanism if the load is evenly spread across the anchor. If the load is not spread evenly then this usually means that the compressive stress at the point of greatest load exceeds the compressive strength of the snow and failure occurs in compression. This is the main failure mechanism in upright top clips.

Snow strength is dependent on the number of bonds (the more the better) and the strength of each bond. The key factors are that; larger crystals have fewer bonds than small crystals for a given volume of snow, bonds are weaker in the presence of water in the snowpack, wet grains are strong when in their frozen state and bonding occurs rapidly close to 0°. We can in some circumstances increase the strength of the snow and therefore the strength of a snow anchor by compressing the snow that we build the anchor in. Compressing snow increases the number of bonds by pushing crystals closer to each other. The useful strength of this compressed snow then depends on the speed of bonding. In moist snow (which is at 0°) this is very rapid. In wet snow (which is also at 0°) bond strength will usually deteriorate over time even though more bonds have been created through compression. In colder snow < -5° bonding is very slow and may not occur fast enough to be of any assistance in making an anchor stronger. Strength generally correlates to hardness and hardness generally correlates to density. The key exception being for wet snow where although it is dense it also has low bond strength.

The best test of whether compressing snow will make the anchor stronger is to make a snowball. If squeezing hard will make a solid snowball then you will create strong snow and

strong anchors. If the snow crumbles which occurs with cold snow it is unlikely to produce stronger snow and may in fact destroy existing bonds and make it weaker. If water drips from a snowball then compressing the snow may give it higher density but bonds are likely to be weak and they may break down rapidly.

Key Points

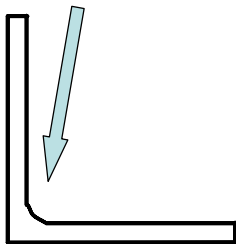
- If you can make the snow stronger by compressing it then do so as you will get a stronger anchor
- If you find yourself needing to use snow anchors a lot in weak snow, then you should be using anchors with a large surface area

Snow Anchor Materials

It is important that the materials used for a snow anchor and the attachment methods used with them are strong enough to handle the potential loads on them and to maximise the strength of the snow they are in. As snow anchors should be able to handle a load of 10 kN then the materials used need to be able to cope with this. Observations of snow anchor failures shows that many currently used snow anchors bend or break at substantially less than this.

In order to keep weight down on snow anchors aluminium alloy is usually used. Ski areas on Ruapehu use a mixture of stainless steel and mild steel for their rescue stakes in order to cope with the icy snowpacks that are common there. The 1.5 mm thick V section stainless steel anchors appear to have very similar strength characteristics as 3 mm V section aluminum stakes, while the 6 mm V section mild steel stakes are significantly stronger but are too heavy to be considered for mountaineering use.

Curved inner corner is likely to be high tensile 6261 T6 angle



Aluminum comes in a variety of different strengths. The higher strength 6261 T6 alloy used by Aspiring Enterprises in its snow stakes comes close to the 10 kN strength being sought but falls just short of this when used as a top clip in hard snow and is well short of this with the point of the V to load as a mid clip in weaker snow.

The shape of the stake section did not seem to matter from the point of view of gaining maximum strength from the snow when used in strong snow. However not enough tests have been carried out to confirm this. It is possible that the shape of the object could change the angle the stress cone comes out from the object at. Shape may be more of a factor in weaker snow but it has not been possible to test this yet. The theory has been that by placing a V stake point of V to load in all circumstances is that it is more stable when being pulled through the snow and that it can create a bow wave effect that compresses and strengthens the snow in front of it, which makes the anchor stronger. However if it were possible to strengthen the snow by compressing it, then it would be better to do it manually when placing the anchor and know that you have created a stronger anchor than to rely on an unknown amount of compression from a moving stake to do this.

Width and length of the anchor are important for getting the area of snow that gives compression strength or producing the size of the stress cone. The shape and orientation of the section is important for determining the structural strength of the anchor material when under load. In very strong snow when an anchor is pulled from a mid clip the strength of the stake is not an issue as it is supported by the strength of the snow and the weakest link becomes the strength of the attachment system. In weaker snow the snow does not give this support, so stakes that do not have sufficient strength (stiffness) will buckle and pull out through the snow. This has been observed at loads of around 7 kN with standard sized stakes.

In hard snow where a top clip is being used stakes pull forward under load as the anchor bends and the snow fails in front of the upper third of the stake. The testing at Plateau in May 2005 in knife hardness snow showed that the stronger the material used in a snow stake the higher the load it could handle. With the weaker materials and the narrower (5 cm wide) MSR Coyote the failure was in compression. With the strong wider stakes shear failures were observed. In order for either of these to happen the upper part of the snowstake has to bend as its lower half is under very little load and is held firmly in the hard snow.



Five upright topclips in knife hardness -10° C snow. Left to right:- Test 1 Al alloy (6261 T6) failed in shear at 9.4 kN. Test 3 Al Alloy failed in compression at 6.7 kN, Test 5 was open part of V to load and failed at 4.4 kN through buckling of the stake. Test 6 was 3mm mild steel which failed in shear at 11.3 kN. Test 12 was a MSR coyote that failed in compression 7.8 kN

To get maximum structural strength from a V section stake the point of the V needs to point towards the load when used as a top clip and the open part of the V needs to point to the load when used as a mid clip in weak to moderate strength snow. In very strong snow orientation does not matter for mid clips as the snow provides the strength. This orientation would also apply to other types of open sections such as C-section.

There is a difference in strength between the 6261 T6 alloy and the weaker alloys. Anyone using snow anchors made from the weaker alloys needs to be aware that their maximum strength will be well below the 10 kN target figure.

The length of a snow stake contributes to its overall area and when used as an upright midclip a longer stake gives a bigger stress cone. In order to gain the benefits of longer stakes the material the stake is made of has to be strong enough to counter the effect of greater leverage. Tests at Ruapehu showed no significant difference between 60 cm and 90 cm stakes used as upright mid clips with point of V to load, both lengths folded in the middle at about the same load. Stakes longer than 60 cm will also not make much difference to hard snow top clips unless they are made from materials that are strong enough to offset the effect of higher leverage on them.

Holes are often drilled into snow stakes in order to provide attachment points, to lighten them and some people advocate it to provide grip. Holes can structurally weaken a stake so care needs to be taken in order to not effect its structural strength. In testing at Plateau this year several stakes that had holes 1/3 of the width of the side of the stake, bent and tore at the

attachment holes placed at the stake mid points. Any holes placed for grip or lightening purposes may in fact reduce a stakes holding power in compression as they potentially reduce the area of snow being compressed.

Any attachment point to a stake needs to be able to handle the anticipated maximum load. This means any slings or cords need a breaking strain of over 10 kN after going over a sharp edge and any knots is taken into account. The only way to be certain with whether a particular combination of tape or cord will be strong enough is to carry out a strength test. In general having tape or cord go over sharp metal edges is not recommended due to the possibility of them being cut on that edge. If they are used then they need to have a large safety margin in their strength in order to compensate for the edge issues. When stakes are used as top clips, clipping a karabiner directly into the stake provides the most secure attachment point. With the Coyote stakes karabiners can also be used for secure mid clip attachments.

Holes large enough for karabiners or to push webbing or cord through in the center of V or C section stakes will tend to weaken the stake and compromise its ability to hold larger loads. If slings are larks footed or clove hitched around the outside of a stake they can squash the stake and cause it to bend at lower loads than other attachment methods. It is important to attach at the middle in order to spread the load evenly. In weaker snow pulling from off centre could lead to rotation which will cause the stake to pull out easily. A 4 mm wire cable passing through small diameter holes and then swaged gives a mid point attachment that will stay in the middle and not effect the strength of the stake. Using 4 mm cable limits the maximum strength of the attachment to that of the cable, the Aspiring Enterprises web site rates their 4 mm cables to 11 kN. An alternative is to larks foot a wire strop through a pair of center holes in the stake that are just big enough to get the strop through. This minimises weakening the stake but unless care is taken with placement it can at times lead to the stake being twisted off center from its long axis which results in less surface area in weaker snow situations.

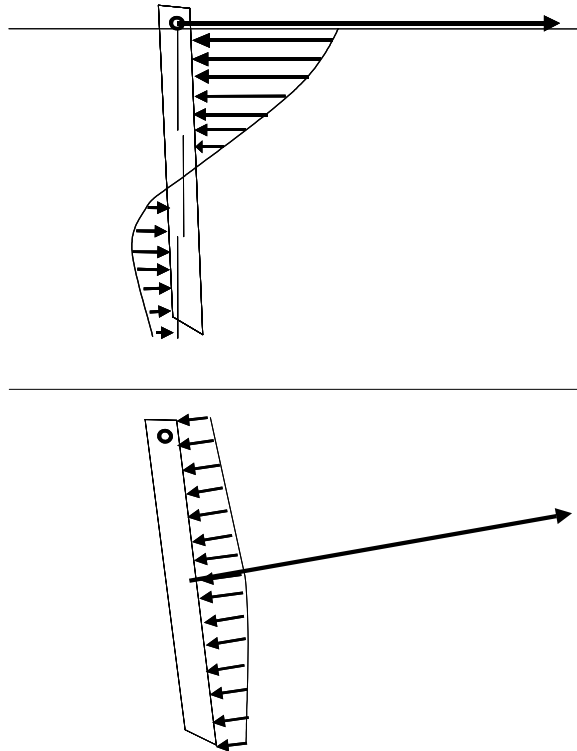
Key points

- Stake material needs to be structurally strong enough to handle anticipated loads.
- Longer stakes are only stronger if the materials are strong enough to handle the higher loads caused through leverage
- Minimise the numbers of holes in a stake as they could weaken it
- Only use attachments that have been tested and found to be greater than 10 kN
- If using V section have the point of the V to load for top clips and open part of the V to load for mid clips

Placement of Snow Anchors

Top clip or mid clip attachments

Snow anchors can be placed in several different modes, as up right stakes, with attachments at the top (top clips) or in the middle (mid clips) that can also be tilted back at different angles and horizontally with attachments in the middle. (T slots)



One of the most critical things that effects snow anchor performance is where you pull from. An upright top clip is in engineering terms a laterally loaded pile. In the Foundation Engineering Handbook by Winterkorn and Fang they say the following about laterally loaded piles. "Piles are rather slender structural elements, usually vertically inclined, and therefore cannot carry high loads which act perpendicularly to their axis." If we look at how the load is spread in the snow for an upright top clip in the diagram to the left, then we see that the majority of the load will be on the snow in the upper third of the stake. The actual cross over point from one side to the other will be dependent on the stiffness of the stake and the hardness of the snow. The stronger they are the further down it will be, which will increase the anchor strength as the load is spread over more surface area.

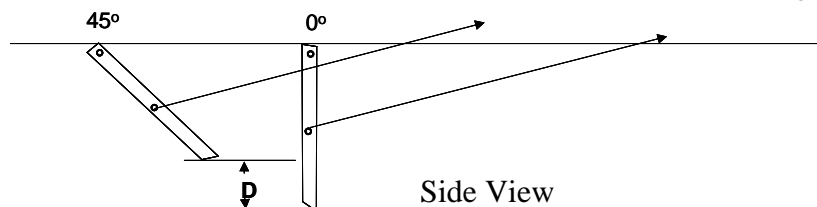
If you pull from the center the load is more evenly spread. If the stake is strong enough it will be even, but if it flexes then there will be higher pressure in the center. Pressure on the snow with a standard sized stake being pulled from the middle with a load of 6 kN is around 150 kPa which is within the range of pencil hardness snow.

During testing at Plateau some upright top clips were observed to start failing in compression at 6 kN in knife hardness snow. As knife hardness snow has a strength in compression of at least 1000 kPa this meant that a pressure of greater than 1000 kPa must have been applied to the snow in its upper third in order for this to happen. This is at least six times the pressure the same load would be applying if pulled from the middle.

The angle of upright midclips

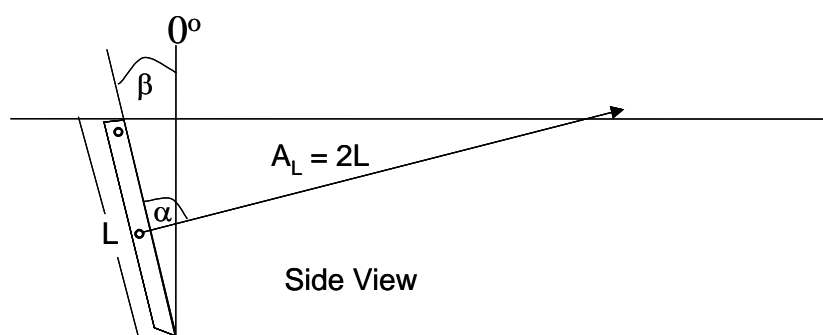
The angle a stake is placed in the snow has a different effect depending on snow strength. What increases strength in strong snow has the opposite effect in weak snow.

The effect of stake angle on the area of the stress cone size (A_s)



As the angle of a stake is tilted back its depth decreases. The difference in depth (D) means that the size of A_s is significantly reduced

The depth of the bottom of the upright mid clip has a major effect on the size of a stress cone in stronger snow. The size of the stress cone decreases the further a stake is leaned back. This would weaken the anchor in strong snow.



In weaker snow where compression is the dominant failure mechanism, leaning the stake back will increase the anchors performance. As the stake moves towards the load as it begins to fail in compression, the angle

of the stake influences whether it pulls straight forward, dives or lifts up out of the snow.

- If $\alpha = 90^\circ$ it pulls straight ahead
- If $\alpha < 90^\circ$ it produces lift and the anchor will come up
- If $\alpha > 90^\circ$ it produces dive and the anchor will go down

If a stake is leaned back about 15° from perpendicular to the snow surface with a stake in at its full length and an attachment coming out of the snow at twice the length of the stake ($A_L = 2L$) it will form the right angle where the attachment meets the stake. Lifting up or pulling straight ahead will both cause the anchor to fail at relatively low loads. If the anchor pulls straight ahead the top of the anchor comes out of the snow and reduces the surface area of snow in the upper half of the stake, which causes it to rotate forward and fail. Tilting the stake back to make angle β , 45° makes the stake dive down into the snow and therefore put more snow in front of itself to pull through. Under load they have been observed to travel down slope by several metres and go down into the snow by more than a metre.

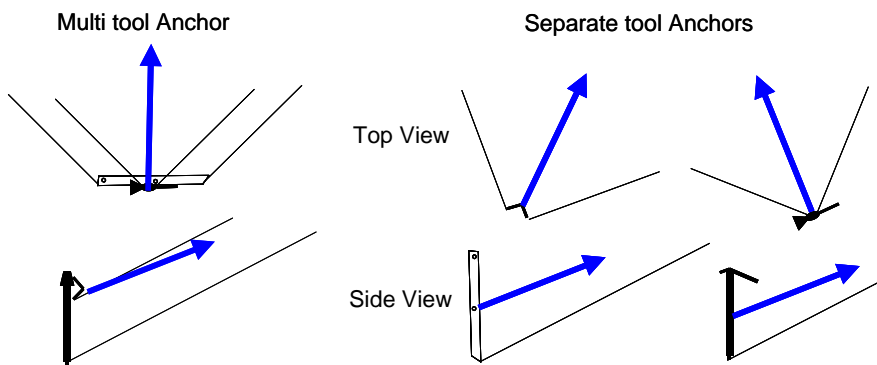
If being placed at 45° to encourage diving, users need to be aware that it can hit harder layers and have the angle flatten out. This usually causes them to pull down slope at relatively low loads until they pop out. Probing the snow with an object longer than the stake would allow the user to identify possible hard layers that could cause this to occur.

There should be an angle somewhere between the 15° and the 45° that causes the stake to stay just below the snow surface as it drags forward and prevents diving down into deeper layers. This needs testing to confirm whether this can be controlled.



This series of photos of an upright mid clip in at 10° back from perpendicular to the snow surface shows it lifting from the snow at around 3 kN. A similar sized stake set back 45° pulled down into the snow and failed at around 7 kN when the stake folded in the middle and the wire cable pulled out of it. The snow was cold <-10° C and between pencil and 1 finger in hardness. It was not possible to compress it to make stronger snow.

Multiple anchors



When there is a need to produce a stronger anchor than can be built with a single piece of equipment a multiple point anchor can be built. If the pieces of equipment are put in close to each other then an issue occurs with overlapping stress cones. Although

combining two tools produces a stress cone larger than one tool it produces less total shear surface area than two separate anchors would because the stress cones overlap. There is also a potential issue with using an upright axe in the multi-tool anchor as it is being pulled from the top, which creates uneven load so it is possible that it is not adding to the size of the stress cone, but is instead contributing to the compression strength of the anchor in an inefficient way. It is also important with anchors that are likely to fail under compression to set them up so that they do not pull through where another anchor was.

When building anchors with multiple pieces of equipment, maximum strength can be achieved by separating them by at least twice the distance of the depth of the deepest anchor and by making sure that you tie multiple anchors together with an equalised system in order to achieve the full combined strength of the multiple anchors.

Effect of an upward force on snow anchors

Snow anchors are designed to be loaded along the surface of the snow. With the buried anchors with midpoint attachments some upwards load will not be a big issue but it could still weaken an anchor. With any top clip anchor any upwards force is an issue. We need to be aware of the ways that an upwards force can go on a snow anchor and take measures to minimise them. The following three situations could all cause lift and weaken the anchor:-

1. Having the rope to the load go up over an object like a pack or the belayers leg if belaying off of the anchor.
2. Having someone lead past a snow anchor and fall after placing a runner or fall over the other side of the ridge.
3. Belaying off of your harness in a sitting position with your feet in a good stance. When the load goes on, the belayers feet act as a pivot point and their legs as a lever which causes their waist to lift up from the slope.

There have been instances of numbers 2 and 3 above causing anchor failures leading to serious accidents. Number 1 can be managed through good rope management and 2 through building a multidirectional anchor (requires two snow anchors) if upwards as well as downwards loads are expected. At Plateau in May 2005 an experiment was carried out to simulate the effect of belaying off a persons harness while tied to an upright top clip anchor. A piece of timber the length of an average sized persons foot to waist height was used to simulate a belayer. This was done with the stake placed at 0.0 m, 0.5 m and 1.0 m away from the person's hip.



Simulated belayer in the system. From left to right. 0.0 m, 0.5 m, 1.0m back from belay point. All photos were taken at point of failure

Anchor distance back from belay point	Approximate angle of pull above snow surface	Failure Load in knife hardness snow
No belayer in system	0°	9.4 kN
1.0 m from belayer	20°	7.8 kN
0.5 m from belayer	30°	5.8 kN
0.0 m from belayer	50°	2.5 kN

This confirms what people are being taught, that if you are belaying off of your body with an upright topclip then keep it some distance away from you. This experiment shows that an anchor needs to be more than 1 m behind the belayer, probably at least 1.5 m to avoid reducing the strength of the anchor.

The other mode for placing a snow anchor is horizontally, otherwise known as a T slot or horizontal mid clip. If the snow can be compressed in front of them to produce stronger snow they are very strong anchors. As stress cone size is heavily influenced by depth they would need to be dug nearly as deep as the length of the anchor in order to get greater strength than an upright mid clip that uses the same object. This would require digging and compressing a large volume of snow. In snow that can be strengthened they will take longer to build than an equivalent strength upright mid clip. In weak snow that cannot be compressed to make stronger snow they become the only option for a snow anchor if you do not have an anchor with a wire cable that can be pulled into the snow. In this sort of snow where moving the snow damages snow bonds, a narrow trench needs to be dug for the cord or tape attachment.

For anchors failing under shear the main features that give it strength is the depth of part of the anchor and evenly loading the surface of the anchor. For anchors failing under compression the main features that give an anchor strength are its surface area, evenly loading the surface of the anchor and having as much snow as possible to pull through before it comes out of the ground.

Key points

- Pull from the center of anchors if at all possible
- Get the anchor as deep as is possible
- To get maximum strength from multi tool anchors separate them by at least twice the depth of the deepest anchor and tie them together with an equalized system.
- In strong snow lean upright stakes back by no more than 10° in order to maximise the size of the stress cone.
- In weaker snow upright stakes failing under compression will either:-
 - move forward and out of the snow if the angle the attachment meets the stake is 90°
 - move forward and lift up out of the snow if the angle the attachment meets the stake is $< 90^\circ$
 - or move forward and go down if the angle the attachment meets the stake is $> 90^\circ$
- Leaning upright stakes back 45° from perpendicular to the snow surface will make them dive and put more snow in front of the anchor, but be aware that the angle could flatten out if it hits a hard layer, which would weaken the anchor.
- If belaying off your harness with an upright top clip then place the anchor at least 1.5 m behind you.
- If using a T-slot in snow that will not get stronger through compressing the snow, minimise disturbance of the snow in front of the anchor and cut the narrowest slot possible for the attachment

Four different categories of snow

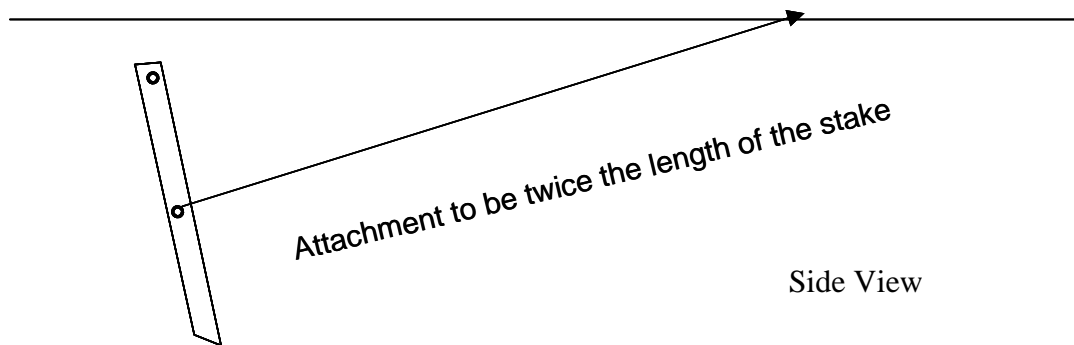
From the perspective of snow anchors there are four different categories of snow. Different techniques are needed for each sort in order to get the strongest anchor for the conditions.

1. Snow that can be compressed to make denser snow
2. Snow that is hard that can not be compacted back into a trench but can have a slot cut into it
3. Snow that is hard that can not be compacted back into a trench and can not have a slot cut into it
4. Snow that is weak and cannot be compressed to make stronger snow. That is bonds will not form easily through pressure. (Very wet snow or very cold snow)

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

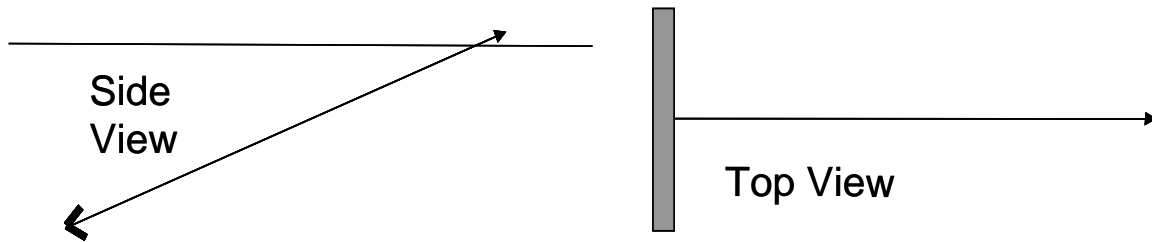
There are two choices with this. Either the upright mid clip or the horizontal mid clip (T-Slot)

Upright mid clip



- Cut a trench that goes from the depth of the bottom of the anchor to the surface with a shovel or ice axe adze in the direction of the load
- Compress the snow in the base of the trench and in the front of where the stake will go in an area larger than the stress cone (out at 45° from the stake and up at 30° from its base)
- Have an attachment (cable or sling) that is twice the length of the stake attached to the mid point of the stake.
- Place the stake at 10° back from perpendicular to the surface so that the top of the stake is below the snow surface. Have it well below the surface if you want to increase its strength further.
- Backfill the trench compressing the snow in it taking care to make sure it is compressed evenly from its base to the snow surface.

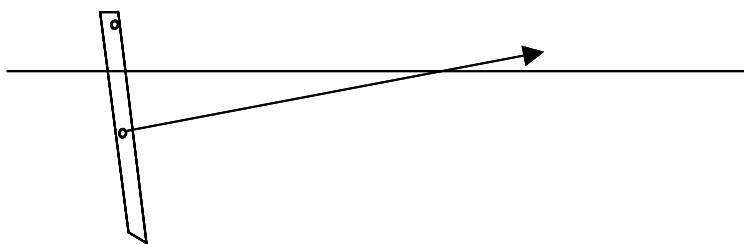
T-Slot



- Dig a trench with a shovel or ice axe adze at right angles to the direction the load will come from. It needs to be nearly as deep as the length of the buried object in order to get as big a stress cone as could be achieved by putting the object in, in an upright orientation.
- Place the stake horizontally in the trench at right angles to the load.
- Have an attachment (cable or sling) that is at least twice the length of the depth of the buried stake attached to the mid point of the stake
- Compress the snow in front of the trench and in an area larger than the stress cone (out at 45° from the stake and up at 30° from its base)
- Backfill the trench compressing the snow in it taking care to make sure it is compressed evenly from its base to the snow surface.

Testing indicates that both of these should produce strong anchors of greater than 10 kN with a standard sized stake if the snow makes a good solid snowball. If the snow pack is wet the strength range is likely to be less than 10 kN. Actual strength will depend on the size and strength of the anchor materials, how deep part of the anchor is and how well it is placed.

2. Snow that is hard that cannot be compacted back into a trench but can have a slot cut into it



This style of anchor requires a wire cable attachment to the centre of the stake.

- Cut a slot with an iceaxe pick or snow saw for the cable
- Hammer the stake in 10° back from perpendicular to the surface until the attachment point reaches the bottom of the slot. 10 cm to 15 cm of stake will be left protruding from the snow if using an iceaxe pick.
- Pull the cable tight at the front

The reduction of depth of the stake through losing some length is made up through pulling from closer to the centre, this more evenly spreads the load and reduces the pressure on the snow near the surface. This now means that the anchor will most likely fail in shear. Although

the stress cone has been reduced by only having 45 cm to 50 cm of stake in the snow the shear strength of the cone produced will be far higher than the strength of the full stake pulled from its top.

Testing indicates that this should produce a very strong anchor of greater than 10 kN with a standard sized stake in snow of knife hardness. Actual strength will depend on the size and strength of the anchor materials and how well it is placed. The weakest link is likely to be the attachment cable.

3. Snow that is hard that can not be compacted back into a trench and can not have a slot cut into it



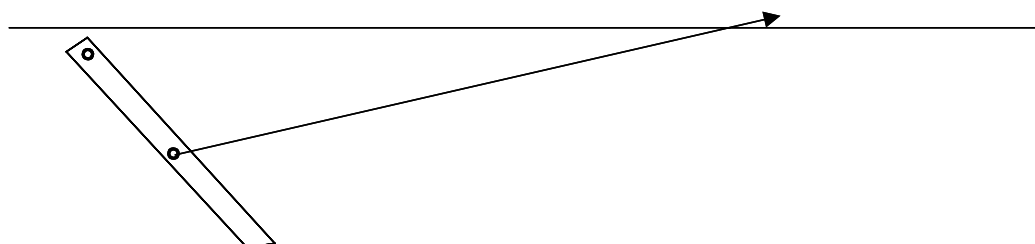
- Hammer the stake in 10° back from perpendicular
- If using a belay off of your waist with this style anchor attach to it at least 1.5 m away so that any upwards force on it is minimised. If belaying off of anchor ensure rope stays close to surface when under load and does not go up over anything.

Testing indicates that in knife hardness snow with a standard sized stake that this should produce a reasonably strong anchor of 7 kN to 10 kN depending on the strength of the anchor material and how well it is placed.

4. Snow that is weak and cannot be compressed to make stronger snow. That is bonds will not form easily through pressure. (Very wet snow or very cold snow)

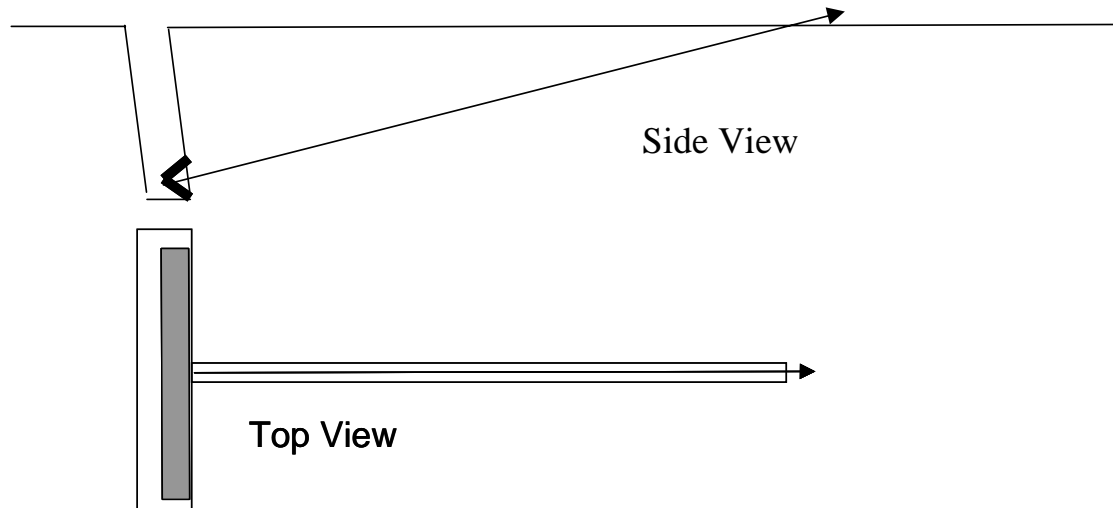
There are two choices with this. If you have an anchor with a cable attachment they can be used as snow pigs where an upright mid clip is leaned back so that it will dive down into the snow. Leaning the stake back 45° will produce this. This diving effect can also be a problem as the anchor could hit a hard layer and lean back further which will cause a loss in strength. The other choice is a horizontal mid clip (T-slot). This is the only choice available when a wired stake is not available or in very weak snow when a large object needs to be buried. With both sorts of anchors in this sort of snow avoid damaging the snow in front of the anchors.

Snow pig



- Push stake into snow 45° to the surface and pull wire down into snow.
- Be aware that the anchor will pull down into snow under load and that it could lean back further and become weak if it hits a hard layer.

T Slot



- Dig a trench a few degrees less than perpendicular to the slope as long as the object to be buried as deep as is practical but at least 40 cm preferably 60 cm
- Cut a narrow slot at right angles to this for the attachment. The deeper the trench and the longer the slot the more snow the anchor has to pull through before coming out.
- Backfilling is optional but may help the anchor sit in the right orientation when it is not under load.

Strength is very variable with either style of anchor in weak snow that will not compress to form stronger snow. Testing indicates you can get strengths of up to 7 kN with a standard sized stake depending on the strength of the anchor materials, how well it is placed and the bond strength of the snow. In snow softer than pencil hardness, 4 kN is likely to be the maximum strength with a standard sized stake. There will also be times particularly in soft cold snow conditions or in very wet snow when it will not be possible to produce a workable anchor with standard climbing equipment. Burying a larger object as a T-slot, such as a ski, snowboard or pack or large bag full of snow and getting that as deep as practical can be effective as strength in this sort of snow is dependent on surface area.

Because snow pigs dive when the loads exceed the compression strength of the snow this means that they will have more snow to pull through than a T-slot, which has a fixed amount of snow to pull through. While this means they should be able to sustain a longer load than a T-slot there is also a risk that they will strike a hard layer and flatten out which will reduce their strength.

Conclusion

There are many snowstakes in use currently that would not be strong enough to handle the upper end loads that a snowstake could be placed under. Some of the techniques that are in use at present such as, not disturbing the snow in front of an anchor in any circumstances or putting multiple pieces of equipment in close together or having the point of the V to load when building a mid clip anchor do not let the users derive the maximum strength from their placements. Although I have no direct evidence to prove it, I am fairly sure that a lot of users do not have a good understanding of the strength of the snow anchors they are using and are probably over estimating the holding power of the anchors they are building.

I think that because snow anchors do not come under the upper end of the loads they could be subjected to (6 kN to 10 kN) very often, that catastrophic failures are infrequent with users. However I would think that there are many people who are operating very close to the failure limits of their snow anchors without realising that. If users of snow anchors were to adopt the following objective and strategies then the chances of snow anchor failures would be minimised.

Objective

To quickly produce a snow anchor that will not fail under the expected loads

Strategies to achieve this

- Be aware of the factors that effect snow strength
- Be aware of the likely loads for the situation
- Know a variety of techniques that will cope with the combinations of snow and loads
- Increase snow strength if possible
- Get anchors as deep as possible
- Pull from the centre of the anchor as much as possible
- In weak snow have as large an anchor as possible
- Use anchor materials and attachments that exceed 10 kN in strength
- Use good quality rope when climbing
- Use a 10:1 load safety factor for rescue

The three key things are to increase snow strength, get anchors deep and pull from the middle.

Further testing requirements

More testing is required in order to quantify aspects of snow anchor placement and strength.

The things that have been identified when doing this document are:-

- Working out the best angle to lean an upright anchor back in order to keep it below the snow surface as it fails under compression.
- How much influence the shape or orientation of the buried object has on shear failure.
- How much influence the shape of the buried object has an on compression failure.
- The best materials to use for snow anchors and their attachments.
- The most appropriate size for a snow anchor.
- Whether further refinements to the snowball test or other simple tests can give users a better idea of likely anchor strength.
- Whether anchors behave differently when subject to dynamic loads.

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Fortini presentation “On the Use of Pickets and Flukes as Snow Anchors” given by Art Fortini of the Sierra Madre Search & Rescue Team to the International Technical Rescue Symposium, Denver, CO, November 2002