ALPINE SNOW AND ICE CLIMBING MANUAL: 2012

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i. Introduction

This document provides instruction for climbing on snow and ice covered slopes. It is meant to serve as a hazard management resource for mountain rescue personnel and should supplement, not replace, formal training in basic mountaineering. The climbing techniques described were selected following a review of the snow and ice climbing literature, and surveys and interviews with more than fifty alpine guides, experienced mountaineers, and mountain rescue professionals. Climbing techniques and equipment were also evaluated using computer modeling, and through field tests and studies funded in part by the Mountain Rescue Association and the New Zealand Mountain Safety Council. Every effort has been made to rely on objectively derived data, best practices, and authoritative consensus. Be that as it may, climbing snow and ice covered mountains is a most decidedly dangerous endeavor.

Despite the inherent dangers, or perhaps because of them, more people are climbing on snow and ice than ever before. Leading a route on steep snow and ice can be both thrilling and unnerving. Millions of people have climbed in alpine environments in North America, thousands have had accidents, and hundreds have died. Successful climbing careers are marked by those adept at assessing and mitigating risks. To this end, climbers must be cognizant of their skill level and the level of risk they are willing to accept. Although climbing accident reports show that some victims made foolish mistakes, many more were reasonably attempting to mitigate hazards. Too often they failed to recognize the rift between the perceived and actual hazards. It is hoped that this manual will help narrow that rift.

So what are the most common hazards faced by alpine climbers? Between 1951 and 2010 the American Alpine Club (AAC) documented over 3000 snow and ice climbing accidents. AAC data reveals that the direct causes of most alpine climbing accidents are those you would expect: Climbers fall onto hard objects and hard objects fall onto climbers. Likewise the injuries most frequently sustained are those we encounter when the laws of motion meet soft tissue and bone.

Practicing poor technique and exceeding abilities figure prominently among the indirect causes of alpine accidents. AAC data also reveals that a significant number of accidents take place due to environmental hazards. Accident victims frequently fail to stay warm, or travel and navigate in an unsafe manner in foul weather. They experience medical conditions associated with the cold and elevation such as hypothermia and reduced mental and physical capacities. Although these conditions sometimes form the basis for a mountain rescue in themselves, more often they are an indirect cause of accidents. When climbers find themselves fatigued, cold, dull, and traveling on steep slopes in low visibility, they are simply more likely to fall. Below is a summary of the main causes and effects of alpine mountaineering accidents.

Top Five Direct Causes of Snow & Ice Climbing Accidents

1. Fall on Snow/Ice
2. Rock/Ice Fall
3. Avalanche
4. Exposure
5. Loss of Control Glissading
Top Five Indirect Causes of Snow & Ice Climbing Accidents

1. Climbing un-roped
2. Exceeding Abilities
3. Placing No/Inadequate Protection
4. Inadequate Equipment/Clothing
5. Weather

Top Five Injuries Sustained in Mountaineering Accidents

1. Fracture
2. Laceration
3. Bruise
4. Sprain/Strain/Abrasion
5. Exposure – cold related medical conditions

Top Four Causes of Slips and Falls on Snow

1. Poor foot work/technique while wearing crampons, e.g., “dragging and snagging”
2. Snow balling up under crampons
3. Inattentiveness
4. Leaning too far back while descending/improper body positioning

Top Four “Problems” Alpine Guides Experience with Clients in the Mountains

1. Fatigue
2. Inadequate physical fitness
3. Climbing beyond their abilities
4. altitude sickness/impairment

\[1\] Mountaineers are far more likely to sustain bruises, sprains, strains and abrasions than fractures and lacerations. However such injuries typically do not require rescue so go unreported.

\[2\] Based on a 2011 survey conducted by the author. Over 50 alpine guides, experienced alpinists and rescue mountaineers from seven countries were surveyed or interviewed for this manual. They average over 27 years of mountaineering experience each, including 12 years of guiding experience. They spend an average of 124 days a year climbing in alpine terrain. Over half are Himalayan veterans who have climbed above 20,000 feet, two thirds have climbed in the Andes and/or the Alaska Range, and over ninety percent have climbed in the Alps. By any measure, these are veteran practitioners of snowcraft. Survey findings are shared throughout this manual where ever you see “Proview”.
It is an hour before dawn. We are stepping into our snow shoes at the trailhead near Dagger Peak in the high Sierra. You are with three members of your search and rescue team. The objective today is to climb the Peak. We have a thirty minute approach to the base and a 3,000 foot climb ahead of us. If all goes as planned, we will summit and be back at the trailhead by 1 p.m. The weather forecast for this morning is clear skies, temperatures in the 20s and 30s with light winds from the west. The afternoon is less certain. They are predicting partly cloudy conditions with westerly winds from 15 to 20 MPH. Today’s high temperature is expected to peak at about 40°F. We drink lots of water and conduct an avalanche transceiver test at the trailhead. All our transceivers give a strong signal. You mark the location on your GPS unit and we hit the trail. We find that snow conditions on the approach are good. Our snow shoes crunch and compress a surface snow that is not too icy. As the dawn light hits the upper peaks we look around for signs of avalanche or unstable snow. None are seen. According to the Sierra Avalanche Center, avalanche hazard is low in this area, especially on southwest facing slopes like the one we hope to climb. We reach the base of our climb and you mark this point on the trail on your GPS unit before we head up into the trees. We ascend the slope in our snow shoes, taking care to avoid tree wells and ground vegetation that could cause us to “post hole” through the snow. We are now traveling in pairs, staying within earshot of each other, but spread out horizontally across the slope.
Before we emerge from the tree line, we drop our packs and take a few minutes to test the snow. You locate a relatively safe and protected area and start digging. We isolate a column of snow from the slope and conduct **Extended Column Test (ECT)** test. Because the layers of snow in the column do not shear or propagate when impacted, we feel we are traveling on a pretty stable snowpack. Thanks to the recent freeze-melt cycles on this southwest facing slope, the eight inches of snow that fell last week has consolidated and bonded to the layer below. So avalanche hazard appears low, at least here near the tree line. While carrying out our ECT we also test the snow’s ability to hold snow pickets. You take a handful of snow from each layer in the column and try to compress it into a snowball. You throw the snowball to see if it stays intact. You were able to make and throw snowballs from the snow in all the layers. Although the snow in some layers compressed a bit more than in others, all the layers passed the **Snowball Test**. You also check the snow’s density by trying to press your fist, then four fingers, then one finger, and then a pencil into each layer of snow. You could not push your fist, four fingers, or one finger into the layers, but the pencil went in. So the snow is “pencil hardness”. The Snowball and **Snow Hardness Test** tell us that, in theory, snow pickets will each hold 4 kilonewtons of force in this snow. With this information we can decide which climbing techniques to employ. The team will opt for **Sierra** or **Vertical Mid-clip** picket placements today. The snow tests took us about 10 minutes. It was cheap insurance. If the snow did not pass these tests we would have turned around leaving this climb for another day. We always have a Plan B, but snow conditions appear favorable and the climb is on.

We pack our snow shoes, pair up, and begin **Free Soloing**. The slope is moderate, wide open, and there is a safe and gradual run out should someone fall. We spread out across the slope, taking care not to climb directly above or below other climbers. We zig-zag up the slope, mixing American, German and French step techniques as needed. The snow crunches and compresses with each step. The snow conditions are ideal for Free Soloing and we move quickly gaining over 1000 vertical feet before the sun reaches the top of the slope. One team member uses two trekking poles to ascend, another uses an ice axe with one trekking pole, while your partner opts for just an ice axe. A fall here would be relatively easy to arrest with an ice axe or a trekking pole. We are on **Class 2** alpine terrain.

After an hour of climbing the slope begins to steepen. The slope above is even steeper so the team decides to stop and put on crampons. We do not wait until we are on steep slopes to put on our crampons. The snow also feels a bit different under foot here. There seems to be more ice in the snow. The last of our trekking poles is stowed in favor of ice axes. We reach a few icy patches and the other team chooses to take out their rope and employ a **Stomper Belay**. The more experienced climber leads, belaying his partner up. We continue on, Free Soloing.

Our plan is to reach the ridge above and follow it to Dagger Peak. Looking up, we see three gullies, or couloirs, below the ridge. We will need to climb one of these gullies to gain the ridge. We are in a race against time. With temperatures predicted to peak at about 40°F we need to reach the peak by noon and get down before the snow turns to slush. We set a turnaround time of 11 a.m. If we are not on the summit ridge by 11 a.m., we will go down.

The slope steepens to about 40 degrees. You and your partner rope up and begin employing a **Rocking Belay**. The Sierra snow picket placements seem to be holding well in the consolidated snow. This works well for us and we all make good progress.
It is time to select a line to the ridge so the team comes together to scope out the gullies above with a monocular. The gullies start at about a 45 degree slope but then steepen considerably below the ridge. One of the three gullies looks very steep below the ridge, perhaps 80 degrees. It is a mixed climb of rock and ice at the top. We all agree that we do not want to climb it. The monocular reveals that the middle gully is chocked with ice and may not be passable. The remaining gully looks clear and is our best bet.

We continue our ascent, reaching the entrance to the gully at about 9:30 a.m. The gully is too narrow and steep to continue employing the Rocking Belay. The center of the gulley is icy. It is also a funnel for objects that would come down from above, the “bowling alley.” You let out some rope from your Kiwi Coil and we begin employing a Picket Line. The Lead climber ascends, placing a line of pickets along the edge of the gully and clipping the rope to each picket while on belay from the Second climber below. She places the pickets closer together at the bottom of the pitch, and then spreads them out as she ascends. Spacing pickets in this manner reduces the Fall Factor or the impact force of the fall. Once at the top of the pitch, the Lead belays the Second up. The Second “cleans the route”, pulling the pickets on the way up while on belay from above and then leads through. We are “inch worming” up the gulley. The team climbs several pitches employing the Picket Line until the slope gets steeper.

The team is now feeling the exposure. The gully is littered with boulders and would make for a bad place to fall. We recently passed the angle of repose. The angle of repose is essentially the point where objects sitting on the slope such as loose rocks, snow, ice and humans are more likely to be pulled off the slope by gravity than held in place by surface friction. The angle of repose is between 35 and 40 degrees for most objects on this slope. Our bodies instinctively sense that we have passed this threshold. After all, we are objects on a slope and the laws of motion apply to us. The slope now exceeds 45 degrees. We are in Class 3 alpine terrain.

As the other team climbs above, small pieces of rock, snow, and ice tumble down the gulley past our position. The climbers above are trying not to climb directly above us, but the gully limits the amount of lateral movement they have. Someone yells “rock” and you hear, and then see, a football-sized rock tumbling down the gully. The rock poses no threat to you, but you can feel the tension building as the consequences of our position becomes evident. Although the snow is still good for climbing, you realize that you would not want to down-climb this gully in slushy snow.

As the gully approaches 55 degrees, you and your partner shorten the rope between you and place pickets closer together. You are employing a Picket Line-Steep angle. She leads the pitch while you leave very little slack in the belay line. You also ensure that there is rope available to slip through your belay device should she fall. If she falls, she will slide until arrested by the last anchor she placed, the top anchor. By allowing some rope to slip through your belay device, you will reduce the peak force placed on the top anchor during her fall. You will, in effect, disperse some of the kinetic energy released during her fall over both time and space. She understands that the snow below the top anchor will theoretically only hold about 4 kilonewtons of force, so she keeps the pickets close together and in a straight line and chooses her moves carefully. The reality is this is no place to fall. A fall here must be short and the top anchor must not fail. But she does not fall and as she belays you up, the slope reaches 65 degrees. Spread out above you is a headwall of mixed snow, rock and ice. You are entering Class 4 alpine terrain.
You volunteer to lead the final pitch up the gully. You begin kicking steps. You front point with your crampons and then drive the shaft of your ice axe deep into the snow above with both hands before each advance. You have shortened the rope to 25 feet now and are placing pickets closer together and taking care to be deliberate with your foot and axe placements. You lose your footing once but self-belay immediately with your ice axe. You slide less than one foot. The snow is firm and the picket just below would have stopped you even if you had failed to self-arrest.

You reach the top of the gully and self-belay with your tethered ice axe. It is time to build a strong anchor. You stagger two sierra picket placements cross slope about two feet apart, then connect them with webbing, making a redundant, narrowly vectored, and fairly well equalized anchor. This makes for a solid belay anchor. You belay your partner up to discuss your next move. You are about twenty feet below the ridge now and the snow gives way to water ice. Snow melt running into the gully has frozen to a thickness of several feet. You will not be able place snow pickets here.

The lead team placed several **ice screws** in the water ice above. You will use them for protection when you climb the ice. The ice is of moderate steepness, perhaps 60 degrees. You are looking at “low angle” water ice or **WI2**. Your partner will belay you from her current stance as you climb. You clip the rope to the ice screw placed near the bottom of the ice, **Anchor #1.** This will significantly lower the Fall Factor should you fall at the start of this pitch. You remove the ice tool from your pack and strap it to your arm. You unclip the ice axe tether from your harness and strap that to your other arm.

You swing the pick of your axes into the ice above, and then kick the front points of your crampons into the ice below. As your front points penetrate the ice, they give a sound and feel that tells you your placements are solid. You climb, taking care to keep your heels low while trying to maintain three points of contact in the ice when possible. With each advance you shift your center of mass onto the support leg, freeing the other leg to step up. You reach the second ice screw after about four feet of climbing. You feel a great sense of relief as you clip the rope into the quick-draw hanging from the screw. You rest for a moment, shaking the blood back into each arm before continuing up the ice which gets easier. You ascend quickly, following the rhythm: advance, squat, stand, swing, advance… easily clipping the rope to the three remaining ice screws. You gain the ridge, and then belay your partner up. She leaves the belay anchor in place at the bottom of the ice. You will use it again on the way down. It is 10:30 a.m. and you are on the summit ridge. You walk passed the wands marking the top of the gully that were placed there by the lead team. You also mark this spot as a waypoint on your GPS unit.

You follow the ridge favoring the windward side, taking care to not wander out onto the leeward cornices. The ridge is about eight feet wide and is not particularly steep so you unrope and Free Solo to the peak. From here you can look down the northeast face. The mountain has a convex shape on the northeast side and there are signs of slab avalanche releases just below the bulge. You know those slabs released more than a week ago because last week’s snow overlies the crown fractures. You are on top by 11:00 a.m. Your pre-dawn “**Alpine Start**”, cardio and strength training have paid off as your team is the first to reach the peak today. Below, you see two teams of climbers log jammed near the top of the gully. There is a climber on the water ice just below the ridge. He is struggling and appears to be unwilling or unable to go up or down.

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3 The use of ice ax tethers on water ice is a matter of personal preference.
You take a couple photos and notice clouds coming in from the west as forecast. They look pretty low and may cover the upper-mountain, impacting visibility.

You descend the ridge and reach the gully just as the other climbers are coming off the ice. You pull your wands, and then clip into the top ice screw. You use your spare 18 cm. ice screw to bore holes in the ice for two **Vertical A-thread** anchors. You thread webbing through the holes add a rappelling ring, creating a redundant, properly vectored, and fairly well equalized multipoint anchor. You thread the rope through the rappelling ring, put knots at the ends of the rope, and perform a safety check on your partner before she rappels down the ice. She clips the rope to all the ice screws on the way down then secures herself to the snow picket anchor left in place at the bottom of the ice. You remove your ice screw and rappel down, removing the ice screws as you descend. You reach the bottom of the ice, and pull the rope down, leaving the A-thread rig in place. The climbers above will likely use your A-threads to get down. Although you are relieved to be off the ice you still need to negotiate a Class 4 descent in the gully.

It is just after noon, the thermometer on your pack reads 40 degrees, and you need to go down. Clouds are creeping up the slope and will soon cut off visibility. The surface snow has changed since you climbed up the gully. It is getting wetter and softer. In two hours this slope will be slushy. You place a picket and belay your partner down as she leads a **Picket Line-Steep**. She down-climbs, kicking steps and placing pickets closer together as she descends. At the bottom of the pitch she places a picket, drops down five feet, drives in her tethered ice axe, and belays you down from below. You down-climb, pulling the pickets as you descend, and taking great care not to slip. A fall from seven feet above a picket would result in a fourteen foot fall. The snow is getting softer and may be losing holding strength. With midday temperatures, the safety margin of your climbing system is reduced. A half dozen 30 foot lead through pitches employing the Picket Line-Steep brings you to safer ground.

Back on steep Class 3 terrain, you let out more rope, space the pickets further apart, and employ a **Picket Line**. There is more sound in the gully now. As expected, rock and ice fall have increased as the day has progressed and you are glad to reach the bottom of the gully. The slope quickly drops back below 45 degrees. You unrope and move quickly now. Your partner chooses to plunge step down while you down climb. Her method of descent is faster while yours is more secure. Finally you both remove your crampons and glissade the final 1000 feet to the tree line. Once at the bottom you notice that the wind has picked up and the ridge is covered in clouds. Hopefully the climbers you passed on the ridge managed to find the top entrance to the gully and are on their way down. The snow is getting too sloppy for them to move quickly now, and rock and ice fall in the gully will be a real concern. They will probably make it down safely, but they face increased exposure to objective hazards, they are more likely to fall, and their anchors and axes are less likely to stop a fall.

You step back into your snow shoes and walk out. You timed it right, exercised good judgment and technique, and had a good day out.

**Debrief**

Let’s review our climb of Dagger Peak. Before arriving we reviewed the Sierra Avalanche Center forecast and planned our climb accordingly, selecting a southwest facing slope for our climb. We also reviewed recent weather for the area and learned that about eight inches of snow fell the previous week. We made sure the new snow bonded to the existing snow pack. We
carried and used avalanche transceivers and conducted an Extended Column Test near the base of the climb. We also looked around for obvious signs of instability in the snow pack.

The weather report for the day of the climb revealed that temperatures could peak at 40°F. We chose an alpine start to get off steep slopes before the snow could get sloppy. We set a turnaround time to ensure a safe descent and stuck to it.

We made good route finding decisions, using our GPS and/or wands at critical junctures, and made use of a monocular to scout the gullies.

We traveled on alpine terrain we rated as Class 2 to 4, and encountered an area of water ice we rated at WI2. We employed seven different techniques to climb, and four to descend. We made efforts to minimize exposure to objective hazards such as rock and ice fall and human projectiles.

We used the appropriate climbing techniques for the changing snow, slope and terrain conditions. When on steep slopes, we opted for stronger, more closely spaced picket placements to catch a short fall. We ensured that there was extra rope available to stretch and to slip through our belay devices in the event of a fall. We climbed up and down the snow slopes of our own accord and did not place our body weight on snow anchors. Our snow anchors were used for safety, not as direct climbing aids.

Even while exercising good judgment, we faced a few moments of exposure and vulnerability. We exercised extreme caution at the crux of the climb and descent, doubling up pickets on our critical belay anchor in the Class 4 section. All and all it was a relatively safe and well executed climb.
Part II: CLIMBING RATING SYSTEMS

Rating System for Alpine Terrain

Class 1: hiking on a maintained trail with little or no exposure. Serious injury from a fall is unlikely.

Class 2: scrambling, hiking off-trail on moderate slopes over uneven terrain, e.g., rocks, deadfall, thick vegetation, snow, talus, and/or scree, light to moderate exposure. Requires good balance and an occasional use of hands. A fall could cause injury.

Class 3: climbing/descending using your hands for balance in steep angle terrain, moderate to high exposure. A rope is sometimes used for safety. A fall could result in serious injury or death.

Class 4: full body climbing with hands and feet in near vertical terrain, high exposure. A rope is usually used for safety. An unprotected fall could result in serious injury or death.

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4 Lewis, p. 11; Military Mountaineering, Sec.1.6.
Class 5: full body climbing with hands and feet in vertical terrain. Requires the use of a rope and anchors, extreme exposure. An unprotected fall could result in serious injury or death.

Rating System for Water Ice

WI2 - low-angle, up to 60 degrees. With good technique an ice climber can ascend this grade with one ice axe. Grades beyond this typically require two ice tools.

WI3 - 60-70 degree ice with occasional near-vertical steps up to 4 meters.

WI4 - near-vertical climbing of up to 10 meters. Requires placing anchors from difficult stances.

WI5 - near-vertical or vertical climbing up to 20 meters. Requires placing multiple anchors from difficult stances.

WI6 - vertical climbing for an entire pitch of 30-60 meters with no rests. Requires top technique and physical fitness.
Part III: CLIMBING & DESCENDING IN TEAMS OF TWO

[photo here]

*Photo of two climbers on Rocking Belay, ground level image of rope running up slope to belay device secured to picket rig manned by 2nd in belay position.*

“There is no easy way into another world.”

James Salter, *Solo Faces*

In most cases, climbing in teams of two is the most efficient way to travel on alpine snow and ice. It takes about twice as long to climb using protection in teams of three. An exception would be glacier travel which favors three or four person teams for safety. Below we describe six climbing techniques for ascending, four for descending and one for traversing. This is not intended to be an exhaustive review of snow and ice climbing techniques. There are many excellent climbing techniques not described here. Moreover, those that are described have several variations that are not covered in full. The techniques discussed below were chosen following a review of the snow and ice climbing literature followed by surveys and interviews with experienced guides, climbers, and rescue mountaineers. The key to practicing good snowcraft is knowing which technique to employ in different conditions. That knowledge comes with experience.

**Definitions**

*Newton and Kilonewton: metric units of measure.* A Newton represents the force required to accelerate a mass of 1 kilogram (2.2 lbs.) at a rate of 1 meter per second squared. A Kilonewton (kN) is 1000 Newtons and adds up to about the amount of force generated by a 224 lb. object hanging idly on a rope.

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5 *Military Mountaineering*, Sec. 6.22.
Ascending Moderate Snow Slopes

Option 1- Free Solo

Ideal for Climbing on low ice, high friction snow with low exposure. Skilled climbers often free solo on moderate slopes with moderate or even high exposure.

Speed: highest
Roped Safety System Security: none

Free soloing is the fastest way to climb. Spread out and do not climb directly above or below your partner or other teams. Free Soloing presents climbers with a conundrum. On one hand, increasing climbing speed can increase safety by reducing the amount of time spent below objective hazards such as cornices, rock and ice fall. On the other hand climbing unroped presents obvious hazards: more ways to experience Newton’s laws of motion.

Option 2- Bucket Seat Belay

Ideal for Climbing on slopes with borderline exposure, and/or for short steep sections with moderate exposure. This “stance belay” works well when an experienced climber is paired up with a less experienced climber. Often used when free soloing is interrupted by short steep sections, exposure, or small areas of ice.

Speed: moderate

Preview: Half those surveyed stated that they employ the Bucket Seat Belay five or more times a year. None stated that they never use the Bucket Seat Belay.

[photo here]
(Bucket Seat Belay)

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6 None for roped safety system security means the climber is ascending/descending using only their ice ax, and/or trekking poles and feet to stop a fall. They are not on belay and must arrest their own fall. Low security means the roped safety system is designed to hold a slip, but not a fall. Moderate means the climber is ascending/descending with an ice ax while on belay and connected to some form of anchor designed (in theory) to hold an expected short fall. Higher security means the climber ascends/descends with their ice ax and is on belay and connected to multiple snow anchors, each designed to hold an expected short fall. Even “higher security” systems can and do fail.
Lead climber ascends tied in to one end of a rope. The Second climber remains in place at the bottom of the pitch. The Second climber drives her/his ice axe into the slope for security. The axe is tethered to her/his harness, belt or the waist and shoulder straps of her/his pack (self-belay).\(^7\) The Second holds the end of the rope on a bight but does not clip in to the rope.\(^8\) The Second feeds rope out to the Lead, ensuring that the rope does not tangle. When the Lead reaches the top of the pitch she/he digs out a “bucket seat” in the slope with the axe adze. The Lead drives her/his ice axe into the slope for security. The axe is tethered to her/his harness, belt, or the waist and shoulder straps of her/his pack (self-belay). The Lead sits in the bucket seat, runs the rope through a carabiner on their waist harness or Rescue Belt, and then around her/his hips and lower back (hip belay).\(^9\)

The Lead then signals to the Second that the Second is on belay. Once on belay, the Second clips the bight at the end of the rope to her/his harness, belt or pack waist and shoulder straps, then pulls their ice axe and ascends while being belayed from above. When the Second reaches the top of the pitch, she/he executes a self-belay with their ice axe, and then unclips the bight. Repeat as needed.

Note: this method of belay works well in softer snow where the “bucket seat” can be quickly dug out of the slope. It is not practical in hard snow. The Bucket Seat Belay is a marginal anchor and requires good technique. It should not be relied on to hold more than about 1 kN of force (body weight). The Bucket Seat Belay is designed to prevent a slip from becoming a fall. It is not designed to catch a fall. The Lead should be the more skilled climber. By using higher stretch ropes you can help reduce peak force placed on this marginal anchor.

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**Option 3- Stomper Belay**

**Ideal for Climbing** on slopes with borderline exposure, and/or for short steep sections with moderate exposure. This “stance belay” is appropriate when an experienced climber is paired up with a less experienced climber. Often used when free soloing is interrupted by short steep sections, exposure, or small areas of ice.

**Speed:** moderate

**Roped Safety System Security:** none for Lead, low for Second climber

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\(^7\) If you are going to tie a climbing rope to your belt, make sure to use a nylon Emergency Rescue Belt designed to sustain the forces associated with a slip or fall. You can also wrap webbing around your waist and clip in. This works for slips but waist belts and webbing can cause back injuries during a fall.

\(^8\) Obviously the Lead is climbing without protection. So why not have the Second belay the Lead up using his/her ice axe as the Belay anchor? In this scenario any fall by the Lead would be a Factor 2 fall (twice the length of the rope out). *In low friction, well consolidated snow conditions*, an ice ax belay will rarely hold a Factor 2 fall. So putting the Lead on an ice ax belay would make it quite likely that the Second would be pulled from their belay station if the Lead falls. The same applies to the Stomper Belay.

\(^9\) When employing the Bucket seat some climbers skip the hip belay and belay the Second using a Münter hitch off their belay carabiner. It is probably not ideal for the Lead to belay the Second up using a Münter hitch when in a Bucket Seat. In the event the Second falls, a Münter could create too much friction (2.5 to 3.5 kN) causing the belaying Lead to be pulled from her/his perch. If you do choose to use a Münter while employing a Bucket Seat Belay, ensure that there is very little slack in the rope, thus minimizing peak fall force applied on you, the human anchor.
**Proview:** The Stomper Belay is used far less often than the Bucket Seat Belay described above. Just under half of those surveyed employ the Stomper Belay one to five times a year. About one third never use the Stomper Belay.

Lead climber ascends tied in to one end of the rope. The Second climber remains in place at the bottom of the pitch. The Second climber drives her/his ice axe into the slope for security. The axe is tethered to her/his harness, belt, or the waist and shoulder straps of her/his pack (self-belay). The Second holds the end of the rope on a bight but does not clip-in to the rope. The second feeds rope out to the Lead, ensuring that the rope does not tangle. When the Lead reaches the top of the pitch she/he finds a small level area to set the ice axe. If there is no level area the Lead can make a small “platform” (about one square foot) in the slope by kicking a step and/or digging with the axe adze. The Lead drives their ice axe into the platform, clips a carabineer to the hole on top of the axe shaft, clips the rope to the carabineer, and stands on top of the axe with both feet facing away from the slope. The Lead runs the rope through a carabineer on his/her harness or rescue belt then up under one arm and around her/his shoulders to employ a shoulder belay. Neither a belay device nor a Münter hitch should be used by the Lead to belay the Second. In the event the Second falls, a belay device or Münter could easily add too much friction causing the Stomper anchor (the ice axe) to fail.

The Lead then signals to the Second that the Second is on belay. Once on belay, the Second clips the bight at the end of the rope in to her/his harness, belt, or pack waist and shoulder straps, pulls their ice axe, and ascends while being belayed from above. When the Second reaches the top of the pitch, she/he executes a self-belay with the ice axe, and then unclips the bight. Repeat as needed.

Note: this method of belay works well in harder snow where the Bucket Seat belay (described above) cannot be employed. It is not safe to employ Stomper Belay in soft or weak snow. The force that can be held by a Stomper Belay is about 1 kN (body weight). It is a marginal anchor that may hold body weight during a slip but it is not designed to catch a fall. The Stomper Belay

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10 If the snow is weak the Lead can dig a trench with adze of her/his ice ax and place the ax in the trench as a “T-slot” or “T-ax” self-belay anchor.
requires good technique and the Lead should be the more skilled climber. By using higher stretch ropes you can help reduce peak forced placed on this marginal anchor.

**Option 4- Rocking Belay**

**Ideal for Climbing** on open snow slopes with few protruding rocks, trees, or moguls. Good for climbs with some exposure.

**Speed:** high  
**Roped Safety System Security:** moderate

[photo here]  
*Rocking Belay*

Two climbers tie in together with enough rope to allow them to be spaced about 15 to 30 feet apart depending on snow strength, slope surface conditions, etc. Any extra rope can be wrapped in a Kiwi Coil, bagged or packed. The climbers spread out *horizontally* across the slope. Climber 2 places a Sierra picket.\(^{11}\) Attached to the picket is a four foot cable or runner. Attached to the end of the cable or runner is a belay device. The rope runs through the belay device to Climber 2’s harness. Climber 2 drops down about 5 feet below the picket. Climber 2 drives his/her tethered ice axe into the slope (self-belay). Climber 2 signals to Climber 1 that “belay is on.” The rope remains fully extended with no slack. Climber 1 ascends above Climber 2, stopping when up at about a 45 degree angle cross slope. She/he places a picket. Attached to the picket is a four foot cable or runner. Attached to the end of the cable or runner is a belay device. The rope runs through that belay device to Climber 1’s harness. Climber 1 drops down 5 feet below the picket.

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\(^{11}\) Rocking Belay should only be employed in snow conditions that are right for Sierra picket placements. Some climbers employ a Rocking Belay using Vertical Top-clip picket placements, but Vertical Top-clip placements are not well suited for Rocking Belay. Vertical Top-clip placement hold best when the force applied is perpendicular to the orientation of the picket, e.g., usually directly down slope. Sierra picket placements can better tolerate the slight multi-directional forces that can result from falls during a Rocking Belay.
and drives in her/his tethered ice axe (self-belay). Climber 1 now signals to Climber 2 that “belay is on”. Climber 2 pulls her/his picket and axe and begins climbing.

Climber 2 is now “on belay” from above. Climber 2 repeats the process by ascending from below Climber 1 to above Climber 1, stopping when at about a 45 degree angle above, cross slope. The rope remains fully extended at all times. Climber 2 places a picket, drops down 5 feet, and executes a self-belay with her/his tethered ice axe. Repeat.

Rope length can be adjusted as needed given terrain features. If the snow makes for sketchy anchors, the belayer can undo a few wraps from the Kiwi coil making rope available to slip through the belay device (dynamic belay). This will allow for addition force absorption during a fall. To speed things up, each climber can keep their snow picket out and rigged while climbing. Climbers can use the picket to assist with balance. The advantage of a rocking belay is that it makes for very quick climbing with protection.

If a climber falls on a rocking belay, they will pendulum down across the slope. A pendulum is effective at dispersing the kinetic energy of a fall. It increases fall time while decreasing falling speed.

**Note:** Although Rocking Belay is not a new climbing technique, I have found no published studies of the physics and forces at play during Rocking Belay falls. As with all climbing techniques, you should carefully exam this technique and employ it at your own risk.

**Option 5 – Running Belay or Simul-Climbing**

**Ideal for Climbing** where self-arrest is likely but where failure to self-arrest could have serious consequences. Often used on low or moderate angle ground above drop offs.

**Speed:** moderate to slow

**Roped Safety System Security:** low to moderate for Lead Climber, moderate to high for Second Climber.

| **Proview:** Many of those surveyed expressed concern about Simul-Climbing, stating that it is frequently employed in an unsafe manner. Of particular concern is its application on steep slopes where self-arrest is unlikely to work. |

[photo here]

(Running belay)
Two climbers tie in together with a given length of rope. The rope runs through a belay device on each climber’s harness. Any extra rope can be wrapped in a Kiwi Coil, bagged, or packed. The Lead places a picket (Anchor #1), clips the rope to Anchor #1 and prepares to ascend. The Second drives in their tethered ice axe (self-belay). The Second signals to the Lead that “belay is on.” The Second belays the Lead up off the belay device on the Second’s harness. The Lead places intermediate pickets as needed given rope length, snow conditions, and slope. The Lead takes care not to back clip the carabiners. After the second or third picket is placed and the rope is played out the Second pulls his/her axe and follows the lead up, pulling the pickets as he/she ascends. After the Lead places the Top Anchor, he/she drives in his/her tethered ice axe (self-belay) and belays the Second up off the belay device on the Lead’s harness. When the Second reaches the Lead the Top Anchor remains in place and becomes Anchor #1 for the next pitch up. The Seconds now becomes the Lead and then leads through. Repeat.

This is not the most efficient way to climb as two. It would be faster to use a Rocking Belay. This method does work well with three climbers. When employing the Running Belay as three the Second climber leaves the pickets in place and the Third climber pulls the pro and Leads through.

**Option 6- Picket Line**

**Ideal for Climbing** in narrow areas, in gullies and on slopes with too many protruding rocks, trees or moguls to make a Rocking Belay feasible.

**Speed:** moderate to slow  
**Roped Safety System Security:** moderate for Lead Climber, moderate to higher for Second Climber

**Proview:** Half of those surveyed climb using a picket line more than 10 times a year. Many of those who do use a picket line expressed concerns about the bulk and weight of carrying pickets and the slow pace of ascent.

Two climbers tie in together with a chosen length of rope. Any extra rope can be wrapped in a Kiwi Coil, bagged, or packed. The Second places a picket at the bottom of the pitch (the Belay
Anchor). Attached to the Belay Anchor is a four foot cable or runner. Attached to the end of the cable or runner is a belay device. The Second runs the rope through the belay device, drops down about 5 feet below the Belay Anchor and drives in their tethered ice axe (self-belay). The Second signals to the Lead that “belay is on,” and then belays the Lead up off the Belay Anchor. The Lead climbs, placing pickets and clipping the rope to each picket as she/he ascends. The pickets are spaced closer together at the bottom of the pitch and further apart towards the top of the pitch. The Lead takes care not to back clip the carabiners. At the top of the pitch, the Lead places the Top Anchor. Attached to the Top Anchor is a four foot cable or runner. Attached to the end of the cable or runner is a belay device. The Lead runs the rope through the belay device, drops down about 5 feet below the Top Anchor, and drives in their tethered ice axe (self-belay). The Lead then signals to the Second that “belay is on.” The Second pulls their pro and ascends. The Lead belays the Second up off the Top Anchor. The Second pulls the pickets as she/he ascends. When the Second reaches the Top Anchor he/she leads through, placing pickets on the next pitch. The Top Anchor stays in place and becomes the Belay Anchor for the next pitch up. Repeat.

**Ascending Steep Snow Slopes**

**Option 1- Picket Line-Steep**

**Ideal for Climbing** in complex narrow areas, in gullies, and on steep slopes. Same as above except rope is shortened and the pickets are spaced closer together as needed based on slope, snow quality, landscape features and exposure.

**Speed:** slow  
**Roped Safety System Security:** moderate for Lead Climber, moderate to higher for Second Climber

[photo here]  
*(Picket Line-Steep)*

**Descending Moderate Snow Slopes**
Option 1 - Free Solo

Ideal for Descending on low ice, high friction snow, with no dangerous run outs and low exposure. Skilled climbers sometimes free solo on slopes with moderate or even high exposure.

**Speed:** highest  
**Roped Safety System Security:** none

Descend unroped if conditions and abilities allow. Spread out and do not descend directly above or below your partner or other teams. You can plunge step (which offers speed with lower security), or down climb (which offers more security at the expense of speed).

Option 2: Bucket Seat or Stomper Belay

Ideal for Descending without pickets on slopes with borderline run outs, and/or for short steep sections with moderate exposure. Appropriate when an experienced climber is paired up with a less experienced climber. Often used when unroped down climbing is interrupted by short steep sections, exposure, or small areas of ice.

**Speed:** moderate  
**Roped Safety System Security:** Low for Lead Climber, none for the Second Climber

Descend with the Bucket Seat in softer snow and the Stomper in harder snow as described earlier in this section only in reverse order.

Option 3: Picket Line

Ideal for Descending in icy conditions, in areas with questionable run outs and/or moderate exposure.

**Speed:** moderate  
**Roped Safety System Security:** high for Lead Climber, moderate for the Second Climber

Two climbers tie in together with a length of rope. Any extra rope is wrapped in a Kiwi Coil, bagged, or packed. The Second places a picket, the Belay Anchor. Attached to the Belay Anchor is a four foot cable or runner. Attached to the end cable or runner is a belay device. The Second runs the rope through the belay device, drops down 5 feet and drives in their tethered ice axe (self-belay). The Second signals to the Lead that “belay is on,” and then belays the Lead down off the Belay Anchor. The Second does not “lower” the Lead down on rappel. The Lead plunge-steps or down cliffs without weighting the rope. The Lead places pickets and clips the rope to each picket on the way down. The pickets are spread out at the top of the pitch, and then placed closer together as the Lead nears the bottom of the pitch. The Lead takes care not to back clip the carabiners. At the bottom of the pitch the Lead places the Bottom Anchor. Attached to the Bottom Anchor is a four foot cable or runner. Attached to the end cable or runner is a belay device. The Lead runs the rope through the belay device, drops down about 5 feet and drives in
their tethered ice axe (self-belay). The Lead then signals to the Second that “belay is on.” The Second pulls their pro and descends while on belay from the Bottom Anchor below. The Second pulls all pickets on the way down. When the Second reaches the Bottom Anchor she/he leads through placing pickets for the next pitch down. The Second now becomes the Lead. The Bottom Anchor stays in place, becoming the Belay Anchor for the next pitch down. Repeat.

**Descending Steep Snow Slopes**

**Option 1: Picket Line-Steep**

**Ideal for Descending** in steep, icy conditions, above dangerous run out, and/or areas with high exposure.

**Speed:** moderate to low  
**Roped Safety System Security:** higher for the Lead Climber, moderate for Second Climber

Same as above except rope is shortened as needed. Again, pickets are spread out at the top of the pitch, and then set closer together as the Lead nears the bottom of the pitch. Some anchor points can consist of two redundant, properly vectored, equalized pickets if needed for added security.

**The Two + Person Traverse**

**Speed:** low  
**Roped Safety System Security:** moderate

![](Two Person Traverse)

Two climbers tie in together. The rope runs through a belay device on each climber’s harness. The Second climber places a picket at the start of the traverse (the First Anchor), clips the rope to the First Anchor, and then drops down below the First Anchor. The Second executes a self-belay with their tethered ice axe in as safe and protected an area as possible, and then signals to the Lead that “belay is on.” The Lead begins the traverse while on belay from the Second, placing intermediate pickets as needed and clipping the rope to each picket. While the Lead is on the traverse, the Second makes sure there is extra rope available to slip through the Second’s belay
device in the event of a Lead fall. This “dynamic belay” will help reduce the force placed on the traverse anchors during the fall. When the Lead reaches the end of the traverse or rope, she/he places a picket, (the Last Anchor), drops down about 5 feet below the Last Anchor, and executes an ice axe self-belay. The Lead then signals to the Second that “belay is on.” The Second pulls their ice axe and begins the traverse pulling all pickets on the way across. While the Second is on the traverse, the Lead makes sure there is extra rope available to slip through the Lead’s belay device in the event the Second falls. This will help reduce the vector force placed on the traverse anchors during the fall.

If there are more than two climbers who need to traverse, the Lead and Second can remain at their belay stations at their respective ends of the traverse. Other climbers can clip into the rope with a tether and traverse from just below the anchors. Again, the Lead and Second should make sure there is some length of rope available to run through their belay devices when safe to do so. They should allow liberal rope slippage through the belay devices in the event of a fall. This dynamic belay will help reduce the high vector forces applied to opposing pickets during a traverse fall.

Note: When traversing in avalanche hazard areas all belays should be hip belays. Neither of the Belayers should be tied-in to the rope.

**Other Climbing/Descending Options: Terrain Belays**

The climbing techniques outlined above assume climbers are traveling on open snow slopes with no natural anchors. However if the route you are climbing has rocks or trees (terrain belays) you should be opportunistic and use them as anchors. As discussed in Section IV below, snow pickets are often marginal anchors. Using a bomber tree or rock as an intermediate anchor or belay station is often better than using a snow picket. Build an anchor and/or belay directly off the rock or tree. With an ATC Guide, Reverso 3, or B-52 oriented in “progress capture” or “autoblock” mode, you can use terrain belays to bring two climbers up safely at the same time. Rocks can also substitute for bucket seat or stomper belay stations. Rather than building a bucket seat or stomper station, just sit or stand on a rock and belay your partner up or down.

[photo here]

*(Belaying off a rock in steep alpine terrain)*
Common Climbing Calls

Climbing calls are short and precise to avoid ambiguity.

“ON BELAY”
After the climber is tied in and safety inspections have been completed, the climber says this to inform the belayer she/he is ready to climb.

“BELAY IS ON”
The belayer replies indicating that the rope is properly oriented in the belay device, carabineer gates are locked, knots are tight, the belayer is in line with the belay, properly positioned, able to brake correctly, and she/he is ready to belay the climber.

“CLIMBING”
The climber says this to let the belayer know she/he is beginning to climb.

“CLIMB ON”
The belayer responds confirming that she/he is ready and the climber can climb on.

“TENSION”
Called by the climber requesting that the belayer tension the rope. The belayer acknowledges this call by responding with “THANK YOU.”

“TAking IN”
Called by the belayer to inform the climber that she/he will take up slack in the rope requested by the climber. The climber acknowledges this call by responding with “THANK YOU.”

“THAT’S ME”
Called by the climber to inform the belayer that the rope is taut and the belayer is now pulling on the climber. The belayer acknowledges this call by responding with “THANK YOU.”

“SLACK”
Called by the climber requesting that the belayer give some slack, usually during clipping or unclipping of runners or lead climbing. The belayer acknowledges this call by responding with “THANK YOU.”

“WATCH ME”
Also, called by the climber when making a difficult move or expecting a fall. The belayer acknowledges this call by responding with “THANK YOU.”

“OFF BELAY”
Called by the climber to inform the belayer that the climber is tied off to an anchor and is no longer dependent on the belay. The belayer acknowledges this call by responding with “THANK YOU.”

“ROPE!”
Called out to warn people below that you are lowering or throwing a rope down.
Part IV: On Traveling in Roped Teams without Using Anchors

“Without warning the man at the end of the line slipped, lost his footing, and shot down the incline... It was impossible for the next man to hold and one by one we were all swept down. It happened in a fraction of a second. The snow was so hard it was impossible to get our axes in deep enough to hold. We rushed down the slope at tremendous speed.”  

Dee Molear, *The Challenge of Rainier*

The efficiency and safety of alpine climbing has progressed markedly in recent decades. This is in no small part due to advances in the materials used in mountaineering equipment. The days of hemp rope, ash wood axe shafts and eight point crampons have passed into antiquity. Climbing techniques that were once taught based on tradition and lore are today put to the test in laboratories, garages, and field experiments across the globe. In applying the scientific method to our movements in the mountains, we have learned what we were doing right and what we were doing wrong. As a result, climbing techniques have changed and for the better. One traditional climbing technique that has lingered is the practice of traveling on steep snow slopes in roped teams without placing protection. Climbing roped together without placing “pro” is somewhat controversial. There are differences of opinion about this technique even among elite alpinists. Tackling this issue is like tackling a porcupine.

I know of only a few circumstances where it is widely agreed that traveling in roped teams without placing pro is the best way to proceed: One is when traveling on glaciers; another is

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12 The narrative is that of Leon Brigham, a surviving member of the “1929 Greathouse Accident” on Mt. Rainier.
when traveling on a ridge. There are also instances where mountain guides find it necessary to rope up to their clients without placing pro. Examples include short roping an impaired, inept or spooked client. These guides are essentially spotting their clients, knowingly increasing their own chances of falling in an effort to decrease their clients’ risk. Finally, sometimes teams travel roped up without pro on short sections of low angle ground between high angle pitches where protection will be used. This is not necessarily done for safety but simply because it is too much of a hassle to unrope only to rope up again.

But even if traveling in a roped team without pro is accepted in these circumstances, it remains controversial in many others. Much of alpine climbing involves traveling in unguided teams on non-technical snow fields. There is no clear consensus on traveling roped up without pro on snowfields.

The editors of *Accidents in North American Mountaineering* have identified two critical elements present in a significant number of alpine climbing accidents. They are:

1.) Climbers are roped together and not placing protection
2.) Climbers are unroped (and therefore not placing protection)

So what is a climber to do to stay safe? The obvious answer is to rope up and place protection. But this will slow you down. On some routes, it will slow you to the point that you must turn around before reaching the summit. In other cases it will slow you to the point where you must descend in slippery afternoon snow with increased rock and ice fall. You can buy some extra time by making an alpine start, but this has limitations. The alpine start works best when used to approach the base of the climb on non-technical snow fields in the dark. However, climbing in complex terrain or on glaciers in the dark presents its own set of hazards and route finding challenges. Indeed, the conundrum of climbing speed versus roped safety system security is not easily resolved.

**Ascending while roped up without placing protection**

In addition to the specific circumstances described above, I believe that traveling roped together without placing pro is advisable while *ascending* on low and moderate snow slopes where the chances of falling are low, the likelihood of self-arrest is high, and the likelihood of team arrest is high. This particularly makes sense when a skilled climber is paired up with a less skilled climber while climbing above drop offs. The skilled climber would serve as the lead on ascent, serving much the same role as an alpine guide. That said I do not see the sense in ascending this way if climbers are of equal skill, and especially if they are highly skilled. Skilled climbers typically free solo when the risk of a fall is low and self-arrest is likely. Roping up would only slow them down.

I would not ascend while roped up without pro on any slope where a fall is likely and where self-arrest and team arrest are unlikely to succeed. This may seem like a no brainer but there is quite a bit of misunderstanding about when self-arrest and team arrest are likely to work. Climbers often

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mistakenly believe they can stop the fall of roped teammates with a group arrest. The reality is that group arrest will simply not work in most cases. Consider the following example on a 35° slope: If roped climbers were spaced 24 feet apart (a typical spacing) when the 200 lb. top climber fell, the rope would go taut on the second after 2.4 seconds. The top climber would be moving in excess of 22 mph when the rope went taut.\textsuperscript{14} Self-arrest at such speeds is all but impossible. The second would be hit with more than 5.6 kN of force, the equivalent of suddenly belaying 1,256 pounds, or the weight of an adult horse. The fall forces at play here are simply too great for the second to hold with his/her ice axe pick and crampon points. It is not just a musculoskeletal issue. Snow, even hard snow, usually cannot sustain 5.6 kN of force when such force is concentrated in the small area occupied by an axe pick and crampon points. So it is very likely that the second would be ripped from his self-arrest position, fall, and in turn pull the next roped team member from his stance. This process would likely play out until all roped team members are “unzipped” and no one is left to hold the fall.

The above example makes clear that the top climber must not fall. If he does fall he has less than 1.5 seconds to stop himself before the energy released by his fall rules out self-arrest, even on a 35° slope. Furthermore, if he does not immediately self-arrest he will almost certainly take the rest of the roped team down with him.

\textbf{Descending while roped up without placing protection}

As a matter of course I consider it unwise to descend roped up on snow fields without placing pro. Conventional wisdom has it that alpine mountaineering falls are more likely on the way down.\textsuperscript{15} Some argue that climbers are more fatigued on descent as they have lost their edge and focus after completing their summit bid. This is certainly often true. Be that as it may, there are very practical reasons for alpinists to refrain from descending in roped teams without placing pro, not the least of which can be seen in the biomechanics of descent.

A descending climber’s advancing foot is not in balance with his torso when being placed. The descending climber must first move his torso down out of balance, and then plant his ice axe and advancing foot. An ascending climber in contrast, plants his ice axe and advancing foot first and then moves his torso up. So we are simply more out of balance when descending and are thus more likely to fall.\textsuperscript{16} Also, self-arrest with an ice axe is more difficult when walking down because we are facing away from the slope and thus our arms and feet are not oriented in the self-arrest position. When falling on the way down we must first roll our body 180 degrees and face the mountain before we are able to fully plant and weight our axe and feet in the slope. Doing this takes time, maybe two seconds for someone well practiced. The physics associated with falling for two seconds under these conditions does not make self-arrest a realistic option. For example, a 200 lb. climber falling on a consolidated 50 degree snow slope for 2 seconds will

\footnotesize{\textsuperscript{14} These figures were generated using the Splat and Junkfunnel fall force calculators, then deducting for slope.}  
\footnotesize{\textsuperscript{15} Data on climbing accidents does not support this bit of conventional wisdom. Accident data collected by the American Alpine Club covering thousands of reported incidents over the past 58 years shows that falls are actually more likely on ascent. The “problem” with the available AAC accident data is that it combines mountaineering and rock climbing accidents. The numbers are skewed since many crag falls occur on ascent. Data provided for the European Alps by Gottlieb Braun-Elwert specific to climbing in roped teams without protection showed that of the 75 such accidents from 1977 to 1982 at least 59 percent occurred while descending and resulted in 97 deaths.}  
\footnotesize{\textsuperscript{16} Gonzales, p. 120.}
be moving in excess of 26 mph.\textsuperscript{17} If the fall involve a team of climbers roped 20 feet apart, the falling top climber will place more than 7.4 kN of force on the Second when the rope goes taut. This is the equivalent of belaying 1,673 lbs., or the weight of an old VW Bug. For this reason, some alpinists prefer to free solo up and then rope up and place protection on the way down. Although physics reveals that descending roped up without pro is a dangerous way to proceed on steep slopes, many alpinists continue to descend this way.

**Short Roping**

Many alpine guides and rescue mountaineers assist climbers up or down snow slopes by applying the short roping technique. As its name indicates, short roping involves climbers being spaced a very short distance apart, typically about 1-3 meters. The American Mountain Guide Association defines short roping as “*the use of a small portion of the rope to lead clients through exposed terrain in such a manner as to safeguard clients from the possibility of a slip or fall by both reducing the likelihood of a slip and by arresting a slip before it becomes a fall.*”\textsuperscript{18} Nearly all 50 alpine guides surveyed for this document said they regularly short rope clients both up and down slopes.\textsuperscript{19} Short roping works when practiced correctly and only when the top climber does not fall. Safe short roping requires considerable concentration by the top climber. Studies show that a standing top climber (guide or rescuer) properly short roping a second (client or subject) can stop the second’s slip to a level roughly equivalent to 80 percent of the top climber’s body weight. The average second’s slip equals about 70 percent of the second’s body weight. *It is therefore imperative that the top climber be of greater weight than the second.* Any fall force beyond 80 percent of the top climber’s body weight could easily pull the top climber from his stance leading to a top Climber fall.\textsuperscript{20} The basic physics of short roping as detailed above also calls into question the practice of short roping more than one person at a time.\textsuperscript{21}

If a team of three short roped climbers were spaced 3 meters apart on a 40° slope, the falling top climber would have about 1.4 seconds to self-arrest before the rope went taut on the second. So any self-arrest attempt by the top climber had better succeed on the very first try. If not, the second would quickly be hit with about 5.9 kN (1330 lbs.) of peak force. Even in the event that

\textsuperscript{17}These figures were generated using the Splat and Junkfunnel fall force calculators, then deducting for slope.

\textsuperscript{18}Alpine Guide Course Manual, p. 54.

\textsuperscript{19}Based on a 2011 survey conducted by the author.

\textsuperscript{20}James, p. 191; Studies were commissioned following the death of a guide and two clients who fell while short roping in New Zealand in 2005. The accident investigation raised fundamental questions about the physics associated with lighter guides short roping heavier clients and the practice of guides short roping multiple clients.

\textsuperscript{21}In 2005 Physicist and long-term Alpine Guide Gottlieb Braun-Elwert evaluated 256 short roping slip/falls in a laboratory environment. The video recorded tests revealed that on a 30 degree slope the top climber (Guide) can hold a maximum fall force of 0.5 kN on the rope before being pulled off balance and into a slip or fall. Moreover, if the top climber was in mid stride (with one foot off the ground) when the second climber (Client) slipped, the Guide would not have the leverage required to prevent the client’s slip from becoming a fall and may well slip or fall himself. Braun-Elwert’s work suggests that under the best conditions, a guide’s ability to hold a client’s slip is roughly the same as the force generated by the “average” client’s slip. With regard to the practice of guides short roping more than one client, Braun-Elwert concluded: “*The chances of a guide holding two clients on such a slope appear to be very slim indeed.*” Some guides expressed skepticism about Braun-Elwert’s findings. A follow up field test was conducted in New Zealand in 2006. All participants were experienced Alpine Guides. Guide and client were on a 30 degree slope of firm snow with 2.5 meters of taught rope between them. The slips/falls were video recorded and forces were measured with a dynomometer. The field tests yielded essentially the same results as Braun-Elwert’s laboratory tests.
the second managed to get into the self-arrest position, he would have no chance of arresting the top climber’s fall. The second would be ripped from his/her moorings, fall, and do the same to the third short roped climber. The third would have the advantage of having 3 seconds to get into the self-arrest position, but it would make no difference. The third would be hit with the force generated by two falling climbers. The peak force on the third would exceed 8 kN, about 1800 lbs. It is difficult to imagine how anyone could stop this process from playing out once the top climber fell and failed to instantly self-arrest.\textsuperscript{22} Even if the fall took place on a 30° slope, it seems to me the fall time is too short (1.56 seconds) and the fall force is too great (4.6 kN / 1030 lbs.) to make either self-arrest or team arrest feasible.

Table 1. below assumes climbers are traveling roped 3 meters (9.8 feet) apart on consolidated snow when the 200 lb. (91 kg.) top climber falls. Remember that when the top climber falls from three meters above the second, he will actually fall 6 meters (19.6 feet) before the rope goes taut on the second.

<table>
<thead>
<tr>
<th>Fall Distance (19.6 feet)</th>
<th>Slope</th>
<th>Time until Rope Taut on 2nd</th>
<th>Speed of Top Climber</th>
<th>Force Placed on 2nd</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 meters</td>
<td>90°</td>
<td>1.1 Seconds</td>
<td>39 km/hour (24 mph)</td>
<td>9.2 kN (2070 lbs.)</td>
</tr>
<tr>
<td>6 meters</td>
<td>50°</td>
<td>1.26 Seconds</td>
<td>34 km/hour (21 mph)</td>
<td>7 kN (1580 lbs.)</td>
</tr>
<tr>
<td>6 meters</td>
<td>45°</td>
<td>1.32 Seconds</td>
<td>33 km/hour (20 mph)</td>
<td>6.5 kN (1460 lbs.)</td>
</tr>
<tr>
<td>6 meters</td>
<td>40°</td>
<td>1.38 Seconds</td>
<td>31 km/hour (19 mph)</td>
<td>5.9 kN (1330 lbs.)</td>
</tr>
<tr>
<td>6 meters</td>
<td>35°</td>
<td>1.46 Seconds</td>
<td>30 km/hour (18 mph)</td>
<td>5.3 kN (1190 lbs.)</td>
</tr>
<tr>
<td>6 meters</td>
<td>30°</td>
<td>1.56 Seconds</td>
<td>28 km/hour (17 mph)</td>
<td>4.6 kN (1030 lbs.)</td>
</tr>
</tbody>
</table>

The debate on short roping would be over if this table told the whole story. It is far from that simple. In some cases the falling top climber can get his ice axe partially in, slowing himself sufficiently to allow the second to catch their fall. It is also often the case that climbers short rope in unconsolidated snow conditions. Soft snow places a considerable amount of surface friction on the falling climber, slowing the fall and making team arrest feasible. Alpine guides have stopped countless client stumbles from becoming falls. So properly executed short roping has saved many lives just as improperly executed short roping has taken lives. The short roping technique functions at or near the margins of roped safety system failure on consolidated snow slopes above 30° and is best left to skilled alpine guides and rescue mountaineers. Any person considering serving as the top climber on a short rope team must have exceptional skill in the short roping technique.

In his 2003 book \textit{Deep Survival}, Lawrence Gonzales profiled a 2002 climbing accident on Mt. Hood in Oregon. The climbers profiled were descending in a roped team without placing protection. Several fatalities resulted when the top climber fell, pulled his team off, and “flossed” a roped team below, carrying some of them to their deaths. In 2007 and again 2009, I climbed

\textsuperscript{22} In the annals of mountaineering, there are a few accounts of roped climbers catching the fall of 2 and even 3 teammates with an ice ax on steep snow and ice. Although these stories seem to defy the laws of physics and human ability, many of them are factual; I group them with other survival stories where people accomplish the seemingly impossible.

\textsuperscript{23} Speeds were rounded off to the nearest whole number.
the route profiled by Gonzales. Five and seven years after the accident, most of the roped teams I observed on the route were still climbing roped together without placing pro. The photo below shows roped teams both ascending and descending the route roped up without pro. This route includes a 60 degree section. Ice axe self-arrest on a 60 degree consolidated snow slope is all but impossible. If “Team A” fell while ascending, they would have flossed “Team B” descending directly below.

![Photo by TPM, 2007](image)

The consequences of a fall here are grim. One thousand feet below the ridge the slope funnels all falling objects into a steaming volcanic vent spewing a hydrogen sulfide gas. No one who craters into that hole comes out alive. Any rescue there is impossible. To avoid being flossed by the bundles of human projectiles above, I opted to free solo a steeper slope off to the side.

Although climbing roped together without placing pro defies simplification, certain truths do apply. The physics of this climbing method dictate that if the top climber falls and fails to immediately slow his fall, the second will not save their bacon. Moreover, it is likely that the entire roped team will go down with the top climber, following gravity to wherever it leads. Alpinists should consider the forces at play in this climbing method, weigh its advantages and follies, and decide if and when it makes sense to climb roped together without placing pro.
Part V: THE ALPINE SAFETY SYSTEM: snow strength, hardware & software

[photo here]

[Loaded picket in snow attached to Dynamometer and rope, next to dyno is a clip board with fall chart stats and a pen]

The Weakest Link: assessing the holding strength of snow

Snow
Snow is a mixture of solidified water and air. The air content of the Sierra and Cascade snowpack varies from a high of 96% in early season powder, to a low of about 50% in late spring. If you are going hang your lifeline on a mixture of one part powdered water and three parts air, you will want to understand when it will hold you and when you should leave the climb for another day. In most cases, the weakest link in your alpine safety system will be the snow. The Snow Hardness Test, Snowball Test, and Anchor Pull Test described below are designed to help you to assess the ability of snow to hold snow pickets and other snow anchors.

The Snow Hardness Test
This test is used to estimate the approximate strength of the snow for holding Sierra and T-slot pickets. It suggests the strength of the bonds between snow granules by assessing the resistance of the snowpack to force. To conduct the Snow Hardness Test, you isolate a column of snow representative of the area to be climbed, (best if done near the base of the climb). Identify each snow layer in the column, and then progressively try to push a fist, then four fingers, then one finger, then a pencil, then a knife blade into each layer. This is often already being done during your avalanche snow stability assessment.

24 Personal correspondence with Randall Osterhuber, UC Berkeley, Central Sierra Snow Lab., October 20, 2010.
For example if you cannot push your fist into a snow layer but four fingers will go in, the snow is said to have “four finger hardness”. The list below shows that such snow can hold Sierra and T-slot pickets in the range of .04 to .4 kN. Even going by the highest holding strength in the range (0.4 kN/90 lbs.), a snow picket placed in this snow cannot even hold the body weight of most climbers. In this case, we would determine that the snow is simply too weak to climb using single snow pickets.

In contrast if you could not get your fist, four fingers or one finger into the snow but a pencil would go in, the snow would be “pencil hardness”. This would suggest that pickets could hold forces between 4-40 kN in the snow tested. This would be acceptable for climbing but we would need to keep our anchors spaced closely enough to ensure that fall forces remain below 4 kN. It is safest to be conservative and go with the lowest holding strength in the range. The snow’s holding strength for snow pickets is as follows:  

<table>
<thead>
<tr>
<th>Type</th>
<th>Holding Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fist</td>
<td>.04 kN or less</td>
</tr>
<tr>
<td>4 Finger</td>
<td>.04 to .4 kN</td>
</tr>
<tr>
<td>1 Finger</td>
<td>.4 to 4 kN</td>
</tr>
<tr>
<td>Pencil</td>
<td>4 to 40 kN</td>
</tr>
<tr>
<td>Knife</td>
<td>40+ kN</td>
</tr>
</tbody>
</table>

The Snowball Test

This test tells you if the snow around the buried picket should be compressed or left alone. More specifically, it reveals if compacting (stomping) the snow at and below the picket in the direction of pull will make the snow (and thus the picket’s holding ability) stronger or weaker. In some cases you can more than double the snow’s ability to support a picket by stomping on the snow at and just below the anchor. It takes a few minutes after stomping for the snow granules to bond and strengthen. In other cases stomping the snow will actually weaken the snow’s ability to support a picket. To stomp or not to stomp is the question. The snowball test is the answer. It is simple. Take a handful of the snow in question and try to make a snow ball. Throw the snowball to see if it stays together as a unit.

If you can make and throw a snowball, stomping the snow at and below the anchor will make the snow stronger. If you cannot make and throw a snowball, stomping the snow at and below the anchor will make the snow weaker.

26 Individual snow pickets placed in finger hard snow cannot be counted on to hold a short fall. However, they can provide some level of security on ascent when the Second is being belayed up by a Lead positioned above the Second. Likewise such pickets in finger hard snow can provide some level of security on descent when a Lead is being belayed down by a Second positioned above the Lead. In both of these cases, the belayer is only preventing the other climber’s slip from becoming a fall. In such instances the belayer needs to maintain very little slack in the belay line. If finger hard snow passed the Snowball Test, you can greatly improve the picket’s holding strength by stomping.
27 An exception to this rule is when the snow is so wet that waters drips out of the snowball. In that case the snow is weak and stomping will not help.
The Anchor Pull Test (APT) 28

You can also perform a more direct test of snow anchor strength. A climber pulling “tug of war” style on a rope secured to a snow anchor can get a basic sense if the anchor will hold the force of a slip. The following is based on tests of 200 lb. climbers pulling on 8 mm. dynamic rope secured to an anchor. Secure the rope to the anchor you want to test, tie an alpine butterfly (or other in-line knot), or attach a prussic to the rope 12 feet away from the anchor. Place additional in-line knots or prussic in the rope at six foot intervals from the anchor.

- One Climber Harness Pull: pulling “tug of war” style on the rope with the bight of rope clipped to their waist harness 12 feet from the anchor. This averages about 0.6 kN of force. If the anchor fails it will not catch a slip or a fall.

- Two Climber Harness Pull: A second climber clips in to a bight in the rope 18 feet from the anchor and both climbers pull “tug of war style” with the rope attached to their harnesses. This averages about 1 kN of force. If the anchor holds it might catch a light slip when combined with a dynamic body belay but not a fall. Very marginal anchor.

- Three Climber Harness Pull: A third climber clips in to a bight in the rope 24 feet from the anchor and all three climbers pull “tug of war style” with the rope attached to their harnesses. This averages about 1.4 kN. If the anchor holds it might catch a moderate slip when combined with a dynamic belay. Still a marginal anchor.

- Four Climber Harness Pull: A fourth climber clips in to a bight in the rope 30 feet from the anchor and all three climbers pull “tug of war style” with the rope attached to their harnesses. This averages about 1.8 kN. If the anchor holds it will likely catch a slip and might catch a very low fall factor fall when combined with a dynamic belay. Still a marginal anchor.

If the anchor you are testing fails during any of the above listed APT tests, you should consider that anchor unsafe for lead climbing. Find a safe place, perform the Anchor Pull Test and select your roped safety system accordingly. 29 Include a margin of safety/error. This test is primitive.

Safety System Strength: hardware

Snow Pickets 30

28 Conservative figures based on 2010, 2011 & 2012 data from100 dynamometer pull tests by 14 members of the Contra Costa County, California Search and Rescue team.
29 Having two or three people pulling on a buried snow anchor presents an obvious problem. If it fails they may have an incoming rope guided surface-to-air missile to contend with. To prevent any unscheduled orthopedic visits, you can throw a prussic hitch on the rope where it emerges from the snow and tie it off to a tree, rock or another snow picket leaving about five feet of slack.
30 Shown: an MSR Coyote snow picket. Pickets are also manufactured by Aspiring Enterprises, Omega Pacific and Yates.
Snow pickets come in a variety of shapes and sizes. Each holds in different ways. As a rule of thumb, snow pickets are used more frequently for climbing in warm, wet, maritime ranges like the Sierras, Cascades, and the Southern Alps of New Zealand than in dryer intermountain and continental ranges like the Rockies and the Alaska Range. This is because pickets hold better in wetter maritime snow packs than in the dry powder common in intermountain and continental ranges. An exception to this rule would be the European Alps, a maritime range which for some reason has not adopted the use of pickets. Pickets are used in the Himalaya but are typically buried and left in place to secure seasonally fixed lines.

This section provides general guidelines regarding the breaking strength of snow pickets. Most modern pickets are made from a T-6 aluminum alloy. Pull and drop tests show that the breaking strength of snow pickets ranges from just over 4 kN to 12 kN. Pull and drop tests also reveal that precise estimates of picket strength is very difficult to predict. Under certain circumstances, pickets have bent or broken when hit with drop forces as low as 4.2 kN. In many cases the snow will fail before the picket breaks, but regardless of the theoretical strength of the snow or the picket, never design a safety system to put more than 4 kN of peak force on any one snow picket. Tests have revealed that pickets begin to behave in unpredictable ways when forces exceed about 6.5 kN.

The numbers below reflect findings of slow pull and drop tests of snow picket hardware. The numbers presented assume (for purposes of this analysis) that the snow is stronger than the hardware of the pickets.

**Forces up to 4 kN:** snow picket hardware functions as designed.

**Forces from 4 kN to 6.4 kN:** snow picket hardware usually functions as designed, but pickets can bend or break in rare circumstances.

**Forces 6.5 to 8 kN:** pickets begin behaving in unpredictable ways, some bend or break.

**Forces 8 kN+:** pickets are unstable and routinely bend or break.

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31 Fortini, *Failure Modes*, p. 8.
32 Personal correspondence with Art Fortini, 2010. Also see Fortini, *Failure Modes*, p. 7.
33 Fortini, *Failure Modes*, p. 8. Why some outliers break in drop tests at such low forces is not well understood.
34 Personal correspondence with Art Fortini, 2010.
35 Twenty four inch MSR Coyote pickets were tested by Bogie in 2002. Some broke at 7.8 kN. Twenty inch Yates mid-clip cable pickets were tested by Art Fortini in 2005. Some broke at 9.3 kN. Twenty four inch Omega Pacific (OP) pickets were tested by Art Fortini in 2005. Most broke at or above 8 kN. One 36” OP picket failed at 4.2 kN.
Snow Picket Placements

When it comes time to select snow picket placements, climbers often face a conundrum. The choice presented is typically between anchor strength and climbing speed. Some picket placements make for fast climbing, but there is a compromise with regard to anchor strength; other placements offer strength, but at the expense of speed. To add to the problem there are many circumstances where climbing speed is an important component in overall security. For example, climbing fast may be the best way to get off steep slopes before the snow turns to slush, or rock and ice fall reach their afternoon zenith. Climbers need to conduct a risk-benefit analysis with picket placement each time they climb. This analysis requires consideration of snow strength, slope angle, exposure, time considerations and the skill of climbers among other things. Below is a list of common picket placements. Their strengths and weaknesses are noted.

**Vertical Top-Clip (traditional picket placement)**

**Ideal for** climbing moderate slopes; can be used on steep slopes if the snow is strong.

**Speed:** highest

**Strength & Security:** lowest

**Can be used as part of two person rescue load system:** not recommended

**Can be used when snow fails snowball test:** yes, but only in hard dry snow, not loose powder or slush

**Sensitivity to snowpack layering:** high

Note: the physics of this anchor placement makes it inherently weak compared to those summarized below. In engineering lexicon it fits the definition of a “laterally loaded pile”. If it moves when loaded it typically gets weaker. 36

**T-Slot (AKA Deadman or Horizontal mid-clip)**

**Ideal for** use as belay or rescue anchor

**Speed:** low

**Strength & Security:** moderate, the deeper they are buried, the stronger they are (theoretically about 175% stronger than Vertical Top-Clip placements)

**Can be used as part of a two person rescue load system:** yes

**Can be used when snow fails snowball test:** yes

**Sensitivity to snowpack layering:** high

Note: T-slot picket depth greatly impacts its holding strength. Bury 24” long pickets in a T-slot trench about 24” deep. Likewise, 36” pickets should be buried in a 36” trench (if possible). 37

**Sierra (AKA Kiwi or Vertical mid-clip)**

**Ideal for** climbing all slopes

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36 Bogie, p. 10.
37 Very few of the 50+ mountain guides, rescue mountaineers, and alpinists surveyed use 36” snow pickets. Their extra bulk and weight bring few benefits.
**Speed:** moderate (high if picket is affixed with steel cable instead of rope or webbing)  
**Strength & Security:** moderate (theoretically at least 2 times stronger than Vertical Top-Clips and about 25 percent stronger than T-Slots)\(^\text{38}\)  
**Can be used as part of a two person rescue load system:** yes  
**Can be used when snow fails snowball test:** no…no…no\(^\text{39}\)  
**Sensitivity to snowpack layering:** low

Note: A Sierra picket’s angle and depth impacts its holding strength. To maximize the snow’s ability to hold a Sierra picket, the top of the Sierra picket should be 5 or more inches below snow’s surface and angled back, up slope. To test if a Sierra picket is properly placed, pull on the rope or cable attached to the picket from down slope. The rope/cable should visibly sink deeper into the snow. If not, the Sierra picket’s angle may need to be adjusted.

**Other Snow Anchors**

### Snow Fluke \(^\text{40}\)

![Snow Fluke Image](image)

- **Ideal for** climbing all slopes  
- **Speed:** moderate  
- **Strength & Security:** low to moderate (depending on burial depth, deeper is stronger)  
- **Can be used as part of two person rescue load system:** not recommended  
- **Can be used when snow fails snowball test:** yes  
- **Sensitivity to snowpack layering:** moderate

**Proview:** for some reason snow flukes have largely fallen out of use by professionals. Almost none of those surveyed use them.

### Snow Bollard

- **Ideal for** down climbing moderate slopes. The real benefit of the snow bollard is that it allows the top climber to descend with protection and then retrieve the rope without leaving pro behind.

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\(^\text{38}\) Bogie, p. 10. Connally, p. 131.  
\(^\text{39}\) Sierra pickets that do not use a cable often require you to make and backfill a small trench in front of the buried picket. Snow that fails the snowball test includes dry powder, brittle dry crust and slush. Backfilling a trench with any of these snow types would make it likely that the Sierra picket will fail.  
\(^\text{40}\) Shown: a DMM “Deadman” snow fluke.
Speed: lowest
Strength & Security: moderate to high (depending on snow quality and the size of the bollard)
Can be used as part of a two person rescue load system: yes
Can be used when snow fails snowball test: yes
Sensitivity to snowpack layering: unknown

Skis

Ideal for climbing all slopes
Speed: moderate when placed as Vertical Mid-clip (Sierra), slow when placed as a Horizontal Mid-clip (T-Slot)
Strength & Security: moderate
Can be used as part of a two person rescue load system: yes
Can be used when snow fails snowball test: no when Vertical Mid-clip, yes when T-slot
Sensitivity to snowpack layering: low when vertical mid-attachment, high when T-slot

Note: Skis do not perform well when placed vertically and tied off at the snow’s surface, e.g., as a “Vertical Top-clip”. Limited slow pull tests revealed that such placements hold only about 2-3 kN in “pencil hard” snow. The same skis placed in the same snow as a Sierra or T-Slot anchor will hold at least twice as much as when placed as a Vertical Top-clip anchor.\(^{41}\)

**Improvised Snow Anchors**

Ideal for establishing an anchor when you have no pickets, skis or flukes, or when snow conditions are not conducive to placing pickets, skis or flukes. Typical buried objects includes snow shovels and backpacks. These types of anchors are commonly used in self-rescue situations.

Speed: usually low
Strength & Security: uncertain and untested
Can be used as part of a rescue system: as a last resort or redundant back up
Sensitivity to snowpack layering: untested and unknown

Note: Burying objects not designed to serve as snow anchors should be considered an emergency measure. A fallen climber may need to be moved. Ski or climbing teams may have a safety rope but no pickets or flukes. They bury skis, shovels and packs and use them as anchors to get an injured or stranded climber up or down. Non-traditional anchors are untested and should be considered marginal anchors.

**Snow Anchor Spacing**

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\(^{41}\) The National Ski Patrol trains its members to use skis as “T-slot” anchors. Properly placed skis can prove to be very strong snow anchors. However since skis have sharp edges their use as anchors requires some basic training. Care must be taken to prevent the sharp edges on skis from coming into contact with rope or webbing.

\(^{42}\) Bogie, Don, and Art Fortini, *Snow Anchors for Belay and Rescue*, unpublished document.
Cross Slope

Multiple snow anchors can be connected to form a critical belay anchor. When joining multiple anchors, the anchor points should be redundant, narrowly vectored, and fairly well equalized. As illustrated in Figure 1. below, anchor placements should also be spaced or “fanned” at least 24” apart cross slope (24” between the end of each anchor not the middle). Each anchor creates its own “stress cone” in the snow. Anchors placed too close together could have overlapping stress cones. This could undermine the integrity of the anchor system.

Up / Down Slope

Snow anchors should be spaced at least twice the length of the anchor up and down slope. A 24”picket should be at least 48” up slope from the next snow anchor. A 36” picket should be 72” up slope from the next snow anchor.
Ice Anchors

Ice is described as a viscoelastic material. It is a complex medium that is difficult to analyze. It can stretch and bend like plastic or shatter like glass. Ice can change from its elastic to brittle state with a temperature change of just a few degrees. In addition to temperature, other factors that impact ice anchor strength include impurities in the ice, ice air content and microscopic cracks.

Ice Anchors

Ice Screws

Ice screws come in lengths from about 8 to 22 cm. and are made of steel or titanium. UIAA Standard #151 requires that all ice screw hardware hold at least 15 kN of force before breaking. When placed in quality ice, screws will hold between 4 and 24 kN, with an “average” 17 cm. ice screw holding about 10 kN of fall force. How do you know if the screw you are placing will hold the average? You don’t. Assume no more than 4 kN from any 17 to 22 cm. ice screw placed in quality water ice. Assume slightly lower holding strength from screws shorter than 17 cm. If in doubt, double up your ice screws and connect them with cord or webbing to form a narrowly vectored, redundant and fairly well equalized multi-point anchor.

Ideal for climbing and descending on water ice

Speed: high

Strength & Security: moderate to high (depends on the quality of the ice)

Can be used as part of a two person rescue load system: yes

Proview: Most popular among those surveyed was 15 to 17cm. screw length, followed closely by the 18 to cm. length.

Reboring

43 Bennett, p. 18.
44 Shown: A DMM ice screw. Ice screws are also manufactured by Black Diamond, CAMP, Cassin, Grivel, Omega Pacific and Petzl.
45 Beverly, p. 7; Blair, p. 5; Pit “Normanforderungen”, p. 52.
46 Pull and drop tests show that even in “high quality water ice”, 1 in 10 screws will fail at less than 7 KN and 1 in 100 will fail at less than 5 kN. As stated, ice is an unpredictable medium.
The alpine climbing community is split on the practice of placing ice screws in screw holes left from previous ice climbs, e.g., “reboring.” Limited studies have revealed that rebored screw placements hold only slightly less fall force than screws placed in virgin ice. By reboring, climbers can prevent filling popular ice walls with new holes which can cumulatively weaken the ice. It is also faster and easier to place ice screws in existing screw holes.47

Proview: Just over half of those surveyed “rebore” ice screws in holes left from previous climbs.

Water Ice Quality and Average Holding Ability of Ice Screws 48

<table>
<thead>
<tr>
<th>16 cm. ice screw in low quality water ice</th>
<th>16 cm. ice screw in medium quality water ice</th>
<th>16 cm. ice screw in high quality water ice</th>
</tr>
</thead>
<tbody>
<tr>
<td>averages 4.6 kN (± 1.3 kN)</td>
<td>averages 11 kN (± 1.9 kN)</td>
<td>averages 19.8 kN (± 1 kN)</td>
</tr>
</tbody>
</table>

Note: Screws should be angled between 10 and 20 degrees toward the load when anticipating a shock load.49 When using multiple screws as part of an anchor system, place them vertically in line with the expected load and space them at least 2 feet apart.50 Ice screws should be placed in recesses or flat spots on the ice, not on outcrops or bulges on the ice.

**Vertical A-threads**

A-Thread anchors will hold between 10 and 17 kN of force in quality water ice. Using longer ice screws (17-22 cm.) to bore holes for the A-thread increases the area of ice in the anchor and thus the anchor’s strength.51 When in doubt double up your A-threads and connect them with cord or webbing to form a narrowly vectored, redundant and fairly well equalized multi-point anchor.

**Ideal For:** down climbing water ice. The advantage of the A-thread is that it allows the Top climber to descend with protection and then retrieve the rope, leaving only a short piece of webbing and a rappelling ring behind.

**Speed:** low

**Strength & Security:** moderate to high (depending on the quality of the ice)

**Can be used as part of a rescue system:** not recommended

Proview: More than 80 percent of those surveyed rappel on water ice using A-threads.

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48 Semmel, p. 66.
50 Water ice anchors of all sorts are staggered vertically to avoid contributing to the natural tendency of ice to fracture horizontally.
51 Beverly, p. 16.
Note: A-threads must be built in quality water ice. The holes should be bored at opposing angles of about 60°. Thread 1” webbing or 7 mm. cord through the holes and tie them off with a water knot or double fisherman’s knot respectively. When using multiple A-threads as part of a non-rescue anchor system line them up vertically and in line with the expected load and space them at least 2 feet apart.

A-thread

Courtesy of J. Marc Beverly UIAGM Guide and Stephen Attaway, Ph.D.

Ice Anchor Spacing

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52 Semmel, p. 66.
Safety System Strength: software

Minimum unknotted breaking strength of ropes, cord and webbing:

- Ropes used as part of a rescue systems are “static” or lower stretch
- Ropes used for climbing are “dynamic” or higher stretch
- 5 mm. cord breaks at about 6 kN
- 6 mm. cord breaks at about 8 kN
- 7 mm. cord breaks at about 11 kN
- 8 mm. cord breaks at about 15 kN
- 9 mm. dynamic rope breaks at about 19 kN
- 9.5 mm. dynamic rope breaks at about 22 kN
- 10.5 mm. dynamic rope breaks at about 29 kN (it varies, use only as a rule of thumb)
- 11 mm. rescue low stretch rope breaks at about 30 kN. (it varies, use as a rule of thumb)
- 1” tubular webbing breaks at about 18 kN (single strand)

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53 Cord strengths were found at fishproducts.com
54 Union Internationale Des’ Association D’ Alpinisme (UIAA) establishes tests criteria for measuring the performance of single and double climbing ropes. The UIAA’s #101 Impact Force Test requires dynamic rope to sustain a falling weight of 80 kg. (176 lbs.) to 12 kN (2697 lbs.) when dropped 4.8 meters (15.7 ft.) on a 2.8 meter (9.2 ft.) section of rope. The rope is passed over a 10 mm. rounded edge to simulate a carabineer. The test approximates a Fall Factor 2, (twice the length of the rope). The impact force on the first fall must be less than 12 kN, and the rope must survive 4 falls. Any “single” climbing rope that passes this test can be used for alpine climbing with snow anchors. Double ropes are subjected to similar test only each strand is weighted with a 55 kg. falling mass and the impact force must be less than 8 kN and the rope must sustain 4 falls. The Impact Force Test does not test the breaking or “tensile” strength of the ropes, but rather determines if the rope can hold enough strain energy to dampen deceleration to the point that a climber can survive a Factor 2 fall.
55 Richards, p. 2.
• Wrap 2, pull 1 anchor made from 1” tubular webbing breaks at about 25 kN
• Wrap 3, pull 2 anchor made from 1” tubular webbing breaks at about 36 kN 56
• Prussics for rescue are 8 mm., nylon, triple wrapped, and slip at between 9 and 12 kN 57
• Prussics for climbing are 6 or 7 mm. nylon and slip at about 9 and 11 kN respectively58
• Knots and hitches weaken rope and webbing by about 1/3 (ranges from about 19% to 45%)59
• The breaking strengths listed above do not account for weakness of cord, rope or webbing due the material being wet, frozen, dirty, sun damaged, old or worn.60 In some cases ropes can lose over 25 percent of their listed tensile strength when wet and dirty.

56 Rigging for Rescue, p. 48.
57 Trihey, p. 3; Moyer, p. 4; Gibbs p. 6
58 Rigging for Rescue, p. 25.
59 Lipke p. 181; Richards, p. 2-3.
60 Costa p. 3; Pitt, p. 2.
Part VI: FALL FORCES: understanding your alpine safety system

“The purpose of the roped safety system and belay is to bring the falling climber to a stop slowly enough so that peak forces do not rise to the point that they break the safety system and climber.”

Craig Connally, The Mountaineering Handbook

It is all about the top anchor!

So far we have reviewed the mountaineering lexicon and described climbing techniques, anchor placements, and the relative strengths of various parts of our climbing safety system, e.g., snow and ice anchors and ropes. This section discusses the forces we can expect to generate from falls on snow slopes. We set up our alpine safety systems to prevent a short protected fall from becoming a long unprotected fall. It is our job to make sure that all parts of the safety system can hold the force generated by a worst case short protected fall. Since snow strength is usually the weakest link in our safety system, much of our focus here involves minimizing the peak force placed on the top anchor, usually an object buried in snow.

Select a climbing system that can hold your worst case protected fall

In Section V above, we identified snow as the weakest link in our safety system and learned how to assess the approximate holding strength of snow for snow anchors. With this knowledge, we have some idea of the amount of force needed to cause system failure. For example, if the snow hardness test tells us each snow picket will hold to about 4 kN, we know we must select a climbing safety system that will not generate fall forces that exceed 4 kN. Which climbing
technique from Section III should we select? Which anchor placement from Section V should be used? That depends on many factors including:

- the weight of the climber
- the distance of the worst case protected fall
- the amount of rope in play to absorb the fall
- the slope
- which type of belay is used (ATC, hip, carabineer, etc.)
- the friction applied at the anchor
- the amount the rope will stretch

There are a lot of variables to consider. Not to worry. Figuring fall forces does not involve advanced math on your part. If you can add, subtract, divide and put a few numbers into a fall force calculator, you can figure the forces at work in your alpine safety system. That said, if the thought of several pages of middle school math is too foreboding, you can skip to the end of this section where we list simple actions you can take to reduce the amount of force on the top anchor. Skipping the math will come at a cost however as you may need to rely on the judgment of others to assess the strength of the climbing systems you use.

According to author Craig Connally, the highest peak force realistically possible from a 26 foot simple Factor 2 vertical freefall of a single climber is about 8.5 kN. A climber could be seriously injured by sustaining 8.5 kN of force. Snow often cannot hold a picket hit with 8.5 kN of force. Moreover, the metal on some snow picks will bend or break at or below 8.5 kN. Fortunately, 8.5 kN is only a theoretical figure. In practice, there are factors that make the forces generated by a worst case controlled fall on snow significantly lower than 8.5 kN.

For example, most protected climbing techniques described in this document involve climbers being on belay. Involuntary rope slip through a belay device can absorb over 20 percent of the energy released by a 26 foot Factor 2 fall. Modern belay devices such as the ATC and B-52 will hold the rope until forces reach about 2 kN. Once the rope in your belay device carries 2 kN of force, your hand simply cannot stop it from slipping. So because of involuntary rope slip through the belay device, the worst case force generated on the top anchor will be reduced when we employ a dynamic belay. For our Running Belays we sometimes place energy absorbing screamers on the intermediate picks. The screamers we use activate when forces exceed 2 kN. These screamers absorb at least 3 kN of fall force. So by using a belay device and/or screamers we significantly reduce peak forces placed on the top anchor to well below 8.5 kN. This is good news since snow anchors are marginal.

The 8.5 kN worst case fall also fails to account for the lower forces generated by falls on the non-vertical terrain where most alpine climbing takes place. Fall force calculators assume the climber sustains a vertical freefall. As every skier knows, the velocity/acceleration generated by descending on a Black Diamond slope far exceeds that generated on a bunny slope. Gravity seeks to pull objects toward the center of the earth, but when mountain slopes get in the way, gravitational force is divided between pulling objects onto the mountain and pulling them off, e.g., between “snug” and “tug”. So an object falling on a 40 degree slope experiences a 36 percent reduction in velocity compared to the same object in freefall. The lower the slope

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62 Bogie p. 3; also see “The Forces on a Slope”, p.3.
angle, the lower the velocity (thus fall force) generated by the falling object on the top anchor. Most mountaineering on snow takes place on slopes below 60 degrees. This is also good news given that many snow anchors are marginal.

So dynamic belays, screamers and slope friction act to reduce the fall forces placed on snow anchors. These forces fall far short of those suggested by fall force calculators. Fall calculators help alpinists understand the interaction between climber weight, available rope, and length of fall, etc., but the numbers they present are for vertical climbing, not mountaineering. They assume a freefall with no belay slip, e.g., it is assumed that the rope is tied to a bomber anchor such as a large tree or rock. In short, the numbers generated by fall force calculators are a useful point of departure for calculating forces in the alpine environment.

Although alpinists can increase their level of safety by blindly following the instructions in this manual, it is important that they actually understand how fall forces work. Real safety comes from understanding the forces at play and making decisions on the mountain that keep you safe. For example, consider this question: Does increasing the distance you fall increase the amount of force placed on the anchor that catches your fall? Common sense may tell us yes, but the answer is often no. A 16 foot fall on 8 feet of rope will produce the same force on the top anchor as a 120 foot fall on 60 feet of rope. Both falls theoretically place about 11 kN of force on the top anchor. Why is this so? Because the Fall Factor for both of these falls is 2. If you do not understand how this works, read on.

**Some Common Snow Geek Terms and Equations**

![Image](https://example.com/image.jpg)

"I'm not a Weenie! I just like knowing how strong things are...that's all....."

from fishproducts.com, used with permission

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63 The point of this example is to demonstrate the relationship between rope stretch and fall forces on the top anchor. It is not to suggest that it is safe to sustain a 120 foot screamer.
**Fall Factor**
In simple speak, the Fall Factor tells you how severe the fall is. It is expressed as a ratio. The distance of the fall is divided by the length of rope available to stretch and absorb the fall. The highest Fall Factor is two. The lowest Fall Factor is zero. High is bad, low is good. *When setting up your alpine safety system, you want to try to keep your fall factor below 1.*

\[
\text{Fall Factor (FF)} = \frac{\text{Distance of the Fall}}{\text{Length of Rope Available to Absorb the Fall}}
\]

**Fall Factor is controlled by maintaining the proper spacing of anchors in relation to the amount of rope in service.** A helpful way to understand the physics involved in Fall Factor is to consider that with a Fall Factor of 2 the rope acts more like a steel cable when it transfers force from the falling climber up the rope to the top anchor (less stretch). With a Fall Factor of 0.2 in contrast, the rope acts more like a bungee cord (more stretch). High stretch rope stores a significant amount of “strain energy”. 64 When the rope acts like a bungee cord, it distributes the kinetic energy released during the fall onto the top anchor over a longer period of time than it would if it were a steel cable. This “bungee cord effect” reduces the peak force applied to the top anchor when catching the fall. With high Fall Factors, the force is transferred up the rope more quickly, and not “stretched” over time and space. As a result, the peak force applied to the top anchor is higher. So Fall Factor determines if the force generated by the fall will hit your top anchor slower with lower peak forces like bungee cord or faster with higher peak forces like a steel cable. 65

Figure 3 below illustrates the importance of incorporating Fall Factor into your climbing safety system. It assumes a freefall of a 200 lb. climber with no belay slip, e.g., it is a static belay. For the sake of this illustration we can assume that the Belayer is secured to a bomber anchor and using an auto blocking belay device. Note that the fall distance between Anchor #2 and Anchor #1 (6 feet) is half the fall distance between Anchors #5 and #4 (12 feet). Despite falling twice as far from #5 onto #4, the falling Lead Climber would generate slightly less fall force on the top anchor than if she/he fell from #2 onto #1.

How do we end up with slightly less force from twice the fall? It is because the anchors were spaced to allow the Fall Factor (and thus peak fall forces applied to the top anchor) to remain about the same.

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64 Strain energy is the energy stored in the rope as the rope is stretched. The energy is the product of the stretching force times the distance the rope elongates. See Attaway, p. 13.

65 Fall Factor is very important but so is the relative ability of the rope to stretch. For example, a 20 foot Factor 1 fall on a steel cable would be fatal while a 20 foot Factor 2 fall on a bungee cord would not injure the falling climber. See discussion on “Rope Choices” in Section VII.
Anchor #5 is six feet above Anchor #4. A fall from here onto Anchor #4 would generate 5.8 kN with a Fall Factor of 0.27

Anchor #4 is five feet above Anchor #3. A fall from here onto Anchor #3 would generate 5.9 kN with a Fall Factor of 0.29

Anchor #3 is four feet above Anchor #2. A fall from here onto Anchor #2 would generate 6 kN with a Fall Factor of 0.30

Anchor #2 is three feet above Anchor #1. A fall from here onto Anchor #1 would generate 6 kN with a Fall Factor of 0.23

Anchor #1: the Belayer places this anchor then drop down 10’, sets their ice axe (self-belay) and assumes belay position

10 feet

Belayer is 10 feet below Anchor #1 to allow more rope stretch, sets ice axe (self-belay), assumes belay position

If Fall Factor still does not make sense to you, try playing with some fall force calculators. By plugging in different numbers for climber weight, fall distance, and the length of rope available to stretch, it is easier to understand how Fall Factor functions.

As illustrated in Figure 3. below, a 40 foot vertical Fall Factor of 2 of a 200 lb. climber generates more than twice the force on an anchor than a 40 foot vertical Fall Factor of 0.2 on the same anchor.\footnote{These figures were generated by using the force calculator at: http://junkfunnel.com/fallforce/. Junkfunnel requires all data be metric.} Why? Rope stretch!
### Figure 4.

<table>
<thead>
<tr>
<th>Fall</th>
<th>FF</th>
<th>Peak Force Generated on the Top Anchor</th>
</tr>
</thead>
<tbody>
<tr>
<td>40' fall</td>
<td>FF = 0.2</td>
<td>4.5 kN</td>
</tr>
<tr>
<td>200' rope out</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40' fall</td>
<td>FF = 0.25</td>
<td>4.8 kN</td>
</tr>
<tr>
<td>160' rope out</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40' fall</td>
<td>FF = 0.4</td>
<td>5.7 kN</td>
</tr>
<tr>
<td>100' rope out</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40' fall</td>
<td>FF = 1</td>
<td>8 kN</td>
</tr>
<tr>
<td>40' rope out</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40' fall</td>
<td>FF = 2</td>
<td>10.8 kN</td>
</tr>
<tr>
<td>20' rope out</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Some fall force, fall factor, and fall speed calculators can be found at: 68

http://www.alpinedave.com/fall_machine.htm
http://junkfunnel.com/fallforce/
http://www.myoan.net/climart/climbforcecal.html
www.anigo.net/personal/climp/speed
www.ajdesigner.com/phforce(force-equation.php
http://www.members.tripod.com/ferforge/Srt002.htm

**Helpful Analytical Software includes:**

- Rescue Rigger ®
- Anchor Equalizer ®

**Calculating Fall Forces**

The Energy of Motion = \( \frac{1}{2} \text{mass} \times \text{velocity}^2 \)

By applying the above formula we can determine the amount of energy placed on the safety system during a fall. Forget about it. Among other things, it requires that we know the speed of

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67 Some people are confused as to how one can sustain a 40 foot fall on 20 feet of rope. This type of fall occurs when the Belayer is not on the ground but up on the slope with the climber. The climber ascends 20 feet above the Belayer (and belay anchor) on 20 feet of rope. The Climber falls from 20 feet above the Belayer until the rope is taut 20 feet below the Belayer. Total fall distance is 40 feet on 20 feet of rope.

68 The author does not endorse the accuracy of data generated by fall force calculators or analytical software. The data provided is to help the reader to understand the concept of Fall Factor, not to provide precise fall force figures. Data presented by fall force calculators should be considered a rough approximation. Don’t bet your life on it.
the falling climber at the moment the rope begins to resist the fall. We can put our stop watches away and just plug the known numbers into a fall force calculator.

Our main concern in mountaineering in snow is not the force placed on the falling climber (although that may seem rather important if that climber happens to be you!), but the fall force placed on the top anchor. If the top anchor fails, the falling climber and belayer may both go down for the snow nap.

**STEP 1: Use a Fall Force Calculator**

Let’s plug some numbers into a fall force calculator to determine the theoretical fall force generated on your safety system by a falling climber. The calculator assumes a vertical freefall with no belay slip.

**The calculator asks us:**

**Climber’s Weight?**
Say 200 lbs. (91 kg.).

**Length of dynamic rope available in the system to absorb the fall?**
Say 50 feet (15.24 meters)

**Distance falling climber is above top anchor when they fall?**
Say 10 feet (3.048 m.).

**Rope-Carabineer Friction?**
An average figure is 0.6.

**Rope Elongation?**
Give a figure for dynamic “higher stretch” rope which averages between 5 and 10% elongation, let’s say 8%.

**The calculator tells us:**

The Peak Force on the Top Anchor from this fall will be **5.4 kN**
The Peak Force on the Falling Climber will be **3.8 kN**
The Peak Force on the Belayer will be **1.5 kN**

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69. Remember when calculating Fall Factor that falling from 10 feet above an anchor on a slope results in a 20 foot fall.

70. The “average” for rope-carabiner friction is in dispute. Estimates range from a low of 0.5 to a high of 0.66.

71. Dynamic climbing ropes are tested and rated with regard to elongation. When weighted with an 80 kg. block, most dynamic ropes stretch between 5 and 12%. This is known as the Static Elongation.

72. Some fall calculators only provide the force placed on the falling climber. To calculate the force a fall places on the top anchor multiply the force on the falling climber by 1.66. In this case 3.8 kN x 1.6 = 6.08 kN of force placed on the top anchor from this fall. To calculate the force this fall places on the Belayer subtract the force on the falling climber (3.8 kN) from the force on the top anchor (6.08 kN). 6.08 kN – 3.8 kN = 2.28 kN placed on the Belayer from this fall. These numbers are slightly higher than the numbers calculated on the fall calculator at junkfunnel.com above. This is because the calculator at junkfunnel.com deducts for carabineer friction which they calculate will reduce force in this case by about 0.3 kN. You will find that fall force calculators differ slightly in how they assess forces.
As stated above, the Fall Factor is figured by dividing the length of the fall (20 feet) by the total length of rope available to stretch (50 feet of rope available to stretch) \( \frac{20}{50} = 0.4 \)

**STEP 2: Deduct for Slope**

As stated above fall force calculators do not account for the reduced velocity (thus force) generated when falling on a slope. The reduction can be considerable depending on the slope angle. To reduce expected freefall forces to account for slope consider the following:

- A fall on a 90 degree slope is a free fall, there is no reduction in fall force due to slope.
- A fall on an 80 degree slope generates 98 percent of freefall force.
- A fall on a 70 degree slope generates 94 percent of freefall force.
- A fall on a 60 degree slope generates 87 percent of freefall force.
- A fall on a 55 degree slope generates 82 percent of freefall force.
- A fall on a 50 degree slope generates 77 percent of freefall force.
- A fall on a 45 degree slope generates 70 percent of freefall force.
- A fall on a 40 degree slope generates 64 percent of freefall force.
- A fall on a 35 degree slope generates 57 percent of freefall force.
- A fall on a 30 degree slope generates 50 percent of freefall force.
- A fall on a 25 degree slope generates 42 percent of freefall force.

So using the example above, the calculator told us a 20 foot freefall with 50 feet of rope out generated about 5.4 kN of force on the top anchor. Assuming the fall took place on a 40 degree slope, we can assume the force generated will be 64 percent of that generated by a vertical “freefall” as stated by the calculator. In this case we can expect a reduction in force of about 2 kN due to the reduction in velocity on a 40 degree slope compared with a vertical freefall. So in the instant case, the expected peak fall force drops from 5.4 kN to about 3.4 kN.\(^7\)

**STEP 3: Reduce for Involuntary Rope Slip at Belay (if applicable)**

Ropes will slip through most modern belay devices once the force on that rope at belay exceeds about 2 kN. Try as she/he may, the belayer will be unable to stop the rope from slipping. You should expect much of the force beyond 2 kN on the belayer’s end of the rope to be absorbed due to involuntary belay rope slip. Involuntary rope slip might occur at belay when fall force at the top anchor exceeds about 5 kN. In the case above, the calculator told us that belayer’s end of the rope was receiving 1.5 kN of force from the fall. Knowing that the force at belay will also be 64% of that generated by a freefall on 40 degree slope, we know the force on the belayer (on the belay device) is only about .96 kN (call it 1 kN). Forces this low (below 2 kN), will generate no involuntary slip through the belay device.\(^8\)

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\(^7\) 5.4 kN x 0.64 = 3.45 kN (round down to 3.4)

\(^8\) An astute Belayer understands the forces at play and can operate their belay device to allow the rope to slip through the device at forces below 2 kN. In such cases, the rope slip goes from involuntary to voluntary.
So the fall force calculator told us that the freefall would place 5.4 kN of force on the top anchor. After reducing 2 kN for slope and 0 kN involuntary belay slip we figured the top anchor would actually sustain about 3.4 kN of force. If our snow picket holds 4 kN, we can theoretically sustain our worse-case controlled fall of 3.4 kN without causing the alpine safety system to fail. Still confused?

**Let’s summarize the math in this example:**

1.) Determine the strength of the weakest link in your climbing system (usually the snow). In this case each snow picket can theoretically sustain 4 kN of force.

2.) Using a fall force calculator, enter your weight (say 200 lbs.), rope stretch (averages 8%), and carabineer friction (averages 0.6). Next enter the data related to the fall we want to measure. So let’s say the total amount of rope in use in the system is 50 feet, and the distance the Lead was above top anchor when they fell was 10 feet. Remember, falling from 10 feet above the top anchor would result in a 20 foot fall.

3.) Get your freefall numbers from the calculator. In this case:
   The Force on the Top Anchor = 5.4 kN
   The Force on the Falling Climber = 3.8 kN
   The Force on the Belay = 1.5 kN

4.) Make sure your Fall Factor is below 1. The Fall Factor is figured by dividing the total fall (20 feet in this case) by the total length of rope in play (50 feet in this case), 20/50 = 0.4. If your Fall Factor exceeds 1, go back to the calculator and change the anchor spacing and/or the amount of rope out for your worst case controlled fall until the Fall Factor is at or below 1.

5.) Subtract for slope. In this case the slope is 40 degrees. A fall on a forty degree slope generates 64% of the velocity (thus fall force) generated by a freefall. According to the calculator, the freefall force on the top anchor would be 5.4 kN. So we calculate 64 percent of 5.4 kN (a 36% reduction in force). We multiply 5.4 kN by 0.64 to get 3.4 kN. Likewise, the force on the Belay due to slope is 64% of that generated by a freefall. The peak force on the Belay drops from the 1.5 kN provided by the calculator to 1 kN. We multiply 1.5 kN by 0.64 to get .96 kN (we round it up to 1 kN).

6.) Subtract for any involuntary rope slip through the belay device. Forces on the belay end of the system that exceed 2 kN will be absorbed through involuntary rope slip. In this case the forces at belay were lower than 2 kN so there was no involuntary rope slip at belay.

**Summary**

The weakest link in our alpine safety system (the snow) will theoretically hold a picket to about 4 kN of force. From our worse-case controlled fall we theoretically expect to generate no more than 3.4 kN of peak force on a top anchor, a snow picket.
Conclusion

The worst case peak fall force expected in our alpine safety system is lower than the holding ability of the snow pcket. Good news. Our anchors can theoretically hold more than the force generated by our worst case fall.

Is a 0.6 kN “margin of safety” satisfactory? That depends on the level of risk you are willing to accept. Search and rescue personnel would not build a rescue safety system designed to fail at 0.6 kN above the worst case theoretical peak load. Want to increase your margin of safety? Add more rope (stretch) to the system, decrease the spacing between anchors, and/or double up your anchors. This will slow you down. Again, the choice is between speed and roped safety system security.

Use a fall force calculator, then subtract for slope and belay rope slip. Together these tools can help you figure the forces at play in your alpine safety system.

Following are some actions alpinists can take to help reduce peak forces on the top anchor:

1. Practice catching slips and short falls with your belay device. Learn to reduce forces on the top anchor by allowing some rope to slip through the device in a controlled manner. This is especially important if you intend to use rope thinner than 9 mm.

2. When climbing using snow anchors do not use a Grigri, Trango Cinch or other auto locking devices when the Belayer is below an ascending Lead climber. Auto lock devices will not allow involuntary or voluntary rope to slip (dynamic belay). If the ascending Lead falls, the belay will lock up placing more force on the marginal top anchor. 75

3. Have the Belayer drop down 5 or 10 feet below the first anchor placed. This will increase the amount of rope available to stretch thus reducing falling Fall Factor at the beginning of the pitch, when anchors #2 and #3 are being placed in a Picket Line, Running Belay, or when ice climbing.

4. Place snow pickets and ice screws in a straight line to reduce rope drag and allow maximum rope stretch. Use runners if needed. This will help keep Fall Factor low. A straight picket line will also help prevent intermediate pickets from popping out of the snow when the rope is tensioned due to a fall on pickets above.

5. When ascending using a Picket Line, place the first few pickets in the pitch close together and then spread the pickets out more as you climb. For example, on moderate slopes Picket #1 could be placed 5 feet above the belay, Picket #2 could be placed 7.5 feet above Picket #1. Picket #3 could be 10 feet above Picket #2, and Picket #4 could be 15 feet above Picket #3. Spacing pickets this way will keep the Fall Factor (and peak forces) low.

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75 According to Forces Involved in Leader Falls by Michael Strong, approximate braking forces provided by various belay methods include Body Belay (1kN), Figure eight in rappel mode (1.5 kN), ATC or B-52 (2 kN), Münter hitch (3 kN), and Grigri (9 kN).
while allowing you to spread anchors as widely as safely possible. See the section discussing Fall Factor above to learn more about how this works.  

6. When ascending using a Picket Line on steep or exposed slopes, you should place the first few pickets in the pitch close together and then spread the pickets out as you climb. For example, Picket #1 could be placed 4 feet above the belay, Picket #2 can be placed 5 feet above Picket #1. Picket #3 can be 6 feet above Picket #2, and Picket # 4 can be 7 feet above Picket #3. Spacing pickets this way will keep both the Fall Factor and peak forces low while allowing you to spread anchors as widely as safely possible.

7. When down climbing using a Picket Line, place pickets further apart at the top of the pitch and then closer together as you near the bottom of the pitch. Same as for ascending (as described above), just placed in reverse order.

8. Having the lightest climber lead a pitch up slope will reduce peak fall force placed on your top anchor during a Lead fall.

9. Have the heaviest climber lead a pitch down slope will reduce peak fall force placed on your top anchor during a Second fall.

10. Use a climbing rope with a high stretch or elongation, above 7.5% when appropriate.

Some Baseline Facts about Forces on the top anchor:

The amount of force placed on the top anchor when a 200 lb. climber hangs on a vertical rope is about .95 kN. We can round it up to 1 kN to keep it simple.

The amount of force placed on the top anchor when a 200 lb. climber hangs and tries to bounce hard on a vertical rope is about 2.06 kN. We can round it down to 2 kN to keep it simple.

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76 This spacing is just an example. Climbers need to take many factors into consideration when choosing anchor spacing.
77 These examples are for instructional purposes only. The climber must determine optimum anchor spacing based on observed snow strength, climber weight, belay dynamics, rope stretch and the desired level of safety.
78 Higher stretch ropes help reduce force on anchors. This works well on open snow slopes but can create problems when climbing in complex terrain where there are rocks and ledges to hit on the way down, e.g. “lithobraking”. If your route includes mixed ground, you may want to favor a dynamic rope with between 5 and 7% stretch. Alternatively, you can double up your higher stretch rope on mixed ground. This will significantly reduce its stretch. Most fall force data available assumes the weight of the average rock climber which has been estimated to be between 165 and 176 lbs. Rock climbers do not typically wear heavy backpacks while climbing. They climb a pitch, and then haul up their bag a.k.a., “the pig” from below. In contrast mountaineers commonly climb wearing packs in excess of 50 lbs. A 176 lb. mountaineer carrying a 45 lb. pack will weigh in at 221 lbs. In this document we depart from the data generated for rock climbers and assume climbers weigh 200 lbs. The figure quoted is based on 40 dynamometer tests of a 200 lb. climber hanging idly on ropes. The tests were conducted by the author on December 5, 2010.
80 Based on forty tests using a dynamometer conducted by the author on December 5, 2010. A 200 lb. climber hung and aggressively tried to bounce on one meter lengths of 11 mm. static rope (2.08 kN peak force), 9.8 mm. dynamic (2.05 kN), 9.2 mm. dynamic (2.04 kN) and 8 mm. dynamic (2.07 kN).
The (top) anchor on a vertical weighted top rope rappel of a 200 lb. climber needs to hold about 4 kN.\(^8\)

Section VI provides information to help you understand and design an alpine safety system. The primary objective of the system should be to keep peak fall forces below the strength of the weakest link in the safety system. Although the math is very useful to apply at home, alpinists should maintain a practical outlook when on the mountain. If a system does not seem safe, assume it is not safe.

Review your topographic maps before you climb to get an idea of the slopes you expect to ascend. Do the math at home and develop a preliminary climbing plan before you reach the mountain. I find that three or four roped climbing systems serve most of my climbing needs on snow slopes. Eventually your understanding of anchor strength, anchor spacing and Fall Factor will become second nature. You will know which systems to employ in most situations.

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\(^8\) Bogie p. 3; Connally p. 116
The following gear is needed for alpine climbing as described in this document:

- a rock climbing helmet
- a mountaineering or climbing harness
- 2 quick draws
- one snow picket (22” or 24” long)
- one 4 foot runner (made of 7 mm. cord, nylon webbing, Dyneema or Spectra)
- 10 meters of 8 mm. dry core nylon kernmantle rope (also referred to as cord)
- 15 feet of 1 inch tubular webbing (to make a chest harness)\(^{82}\)
- mountaineering boots (water proof with a \textit{fully rigid} sole)\(^{83}\)
- a three piece 6 or 7 mm. Purcell prussic system (short Purcell, long Purcell, prussic loop)
- snow shoes (preferably those that allow you to add/remove tails)
- mountaineering ice axe with a 3 to 4 foot adjustable tether (not an ice climbing ice axe/tool)
- 12 or 14 point mountaineering crampons (not ice climbing or aluminum crampons)
- an avalanche beacon
- an avalanche probe
- collapsible metal snow shovel

\(^{82}\) Studies have shown that the waist harness is inadequate to protect climbers against so called “reverse jackknife” falls. The falling climber essentially snaps in half, sustaining fatal spinal fracture under fall forces as low as 4 kN. Such falls can be prevented by building an improvised chest harness with a piece of webbing.

\(^{83}\) If the boot’s sole bends more than \(\frac{1}{4}\)” when you walk they are not acceptable mountaineering boots. Crampons tend to pop off boots with soles that bend more than a \(\frac{1}{4}\)”. In fact, crampons tend to pop off such boots at the exact time they are needed most. Also, it is difficult and often painful to kick steps with boots that are not fully rigid.
- two locking carabiners (one should be pear shaped)
- belay device such as the Black Diamond ATC Guide, Petzl Reverso 3, or Trango B-5284
- 20 feet of 1 inch tubular webbing (for building anchors)
- an ice climbing tool (specialized ice climbing ice axe)
- an ice screw (17 to 22 cm. length works well for boring “A-Threads”)
- 1 or 2 trekking poles
- polarized sun glasses
- leather rope gloves
- 4 feet of 1” webbing and a rappelling ring (for rigging A-Threads)

Rope Choices

Thickness and length matter, as does stretch.

**Thickness**

For mountaineering in snow, we often use dry core dynamic (higher stretch) ropes ranging in thickness from 8.6 to 9.1 mm. This thickness range works well on open snow slopes below 50 degrees. These ropes have a tensile breaking strength of about 17 and 20 kN respectively. When knotted, these ropes will hold about 11 and 13 kN respectively. A 40 foot Factor 2 fall of a 200

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84 Rope manufacturers have now managed to get single climbing ropes down to diameters below 9 mm. Thinner ropes are lighter but harder to grip during belay. Moreover, traditional belay devices were designed to create friction on thicker ropes. To deal with the widespread use of thinner ropes, equipment manufacturers now offer all manner of belay devices with “V” shaped and/or ribbed plates designed to increase rope friction. When used on thicker ropes, these devices can bring a falling climber to screeching halt. They are useful under certain circumstances when top roping, sport climbing and guiding but they can create problems when belaying climbers on standard sized ropes (9.8 mm.+), secured to single snow or ice anchor. They increase friction, adding force to the top anchor, the climber, and the entire safety system. Belay devices used with single snow anchors should be employed to bring the climber to a slow stop. Unless you are using thin ropes (less than 9 mm.), stick with simple friction reducing devices such as the ATC or select a device that gives you the option of applying lower friction for standard sized ropes and higher friction for thin ropes. It takes practice to effectively catch a fall on ropes thinner than 9 mm.
lb. climber on a 50 degree slope with involuntary belay slip will (in theory) generate 7.4 kN of force on a rope. The relative strength of the different components in our alpine safety system discussed in Part V above revealed that software such as rope and webbing are typically stronger than either the snow pickets or the snow. The snow and the hardware on most individual snow pickets will fail before 8.6 mm. to 9.1 mm. rope will break. Many alpine rescue manuals suggest your rope be designed to hold ten times the static weight of the load. This is referred to as the Static System Safety Factor (SSSF) of 10:1. A knotted 8.6 mm. rope meets the 10:1 SSSF standard when holding a 225 lb. climber (although it is not a lower stretch rescue rope). The 9.1 mm. thickness is convenient in that its 13 kN knotted breaking strength is just above the maximum “theoretical” force a falling climber can place on a rope in a Factor 2 fall. It is also believed to be about the maximum fall force a climber can survive. The drawback to rope of this thickness is its relative vulnerability to being damaged or cut on sharp edges when weighted. Although this is an extremely rare occurrence the consequences are dire. When climbing slopes above 50 degrees or over sharp rock or ice, you can simply double up the 8.6 to 9.1 mm. rope. With a double rope you can create a redundant line that can hold 224 kN. According to the UIAA Safety Commission, there are no recorded climbing accidents involving both double ropes being cut.

**Proview:** A slight majority of those surveyed climb with rope in the 8.6 to 9.1 mm. range followed closely by those favoring 9.2 to 9.8 mm. rope. Rope in the 9.2 to 9.8 mm. range is easier to pull and grip during belay and it does not need to be doubled up, but it does add a couple pounds to your pack.

**Length**

Rope length is the topic of much discussion. Alpinists typically climb shorter pitches than rock climbers. None of the climbing techniques describes in this manual involve having more than 120 feet of rope in play. Any extra rope can be wrapped in a Kiwi Coil or stuffed in your pack. Carrying a 70 or 80 meter rope for mountaineering on most snow slopes in California would be impractical and add unnecessary bulk and weight to your kit.

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85 McMillan p. 6.
86 When subjected to fall forces above 13kN (2912 lbs.), the internal organs of humans begin to liquefy. Fall forces above 15 kN (3366 lbs.) can tear the human heart from its moorings.
88 Personal correspondence with Jed Williamson, editor of Accidents in North American Mountaineering, November 2, 2010. Mr. Williamson confirmed that climbing accidents caused by cut ropes are extremely rare. Also, a review by the author of Accidents in North American Mountaineering for the five year period between 2006 and 2010, revealed that of the 571 accidents reported, only two involved a fall due to a cut climbing rope. In both cases (in Pennsylvania in 2007 and West Virginia in 2009), the rope was cut when the climber fell while trad climbing in vertical terrain. So 99.7% percent of reported mountaineering accidents during this period were due to issues other than cut ropes. That said it is worth noting that the cut rope in the West Virginia accident resulted in a fatality. So a cut rope is a low probability, high consequence event.
89 Pitt, p. 13; Twight, p. 160.
90 An example of using the full 120 feet of rope would be a 50 foot Picket Line using an 8.6 mm. rope. If the rope was doubled up due to steep and/or rocky terrain you would have 110 feet in service at the end of the 50 foot pitch. There would still be about 10 feet of double rope left on the belay end to allow some rope to slip through the belay device in the event the Leader fell while placing the top anchor. See Appendix A for more detail.
**Proview:** A little over half of those surveyed favor a rope length of 60 meters (197 feet). About one third carry a 50 meter (165 foot) rope.

**Stretch**

Ropes with more elongation can help reduce peak forces placed on the top anchor, particularly when you are using higher friction belay devices such as a Grigri, Trango Cinch, a Münter hitch or any belay device oriented in progress capture or auto lock mode. Rope stretch is not that important when employing more dynamic belays such as when you use an ATC. Dynamic ropes will stretch between 5 and 12 percent when weighted.\(^91\) Elongation above 8 percent works well when climbing on open snow slopes with snow pickets. Elongation above 8 percent can create problems when in vertical terrain with ledges or when climbing in complex, rocky landscapes, e.g., mixed climbing. Put simply, the highest stretch climbing ropes are best suited for terrain where there is little to hit on the way down. To reduce the stretch of higher stretch ropes while in complex terrain, you can simply double them up.

Regardless of the rope thickness, length or stretch you choose, make sure your alpine rope is dry core/dry treated. Also, any climbing rope you purchase should bare the CE or UIAA label.\(^92\)

Proficiency with the following knots, hitches and coils is needed to climb as described in this document:

- Alpine Butterfly knot
- Bowline
- Clove hitch
- Figure Eight follow through
- Figure Eight on a bight
- Kiwi Coil (optional)
- Overhand knot (double overhand as well)
- Prussic hitch
- Water knot (for webbing)

**Proview:** About half those surveyed use the alpine butterfly to tie into the middle of climbing rope. Most of those that remain favor an overhand on a bight or an in-line figure 8; The figure 8 follow through is still the undisputed king for tying in to the end of a climbing rope. Over 95 percent of those surveyed tie in with this knot. The only other knot mentioned for tie in was the bowline with a Yosemite finish; Half those surveyed use the Kiwi Coil most of the time. Most of

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\(^91\) This is the amount of stretch the dynamic rope will experience when weighted with a “static” 80 kg. hanging block. During a fall these ropes are designed to stretch more than 25 percent of their length.

\(^92\) CE and CEN stand for “Comité Européen de Normalisation”.
those that remain use it sometimes. To learn these knots visit Animated Knots at:
http://www.animatedknots.com/indexclimbing.php

Part VIII: A WORD TO THE WISE

“If you’ve tallied a lot of experience in dangerous, iffy environments without significant calamity, the mental path of least resistance is to assume it was your skill and savvy that told the tale. That same trap kills a lot of experienced climbers...”


This document reviews climbing techniques, anchor placements, and fall forces applicable to snow and ice covered slopes. Climbs on alpine rock and glaciers requires knowledge of climbing techniques not covered here. Alpinists can select from the menu to assemble an alpine snow and ice safety system. Each technique and placement has strengths and weaknesses. The knowledge, experience and common sense of the alpinist are the most critical components in the safety system.

You, as the alpinist, must identify the weakest link in your safety system. You must determine the maximum forces the weakest link can sustain. Your choice of climbing technique, anchor spacing and placement should be designed to keep peak forces below what the weakest link can sustain. You should always allow for a margin of safety. Placing a snow picket or ice screw that cannot hold a short fall is an illusion of safety. It wastes time and energy in an environment where time and energy are at a premium. Under such conditions, it may be better to leave the rope, pickets and screws behind and free solo. You will climb faster. If anchors cannot hold a fall and conditions are not conducive to free soloing, make the prudent decision to forgo climbing.
Although it is very important to understand the forces at play in your alpine safety system, it is not possible to reduce snow and ice climbing to a series of equations. Today’s materials sciences give us an accurate account of the strength of rope, carabiners and Yosemite granite. But have no illusions; the mediums of snow and ice will not be held to the standards applied in materials science. Alpine climbing involves real risk. The quality and strength of snow and ice can change in just a few hours or over just a few meters of travel. As we have seen, “pencil hard” snow can theoretically hold snow pickets at forces between 4 and 40 kN. This represents an entire order of magnitude and exemplifies the crude measure with which we assess the most unreliable link in our safety system: the snow. Snow and ice are in a constant state of metamorphosis. We can liken snow and ice climbing to steering a ship made from sheet metal that varies in thickness, strength and flexibility from hour to hour and place to place.

Even when we set up a “safe” climbing system, all risks are not avoided. Objective hazards such as rock and ice fall, and avalanche are ever present, even when climbers take precautions to avoid them. We must be cognizant that it is the nature of mountains to crumble and fall. The relentless pull of gravity exploits each and every weakness. Even when exercising good judgment, skilled and experienced alpinists have fallen victim to “bad luck.”

Be that as it may, the uncertainty presented by snow quality and objective hazards pales in comparison to the uncertainty created by the human factors in mountaineering. Ambition, fatigue, misinformation, ego, and group dynamics contribute to many mountaineering accidents. Each year the American Alpine Club publishes Accidents in North American Mountaineering. In the 2006 to 2011 editions, the anatomy of accidents profiled includes titles such as:

“Fall on Snow, Unable to Self-arrest, Inadequate Equipment, Inexperience”

“Fall on Snow, Inadequate Belay”

“Weather, Failure to Turn Back, Inadequate Clothing”

“Avalanche, Did Not Read Published Avalanche Warning, Poor Position, Beacon not On”

“Falling Rock, Dislodged by Climbers Above”

“Unable to Kick Steps, Unable to Self-Arrest (Soft-Slushy Snow), Fatigue”

“Falling Rock, Weather, Late Start”

“Frostbite, Dehydration, Failure to Pay Attention to Warning Signs”

*And my personal favorite…*

”Jumped into Crevasse (broke tibia) and then Later Fell at Camp While Urinating (dislocated shoulder)”

Each year we find the same errors are repeated, only the names and places change. Although interviews with accident victims reveal that they usually considered how they should proceed, too few considered if they should proceed. Mountaineering accidents tend to follow a pattern: A fundamentally bad decision is made which complicates and compounds subsequent decisions. As the situation deteriorates protocols are compromised, team structure breaks down and an accident

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93 Gonzales p. 115-129; Waterman pp. 130-133.
94 This raises another issue altogether, that of being selective in choosing your climbing partners.
follows. Quit often the “fundamentally bad decision” that led to the accident involved a failed attempt at mind over matter. Before reaching the mountain, climbers often build a mental model of how the climb will proceed. When they arrive on scene, they often find that conditions on the mountain differ from their mental model. Rather than building a new model, they proceed with the original plan. A big part of successful mountaineering involves having flexibility in problem solving and expectations. If you were expecting to climb a banana but arrived to find a lemon, do not fight it. Make lemonade! Statistics reveal that it is often emotion and ambition that brings alpinists to terminal velocity. We can learn from the mistakes of our brethren.

Alpinist Ed Viesters is the first American to climb all of the world’s 8000 meter peaks without supplemental oxygen. He has chosen to turn around on numerous climbs, sometimes while very close to the top. In many cases his equally talented peers continued on to the summit only to be forced to contemplate their views on the afterlife. Ed Viesters has had to return to some mountains three or four times before summiting. During his decades in the mountains, he has not suffered as much as a frost bitten pinky. He exemplifies the patience, perspective and discipline of the veteran mountaineer. It is said of mountaineers that there are reckless novices and cautious veterans, but few reckless veterans. It seems that the mountains are indifferent to our fate; we would do well to proceed with caution and afford them respect.

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