

Drop Testing with Snow Anchors

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FAILURE MODES OF SNOW ANCHORS DURING DROP TESTING

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Abstract

Previous slow-pull testing of snow anchors in medium- to high-strength snowpacks has demonstrated that pickets and flukes can hold loads up to 1,500 lb, and occasionally loads up to 2,000 lb can be held [1].

A series of drop tests were performed using various forms of snow anchors, including pickets in various configurations, flukes, and bollards. Slow-pull testing was done in the same snowpack to establish a baseline for comparison with the drop-test data. For the drop testing, a 215-lb (0.96-kN) Cascade litter was used as the test mass and slid 26 ft (8 m) down a 31° snow slope with 26 ft of 7/16" KM-III rope between the test mass and the snow anchor. Peak impact forces were measured with a dynamometer and correlated with whether or not the anchor survived and the type of failure that was seen. Whereas slow-pull testing in high-strength snowpacks generally results in shear failure of the snow, all of the current tests, both slow-pull and drop tests, led to compressive failure of the snow. Recorded peak impact forces during drop tests were roughly one third to one half the force needed to fail a similar anchor during slow-pull testing. In tests when the anchor held the fall, it was noted that as the travel distance of the anchor through the snowpack increased, the measured peak impact forces decreased.



Figure 1. Drop testing with a loaded litter on a snow slope.

Disclaimer: The information contained in this document is based on limited field testing. The user should verify the results and practice the techniques before applying them to a live or critical load. Failure to do so may result in serious injury or death to personnel and/or damage to equipment.

Background

Different snowpacks throughout the world have different characteristics. Even within a given snowpack, the characteristics of the snow can vary dramatically depending on the slope aspect, how it was deposited, moisture content, temperature, etc. Because snow can be so variable, different anchor types may be better suited for different snowpacks. This author has yet to find a one-size-fits-all solution to the problem of creating a reliable anchor in snow. The conflicting needs of set-up speed and anchor strength, confounded by the variable quality of the material that Mother Nature has given us to work with, make this an unrealistic expectation. An anchor that performs well in a maritime snowpack may perform poorly in a continental snowpack, or even in the same maritime snowpack a week later [2].

In addition to being knowledgeable and adept in setting up various types of snow anchors, it is always recommended that multiple anchor points be used when live subjects will be relying on the overall anchor system for their security.

Previous slow-pull testing of various types of snow anchors has demonstrated that when moderate- and high-strength snow is used, anchor strengths can be predicted with a fair degree of reliability, and in high-strength snow, anchor strengths up to 1500 lb can be achieved with a similarly cautious degree of reliability [3].

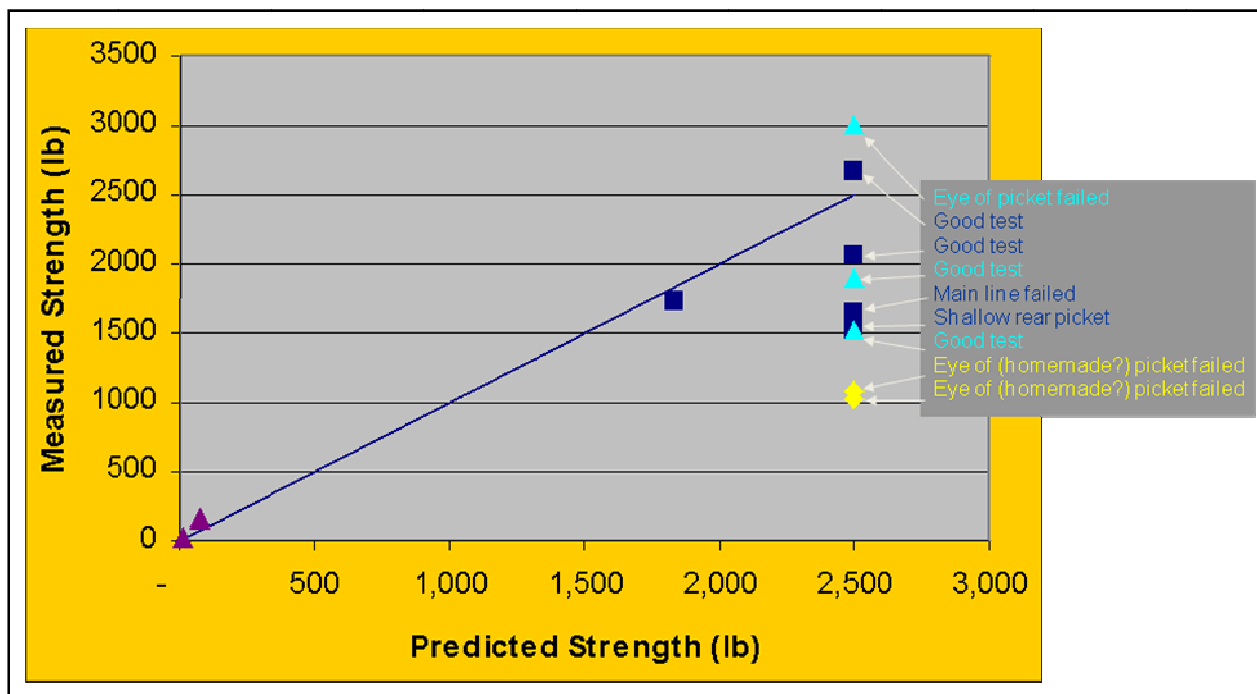


Figure 2. Measured and predicted strengths of Sierra Pickets in high-strength snow.

Anchor Types

The types of snow anchors studied in this investigation include horizontal pickets, Sierra Pickets, flukes, and bollards. Tradition pickets (vertical placement, top-clip) were not tested because they generally perform poorly in anything but icy conditions.

As used in this paper, the term “horizontal picket” refers to a picket that is attached to the rest of the anchor system at the midpoint of the picket. The picket is buried in a horizontal orientation with the direction of pull perpendicular to the long axis of the picket (Figure 3). Generally speaking, the depth of the picket should be at least 1 foot, but modeling and slow-pull testing have shown that deeper burial generally results in greater strength [1,3].

The term “Sierra Picket” is used to refer to a picket placement where the connection is again at the midpoint of the picket, but the picket is placed in a vertical orientation (Figure 4). The top of the picket must be no higher than the surface of the snowpack, otherwise the picket will rotate forward and fail at undesirably low loads. Like horizontal pickets, deeper placements will generally result in greater strength.



Figure 3. Top view of a horizontal picket placement



Figure 4. View of Sierra Picket prior to and after placement.

Flukes are metal plates that use their surface area to resist motion through the snowpack. Older flukes typically come with swaged cables that fix the rake angle—the angle between the direction of pull and the plane of the fluke. Newer flukes, such as the one available from DMM, enable the user to set the rake angle. Previous slow-pull testing has demonstrated that the highest strengths were achieved with a rake angle of 90° (i.e., the plane of the fluke being perpendicular to the direction of pull) [1]. Old-school dogma indicated that you wanted a rake angle greater than 90° so the fluke would dig down deeper into the snowpack under heavy loads. Testing, however, has shown that a moving fluke is susceptible to reorienting itself in an undesirable manner. For example, it if digs down and hits an icy layer, it is prone to rotating such that the plane of the fluke is now parallel to the pull direction—a configuration that provides little strength.

A bollard (Figure 5) is teardrop-shaped trench dug into the snow with the point of the teardrop pointing in the direction of pull. Bollards can be quite strong, but they generally require the greatest amount of time to build. It is generally recommended that the contact points between the rope/webbing and the mushroom stem of the bollard be padded to prevent the rope from slicing through the snow like a cheese wire. For the testing conducted here, the padding was omitted to simulate a worst-case scenario



Figure 5. Bollard prior to drop testing. Note the lack of padding between the webbing and the snow.

Failure Modes

Throughout this paper two failure modes are referred to: compressive failure and shear failure. In compressive failure, the buried hardware is dragged through the snow, and only the snow directly in front of the hardware is failing. The rest of the snowpack essentially remains in place. Imagine the snowpack to consist of a swimming pool filled with marbles. The marbles will provide resistance to the motion of the picket, but at a high enough load, the marbles in front of the picket will be pushed out of the way. For the most part, only the marbles directly in front of the picket, and perhaps a picket width or so on either side, will move.

Shear failure is typically seen in stronger snowpacks where the snow is strong enough to resist compressive failure. Since the snow isn't failing in compression, it eventually fails in a different manner. In shear failure, a large block of snow in front of the picket or fluke is usually ejected from the snowpack in a sudden, explosive manner (Figure 6). Consider the surfaces where the ejected block of snow used to contact the rest of the snowpack. Those surfaces failed due to a mixture of shear and tensile forces, but for the sake of simplicity, this will be referred to as shear failure. For comparison, the crown of a slab avalanche fails in tension, and the avalanche bed fails in shear where the sliding slab separates from the rest of the snowpack.

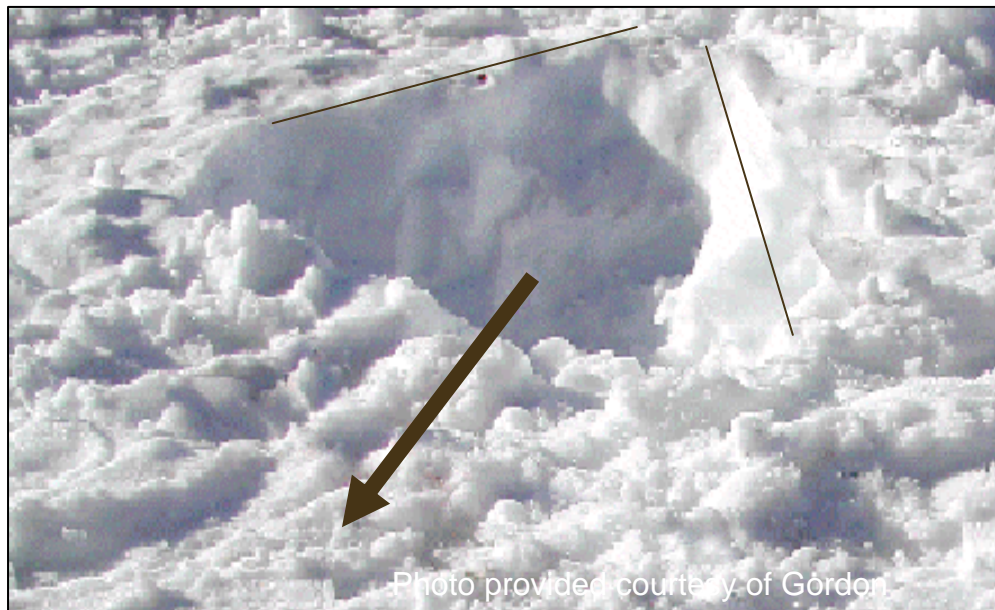


Figure 6. Shear failure of a Sierra Picket sowing the size of the ejected chunk of snow. The picket was originally located at the rear of the wedge shown by the thin lines.

Baseline Testing

Prior to doing the drop testing, a series of slow-pull test were performed using a gasoline-powered winch and a 3:1 mechanical advantage system (Figure 7). A schematic of the setup is shown below. Note the change of direction pulley, which was used to protect the winch operators from flying hardware. Low stretch rope was used, and an electronic dynamometer with a peak-hold function was used to capture the data. The testing was

performed in the San Gabriel Mountains in southern California in a maritime snowpack on a north-facing slope. The snowpack was pencil hard (i.e., a pencil could be pushed into the snow with about 5 pounds of force).

Four tests were performed using a 2'-long V-shaped Yates picket with a factory-swaged cable attached to the midpoint of the picket. The picket had been subjected to previous anchor-test investigations, and on this day it was tested in the Sierra Picket configuration.

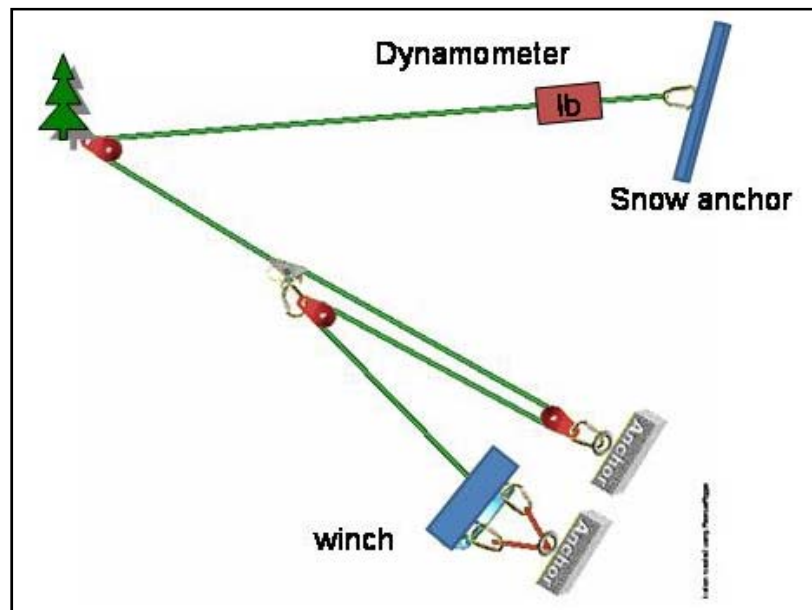


Figure 7. Test setup for slow-pull testing of snow anchors

On the first test, the far end of the swaged cable failed at an applied load of 2100 lb. The next test used the small loop of cable right at the picket as the connection point, and it held 1870 lb, at which point the picket rotated forward due to compressive failure of the snow in front of the upper half of the picket. The next test held 2060 lb and the failure mode was backward rotation of the picket due to compressive failure of the snow in front of the bottom half of the picket. The fourth test was loaded up to 2000 lb, and the picket traveled approximately 1 foot through the snowpack without sudden failure.

Previous testing with both the Sierra Picket and horizontal pickets showed that when the applied load exceeded 1500 lb, other failure modes started to become common. For that reason, it was recommended that the maximum design load for either picket configuration be no greater than 1500 lb [3].

Drop Testing

The drop testing performed in this investigation used a Cascade litter containing a Rescue Randy mannequin and a backboard. The total weight of the test mass, including the litter and rigging, was 215 lb.

The testing was performed within 30 feet of the baseline test location on the same slope. The snowpack was hard enough that the litter didn't compress the snow beneath it to

any measurable extent, and the angle of the slope was measured to be 31°. A piece of 7/16" KM-III rope with a net length 26 feet was secured to the litter with a figure-8 knot, and a similar knot was placed in the rope at the other end. The latter knot was connected to the dynamometer, which was in turn connected to the anchor. Both knots were pre-tensioned to >2000 lb during the previous slow-pull test series. A safety was connected between a stout tree and the dynamometer to prevent the load from going to the bottom of the hill in the event of an anchor failure.

With the load hanging statically from the anchor, the dynamometer read 110 lb, which would imply very little friction between the snow and the litter.

For each test, the litter knot was held on the hillside such that the litter knot was even with the dynamometer knot. The litter was then released and allowed to slide 26 feet with only snow friction and wind resistance to slow it down. One could think of it as a sideways fall factor of 1.0. The true vertical distance traveled by the litter is given by $26' \times \sin(30^\circ) = 13.4'$, so the true fall factor would be $13.4/26 = 0.52$, which is still a severe fall.

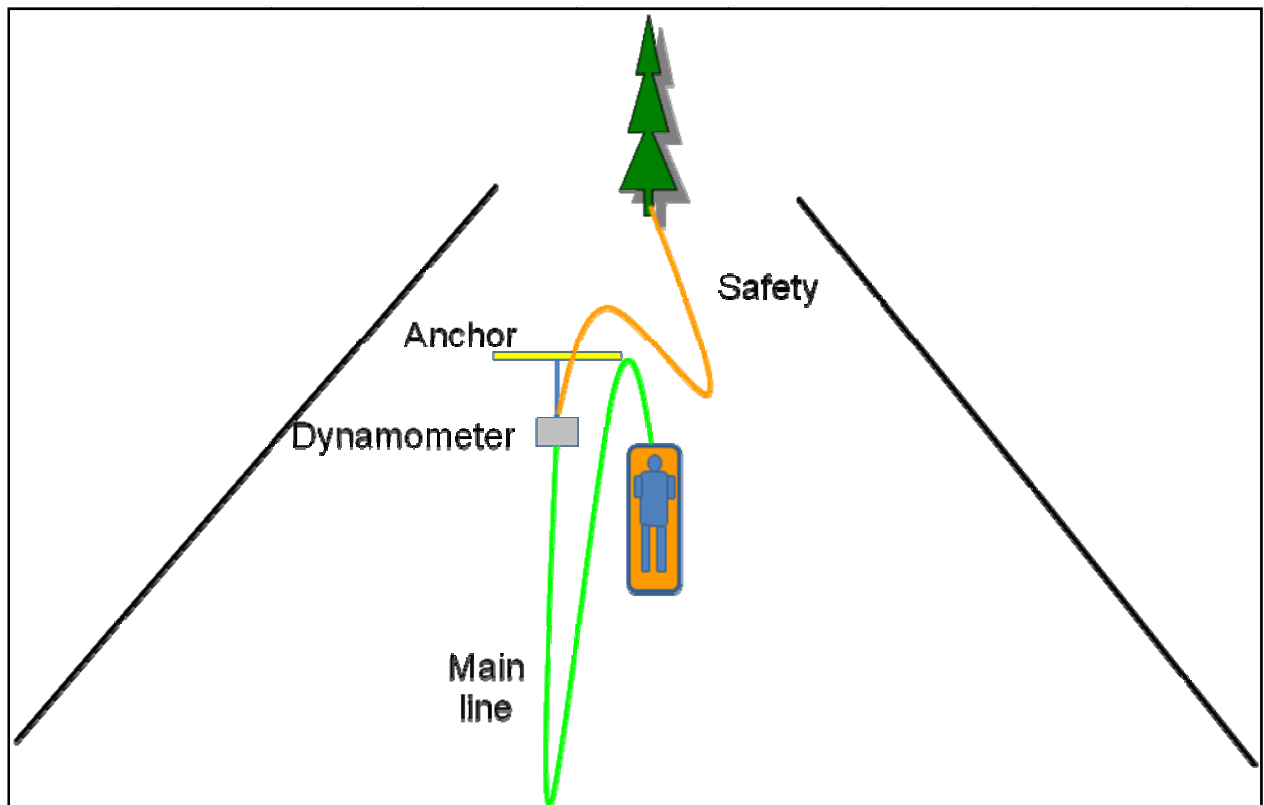


Figure 8. Drop-test configuration viewed from above.

Sierra Picket Testing

The first 4 drop tests used a 2' V-shaped picket in the Sierra Picket configuration. In two of the test, the snow in front of the picket failed in compress at peak impact forces of 635 lb and 735 lb. This is significantly lower than the 2000 lb results achieved minutes earlier during slow-pull testing on the same slope.

The next test resulted in a successful catch with a peak impact force of 1300 lb and minimal travel of the buried hardware. A second drop was performed on the same anchor, and the snow in front of the picket failed in compression with a peak impact load 1260 lb.

Horizontal Picket Testing

The same 2' V-shaped picket was next tested in a horizontal configuration, and it held the fall with a peak impact force of only 640 lb. The anchor traveled 3 feet as it was arresting the fall, which is believe to be the reason for the low peak impact force.

Two additional tests were done with 2-foot T-shaped MSR picket in the horizontal configuration. On the first test, it held the fall. The peak impact force was 895 lb, and the travel distance was 3 feet. On the second test, the carabiner at the dynamometer failed with a peak impact force of 920 lb. Examination of the biner suggests that it was not cross loaded.

Following replacement of the carabiner, two additional tests were done with the same picket. These held 1215 lb and 1155 lb, and the travel distances were small (<2") in both cases.

A 3-foot Omega Pacific picket was tested in the horizontal configuration, and the picket itself failed on the first test. The peak impact force was only 960 lb, but the carabiner tore through the eye of the picket (Figure 9).



Figure 9. 3-foot horizontal picket after testing. The carabiner hole failed at a peak impact load of 960 lb.

Fluke Testing

A 9 x 6½" DMM fluke was tested next, and the rake angle was set to 90°. The first test resulted in a successful catch, but the dynamometer did not have the peak hold function enabled. But because the fluke traveled 2.5 feet, it is anticipated that the peak impact force was low.

The load was dropped onto the anchor again, with no modification of the anchor. The fluke traveled 1 foot before the safety line took the load—we neglected to lengthen it prior to the test. The anchor was tested again. Despite 4 feet of slack in the safety line, the fluke moved sufficiently far to transfer the load to the safety again. These last two tests recorded peak impact forces of 940 lb and 505 lb, respectively. The anchor was tested again, and this time it caught the load without interference from the safety line. The peak impact force was 815 lb, and the travel distance was 1.5 feet. When the anchor was dug out, a 9-foot long tunnel was visible that led to the fluke's starting location. Because the rake angle was set to 90°, the fluke did not dig down, nor did it rotate.

Three additional tests were done with the fluke, but with a 120 ° rake angle (i.e., tipped backward 30°). The first drop resulted in a failure. The next test, which was identical in nature, recorded a peak impact force of 690 lb, and 2.5 feet of travel was noted. The anchor was retested with no modification, and it held the load again with 3 feet of travel and a peak impact force of 810 lb.

Bollard Testing

The final anchor type tested was the bollard. A 5' x 8' x 1.5' deep bollard was dug and wrapped with a single strand of 1" tubular webbing. No padding was used between the webbing and the bollard to achieve a worst-case scenario. Four drop tests were done, and with each of the first three tests, the webbing cut several feet into the stem of the bollard, but the bollard did not fail. It was only on the last test, when the bollard measured just 1' x 3', that the webbing cut through the remaining snow, and the bollard failed. On the prior test, when the bollard was 3' x 4', it survived. In each of these tests, the master point moved approximately 3' downhill during each drop.

Observations and Discussion

Three of the 22 tests resulted catastrophic failure of hardware instead of the snow. The swaged cable of a picket failed at 2100 lb, a carabiner tore through the eye of a picket at 960 lb, and a carabiner failed at 920 lb. Failure of the cable at 2100 lb is not unexpected, especially in light of the prior abuse sustained by that particular picket during previous rounds of snow-anchor testing [1,3]. Failure of the picket was unexpected because previous slow-pull testing of commercial pickets only demonstrated this phenomenon (eye failure) at loads on the order of 2000 lb [1,2]. The prior failures, however, were always with 2' pickets. One can argue that the added leverage of the 3' pickets, combined with moderate density snow, made them more prone to bending, which would put additional tensile stresses on the eye where the carabiner tore through. On the other hand, previous slow-pull testing of horizontally placed 3' pickets supported loads up to 2010 lb without hardware failure. More testing is warranted in this area. It should be noted, however, that data collected to date do not show horizontally placed 3' pickets to be stronger than similarly placed 2' pickets.

The failed carabiner was examined, and it appears that the sequence of events was failure of the gate at the open end, deformation and straightening of the top of the biner, and failure of the main bar stock where the spine meets the top. This is consistent with tensile

failure of a properly loaded carabiner. The biner had undergone four slow-pull tests and 15 drop test prior to failing.

Conclusions

This test series consisted of only 4 slow-pull tests and 22 drop tests. Because no single anchor configuration was tested more than a few times, one must be cautious not to put too much credence in the trends noted below. It would be statistically inappropriate to make any categorical statements regarding a specific anchor type based on this data. If 100 people each flip a fair coin 5 times in a row, at least a few are likely to get 5 heads. Though unlikely, it is possible that the data collected in this test series was from the “5 heads” group.

With the above caveat in mind, one trend that does appear to hold truth is that all of the anchors failed under conditions where the peak impact load was significantly less than the expected slow-pull strength. Very roughly speaking, the impact forces were one third to one half the expected (or measured) slow-pull strengths.

Given the condition of the snowpack, shear failure was expected for most, if not all of the tests. In the few slow-pull tests that were done, however, compressive snow failure was observed. Despite the change in failure mode from compressive snow failure to shear failure, the strengths measured in slow pull testing were in the expected range.

The three slow-pull tests notwithstanding, some shear failures were expected in the subsequent 22 test, but none were observed; every test that resulted in snow failure had the snow failing in compression. This prompts one to believe that under high strain-rate loading, the mechanical properties of the snow may perhaps be different than at low strain rates. More specifically, this suggests the possibility that the compressive strength of snow decreases with increasing strain rate. This result is consistent with compressive strength measurements made on defect-laden ice samples taken from the Taylor Glacier in Antarctica [4]. As the strain rates of their ice samples increased by a factor of ten, the measured strengths decreased by roughly a factor of ten. While it is a stretch to assume that moderate- to high-strength snow will behave like glacier ice containing dirt, their data does demonstrate that such an effect is possible. Additional testing is warranted to see if compressive failure is the rule with high strain rate testing of snow anchors.

When a given anchor type was tested several times, as the travel distance of the hardware increased, the peak impact force decreased. Given that the falling litter will have a fixed and relatively constant amount of kinetic energy from one test to the next, the above observation makes qualitative sense due to conservation of energy. More subtly, it suggests that the snow behaves in a reasonably homogeneous manner. If the snow were lumpy or if it contained isolated areas of high hardness or greater strength, one would expect the impact-force and travel-distance numbers to be less correlated.

Summary

A series of drop tests was performed by sliding a 215-lb test mass down a 31° snow slope in a quasi-fall-factor 1 scenario. Peak impact forces were measured and failure modes

were noted. Whereas slow-pull testing in medium- and high-strength snowpacks generally results in shear failure of the snow, drop testing led to compressive failure of the snow. Recorded peak impact forces during drop tests were roughly one third to one half the force needed to fail a similar anchor during slow-pull testing.

Acknowledgements

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References

1. A. Fortini, "On the Use of Pickets and Flukes as Snow Anchors," presented ITRS, Denver, CO (2002).
2. A. Fortini and J. Morales, "Failure Modes of Snow Anchors," presented at ITRS, Denver, CO (2001)
3. A. Fortini, "Predicting Failure Modes of Snow Anchors," presented ITRS, Denver, CO (2005).
4. W. Lawson and C. Elliott, "Strain-Rate Effects on the Strength of Debris-Laden Glacier Ice," *New Zealand J. Geo. And Geophys.*, **46**, p 323 (2003).

