A Comparison of Stretch and Forces Between Low- and High-Stretch Ropes During Simulated Crevasse Falls

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Abstract

Roping glacier travelers together to safeguard against the potentially catastrophic consequence of a crevasse fall has been standard safety practice for decades. Being roped up, however, is not a guarantee against injury. Anecdotal evidence suggests that injuries sustained during roped crevasse falls are the result of striking the walls, obstructions, or “corking” in a constriction. In addition to using proper glacier travel techniques and effective self arrest, the question has been raised: Would the use of low-stretch ropes be a better alternative than high-stretch ropes to limit the length of a crevasse fall and thereby decrease the possibility of injury?

To answer this question, a study was conducted to collect comparative rope-stretch data between small diameter, low- and high-stretch ropes, and large diameter, low- and high- stretch ropes (see note). The study also recorded impact forces at the test mass and the arresting anchor. The test method simulated glacier travel situations. A full 25 meters of rope was deployed for each test, and test masses of 100kg (which approximates the weight of a traveler and pack) and 118kg (which approximates the weight of a traveler, pack, and sled) were used. In total, 21 drop tests were conducted.

Preliminary results point toward low-stretch, small-diameter ropes as an alternative to the traditional use of high-stretch ropes for safely limiting the length of crevasse falls and thereby reducing the probability of injury.

Note:

To define the terms low- and high-stretch I looked to the British Columbia Council on Technical Rescue which defines low-stretch as those ropes that elongate less than 5% under 2kN of tension and high-stretch as those ropes that elongate greater than 10% under 2kN of tension. The Cordage Institute standard 1801-98, defines static ropes as having less than 6% elongation at 10% of minimum breaking strength (MBS), a low stretch rope as having between 6 and 10% elongation at 10% MBS and a dynamic rope having greater than 10% elongation at 10% MBS. Using this standard, the corresponding terminology would be: I tested small diameter low-stretch ropes, small diameter dynamic ropes, large diameter static, and large diameter dynamic ropes.

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Glacier travel is an important mountaineering element for most alpinists. The majority of glacier travel time is spent slogging across what can, at times, seem like a giant white parking lot. But there is the persistent possibility of suddenly plummeting into the bowels of a crevasse. Most glacier travelers find it prudent to avoid this possibility by taking the following measures: avoiding the firn zone, planning trips during times of deeper and more solid snow pack, avoiding travel during the heat of the day, using the proper floatation (skis or snowshoes), and selecting a route with fewer crevasses. In addition to these precautions, most glacier travelers prepare for the possibility of a crevasse fall by tying themselves to their companions, commonly known as roping up.

To achieve the maximum benefit of roping up, each party member should be trained to prevent crevasse falls. Unfortunately, despite prevention measures, falls occur, and travelers are sometimes injured during these falls. Anecdotal evidence suggests that the dynamic properties of ropes work to prolong the fall and increase the possibility of injury. According to Jed Williamson, editor of *Accidents in North American Mountaineering*, most crevasse fall injuries are initially due to people hitting the crevasse wall, hitting themselves with their axes, or getting wedged (cited in “Low Stretch Rope Use for Glacier Travel” [NOLS newsletter, ca. 1999]).

Thus, the questions: Is there a substantial difference in the length one falls if a high-stretch rope is used versus a low-stretch rope (all other variables being equal)? If yes, what is it? Could the length of a crevasse fall be shortened significantly by using a low-stretch rope? If a low-stretch rope is used, what peak forces would be generated during a fall? If a climber plus gear weigh a given amount, and are using a given type, and diameter of rope, what length of fall should be expected?

To begin it is necessary to define the terms low- and high-stretch. For this I looked to the British Columbia Council on Technical Rescue which defines low-stretch to refer to those ropes that elongate less than 5% under 2kN of tension and high-stretch as those ropes that elongate greater than 10% under 2kN of tension. The Cordage Institute standard 1801-98, defines static ropes as having less than 6% elongation at 10% of minimum breaking strength (MBS), a low stretch rope as having between 6 and 10% elongation at 10% MBS and a dynamic rope having greater than 10% elongation at 10% MBS. Using this standard the corresponding terminology would be that I tested small diameter low-stretch ropes, large diameter static ropes, and small and large diameter dynamic ropes.

Some research has already been completed in this area. John Hauf, formerly of the National Outdoor Leadership School (NOLS) and Kirk Mauthner, formerly of Rigging for Rescue, conducted drop tests using low-stretch ropes to approximate a relative worst-case crevasse fall. They tested for the possibility of a fall factor .5, which could occur if a climber falls half of the distance that exists between that climber and his or her arresting partner. (Put another way, a fall factor .5 would occur if a climber falls seven meters and there is only 14 meters between climbers.) If high peak forces could be generated with low-stretch rope, it would be in this instance. Yet, when a 1.5 meter drop was made on 3 meters of rope, it was found that a peak force of only 8.2 kilonewtons (kN) was obtained. (A 9mm low-stretch New England KM-

III rope and a 120kg test mass were used). This peak force is well within the limit of the UIAA standard allows 12 kN for arresting a human body. Also note that UIAA tests are done with an 80 kg mass, whereas 120 kg mass was used by Hauf & Mauthner to represent a climber plus equipment. Therefore the 8.2 kN force observed would have been distributed proportionally between the climber and equipment, meaning that the climber would have been subjected to considerably less than 8.2 kN.

Further tests were done by Loui Clem, of Pigeon Mountaineering Inc. (PMI). When Clem tested PMI 9mm accessory cords using a fall factor of one and a 100 kg test mass, forces of 11.6 kN were recorded. Additional PMI tests were conducted using various low-stretch 11mm ropes. A larger test mass and a more realistic fall factor of .25 produced peak forces of only 5.45 to 7.47 kN. These tests answer some of the questions posed earlier, and provide a valuable foundation for further study.

Using these tests as a spring board, I decided to conduct tests that more accurately reflect situations found in glacier travel. I believed this could help quantify the actual forces and determine how much low-stretch ropes would shorten a fall. Each mountaineering situation has its own unique variables, and the purpose of this study was not to come up with a recommendation regarding rope type or diameter. It is hoped that glacier travelers can use the data from these tests to gain a realistic idea of the potential consequences (good and bad) of their rope choice.

Procedure/methods

There were several challenges associated with conducting drop tests on an actual glacier. The study required several test sessions, and over time several variables would likely change, such as snow depth, density, and the friction of the snow surface. Further, the drop/stop distance required a crevasse at least 14 meters deep. Vertical walls were needed to allow for a frictionless drop, and a safe vantage point to observe the amount of rope stretch was required. A perfectly horizontal, crevasse free surface of 25 meters was needed to deploy the test rope. Although an environment like this might exist, it was not easily accessible.

Consequently, the tests were conducted off a bridge. The bridge met all the test requisites and has been converted to pedestrian-only use. It is a large, sturdy, steel structure with multiple anchor points and drive-up access (Figure 1). It provided an excellent venue for conducting multiple tests with minimal environmental change over time.

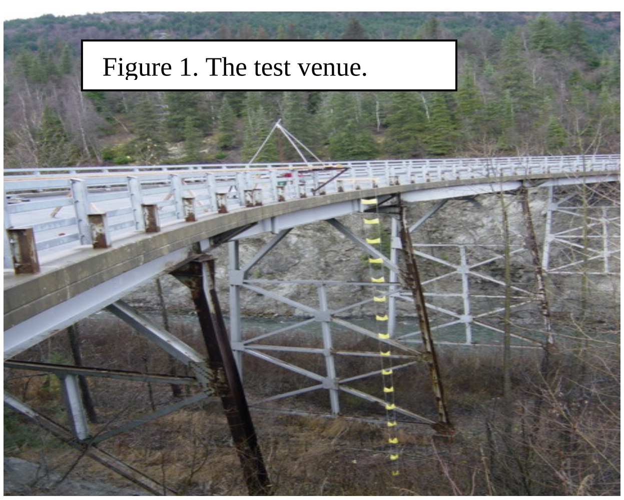

Figure 1. The test venue.

Test masses of 100kg (which approximates the weight of a traveler and pack) and 118kg (which approximates the weight of a traveler, pack, and sled) were used. To position the test mass for dropping, a home-built tetrahedron was used; there was a haul system at its apex. The tetrahedron was attached at the edge of the bridge so that the test mass could be suspended just past the drop edge. The drop edge was a 3-inch stainless steel pipe; it was supported by a ¼ inch steel triangular frame that was clamped to the side of the bridge. This edge mimicked the low amount of friction that a crevasse edge would provide in a firn zone. The test did not provide any energy absorption that would come from a snow corniced crevasse edge.

A rope track made of 8-inch wooden truss-joists was placed perpendicular to the drop edge. Twenty-four meters away, the bridge framing and railing were used as a solid anchor (Figure 2).

Figure 2. The whole set-up with the test mass deployed.

To capture the rope stretch data, my mother-in-law (Martha) made a giant tape measure. It consisted of large yellow flags positioned on chains every meter (Figure 3).

Figure 3. Martha's giant tape measure.

To capture the force data, a Honeywell Load Cell s/n 1014321 (with an upper range of 10,000 pounds) was used (Figure 4). I also used a data acquisition box and program that converts the output to kilonewtons. This program made a graph that displayed the entire sequence of force (This equipment was provided courtesy of the Alaska Mountain Rescue Group and the Mountain Rescue Association.)

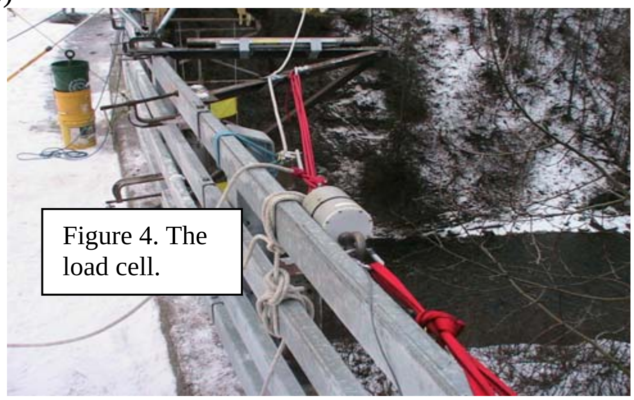

Figure 4. The load cell.

Four ropes, all new, were used for each series of tests: one low-stretch 10mm, one low-stretch 8mm, one high-stretch 11mm, and one high-stretch 8.8mm. (All ropes were provided by Sterling Ropes.)

To conduct the tests, a test mass was positioned one meter vertically above the edge and one meter horizontally beyond the edge. The rope was placed on the rope track in a straight line going directly to the bridge abutment where it was tied. The rope was perpendicular to the drop, there was no excess slack, simulating good rope management and a perfect arrest of the fall. There was 25 meters of rope between the test mass and the anchor, which was used to simulate a three person rope team (assuming a 50 meter rope). This would likely be the farthest distance climbers (most commonly) are apart. An observer was positioned below the bridge abutment and level with the anticipated drop.

Results:

The results are presented in tables 1 through 4.

Table 1

Test	Rope type	Diameter	Total drop	Peak force kN	
1	Low-stretch	8.0mm	5.0 m	4.30 kN	
2	High-stretch	8.8mm	11.5 m	3.60 kN	
3	Low-stretch	10.0mm	N.C.	5.00 kN	
4	High-stretch	11.0mm	7.5 m	4.75 kN	

This data was collected using a 100kg test mass and positioning the load cell at the anchor. N.C.= Not Collected

Table 2					
Test #	Rope type	Diameter	Total drop	Peak force kN	
5	Low-stretch	8.0mm	6.5 m	4.75 kN	
6	High-stretch	8.8mm	11.0 m	3.48 kN	
7	Low-stretch	10.0mm	8.0 m	4.80 kN	
8	Low-stretch	10.0mm	8.5 m	4.80 kN	
9	High-stretch	11.0mm	10.0 m	3.40 kN	

This data was collected using a 100kg test mass and positioning the load cell at the test mass.

Table 3				
Rope type	Diameter	Total drop	Peak force kN	
Low-stretch	8.0mm	5.75 m	4.50 kN	
High-stretch	8.8mm	11.25 m	3.54 kN	
Low-stretch	10.0mm	8.25 m	4.80 kN	
High-stretch	11.0mm	8.75 m	4.10 kN	

This is a summary showing the average values for the tests using a 100kg test mass.

Table 4					
Test #	Rope type	Diameter	Total drop	Peak force kN	
10	Low-stretch	8.0mm	7.00 m	3.7 kN	
11	High-stretch	8.8mm	9.75 m	3.3 kN	
12	High-stretch	8.8mm	10.50 m	3.4 kN	
13	Low-stretch	10.0mm	7.00 m	4.4 kN	
14	High-stretch	11.0mm	9.00 m	3.1 kN	

This data was collected using a 118kg test mass and the load cell positioned at the anchor.

Discussion:

According to the data from Table 1 through Table 4, the low-stretch, small-diameter rope stretched least when compared to all rope types. The difference in rope stretch is especially pronounced when the low-stretch, small-diameter rope data are compared to those created by the high stretch small diameter rope. It appears that half of the fall distance (5.75 meters versus 11.25 meters) resulting from rope stretch can be eliminated by using small diameter low-stretch ropes over small diameter high-stretch ropes at the cost of adding approximately 1 kN of force to the arresting system. This seems to be true regardless of the test mass weight. Also noteworthy, concerning the high-stretch, large-diameter rope is that it seems to occupy the middle ground between low-stretch, small diameter and high-stretch, small diameter, making it perhaps a more versatile choice.

After the initial tests in which 25 meters of rope was used, secondary tests were conducted using only six meters of rope. This distance would approximate the type of fall a lead climber might expect if he or she fell into a crevasse immediately after leaving a safe zone. Table 5 presents data on the possibility for the highest peak forces.

Table 5

Test #	Rope type	Diameter	Total drop	Peak force kN	
15	Low-stretch	8.0mm	3.85 m	6.6 kN	
16	High-stretch	8.8mm	5.00 m	5.5 kN	
17	Low-stretch	10.0mm	4.20 m	7.3 kN	
18	High-stretch	11.0mm	5.00 m	5.0 kN	

This data was collected using a 100kg test mass with 6 meters of rope in service. The same one meter vertical distance above the edge and one meter beyond the edge was used for test mass positioning.

These findings suggest that no matter which type or diameter of rope is used; if there is a possibility of a low-friction fall, every effort should be made to put more rope into service (such as moving the belay to the far side of the safe zone), strengthen the belay (lowering the center of pull on the belayer, having the rope tight to more bodies, or belaying directly off a bomb-proof anchor) and belay with a device appropriate for the possible force.

With this last point in mind, I conducted a test to ascertain which type of device would be good to use with low-stretch, small-diameter ropes. I also assumed that whatever worked on the smaller diameter ropes would also work well on larger diameter ropes (Table 6).

Table 6

Test #	Rope type	Diameter	Grip force	Belay Device
19	Low-stretch	8 mm	3 kN	Single B52
20	Low-stretch	8 mm	0.95 kN	B52 backed up w/ ATC
21	Low-stretch	8 mm	Zero	6mm prussic

This data was collected using 100kg test mass with 6 meters of rope in service. The test mass was positioned 1 meter out and 1 meter up from the edge with no extra slack. The load cell was placed behind the belay systems to determine the amount of grip strength required to stop the load.

It is useful to note that only the prussic was able to fully stop the fall during these tests. However, with enough hand protection and control of the rope, a fall eventually could be stopped using doubled stitch-plate-type devices. It is likely that a substantial bit of luck would be needed to stop a fall using a single stitch-plate-type device.

The opportunities for further study are many. I propose next to conduct tests on a glacier, dropping test masses through corniced lips in order to somewhat quantify the energy absorption of snow. I also would like to test alternative roped glacier travel methods, such as double rope and knotted systems and test the effect that is created by using varying amounts of rope.

As an instructor and guide I'm sometimes asked by climbers intent on saving weight: "What is the smallest diameter of rope one can use and still retain enough strength to arrest the most likely crevasse falls?" I point out that strength is only one part of selecting a proper rope for any project. Other considerations, such as: What is the total weight of each climber? How many people and how far apart are they? What is the character of the crevasse hazard? What type of snow cover is there? What is its depth and density? What type of rescue systems will be used, and are they appropriate for the diameter and type of rope that will be used? And lastly, how much rope stretch is acceptable? All these factors come into play. My advice is that dogma and/or speculation should not provide the answers to these questions. Test things out and let the data speak for itself. In that spirit, hopefully this information, and more to follow, will help in selecting a safer rope for glacier travel.

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