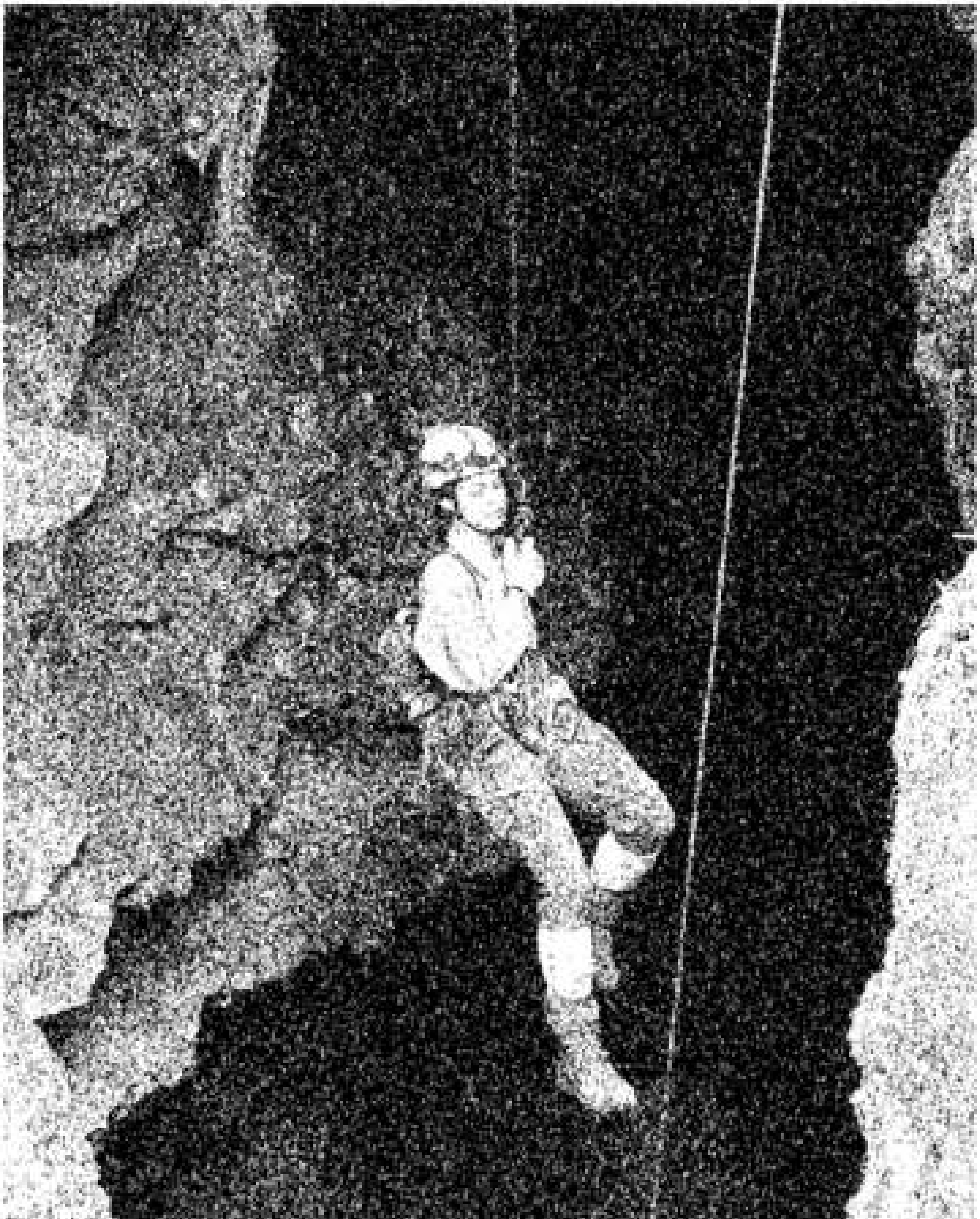
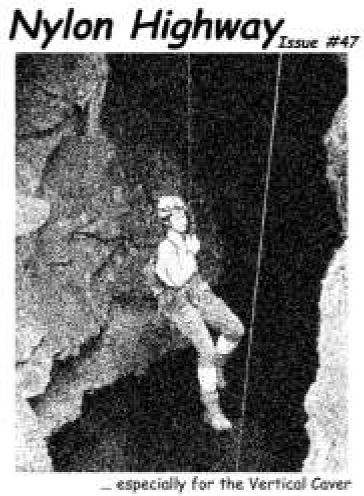
Nylon Highway Issue #47



... especially for the Vertical Caver

#47

Contents



Overleaf

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The Frog System - Revised

By Peter Penczer

In November 2000 I spent two weeks caving in France, where I learned some valuable tips about the frog system. I had been using this system for about six years, and I always thought that it was inefficient. In reality, it was only *my* frog system that was inefficient.

Naturally, the French don't call it the frog system, any more than they refer to French fries as French fries. It's the only system they have for climbing a rope, and as best I could determine, there is no French term for vertical gear. The rigging, anchors, and climbing gear are part of one integrated system for tackling vertical caves. Everyone in France goes vertical caving the same way, so they know their system very well. Here are a few things I learned:

The chest harness is critical for climbing efficiently. French caver Joel Raimbourg showed me how to make a simple chest harness that makes climbing much easier. It supports some of the weight of my upper body, holding it close to the Petzl Croll and saving me from doing a pull-up with every climbing stroke. To make the harness, tie a piece of one-inch webbing into a loop 34 inches long (I am about five feet and ten inches tall). Twist it once into a figure-eight, and put one arm into each loop. Grab the part of the loop where the webbing crosses itself and pull it over and behind your head, onto your back. Next, grasp the two pieces of webbing that cross your shoulders and pull them together and clip them into your Croll with a small carabiner. Use the type of 'biner that is intended to be used as a key chain. A full-sized carabiner is too large and will make your system less efficient.

The chest harness should be so tight that you can't stand up straight when you're not on rope. I clip the two shoulder loops together with the small carabiner and wait until my Croll is on the rope to clip the 'biner into the Croll. After I climb, I unclip the chest harness before I get off rope, unless I'm only a few feet from another climb. Ralph Hartley reported that on one occasion this type of harness tightened up painfully at the top of a tight pitch, presumably because his seat harness slipped down. He recommends installing a quick-release buckle on the harness.

If you don't understand my description, look at the drawings on page 7 of the book *Vertical* by Alan Warild. In Europe, you can buy a ready-made frog chest harness that looks like a ropewalker chest harness without the roller. Several varieties can be found in the Expe' catalog (the biggest speleovender in France), and might be available from American speleovenders as well. I used to use a Petzl Torse, and it made for very inefficient climbing.

In France, there is a great deal of variation in chest harnesses. A typical configuration is a loop that is attached to the seat harness in back, extends over each shoulder without crossing over itself, and attaches to the Croll in front. This loop is loose enough that the caver can leave it attached all the time. I have found the figure-eight style harness to be more efficient.

The seat harness leg-loops should be tight. This is not important with a ropewalker, but very important with the frog. If there is two inches of slack in your leg loops, your body will drop two extra inches every time you sit down on your Croll, which you do with every climbing stroke.

Keep your foot loop short. A foot loop that is too long will make it difficult to pass rebelays. Moreover, when you are climbing, your arms will be stretched out above your head when you start the motion of standing on your foot loop. When you stand up, you're trying to hold your upper body close to the rope, and if your arms are above your head, you won't have much leverage. That's not very efficient.

To be sure your foot loop is the proper length, get on rope and stand up straight in your foot loop with both feet. Your Croll and the ascender on your foot loop should touch. I use a handled ascender (a Petzl Expedition) on my foot loop, but I find it easier to climb if I hold the frame of the ascender near where it contacts the rope, rather than holding the handle. Some French cavers use a Petzl Basic on their foot loop to save weight.

Use the Petzl Pantin. The Pantin is a small foot ascender made for use with the Frog system. You wear the Pantin on your right foot and put your left foot through your Frog foot loop. Its purpose is to make the Frog system more efficient and not to provide an extra margin of safety. The Pantin is made to pop off the rope fairly easily so that the user doesn't have to bend over when detaching it (e.g., when passing a rebelay). Some people have complained that it comes off too easily, but I have never found this to be a problem. When I was in France, a lot of people used the Pantin and liked it. I use mine for longer drops. When climbing with it, I stand up using both feet at one time, as I would without it. I find that it makes climbing easier by a good margin.

The following tips are more for safety than efficiency:

Close the gates on your ascenders. The gate on your Croll is not all that strong. If you leave it open as you pass through the cave, it might catch on something and get damaged.

The D-link should be properly oriented. The opening should be on your left. If it is on the right, the movement of the rope as you are climbing will unscrew the gate, leaving the D-link open. This happened to me twice before I realized what the problem was.

Karabiner Breakings when Using a Figure-of-Eight

Neville McMillan

Introduction

For decades climbers have been using a Figure-of-Eight (Foe) as standard equipment for abseiling. Both experts and complete novices have used this piece of equipment, invariably attached to their harness or waist belt by a screwgate karabiner, without any reported problems. Yes, there have been many abseiling accidents, due to an inadequate anchor point, or the rope getting cut, or abseiling off the end of the rope, or losing control of the free end of the rope, etc, etc. But until five years ago there had not been any reported failures of the Figure-of-Eight (FoE) or its attachment karabiner.

Then in 1995 in England a climber had a lucky escape whilst abseiling, when his FoE levered open the gate of the attachment karabiner but failed to come free. The following year a student at an adventure centre was not so lucky, his FoE levered itself out of the attachment karabiner, and he fell 40 metres to his death. Before the ink was dry in reporting and analysing that accident, an accident occurred in Germany in 1997, due to an identical failure mode. This time the accident occurred whilst belaying with a FoE. A sport climber fell, and the sudden pull on the rope caused the FoE to break out of its attachment, leaving an opened screwgate karabiner attached to the belayer's harness.

The problem is not really with the Figure-of-Eight, but with the typical climber's screwgate karabiner, which is just not strong enough to withstand the levering action of a FoE in these abnormal configurations, and does not prevent these abnormal configurations from occurring. But the levering effect is not restricted to a FoE. More recently, the same mode of karabiner failure has occurred due to the levering action of an energy absorbing system (see article by Charlet).

The First Failure – a Lucky Escape

A climber had set up an anchor point for top-roping at the top of a single pitch route. He then prepared himself for abseiling to the ground. He wore a

Fig. 1

Black Diamond X harness. The make may be significant, because some Black Diamond harnesses, notably the BOD, do not have a tape loop (the belay loop) connecting the leg loops to the waist belt. When he purchased the harness he was advised to connect the leg loops to the waist-belt by a karabiner for abseiling; the same advice is commonly given to purchasers of the BOD harness. Depending on the size of the harness and the size of the climber, this arrangement often results in the karabiner not being free to rotate but being held roughly horizontally whilst abseiling. At the start of an abseil, when the rope is more horizontal than vertical, depending on the orientation of the karabiner, this can allow the FoE to apply a large force to the gate of the karabiner, and lever it open, breaking a notch out of the locking-sleeve (see Fig. 1).

It is thought that this happened at the start of this abseil, though the climber did not realise it at the time. A little fur-

Fig. 2

photos: N. McMillan

ther down, he felt a jolt, and looked down to see that he was connected to the abseil rope as shown in Fig. 2. As he was still 30 metres above the ground, he was a little alarmed, but managed to remain calm. He scrambled to a ledge where he replaced the karabiner, and then continued safely down.

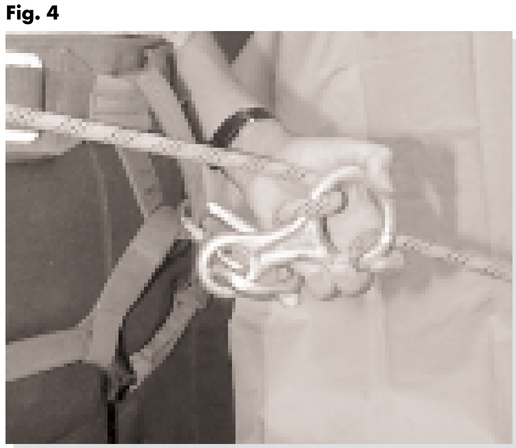
The Second Case – a Fatality

A mature student at an adventure centre had carried out an abseil for the first time in his life. That evening he was persuaded by fellow students to do a free abseil, off a bridge, the following day. The bridge was modern, with a substantial steel railing giving a solid anchor point. The aim was to abseil off the parapet at the side of the bridge, down to a minor road 40 metres below. The student was using the conventional FoE and screwgate karabiner, controlling the free end of the rope close to his body, keeping his hand just behind his waist, as he had been taught (Fig. 3). He started to lean out and lower himself, then looked down and his confidence failed him. He pulled himself back into an upright position whilst he wondered whether to carry on. He was persuaded by his fellow students and the instructor to have another go. Which he did, but a second time nerves overcame him and he pulled himself back again. Each time he pulled back again, the FoE and the karabiner went slack (Fig. 4), and, each time he restarted, the instructor made sure that these two items of equipment were correctly aligned. This scenario was repeated several times, until finally he plucked up courage and launched himself into the abseil. Unfortunately for him, he did this too quickly for the instructor to correct the alignment of the FoE and karabiner. As he launched himself into the abseil, these two items moved into the abnormal configuration shown in Fig. 5, and his body-weight was sufficient to cause the FoE to lever open the karabiner gate, breaking a notch out of the locking sleeve as it did so. The FoE was then released from the karabiner , leaving him with only his hands on the rope. He died from the injuries received when he hit the road 40 m below.

When this failure mode was first analysed, many competent people thought that the abnormal configuration could not be maintained long enough for failure to occur. But experiment showed that it can occur, and it can be repeated in demonstrations. Furthermore, the load required to produce the failure is only slightly above a typical climber's *static* weight, and well within his *dynamic* weight. Karabiner gate-locking sleeves are only designed to prevent the inadvertent opening of a karabiner gate; they are not designed to resist the leverage which a FoE can apply in such configurations.

Fig. 3

Fig. 4



photos: N. McMillan

Fig. 5

The Third Case – Belaying – Luckily only Minor Injuries

This case was reported from Germany by Pit Schubert. Two young sport climbers were at a crag on a warm, sunny day. The belayer was using a FoE attached to his harness by a screwgate karabiner. He was lying on the ground, sunbathing, talking to other climbers nearby, and not paying too much attention to what his leader was doing. The leader fell off, the rope came tight, there was a sudden jolt on the belayer's harness, and the next thing he saw was the FoE travelling up the crag to the first bolt, as the free end of the rope accelerated through his hand.

Luckily the leader was not far above the ground, anticipated his fall, and escaped a potentially serious accident with relatively minor injuries.

The Consequences

In all these cases, after the accident the Figure-of-Eight stays where it was on the rope at the time of the failure. The attachment karabiner is found on the harness, with the gate open, the locking sleeve screwed up, and a notch taken out of the locking-sleeve. These are the tell-tale signs of this failure mode. But it would be good never to see these signs, because the potential consequences of this failure mode are fatal.

So what can be done?

Many things are possible; the question is: "What are climbers prepared to accept?"

- For belaying there is no need to use a FoE. The FoE was designed for abseiling not belaying, so it could be argued that using it for belaying is a misuse of equipment.
- For abseiling, a cord sling can be attached to the abseil rope by a prusik

knot, and clipped to the harness. This does not avoid the mode of failure described, but does provide a safety backup in the event of any failure of the abseiling device. The prusik can be attached either above or below the abseiling device, as described in many climbing textbooks.

- Clipping the attachment karabiner to both leg-loops and waist-belt should be avoided (see article by Harremoës)
- Karabiner manufacturers do not currently consider it practicable to make gate-locking sleeves sufficiently strong to prevent gates being levered open in all possible configurations. However, there are now karabiners available on the market which make the FoE captive at one end of the karabiner, thus preventing the levering action from occurring. The DMM Belaymaster is one such device.
- Alternatively, the FoE could be attached to the harness by a small stainless steel quicklink or Maillon Rapide. This is slower and less convenient to use, but is very unlikely to be levered open by a FoE.
- Finally, one can take great care to ensure that the Figure-of-Eight and attachment karabiner are always in the correct configuration, and always under load, especially when abseiling over an edge or round a bulge. Jumping over an edge should be avoided.

In the end what one does is up to the individual climber, but being aware of this failure mode, and its potential consequences, should make a climber better able to make decisions about the equipment he uses and the way he uses it in any particular situation.

The author Neville McMillan is the UK National Delegate to the UIAA Safety Commission and the Technical Director for the English language. He is the Chairman of the British Mountaineering Council's Technical Committee, which investigates failures in mountaineering safety equipment in the UK.

Presented to the International Technical Rescue Symposium, November 2001

Presented by: Chuck Weber, PMI Quality Manager

Abstract

This paper presents the results of 162 individual drop tests performed at PMI and slow-pull elongation data for five different life safety ropes. It was confirmed from this line of testing that the static and low stretch ropes exhibit a trend of increasing impact forces generated as the length of drop and rope are increased for any given fall factor. While this trend may be considered minimal at FF 0.25, the trend of increasing forces for FF 0.5 and greater was in fact significant.

While this report may prove useful as educational and reference material for professional rope users, it is NOT intended to be a "user's guide" at this point in time. Rather, the purpose of this report is primarily to report these initial findings of the larger effort to more accurately model the performance and limitations of life safety ropes.

Background

Last year's ITRS attendees should recall an interesting report on Fall Factors presented by Jim Kovach. The test data from that report suggested that static rescue ropes, unlike dynamic climbing ropes, did not always follow the universally accepted model of Fall Factors at high load and fall factors. It was observed through testing that measured impact forces for any given Fall Factor would in fact increase versus stay the same as the length of drop/rope was increased. This was especially noticeable in Fall Factors of 0.5 to 2.0.

This new report is our effort to validate the prior testing and further this line of study. We feel this effort is very important for all of climbing and rescue communities so that we can all know for certain that we are in fact applying the concept of Fall Factors appropriately for all types of life safety ropes: static, low-stretch, and dynamic.

Definitions

- **Low Stretch Rope.** A rope with an elongation greater than 6% and less than 10% at 10% of is minimum breaking strength. (ref. CI 1801-98)
- **Static Rope.** A rope with a maximum elongation of 6% at 10% of its minimum breaking strength. (ref. CI 1801-98)
- **Dynamic mountaineering rope.** Rope, which is capable of arresting the free fall of a person engaged in mountaineering or climbing with a limited impact force. (EN 892:97)
- **Fall Factor.** A measure of fall severity calculated by dividing the distance fallen by the length of rope used to arrest the fall. (NFPA 1983:2001)

Test rig and basic drop testing sequence and setups

PMI's in-house drop tower was used to perform all the drop tests mentioned in this report. Each test rope was tied to a rigid two-chain anchor atop the 30-ft. tall drop tower and the other end was tied to a steel basket, a.k.a. the "test weight." Follow-through Figure 8 knots were used for both rope end connections. All the drop tests were performed in an identical manner.

The tower was designed in part to meet the specifications of various EN standards for rope testing. The basket had a 10,000 # load cell connected via cable to a portable handheld meter, with sampling rate of 1000 times per second. The calibration of this testing setup was verified by 3rd party services. The rig is also known to produce accurate results when compared to official CE laboratory reports for the same product. An especially useful design aspect was custom fit steel plates that can be added as needed to adjust the weight between an "empty basket" weight of 155# and a "full basket" weight of 500#.

The basket was easily lowered and raised to any position along its vertical path by a mechanical pick-up device and electric winch. The basket traveled freely between two steel I-beams, which were set in the concrete floor below and affixed to the roof framework of the building. There was no appreciable drag in this system. A quick-release mechanism efficiently released the test weight for free fall at the desired moment.

The test weight was applied to the knotted rope of every test for ~1 min. before the drop test was performed. During that time the exact rope length was measured to ensure that it was +/- 2 inches of the desired total length. Often the rope length had to be adjusted 2 or 3 times to ensure the proper length was achieved. We felt it was important for every test rope to be preloaded with the test weight prior to the drop to minimize the knots' effect on the resulting data and be as consistent as possible. Knot lengths were kept to 8" or less.

162 individual drop tests were performed on 5 different rope diameters and types. Both 176 and 500# test weights were used in Fall Factors of 0.25, 0.5, 1.0, and 2.0. Ropes tested were:

- PMI Classic EZ-Bend, 12.5 & 11mm, Static Rope (also some limited 10mm)
- PMI Impact, 13mm, Low Stretch Rope
- Blue Water II+Plus, Low Stretch Rope
- PMI 10.6mm Dynamic Rope

The basic progression and focus of this study was to start with a single rope, test weight, and FF; then perform a series of drop tests of different rope lengths while maintaining the desired FF. To make the test data as consistent as possible each rope was cut from long continuous lengths and each drop test was performed on a brand new and unused section of rope.

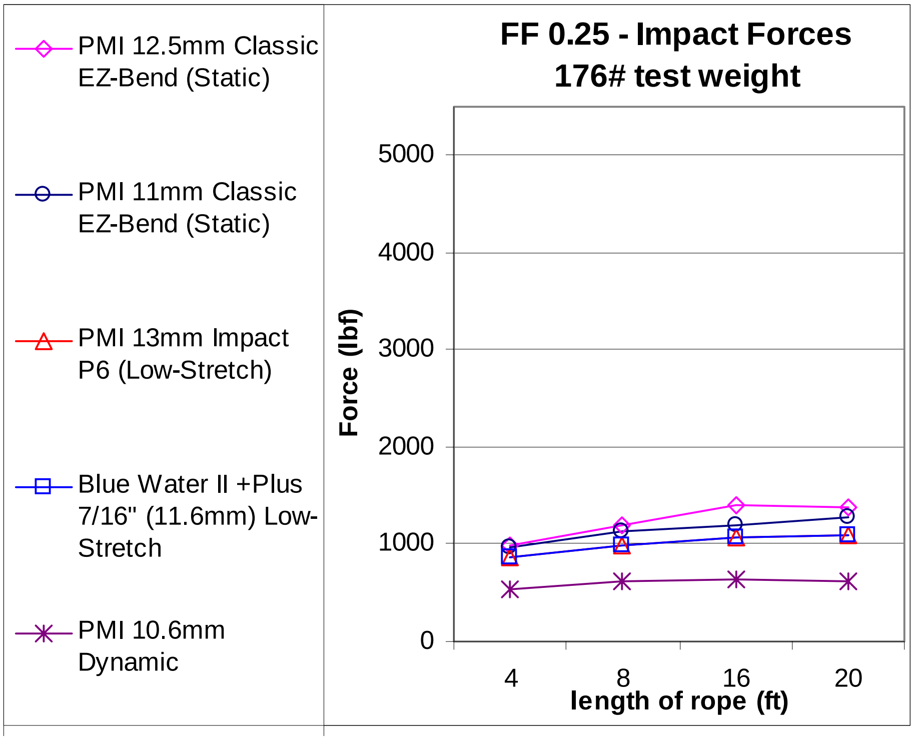
During each drop test the following were recorded:

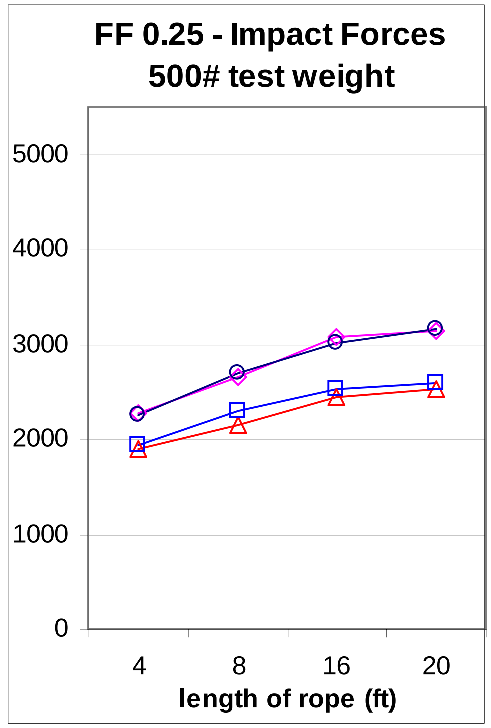
- pre and post test resting positions (holding test weight)
- Peak Impact Force (measured during drop)
- maximum elongation (on selected longer rope lengths only)

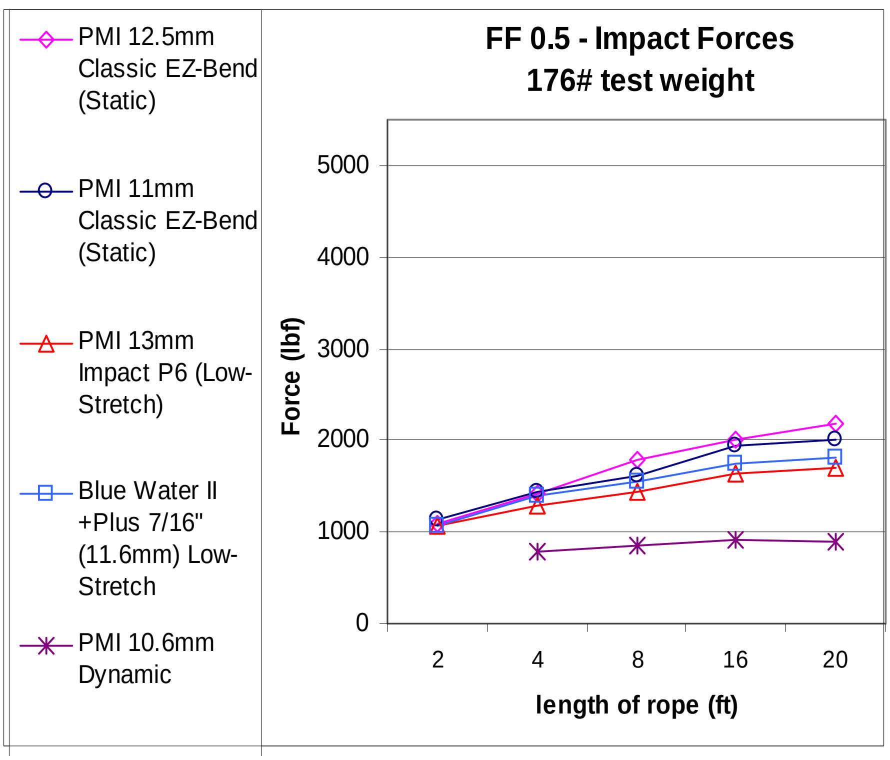
The next two pages of graphs represent the majority of the data.

Impact Forces for all ropes grouped by FF

Note: 1) graphs all scaled 0 to 5500 #, except for the last two 500# test weight graphs
2) tests with total rope failure not shown here







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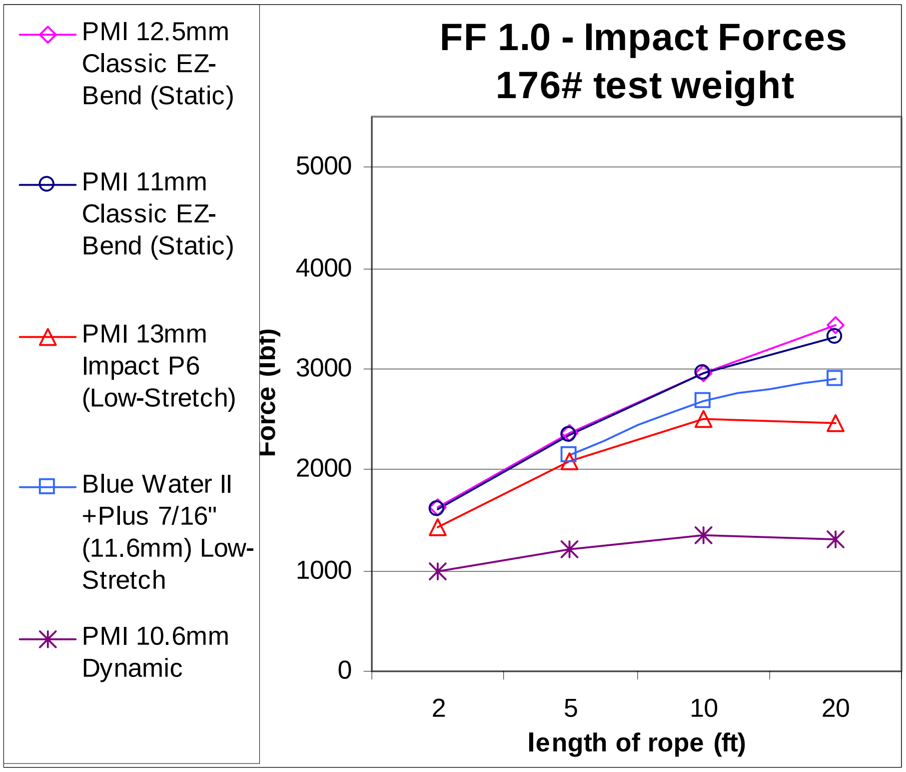
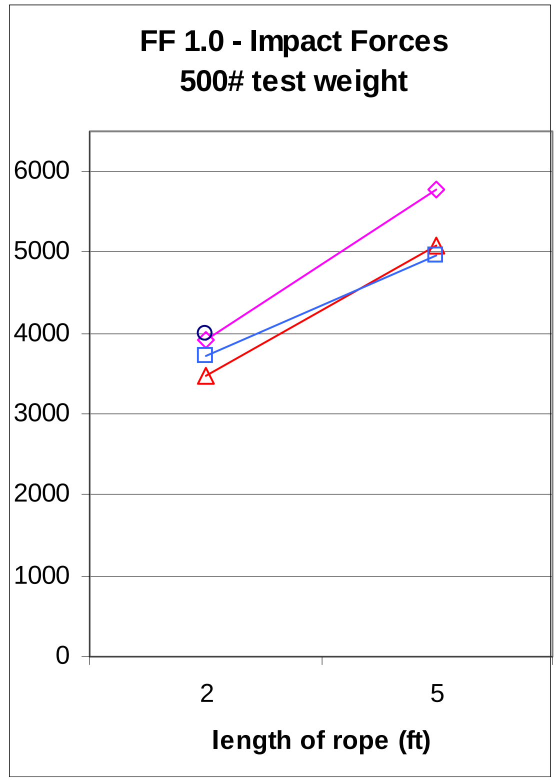
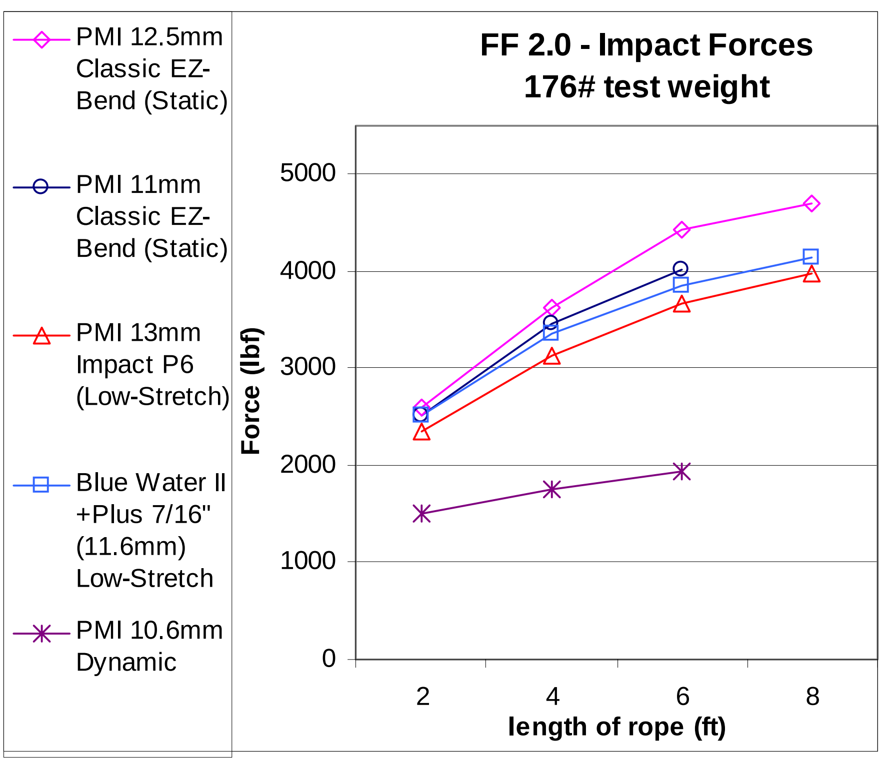
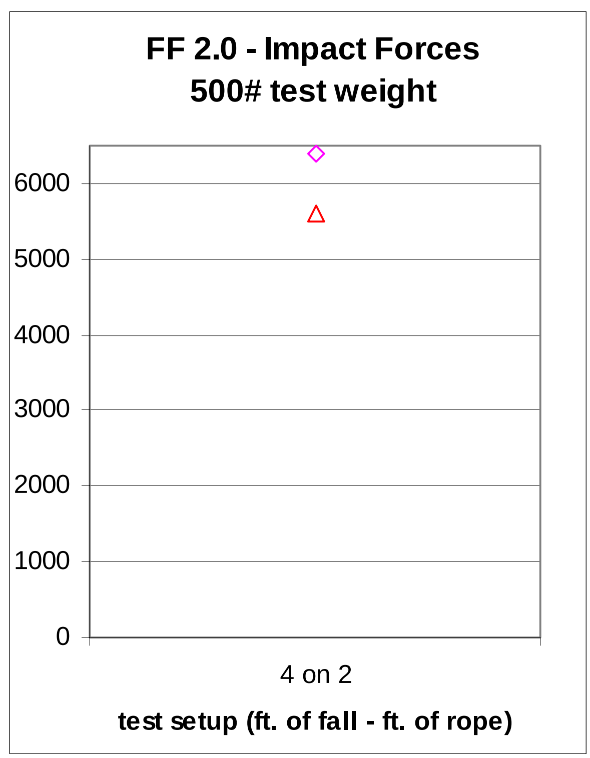






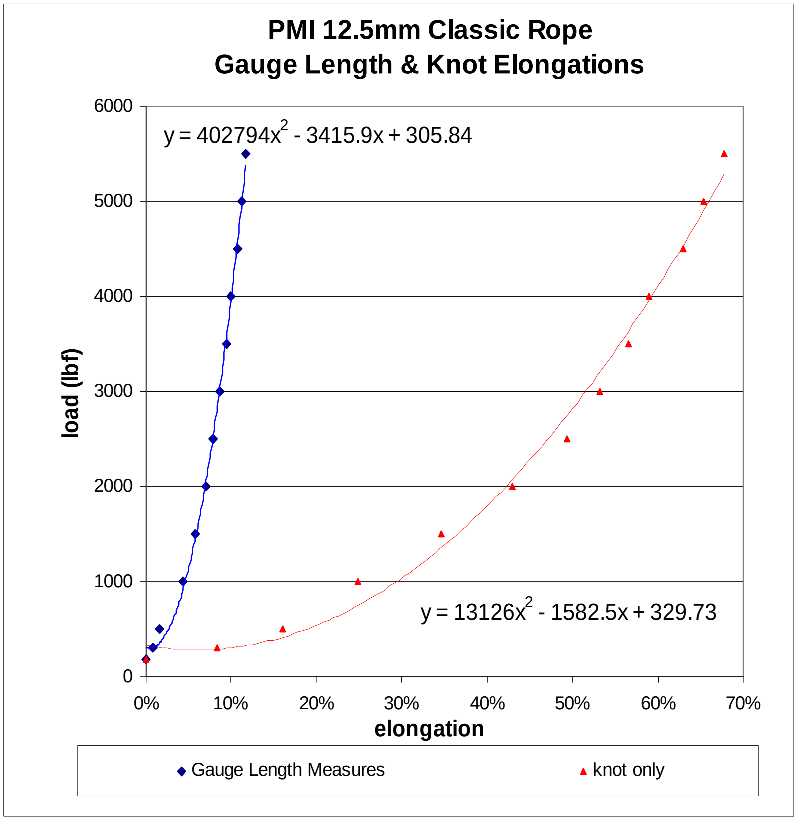


Slow-pull Tests

Most users would certainly agree that a knotted rope elongates when loaded more than the rope itself does for the same load. To better quantify that fact, we performed slow pull tests to measure both the elongation of a) the knotted end of a rope and b) a gauge length marked on the straight section of loaded rope. All the test ropes were tied into about 3 ft. test lengths with a follow-through figure 8 knot at both ends and gauge mark (200-250mm) was applied under 10# dead weight. Then dead weights of 176, 300, and 500# were applied and the measures recorded. The remainder of the elongation testing was performed by slow-pull testing on PMI's Dillon Tensile Tester equipped with a 10,000 # Dynamometer (50# increment scale).

The following graph is an example to show the typical difference between the elongation of the rope and a knotted end of the rope under the same forces. All other ropes tested exhibited the same basic result. The best-fit 2nd order polynomial equations shown were used in the rope+knot slow pull model used (see explanation and data table later in report) to estimate total rope length for a given impact force.

The next two pages give the actual data tables and show the resulting graphs for all ropes tested.



Note: Equations shown are flawed at the very low end; x=0 gives inaccurate loads, but the formulas are reasonably accurate for the purpose of an elongation model.

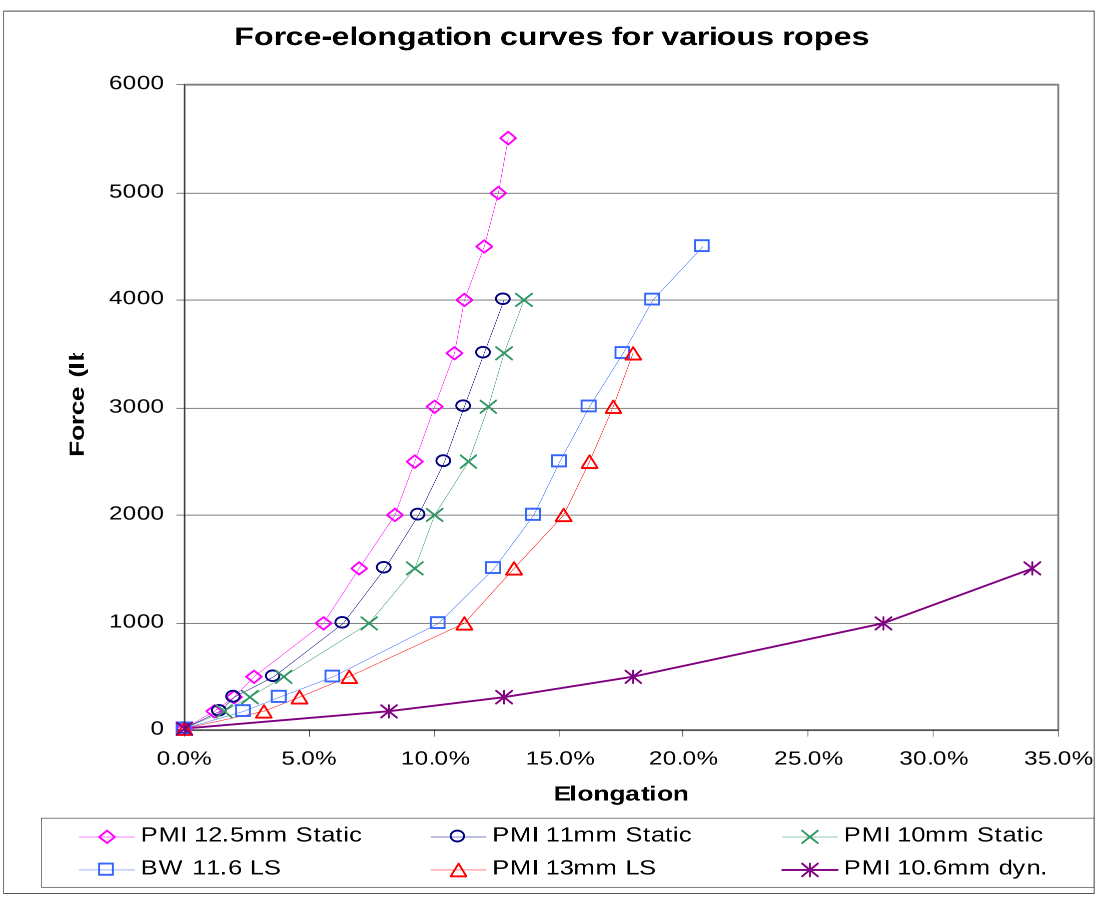
Rope Gauge Length Elongation Measures

	Static Ropes						Low-Stretch Ropes				Dynamic Rope	
Force	PMI 12.5mm		PMI 11mm		PMI 10mm		PMI 13mm		BW 11.6		PMI 10.6mm	
(lbf)	elong.	Modulus	elong.	Modulus	elong.	Modulus	elong.	Modulus	elong.	Modulus	elong.	Modulus
10	0.0%	n/a	0.0%	n/a	0.0%	n/a	0.0%	n/a	0.0%	n/a	0.0%	n/a
176	1.2%	14667	1.4%	12571	1.6%	11000	3.2%	5500	2.4%	7333	8.2%	2146
300	2.0%	15000	2.0%	15000	2.6%	11538	4.6%	6522	3.8%	7895	12.8%	2344
500	2.8%	17857	3.6%	13889	4.0%	12500	6.6%	7576	6.0%	8333	18.0%	2778
1000	5.6%	17857	6.4%	15625	7.4%	13514	11.2%	8929	10.2%	9804	28.0%	3571
1500	7.0%	21429	8.0%	18750	9.2%	16304	13.2%	11364	12.4%	12097	34.0%	4412
2000	8.4%	23810	9.4%	21277	10.0%	20000	15.2%	13158	14.0%	14286		
2500	9.2%	27174	10.4%	24038	11.4%	21930	16.2%	15432	15.0%	16667		
3000	10.0%	30000	11.2%	26786	12.2%	24590	17.2%	17442	16.2%	18519		
3500	10.8%	32407	12.0%	29167	12.8%	27344	18.0%	19444	17.6%	19886		
4000	11.2%	35714	12.8%	31250	13.6%	29412			18.8%	21277		
4500	12.0%	37500							20.8%	21635		
5000	12.6%	39683										
5500	13.0%	42308										
6000												
Failure	*6800*		*5200*		*4500*		*n/a*		*4900*		*n/a*	

Note: 10-500# measures made with dead weights, then same sect. of rope transferred to Dillon 10K# Tensile Tester for 1000# and up measures

Modulus Details

Avg.:	27339	20835	18813	11707	14339	3050
High:	42308	31250	29412	19444	21635	4412
Low:	14667	12571	11000	5500	7333	2146

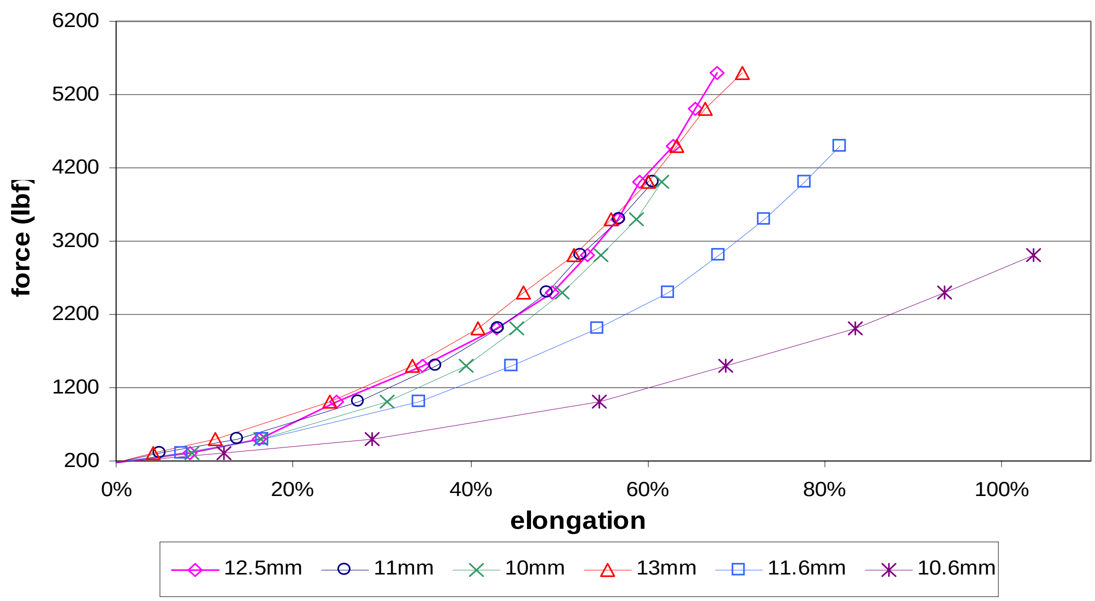


Rope Knot Elongation Measures (mm) and Elongations

Load	Static Ropes						Low Stretch Ropes				Dynamic Rope	
	PMI 12.5mm		PMI 11mm		PMI 10mm		PMI 13mm Impact		BW II+Plus 11.6mm		10.6mmPMI	
(lbf)	meas (mm)	% inc.(1)	meas (mm)	% inc.(1)	meas (mm)	% inc.(1)	meas (mm)	% inc.(1)	meas (mm)	% inc.(1)	meas (mm)	% inc.(1)
176	205	0	183	0	177	0	215	0	175	0	198	0
300	222	8.3%	192	4.9%	192	8.5%	224	4.2%	188	7.4%	222	12.1%
500	238	16.1%	208	13.7%	206	16.4%	239	11.2%	204	16.6%	255	28.8%
1000	256	24.9%	233	27.3%	231	30.5%	267	24.2%	235	34.3%	306	54.5%
1500	276	34.6%	249	36.1%	247	39.5%	287	33.5%	253	44.6%	334	68.7%
2000	293	42.9%	262	43.2%	257	45.2%	303	40.9%	270	54.3%	363	83.3%
2500	306	49.3%	272	48.6%	266	50.3%	314	46.0%	284	62.3%	383	93.4%
3000	314	53.2%	279	52.5%	274	54.8%	326	51.6%	294	68.0%	403	103.5%
3500	321	56.6%	287	56.8%	281	58.8%	335	55.8%	303	73.1%		
4000	326	59.0%	294	60.7%	286	61.6%	344	60.0%	311	77.7%		
4500	334	62.9%					351	63.3%	318	81.7%		
5000	339	65.4%					358	66.5%				
5500	344	67.8%					367	70.7%				
6000	n/a											
Failure	*7200*		*5200*		*4200*		*5700*		*5000*		*3500*	

Notes: (1) 10-500# measures made with dead weights, then same sect. of rope transferred to Dillon 10K# Tensile Tester for 1000# and up measures, (2) 0 measure assigned to 176#

Fig. 8 Knot Force-Elongation Curves for various ropes



Rope+Knot Slow Pull Model

The purpose of the model was to insert the maximum impact forces from actual drop tests and calculate a theoretical maximum elongation value for comparison. The next page is the complete comparison table.

The model used a simple equation in which the length of the knots and exact length of rope (w/o knots) were each increased by their respective slow-pull elongation percentages (corresponding to the force recorded in the actual drop test). These two values were then added together to give the model's estimated new maximum rope (with knots) elongation.

The following general trends were noted when comparing the measured drop test forces and corresponding elongation values to both the measured slow-pull testing value and the calculated estimate from the rope+knot elongation model:

- 176# test weight
  - In the 0.25 FF tests, the actual measured total rope (w/ knots) elongation values were ALWAYS ABOUT EQUAL TO OR LESS THAN the slow-pull measured GAUGE LENGTH elongation values.
  - This is an interesting point, as one might normally expect a drop tested rope length with knots at each end, which knowingly extend a great deal, to have greater elongation than just the gauge length from a slow-pull.
  - However, in the 0.5, 1.0, and 2.0 FF tests, the combined knot and rope slow-pull elongation model was usually more accurate.

- 500# test weight
  - Essentially ALL drop tests of any FF had total rope (w/ knots) elongation values GREATER than the rope gauge length slow-pull values. The predicted elongation values of the rope+knots slow-pull model were more accurate in virtually all cases.

Total Rope Failure Test Results

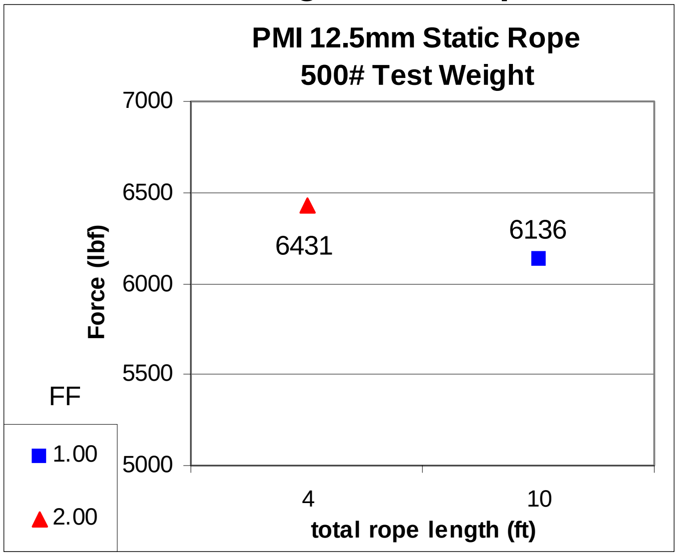
11 of the 162 tests resulted in total rope failure (see graphs on following pages). It is interesting to note that the recorded breaking strengths are in fact within 10% or less of the expected breaking strength of the knotted ropes as determined in the slow-pull tests. The good news is that the failure loads under the "dynamic conditions" of a drop test did not produce any surprisingly low force failures.

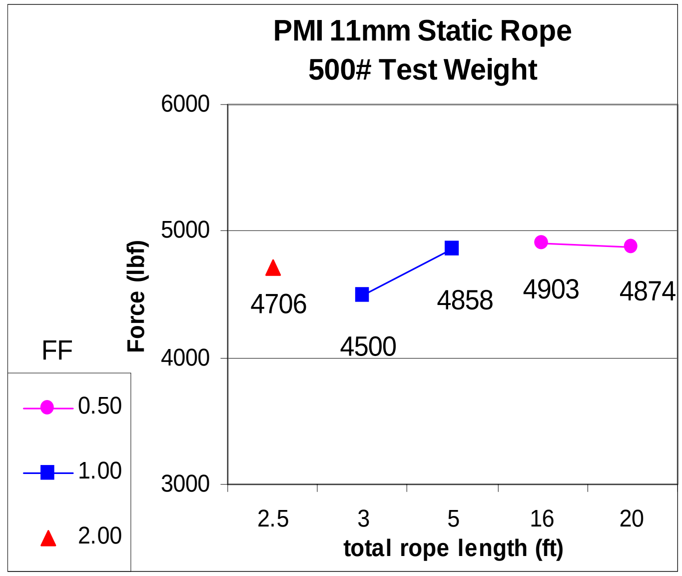
It was also noted that some of the test ropes that did NOT FAIL were in fact very close to the knotted rope's expected breaking strength. (Ref. to earlier slow-pull data table)

Note: PMI 10mm Static and 10.6mm Dynamic Ropes were not tested to failure.

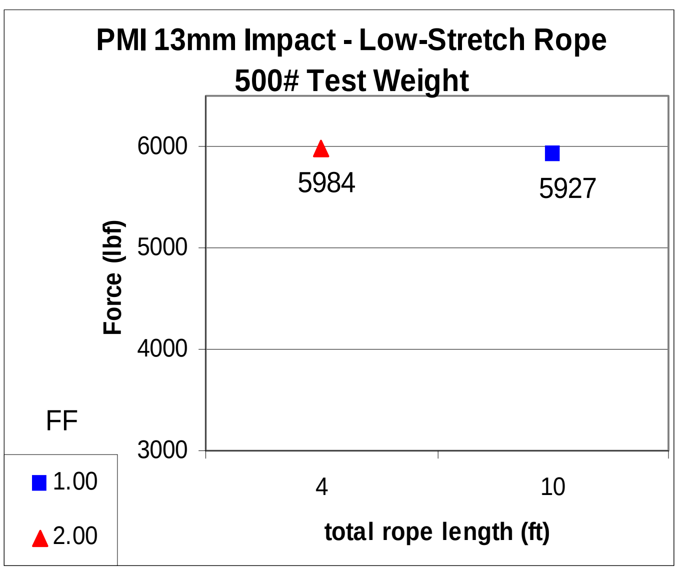
Max. Elong. Comparisons between Actual Drop Tests and Slow Pull Model											
						Actual Measures.		**Compared to Slow-pull model Elong. Values for same load**			
rope	test wt. (lb.)	**FF**	drop (ft)	rope (ft)	test #	Impact (lbf)	Max. Elong.	rope w/ fig. 8 knots	ratio to actual	*rope only*	*ratio to actual*
PMI 12.5mm Static	176	**0.25**	5	20	92	1383	4.9%	7.8%	1.59	*5.2%*	*1.06*
		0.25	5	20	131	1292	4.2%	7.6%	1.81	*5.0%*	*1.19*
		0.50	10	20	97	2180	7.5%	9.4%	1.25	*6.9%*	*0.92*
		0.50	10	20	132	2046	8.3%	9.9%	1.19	*6.7%*	*0.81*
		1.00	10	10	100	2961	11.0%	13.9%	1.26	*8.2%*	*0.75*
		1.00	20	20	101	3426	n/a	12.6%	n/a	*9.6%*	*n/a*
		1.00	20	20	133	3176	12.4%	11.4%	0.92	*8.5%*	*0.69*
PMI 11mm Static	176	**0.25**	5	20	134	1096	5.7%	6.4%	1.12	*4.7%*	*0.82*
		0.50	10	20	135	1979	8.5%	9.4%	1.11	*7.1%*	*0.84*
		1.00	20	20	14	3314	13.0%	12.8%	0.98	*9.7%*	*0.75*
		1.00	20	20	136	3106	11.4%	12.2%	1.07	*9.3%*	*0.82*
PMI 13mm Low-Stretch	176	**0.25**	5	20	143	1067	7.9%	8.2%	1.04	*6.9%*	*0.87*
		0.50	10	20	114	1695	10.2%	11.0%	1.08	*9.2%*	*0.90*
		0.50	10	20	144	1593	10.6%	10.7%	1.01	*8.9%*	*0.84*
		1.00	20	20	119	2695	13.9%	14.7%	1.06	*12.0%*	*0.86*
		1.00	20	20	145	2434	13.6%	13.6%	1.00	*11.3%*	*0.83*
		2.00	16	8	123	3982	20.6%	22.2%	1.08	*14.8%*	*0.72*
BW 11.6mm Low-Stretch	176	**0.25**	5	20	75	1090	6.8%	10.8%	1.59	*9.1%*	*1.34*
		0.25	5	20	140	1067	7.5%	10.6%	1.41	*9.0%*	*1.20*
		0.50	10	20	80	1819	10.4%	11.9%	1.14	*9.4%*	*0.90*
		0.50	10	20	141	1646	9.9%	11.2%	1.13	*8.8%*	*0.89*
		1.00	10	10	83	2682	14.0%	18.4%	1.31	*12.1%*	*0.86*
		1.00	20	20	84	2901	13.3%	16.3%	1.23	*12.8%*	*0.96*
		1.00	20	20	142	2605	13.9%	15.1%	1.09	*11.9%*	*0.86*
		2.00	16	8	88	4138	16.4%	25.6%	1.56	*15.9%*	*0.97*
PMI 10.6mm Dynamic	176	**0.25**	5	20	137	623	11.0%	13.6%	1.24	*11.9%*	*1.08*
		0.50	10	20	138	893	16.2%	18.5%	1.14	*16.3%*	*1.01*
		1.00	19	19	139	1312	24.1%	24.8%	1.03	*21.9%*	*0.91*
PMI 12.5mm Static	500	**0.25**	5	20	34	3131	9.1%	8.4%	0.92	*6.7%*	*0.74*
		0.25	5	20	146	2917	7.8%	8.0%	1.03	*6.4%*	*0.82*
		0.50	10	20	39	5126	9.6%	11.4%	1.19	*9.1%*	*0.95*
		0.50	10	20	152	5045	10.5%	11.2%	1.07	*9.0%*	*0.86*
PMI 11mm Static	500	**0.25**	5	20	147	2957	8.8%	8.4%	0.95	*6.6%*	*0.75*
PMI 10.6mm Dynamic	500	**0.25**	5	20	150	1443	n/a	23.9%	n/a	*23.4%*	*n/a*
PMI 13mm Low-Stretch	500	**0.25**	5	20	57	2534	8.2%	8.8%	1.07	*7.1%*	*0.87*
		0.25	5	20	148	2514	9.5%	8.7%	0.92	*7.1%*	*0.75*
BW 11.6mm Low-Stretch	500	**0.25**	5	20	48	2595	11.7%	9.7%	0.83	*7.6%*	*0.65*
		0.25	5	20	149	2612	9.1%	9.7%	1.07	*7.6%*	*0.84*
		0.50	10	20	53	4197	11.0%	14.5%	1.32	*11.7%*	*1.06*
		0.50	10	20	151	4173	13.3%	14.4%	1.08	*11.6%*	*0.87*

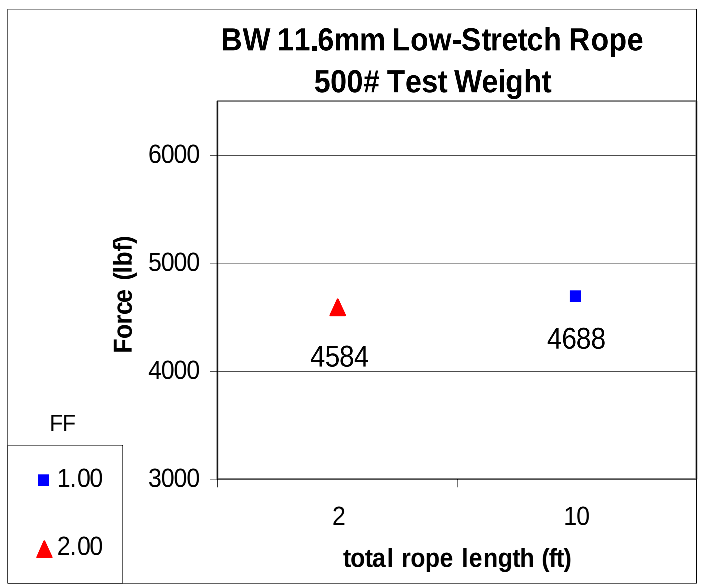
Tests resulting in total rope failure





Tests resulting in total rope failure





Notes about interpreting this report
CAUTION - "Fall Factor," without a doubt, remains a significant and useful tool for all rope users and this report does not dispute its usefulness.

Minimizing Fall Factors remains an essential responsibility to all Rope-Use Professionals.

The 0.5, 1.0, and 2.0 drop tests conducted in this study may be unrealistic scenarios to everyday use, but they are in fact important to help model and better understand the rope's performance over its entire range before failure occurs.

A margin of error of approx. +2/-0 inch did exist in our ability to accurately measure the maximum elongation. Method used was a simple array of horizontal fishing lines, tied on one side and lightly held on the other with Velcro, spaced every 2 inches, and repeatedly positioned across the anticipated lowest area that the falling basket would cross. The lowest displaced line was measured and used to determine the point of maximum elongation. This margin of error made it difficult to derive any highly accurate conclusions from the energy study of data collected (not detailed in this report).

Summary
- For all static and low-stretch ropes tested, the results indicate that impact forces do increase as the length of rope & fall increase for any given Fall Factor.
- The reassuring news for Rope-Use Professionals is that this "trend" is much smaller and arguably insignificant in FF 0.25, which is a much more realistic FF that could be experienced in the field.
- Also worthy of note is that this trend appears to be "leveling off" so to speak after 20 ft rope lengths, but further testing is need to verify the actual trend.
- Dynamic rope in comparison only showed minimal increased impact forces when rope lengths and FF were increased.
- Knots are significant energy absorbers compared to rope itself.
- The length of knots in many of the "short rope length" (<4ft) drop tests is a considerable % of total test rope length. This makes those data points less applicable to any real-life applications.
- The entire report data set is available in a MS Excel spreadsheet if interested.

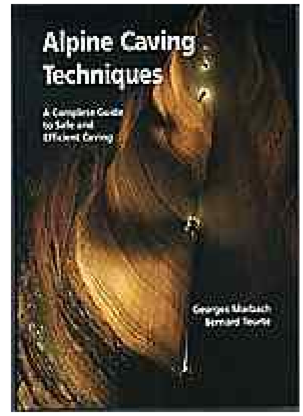
Future testing considerations
- Further drop testing of rope lengths >20 ft following a similar sequence of various fall factors would make this line of study more comprehensive.
- Further analysis of this test data using conservation of energy principles (potential, kinetic, and strain energy relationships) and rope modulus and stiffness factors was investigated but not completed for this report. It is believed that special attention given to the ropes' energy absorbing ability in both the elastic (low forces, <10% total strength) and plastic regions (higher forces) of the rope's force-elongation curve will prove most useful in better understanding rope performance.

Special thanks to **Jim Kovach, Ron James,** and **Steve Bellamy**, for their significant help in conducting most of the drop tests at PMI and **Steve Hudson** for allowing me to pursue this research while on PMI's payroll.

A Book Review ...

by Jay P. Kennedy, MD

ALPINE CAVING TECHNIQUES --
A Complete Guide to Safe and Efficient Caving



- **Georges Marbach and Bernard Tourte.**
- **English Edition, 2002**
- **Translated and adapted by Melanie Alspaugh.**
- **320 pages, 395 figures, 44 b/w photos, color covers.**
- **HB $30.00**
- **ISBN 3-908495-10-5**
- **SPELEO PROJECTS**
- **Available from Speleobooks or Inner Mountain Outfitters**

Marbach's original treatise on single rope techniques, *Techniques de la Speleologie Alpine*, was last revised in 1981 prior to the publication of the much-updated third edition in 2000. Only now has this seminal work on caving "the French way" become available in English. As European rebelay-style rigging and the "Frog" system of climbing rope gain popularity in North America, this work replaces Alan Warild's *Vertical* (published in second edition in 1990, recently upgraded on a CD edition) as the definitive work on European-style vertical caving. Many of Europe's premier caving areas are located in mountainous "alpine" environments and may explain the title, but I find the techniques applicable to caving in general and not just the cold, wet, vertical caves found in our Rocky Mountains and the high plateaus of Montana (where I have been doing most of my caving of late).

Melanie Alspaugh has done a superb job in translating the technical French of the original edition. My collegiate French allowed me to understand the captions, tables and most of the simpler concepts presented in the 1981 edition but the slang and technical terminology were problematic. That is not the case with this English translation; it presents complicated procedures (such as pick-offs) clearly. Melanie's translator's note in the foreword explains her aim to make this book "...as relevant and complete as possible for all English readers..." although she favors American terms(specifically, Texan, by her admission!)

The illustrations by Jean-Yves Decottignies are immensely useful, particularly in clarifying pitch-rigging concepts and several techniques for removing an injured caver from a rope (pick-off). Blue color is used to emphasize ropes and periodically a blue-toned "X" will be plastered across an illustration to emphasize that the concept depicted is WRONG. Jean-Yves' use of stippling and grey-tone make his illustrations of even such mundane gear as bolt hangers visually pleasing. Astute readers will recognize several illustrations from the Petzl catalog (used with permission). The authors specifically preferred illustrations in the updated French edition for reasons of clarity. Depicting concepts such as crossing a rebelay can be shown from the perspective of being inside the rock, looking out past the anchor. Such perspective is impossible to capture on film.

The book is divided into four sections: Equipment, Physical and Mental Aspects, Underground and Conclusion. Equipment aids the novice caver in selecting proper clothing, cave packs, lighting and elements of the single rope technique system, as well as items necessary to rig the cave such as ropes and anchor hardware. The section dealing with physical and mental aspects covers only eight pages, something I would like to see expanded in future editions. Caving movement, both so-called horizontal techniques as well as technical rigging and dealing with common emergencies constitute the majority of the book. Early in the book the safety standard of the European Community is explained, denoted by the "CE" mark (Conformite aux Exigences) if a product meets standards of regulation within its category. Such a mark is a guarantee of at least a minimum of safety. Although no such "community" standard exists in North America, it is comforting to know such tightly controlled testing of European-manufactured gear does occur.

As to content, I found the book very informative about items of equipment that normally are not covered well in recent caving books dealing with technique, especially vertical caving. This is especially true regarding caving oversuits and undersuits, which are gaining in popularity among American cavers. The authors include key points, tips and maintenance suggestions in the text. American cavers will likely never see a cagoule or pontonniere (specialist garments similar to a rain jacket and waders, respectively) but it is nice to know such evolved gear exists. Remote generator carbide lamps are thoroughly covered; I gleaned several interesting suggestions from this chapter that made my Petzl Ariane run more smoothly. Some interesting concepts are presented, such as the use of a foot ascender (best exemplified by the Petzl Pantin) to better enable a "vertical orientation" of the body while climbing. The insistence on using 8mm self-drive bolts as the primary anchors for vertical rigging will no doubt be controversial. These anchors are less likely to meet universal acceptance in the United States, where stainless steel studs and hammer drills are gaining in use. Several methods for doing a pickoff are presented but not the Sawatsky technique favored by many of my caving colleagues from Canada and Montana.

Some cavers will disagree with the authors' views--that's fine. Marbach and Tourte are outlining the concepts widely used in Europe, especially as taught at the EFS (French Speleology School). Marbach himself sums it up beautifully: "This edition is of course only a snapshot of French techniques for exploring vertical caves in the year 2000." It is up to the individual reader to decide what he finds useful and chooses to add to his personal arsenal of caving tricks. Some of the information is merely interesting. I found the book so mesmerizing that I finished it in a single long night of reading. The next day I made several minor changes to my own Frog rig, ordered a second copy of *Alpine Caving Techniques* (to loan to friends) and cleaned my Ariane acetylene generator. If you are interested in a single source textbook on European caving technique, buy this one. You will not be disappointed.

Long-life bolts-what are the options?, which is the best one?

Jeff Butt

Reprinted from: Australian Caver, Number 146, February 1999. (pp 19-29).

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Placing bolts in caves has an impact; so the ethically minded caver considers the options carefully, only placing bolts if suitable naturals can't be found, or if a bolt (or bolts) are needed to avoid some hazard (e.g. waterfall, dangerous rocks). However, in the past even so-called ethically minded cavers haven't necessarily thought about the long-term situation and have placed comparatively short lived bolts. It would be good to address this issue, so that we can be confident that any bolt placed will have a useful life of something like 20-50 years or even more!

I found that I wanted to learn more about this subject, so did a bit of research on the subject. Note that I don't claim to be any sort of expert, but did think that others might also be interested in what I discovered. If anyone has more to tell, especially in relation to their own practical experiences etc., then I for one would be interested to hear from them (contact details at the end).

1. An historical Introduction-a Tasmanian perspective

The first "standard" for bolts used in Tasmanian caves was the large eye-bolts (made from 1/2" diameter galvanised rod), screwed into galvanised Loxin anchors (thin-walled expansion casings). These were installed in the 60's and early 70's for anchoring ladders. At that time, the only available welded and galvanised eye-bolts available were large in size (1/2" diameter, 5" long), and so the large diameter Loxins (requiring a 7/8" diameter hole, 2 & 1/2" deep) were chosen to suit. The hole was drilled by hand (with a star drill and a club hammer-watch your thumbs!), each bolt taking around 1-2 hours to drill and place, which was the major disadvantage. The following quote from Stuart Nicholas (1998), summarises this pretty well. *"Installing a bolt was something that one never undertook without some considerable search first for natural belays and anchor points. Bolting trips were a major source of Forward Programme entries as I recall but not too many people went on them after their first time . . . normally a choofer stove was to hand and someone made the tea/soup/coffee while others drilled, and swapped turn about. It was a welcome respite from the bone chilling cold when one's turn to drill came up!!!!"* The eye-bolt could be removed and regularly inspected, although the actual Loxin could not be accessed.

This bolting system has stood the test of time, many of these bolts still exist (e.g. in Midnight Hole, Khazad Dum, Niagara Pot) and are regularly used (when loaded they do flex somewhat, this is consistent with the fact that the captive nut into which the bolt is screwed resides in the bottom of the Loxin). Being large chunks of steel, they are long lasting and hard wearing (the one's in Midnight Hole have been used regularly for trips for over thirty years, although those on the last two pitches are now showing significant wear (~30-40 % worn through) due to the large number of pull-through trips). Apart from the placement (i.e. back from the edge of the pitch), in many respects this bolting system resembles some of the more robust systems that are in use today.

Sources of the eyebolts dried up in the mid-70's, which was the main reason for discontinuing their use, (Nicholas, 1998). About this time, with the advent of SRT (a faster way to cave), a faster method for installing bolts was called for. Cavers looked to rock-climbers to see what sort of bolts they were using. At the time rock-climbers were using the so called Australian Rock Bolt, or Carrot bolt (basically a 5/16" diameter, 2 & 1/2" long high tensile bolt with a head; the thread was ground to a partial square taper to make it pointy with ridges of thread between; the bolt was then generally pounded in with a hammer). Stuart Nicholas says *". . . these were fraught with hazard of course as you never knew what internal/structural damage you were doing to the bolt while it was being driven in. . . . always provoked some level of fear seeing the bolt head bend and twist as it was pounded with a hammer!!!!"* A keyhole style hanger (or a small wired chock or a sling) was used to attach a krab to the anchor. These bolts were comparatively short lived and many of the heads have rusted/broken off. Some can still be seen (e.g. top 2nd and 6th pitches in Dwarrowdelf, top of the big pitch in Three-forty-one, at the top of the third pitch in Mini-Martin). Indeed the one in Mini-Martin is still regularly used! Both rock-climbers and cavers moved on from these sorts of bolts in the 70's. New technology from overseas provided better (generally better due to ease and efficiency of installation, as opposed to strength and longevity!) options.

The defacto international standard bolt for caving then became the 8 mm self drilling bolt-casings, knows as "Spits" or "Terriers" or simply just "Bolts", as shown at right. The casing is 30 mm long, 12 mm diameter, has a toothed drilling end and is threaded internally to accept an 8 mm diameter bolt. A larger (10 mm) size Spit (15 mm diameter casing, 40 mm long, accepting a 10 mm diameter bolt) was also available but was rarely used in Tasmania. The casing is held in place by the spreading of the inner end against a metal cone compressed against the bottom of the hole. Such a bolt can be installed in 10-15 minutes by someone who knows what they are doing and so allowed pitches to be rigged quickly. When properly installed they have a shear strength of around 1400-2200 kg in good rock, 700 kg in soft rock-Warild (1988). The casings are made from steel but have a coating (i.e. plated steel) to prevent corrosion. Of course, they still do corrode, the plating is damaged when installation occurs. Generally an Aluminium alloy hanger is fitted to the casing by a high tensile 8 mm diameter steel (Grade 8.8) bolt (a twist hanger is shown at left). Some cavers leave the hanger in-situ, others remove it and leave a plastic marker (so the spits can be found again) in it, others just remove the hanger and don't mark the casing (in which case, if another caver doesn't find the existing casing, they may install their own!). Leaving the hanger in situ enhances the corrosion potential of the anchor; Aluminium and steel in close proximity in a wet environment leads to electrochemical corrosion.

In relation to these self-drilling anchors, it is interesting to note that they are definitely out of flavour with the climbing fraternity, as evidenced by the following quote by Hirst (1998). *"The self drilling bolt set-up is about the worst system you can still buy . . . you wind up with about the weakest bolt on the market. These come in two sizes, Worthless (8 mm) and Lame (10*

mm) . . . The small self-drive bolt is "officially" approved for caving and not for climbing. If you own such a kit, sell it to a caver."
Of course, rock-climbers generally use their bolts in a different way than cavers. For climbers, bolts are for protection; they are generally not loaded, but if/when they are the loading is generally a higher shock load transmitted through a fall on an attached dynamic rope. For cavers the bolt is statically loaded at a comparatively low level via abseiling and prussiking on an attached static rope.

Anyway, the fact is that these self-drilling bolts gradually decay and the integrity and safety of the anchor begins to diminish. Many of the spits in Tasmania have were installed in the heady days of the 70's or early 80's and so many of these have been installed for one to two decades. Some have had hangers left in them (to assist in relocation), these are more likely to be in a worst state due to electrochemical corrosion (see below). I have not heard of any failing (yet), but from experience overseas, this will gradually begin to occur. Incidentally, many of the original installations were done for speed, not safety and so often you will find a pitch-head equipped with a single bolt, the rope being tied back to another anchor. In these types of situations, if the bolt at the pitch head fails the consequences are more severe. (In the ideal world, two bolts would have been installed at the pitch-head for safety). Also, the 'speed' often meant that the casings weren't greased (as recommended) to prevent the ingress of water and the onset of corrosion.

So, very soon many of these ageing spits will need replacing. It would be good to replace them with some longer lived type of anchor. In addition, since the spits are often in the best position (w.r.t. rope hang), it would be good to re-use the existing location (if possible) for the replacement anchor.

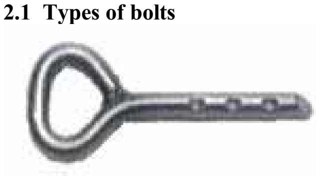
There are several different contenders to use for replacing them. Cavers in different countries use different devices; often rock-climbers and cavers in the one area use different methods (of course, the bolts often serve different purposes). There is not an easy answer to the question: "What is the best system to use?" as the several possible systems each have their own good and bad points. I thought that I'd scan the literature (and Internet) to see what sorts of systems are in use about the place and present the information so that we can make a more informed decision about what is the best method to use.

These days, the existence of high-powered portable drills means that a substantial hole can be drilled quite quickly, and as a result the bolts of this modern day era tend to me much more substantial (like the eye-bolts of old, those oldies did seem to do it properly!).

2. Some background

Prior to having a look around and seeing what sorts of bolts are in contemporary use, it is instructive to have a look at some basic concepts, to get a feel for some of the potential problems that a good bolting system will have to deal with.

2.1 Types of bolts



Bolts can be divided up into two sorts by the methods used to fix them to the rock. Bolts can be either mechanically fixed (e.g. via expansion cone(s), expansion sleeve, compression ridges, or simply a friction fit) or chemically bonded (e.g. epoxy resin, commonly referred to as 'glue') to the surrounding rock. An example of a mechanically fixed bolt (expansion sleeve) is shown at right, whilst an example of a chemically fixed eyebolt is shown at left. Mechanically fixed bolts are the most appropriate for hard rock, whilst chemical bolts are best suited to soft rock. If a mechanically fixed bolt is used in soft rock, then it is only held in place by a comparatively small surface area (e.g. the flared area around a cone), if the rock fails in that area the bolt can come out. A chemically fixed bolt is held everywhere along the glue-rock and bolt-glue interfaces, and thus is less likely to be affected by localised failure. Because of this large surface area of holding power, chemically set bolts have a very high pull-out strengths (which also means that it can be hard to remove them if you want to!). In fact properly prepared chemically fixed bolts are only limited by the quality of the surrounding rock. Chemically fixed rocks obviously will work well in hard rock as well. Sometimes mechanically fixed bolts are specially made so that they don't rely on a single mechanical fixing (e.g. a double expansion bolt), which makes them safer in soft rock than bolts with a single mechanical fixing.

2.2 Forces on bolts

The two main forces on bolts are an outwards force parallel to the rock (tension) and a breaking force perpendicular to the bolt (shear). If the tensile force is exceeded, the bolt will be pulled out of the rock. If the shear force is exceeded, the bolt will break off. When the "strength" of a bolt is quoted, people are usually talking about the shear strength. When a bolt is loaded in caving (or climbing applications), it is generally primarily loaded parallel to the rock surface, but there may also be a small outwards loading, as shown in the diagram opposite. (Sometimes, e.g. for a bolt in a roof, the loading might be primarily in tension, in which case a suitable hanger (ring) must be used!).

Component	Typical Strengths
10 mm diameter Stainless steel anchors	25-29 kN, Shear. 23-40 kN, Tensile (mechanically fixed bolts). 25-50 kN, Tensile (chemically fixed bolts).
10 mm diameter karabiner/maillon	Various (long axis, gate closed) in the ranges 18-32 kN (alloy), 22-45 kN (steel)
Static rope	Various in the range 18 kN (9 mm diameter)-30 kN (11 mm diameter)
Tape	Various in the range 11 kN (14 mm wide)-21 kN (26 mm wide)

In relation to strengths, it is worth keeping in mind that the anchor is only as strong as the weakest component in the system. Typical ratings of the various components normally used are shown in the adjacent Table. Modern day stainless steel bolts are generally the strongest parts of the anchor system; in the event of a fall the bolt will be the least likely component to fail.

2.3 Strength of limestone
A few physical properties of different rock types are shown in the table below. Limestone when compared to other types of rocks has a low hardness and will withstand less compressive force. Consequently limestone is generally regarded as a soft rock. The quality of the limestone in Tasmania can be quite variable, but most seems to be reasonably hard beneath the often weathered surface. The vast majority of bolts used in Tasmanian caves have been mechanically fixed ones.

For a given type of natural rock there can be a substantial variation in physical properties (see opposite Table), thus it can be difficult to make hard and fast rules about the types of bolts best suited to different types of rock. In general, the softer the rock, the beefier the bolts need to be for the same holding power. Shorter mechanically set bolts may be adequate for hard rock, but for softer rock, longer chemically set bolts are better suited.

Material	Density[1,2] (kg/m^3)	Hardness[1] (Mohrs Scale)	Load (kg) to cause a standard test cylinder to compressive failure.[3]
Concrete (anchor testing grade)	2700-3000		1800
Gypsum	2320	2	
Limestone	2680-2760	Calcite 3/Marble 3.5	400-2000
Dolomite	2840	3.5	
Sandstone	2140-2360		400-9000
Granite	2640-2760		1800-18000
Dolerite	2890		
Quartzite	2647	7	

Notes. 1 from CRC (1996)
2 from CRC (1997)
3 from Raleigh (1989)

2.4 Stresses placed on rock by bolts
When a bolt is placed in rock, stresses are placed upon the rock. For uniform rock, the so-called stress zone resembles a cone radiating outwards from the bottom of the hole to the surface of the rock, the radius of cone at the surface being about the depth of the hole. When a bolt is loaded, it will stress the rock in this cone of influence; a shorter bolt means a smaller volume of rock is stressed and thus it is less secure than a deeper bolt, where the stress can be spread over a larger volume. Expansion bolts further stress the rock by the deformation of the cone to hold the bolt within the rock. Chemical bolts do not have this added stress mechanism.

Because of the consequences of failure, it is advised that when bolts are used, a minimum of two are used. To ensure that the failure of one bolt doesn't affect the integrity of the backup bolt, it is desirable that the stress cones are not overlapped. Various statements are made about the minimum spacing, e.g. no closer than 20 hole diameters apart, or no closer than 25 cm to each other. I have seen a pitch bolted (not in Tasmania, I'm pleased to say) with two spits placed right next to each other, under 5 cm apart. In this case two spits are probably less secure than one alone!

Any rock that is weathered will be weaker near the surface, and so a deeper bolt will be more secure than a shallower bolt. Similarly, a bolt with some mechanical gripping will be more secure if the gripping is deeper in the hole. The standard spit has the gripping at the end of the hole, in the best possible position. Compression bolts (see below) grip the hole mid-way along the hole, where the rock could be weaker. A chemically set bolt grips the hole everywhere along the glue-rock interface.

2.5 Materials for bolts and hangers
Generally bolts are made from high tensile steel, or stainless steel. Hangers are made from the same materials, but can also be made from Aluminium alloys. Aluminium is weaker than steel, and so hangers made of it are thicker than those made from steel. For example, a Petzl twist hanger is about 4 mm thick, whereas an RP steel hanger is about 2 mm thick.

There are many different grades of steel and alloys used for different components. Steel components could be standard mild steel, or high tensile steel (Grade 8.8), or a so called austentitic stainless steel, (which comes in many different varieties; types, 303, 304, and 316 are common classes). Types 304 and 316 are commonly used in climbing protection (Law et al. (1992)), but 316 (commonly known as Marine Grade) has better corrosion resistance and a better choice than 304 in coastal environments.

Many of these modern alloys have been specially treated (e.g. through controlled heating and cooling processes such as tempering, annealing) when being made, and often again after being fabricated into the end products (e.g. some high strength karabiners). Any modifications (e.g. bending, hammering, drilling, grinding, welding) to the end product may modify the strength and/or corrosion properties of these, and so should be avoided as much as possible. If any modifications need to be done, then it is best to do them gently and avoid heat as much as possible, this may necessitate doing the work in small stages and quenching in between.

2.6 Corrosion
When two different metals (or grades of the same metal) are in contact, especially when moisture is involved there is a potential for electrochemical corrosion (i.e. galvanic coupling). A stainless steel expansion bolt might be fitted with components made from different grades of stainless steel. Aluminium alloy hangers are fitted with a high tensile steel bolt. Often components made of steel (e.g. bolt casing) are plated with another material (e.g. Cadmium or Zinc (i.e. galvanised)) to prevent/slow corrosion. So, any

particular anchor can have a variety of metals in intimate contact. Ideally all components in an anchor will be made of the same material.

Sharp bends and deformities (e.g. crevices, welding dags) can encourage local corrosion. Thus it is good to avoid these by choosing well designed and well finished products, i.e. those with only large radius bends and free from welds; or if welded, well finished welds.

Stainless steel does still corrode, it just does it at a much slower rate than normal mild steel. In sea-water, where a mild steel will corrode at a rate of about a millimetre every six years, an austentitic stainless steel will corrode about a millimetre every 200 years. This corrosion can be greatly accelerated by galvanic coupling when two different grades remain in contact. Hellyer (1988) reports that in Thailand, on seeping limestone sea cliffs, (where climbing is popular), six year old stainless bolts have already begun to show visible signs of corrosion. There have been several failures causing several serious injuries.

Obviously the corrosion potential in an inland Tasmanian cave will be a lot lower than by the sea in Thailand, but it is still present. Many existing spits have obviously rusted (exacerbated by them not being greased when installed?); and of course you can only examine the internal thread, not the remainder of casing. In some caves, hangers have been left in-situ for a more than a decade and anchor could be in a very bad condition (e.g. the hanger on the rebelay on the 55 p in JF371, was recently examined after 14 years residence, the hanger was very badly pitted, but both the bolt and thread in the casing appeared to be okay). Karabiners that have been left in a cave for 6 months can often show substantial surface corrosion. One way of minimising this corrosion potential is not to leave hangers installed in casings, but to instead to insert a greased and non-metallic plug, which prevents the ingress of moisture and also aids the relocation of the casing. (This is the current practise in Tasmania, the nylon bolt being fitted with a reflective marker.)

2.7 Thermal cycling

When on the surface, bolts can undergo large thermal cycling. This regular heating up and cooling down leads to thermal expansion and contraction of the bolt, which can lead to loosening the mechanical fixing and make the bolt subject to failure. Fortunately, apart from in the entrance region, the cave environment is very stable and so any sort of thermal cycling problem should be minimal.

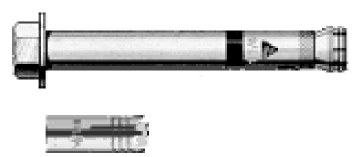
3. The types of 'long-life' bolts used around the world

I don't claim this to be exhaustive, but it probably represents a reasonable assessment of the different types of long lasting bolts used around the world. Note, that I have excluded spits because of their relatively temporary nature and lower strengths. They (even if available in a stainless steel form) just don't measure up with many of the more substantial types of bolting hardware available around the world.

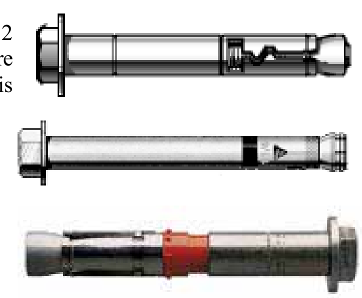
3.1 Mechanically set bolts

Most of the these types (and there are a multitude of different shapes, styles, sizes, materials, mechanisms) of bolts on the market have been designed for fastening things to concrete. Acceptable loads for the different types of bolts are carefully stipulated by Construction Codes for specific grades of concrete. The appropriate loads in natural rock aren't specified. These types of fasteners are most suited for use in hard rock. Some fasteners are more suitable for use as caving or climbing anchors than others. A few types have been specifically made for caving/climbing anchors.

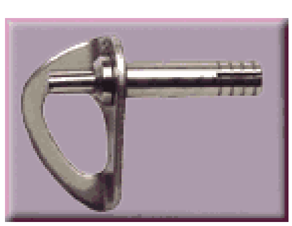
Fasteners used for permanent anchors in cliffs or caves are substantial pieces of metal (say 60-100 mm long, 10 to 12 mm diameter, made of stainless steel), with some sort of expansion mechanism to allow the bolt to be held firm in the rock. When compared to a spit (see the scaled diagram opposite) there is no comparison!, the spit looks like a total safety compromise!



The mechanical fastening can be made by many different mechanisms; these are briefly described below:

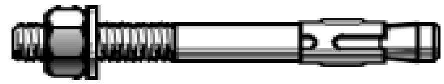


- **Sleeve:** have an outer sleeve (along the full length of the bolt, but sometimes this is in 2 parts) around the bolt and a cone at the end. Some types are fitted with a bolt, others are threaded to accept a nut. The standard Dynabolt is a very low technology example of this type of bolt and the holding power and security of a Dynabolt is low compared to some of the other types; some of which are designed to hold in concrete with cracks in it (e.g. the top of the three bolts shown at right). For the higher tech. models (e.g. Rawl '5-piece' or equivalent), as the bolt is screwed into the cone the end of the sleeve deforms outwards to grip the rock. Further tightening causes a nylon compression ring between the two parts of the sleeve (e.g. as in the lower two of the three bolts pictured at top right) to deform and bind to the rock. For this particular example, the actual bolt and outer part of the sleeve is removable, but the bound portion of sleeve and cone isn't. Rock-climbers in the USA extensively use this type of bolt, Hirst (1998). For sleeve bolts, the diameter of the hole is greater than the diameter of the actual bolt to allow space for the sleeve, and the diameter of the hole must be selected to match the diameter of the bolt.



Petzl (France) make a permanent anchor that instead of having a nut on the end has a captive hanger and a protruding pin, to set the bolt (expand the end) the pin is driven in. Once installed, it is not removable, hence the name. Presumably cavers and climbers in Europe use this bolt, but it is expensive.

- **Wedge:** are basically a solid stud, threaded on the outside end to take a nut, and machined into a wedge on the inside end to accept a small wrap around sleeve. When the nut is tightened, the wedge forces the sleeve to bind to the rock. Once they are in and the sleeve is deformed, that's it and they won't come out. However, if the hole is over-drilled (i.e. deeper than the bolt) by about two centimetres, then the actual bolt can be bashed in and the bolt hidden. Some bolts may have more than one wedge/sleeve pair, as shown in the lower example (made by Fixe in Spain). The hole is drilled to be the same diameter as the bolt, which gives the maximum shear strength in relation to hole size. Fixe double expansion bolts of this type have been used in the first stage of rebolting pitches in Ice Tube, Hawkins-Salt (1998a). Rock-climbers in New Zealand use wedge bolts (e.g. Hilti HSA or Ramset Tru-bolt) for hard rock, Newnham (1995); these models have good expansion reserves (see below).



- **Compression:** are split shaft studs which compress for a spring fit when pounded into drilled holes. The hole is drilled to be the same diameter as the bolt. Supposedly they are fairly strong when new, but lose their grip after about ten years. With the application of some force (e.g. through leverage) they are removable, or if the hole is over-drilled, they can be bashed in and hidden. Note that from the outside of the rock, wedge and compression bolts look the same. I haven't found evidence of the availability of these bolts, let alone availability in stainless steel. Various people, e.g. Child (1995), recommends against using them, except for alpine climbing when a quick and light bolt is required. Apparently a 1/4" diameter version (non-stainless steel) were very popular in the USA in the past, but these rusted badly and the grip weakened resulting in them readily failing (for this reason they are referred to as "coffin nails").

Collectively, Sleeve and Wedge mechanism bolts are known as Expansion Bolts. Law et. al (1992) talks at length about these, and divides them up into two types, deformation-controlled and load-controlled. The deformation-controlled type (e.g. spit) once in are in and cannot be tightened, they have no expansion reserves. The load-controlled type (e.g. Sleeve) have a reserve of expansion holding power, i.e. they can be nipped up to counter any changes in the rock (e.g. local failure). Note that these bolts have a specified torque that they should be tightened to. The long and short of it is that Deformation-controlled bolts are recommended against (another nail in the coffin of the spit), and only the Load-controlled expansion bolts that have a high expansion reserve are recommended.

The properties for all these types of bolts (in stainless steel) is summarised in the Table below.

Mechanism	**Typical hole size required**	**Longevity and how limited.**	**Relative[1] Shear Strength**	**Relative[1] Tensile Strength**	**Expansion Reserve[2]**	**Removability**
Sleeve	2 mm wider than bolt, 50-75 mm deep	?? years due to corrosion.	64 %	> 100 %	Medium-High	MOSTLY, the internal bolt and outer sleeve section can be removed.
Wedge	same diameter as bolt, 50-75 mm deep	?? years due to corrosion.	100 %	100 % (> for double wedge)	High	NO, but it can be bashed in if the hole is deep enough.
Compression	same diameter as bolt, 50-75 mm deep	?? years due to corrosion, but even less to spring fatigue?	100 %	< 100 %	None	YES, with force. Can also be bashed in if the hole is deep.

Note: 1 For a 10 mm diameter hole in the rock
2 For a good high tech. example

A summary of the different types of stainless steel mechanically fixed bolts that are in use (or are available in outdoor gear shops) is shown in the Table below:

Brand name/origin	Mechanism	Typical Sizes Used Diameter	Length	Hole Diameter	Strength[1] Tensile (kN)	Shear (kN)	Notes/ Applications etc.
Petzl /France	Sleeve	12 mm		12 mm		25	Integral hanger
Coast /USA	Wedge	3/8"	2 1/4-3 3/4"	3/8"	24	18	MEC-Canada. Climbing.
Fixe /Spain	Twin wedge	10 mm	98 mm	10 mm	31	23	Several countries. Climbing, Caving
Rawl	Sleeve	10 mm 10 mm	65 mm 90 mm	10 mm 10 mm	32-37 38-40	23-28 25-34	USA-Climbing
Ramset Trubolt	Wedge	10 mm 12 mm	75 mm	10 mm 12 mm			Good expansion reserves. NZ-Climbing.
Hilti HSA	Wedge	10 mm 12 mm	75 mm	10 mm 12 mm	23 38	27 43	Good expansion reserves. NZ-Climbing.

Notes. 1 from Manufacturers specifications or Equipment Suppliers catalogues, unless otherwise shown

3.2 Chemically set bolts

Chemically set bolts were initially designed to hold rock, or concrete together, e.g. at dam sites, road cuttings, in mines. With some adaptations, mainly to the shape of the fastener, this system has been adapted for use as caving or climbing anchors.

Again, as with the mechanically set bolts, chemically set bolts are substantial pieces of metal. There are two types of chemical set bolts; bolts which take a hanger and 'hangerless' bolts where the design results in a loop of steel protruding from the rock.

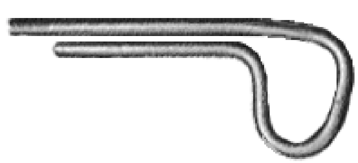
The chemical setting agent (the 'glue') is generally a two part epoxy resin, discussed below. Some of these resins will even set underwater whilst others are tolerant of a damp environment. The hole for the bolt has to be larger (2-4 mm in diameter, e.g. 10-12 mm hole for 8 mm bolt) than the bolt to allow an annular space for the resin. The cleanliness of the hole is paramount to the adhesion of the resin to the rock surface, all traces of dust/rock powder must be removed. The safety of glue-in bolts is critically dependant on the installation being done correctly. Some of the References at the end of this article go into much more detail about this, see CNCC (1998).

For the 'hangerless' variety, there is only one piece of metal, which means that the problem of galvanic corrosion doesn't occur. Also, for this variety of bolt, the surface is generally roughened, or deformed (e.g. with dimples), and/or the ends are bent to increase the bonding between the glue and the metal. In addition, the ends of glue-in bolts are generally sharpened/angled to assist in preventing air pockets forming around the bolts as the bolts are pushed into the glue. Hellyer (1998) reports that in the early days of chemically set bolts, there were several accidents due to failure of the resin to adhere to the smooth steel shafts of Staples. The thread on machine bolts and threaded rod allows the glue to get a better grip on these bolts, which are rotated as they are inserted to ensure good adhesion of the glue.

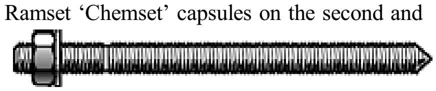
The bolt itself can have many different shapes and forms, the main ones are described below:

- **Staples:** are made out of 8 mm marine grade stainless steel (316) rod bent into a "U" shape such that the two straight ends or "legs" are parallel. Overall the U is about 90 mm long; with one leg about 10 mm shorter than the other. The long leg is embedded about 60 mm, the short 50 mm. The internal gap between the two legs is about 30 mm. One hole is needed for each leg; care must be taken to keep the holes parallel! The commercially produced version (as shown at right) is shaped to give a nice position for an attached karabiner; in addition, the entrance to the bottom hole is shaped so that where the leg curves, it sits hard on the rock. The home-made version is generally just a straight "U", and so an attached karabiner is forced to rest against the rock-face. Home-made "U" anchors of this type have been used by local rock-climbers at a number of locations (e.g. Coles Bay, Fruehauf Quarry, Adamsfield), over the last 5 years. Two glues/systems (see below) have been used: the Hilti "HY-150" injection system, and a hand-mix/syringe system using "Megapoxy HT"; Parkyn (1988).

- **P Hanger:** This is basically a variant of the Staple ("U"), where both legs are placed in the same hole to give a "P" shape. The DMM Eco-hanger (shown at left) is made from a single piece of 8 mm marine grade stainless steel (316) rod, which is installed into a single massive (18 mm diameter, 100 mm deep) hole. This style of hanger is extensively used by the Caving fraternity in the UK, CNCC (1998).



- **Eyebolts:** are generally made out of 10 mm stainless steel (or bigger, e.g. the Petzl Batinox is made from 14 mm diameter rod). A single hole, 2 mm larger in diameter than the bolt shaft diameter is used. A few examples are shown here. Shapes for the eye vary, the closer the hanger sits to the rock surface, the less leverage and the stronger the anchor. Again, as with staples, some custom shaping of the hole allows the bottom of the eye to be recessed slightly, this prevents any rotational force on the hanger, which would tend to twist the hanger out.
- **Bolts that take a hanger:** basically these are the glue-in equivalent of mechanically set bolts, but with an increased holding power in soft rock. Bolts with heads (and thus captive hangers) can be used, as can threaded rod. The only glue-in bolts that the hanger can be removed is the headless variety (e.g. threaded rod). Stainless steel (316) machine bolts (10 mm by 120 mm) with captive stainless steel hangers were installed (in 1996) with Ramset 'Chemset' capsules on the second and third pitches of Slaughterhouse Pot by John Hawkins-Salt (1998b).



The properties for all these types of chemically set bolts (in stainless steel) is summarised in the Table below.

Type	Typical hole size required	Longevity and how limited.	Relative[1] Shear Strength[2]	Relative[1] Tensile Strength[3]	Removability	Volume[4] of resin (ml)
Staple ("U")	2 holes, 10 mm diameter, 50 mm & 60 mm deep.	Life of the resin.	100 %	69 %	NO	9

Eyebolt	2 mm wider than bolt, 70-100 mm deep	Life of the resin.	78 %	71 %	NO	9
"P" hanger	18 mm diameter, 100 mm deep	Life of the resin. (bolts in the UK have been in use for ~10 years to date)	100 %	100 %	YES, drill down the sides of the hanger (5 mm bit), and with a big bar through the eye rotate it out.	19
Machine Bolts	2 mm wider than bolt, 70-100 mm deep	Life of the resin, or corrosion.	78 %	71 %	NO	9
Threaded Rod	2 mm wider than bolt, 70-100 mm deep	Life of the resin, or corrosion.	78 %	71 %	NO	9

Notes: 1 For the normal sizes used, e.g. 10 mm rod for bolts/rod/eyebolts, 8 mm rod for staples/P hangers and for the maximum sizes shown in Column 2.
2 Based on the cross-sectional area of the bolt material.
3 Based on the surface area of the bolt material.
4 Assuming a wastage of 20 %.

A summary of the different types of stainless steel chemically fixed bolts that are in use (or are available in outdoor gear shops) is shown in the Table below:

Brand name/origin	Type	Typical Sizes Used Diameter	Length	Hole Diameter	Strength[1] Tensile (kN)	Shear (kN)	Notes /Applications etc.
DMM Eco-hanger/UK	P	2x8 mm	100 mm	18 mm	18-54[2]		Cavers in the UK and elsewhere
Fixe /Spain	Eyebolt	10 mm	100 mm	12 mm	36	40	Cavers
Home-made	U	2x8 mm	60 mm	2x12 mm 2x10 mm	18[3] 32[4]		Rock-climbers in several countries
Petzl	Eyebolt	10 mm 14 mm		12 mm 16 mm		25 50	France-cavers and climbers
Threaded Rod	rod	10 mm 10 mm	60 mm 115 mm	12 mm 12 mm	30 50	29 29	Rock-climbers
Machine Bolts	bolts	10 mm	120 mm	12 mm	~50	~29	Rock-climbers/cavers

Notes: 1 from Manufacturers specifications or Equipment Suppliers catalogues, unless otherwise shown
2 CNCC testing, range for pull-out of DMM bolts, for all types of hole preparations. Hanger deforms at 19 kN.
3 from Hellyer (1998), a single test.
4 Parkyn (1998), a single test. with two U anchors in series. Failure was ductile in nature.

3.3 Chemical Setting agents

Various different types of chemical setting agent (i.e. the 'glue') are used, the main ones being two part epoxy resin; the resin itself and a hardener. The resins available were designed for any number of industrial and construction applications, for example the insertion of steel reinforcement rods into concrete.

There are several different types of resin, e.g. Epoxy, Polyester, Urethane. Polyester resins (according to reports) are much easier to work with as they have a lower viscosity. However, manufacturers specifications show that Polyester resins are not as strong as the Epoxy resins.

Which is the correct resin to use for which rock type is the subject of much debate and is more often dictated by what is locally available. A summary of the different commonly available stronger resins, and who uses them is shown in the table below. Note that Hellyer (1998) reports that a large amount of research has been carried out by the UK National Caving Association (NCA), concentrating on resins suitable for limestone. Please note that some internationally distributing companies sell different products in different countries. Also, the use of proprietary brand names, (which often sound similar) can cause some confusion. The manufacturers specifications need to be carefully checked.

Resin Brand name/ type	**Made in/ Available from**	**Recommendations**	**"Rucksack" sport users**	**How available**
Exchem Resifix 3 Plus	Exchem, UK	Recommended by the UK National Caving Association (UK-NCA) for massive limestone. [Formerly Hilti C50 resin was recommended, but no longer is due to environmental concerns.]	Cavers in the UK [CNCC (1998)], Canada [Horne (1998)]	dispenser pack
Vivacity Megapoxy HT	Vivacity Engineering, NSW	Epoxy Resin. Australian Rock-climbers. Manufacturers claim this glue to be hydrophillic.	Rock climbers in Aust. [Parkyn (1988)]	bulk
Ramset Epoxy-Set	Ramset, Australia	Epoxy resin. Manufacturer recommends for concrete, solid brickwork and stone. Excellent	Rock climbers in NZ [Newnham	capsule or dispenser pack

		resistance to alkali and moisture. Capsules can be used underwater.	(1995)]	
Hilti HY 150	Hilti, Australia	Manufacturer recommends for concrete and hard natural stone. No problem with wet environments.	Some rock climbers in Aust. [Parkyn (1988)]	dispenser packs
Hilti HVU	Hilti, Australia	Styrene free Vinyl Urethane resin. Manufacturer recommends for concrete and hard natural stone.		sachets
Rawl Kemfix	Rawl, Australia	Manufacturer recommend for solid concrete and masonry materials.		capsule
Rawl Foil Fast	Rawl, Australia	Manufacturer recommends for concrete and other solid base materials.		dispenser packs

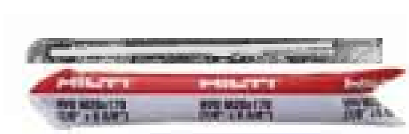
The life of the installed resin is somewhat open-ended or ill-defined. Many of the applications that cavers/climbers are using it are outside the normal commercial/industrial types of use. Resin in caves is not subject to ultra-violet light, but conditions are generally more humid. The longevity of the resin is an unknown; they certainly last a significant time; they may last 50 years. No one really knows, only time will tell. Some bolts installed by the NCA have been in use for ~10 years without showing any signs of old-age.

The resins generally have a low shelf life (some are 2 years, others 12 months), and so one needs to get fresh stock and use it quickly.

It is crucial for the resin and hardener to be properly mixed. Like most chemicals, the vapours and the material itself are dangerous (avoid breathing or skin contact or exposing to flame).

Once mixed the resins have a setting time that is primarily temperature dependant. Setting times are also dependent on the volume of resin used, i.e. shorter for greater volumes. Typical gelling times are, 20 minutes@20°C, 30 minutes@10°C, 1 hour@0°C and 5 hour@-5°C. Some manufactures recommend that temperatures be above 5°C for best results and that if used for lower temperature on-site testing be carried out.

Resin comes in either bulk packs (e.g. Expellable containers, or tins) or single shots. Some bulk packs are designed for use in special dispensing guns which expel the resin and hardener from a the pack in the appropriate ratios and mix it via nozzle equipped with many spiral baffles. Between jobs you may need to replace the nozzle and you are set to go again. Often a colour change is used to indicate complete mixing. Other bulk resins come in tins/containers. This system is a Batch system, where you measure out the appropriate amount of resin and hardener, mix it, then dispense it via a caulking type gun/syringe etc. You have to use the entire mixed batch before it sets (typically 30 minutes). Single shot resin packs consist of resin and hardener in either a glass ampoule or foil sachet. The ampoule or sachet (sachets don't fall out of downward pointing holes) is inserted into the hole. The stem of the bolt is then driven into the resin container and mixing is effected by rotating the bolt (e.g. via an attachment to a drill). This system can't be used for Staples; asymmetric hangers would be difficult to spin as well.



There are a variety of advantages/disadvantages between the Bulk and Single-Shot Systems, these are summarised in the table below.

System	Methods	Advantages	Disadvantages
Bulk (Gun Dispenser)	The resin is automatically mixed as it is injected into the hole. The hole is 2/3 rd's filled, from the back. The bolt is placed in and any excess resin is cleaned up as it exudes.	- The cartridge holds enough glue for many bolts. - Accurate dispensing ratio of resin and hardener. - Via the clear mixing nozzle, have a visible indication (colour change) of correct mixing. - Easy to take a sample of resin home to ensure it sets.	- Potentially messier. - Have to install a large number of bolts to make the best use of the larger amount of glue.
Bulk (Batch Mix)	Measure out resin and hardener, thoroughly mix it and transfer to an injection gun, then proceed as for the Dispenser Gun; however all the mixed resin needs to be used before it sets.	- The least expensive method. - Can mix as much resin as is required.	- Much messier and there is a lot more mucking around and potential for spilling etc. - Potentially more wastage of resin. - Potential for inaccurate ratios of resin/hardener.
Single-Shot (Ampoule or Sachet)	The ampoule is inserted into the hole, the stem of the bolt is inserted through the ampoule	- Easy to do a single bolt at a time. - Can purchase a single shot of resin at a time, so it's up to date.	- Can't see how well the resin is mixing.

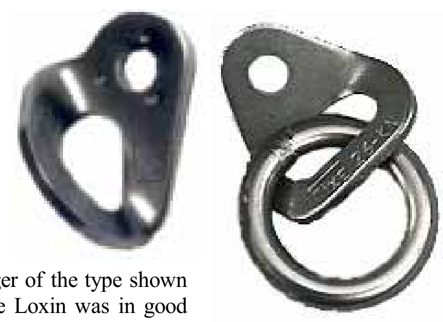
	and rotated to mix the resin.	a time, so it's up to date. • Less waste of resin. • Less potential for polluting the cave environment. • Accurate amounts of resin and hardener.	• Resin is contaminated by Ampoule/Sachet debri. • More expensive.

Temperatures in Tasmanian caves being in the 4-14°C range means that gelling times will be 30-40 minutes. This is not a long period, especially if you have to move between pitches. As a result one needs to be well organised and spare mixing nozzles carried just in case. The quick thinkers will have realised that other anchors will have to be used for the installation process. Newly installed chemically bonded anchors are normally allowed ~ 24 hours before use.

Once installed, the resin sets harder than rock and is thus difficult to remove. The P hangers can be removed via drilling 5 mm holes along both sides of the stem and then by rotating the hanger via a bar through the eye. Some two part resins soften with heat (e.g. Araldite), and so it may be possible to use a blow torch or similar to heat the hanger and soften the glue, thus allowing it to be removed?? This is something that would need to be checked by practical testing.

3.4 Hangers and Anchor Systems.

All the Mechanically fixed bolts (presented in Section 3.1) and the non-hanger integral chemically fixed bolts (discussed in Section 3.2) need to have hangers affixed. Ideally these should be of the same material as the bolt, to minimise the potential for galvanic corrosion.



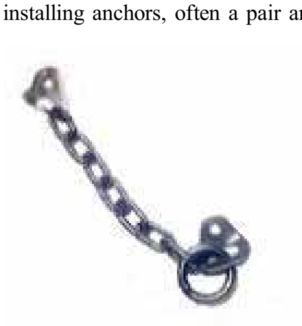
There are many good and strong hangers around, some come equipped with one or two stainless steel rings to facilitate pull-through style trips. Some are even available in environmental colours to make them blend in with the rock.

Systems with replaceable hangers have an obvious advantage in that if a hanger (or ring attached to it) becomes worn, it can be easily replaced. It should however be noted that stainless steel is very hard wearing. The large eyebolts in Midnight Hole have probably seen the most use of any bolt installed in a Tasmanian Cave. After over thirty years of trips (mostly pull-through trips), the mild steel eyebolts on the longer pitches are showing significant wear, about 30-40 % of the way through the 1/2" stock. The time is near to replace these, a hanger of the type shown above (captive ring, made from 10 mm diameter material) would be ideal. If the Loxin was in good condition, a 1/2" diameter bolt could be used to affix one of these hangers (with the hole enlarged) to the existing Loxin anchor as a short term solution.

Most of these hangers are very strongly rated. The two Fixe hangers above are rated at 40 kN (Twist hanger) and 26 kN (Flat hanger with Ring, itself rated at 40 kN).

Nuts for any of the threaded bolts may loosen up with time, so it makes sense to use locking nuts (i.e. those with nylon inserts), or use some sort of proprietary Loc-tite material. Note that the outside end of the a threaded bolt is generally tapered to allow it to be tapped into the hole without burring the thread, and so it is not possible to simply burr the end of the bolt over to ensure the nut stays on.

When using artificial anchors the accepted practise is to use at least two, i.e. to never put ones faith in a single anchor. When installing anchors, often a pair are thus required. In the case of the hangerless variety, this generally means installing two bolts (no less than 20 hole diameters (e.g. 240 mm for 12 mm holes) apart!), and the rope is threaded through both. Note that the "eyes" should be oriented with due consideration to where the rope will lie and the direction of pull.



Some manufacturers make abseil stations, which include a pair of bolts, joined by a 25 cm long section of stainless steel chain (itself rated at 26 kN). Two examples are shown here, for both mechanically and chemically fixed bolts. These are probably more suited to rock-climbing situations (as abseil stations), than for caving situations, however, the rope drag on a single ring will be less than that for two anchors.

3.5 Prices of Hardware.

This section has been removed to reduce the size of this article. Details are available from the author; Contact details at end.

4. The Best Option is????

To my way of thinking, the ideal bolt should:

- be absolutely secure,
- be well situated,

- be easily locatable (unlike some unmarked spits),
- be long lasting (i.e. corrosion resistant),
- be replaceable,
- cause minimal impact on the cave environment (e.g. no nasty chemicals being spilled during installation or leaching out afterwards) and the installer (e.g. no nasty fumes or dangerous chemicals),
- be reasonably priced (i.e. inexpensive over it's lifetime),
- be easily installed,
- and have a known history (i.e. records kept of the installation and periodic checking).

A comparison of all types of permanent anchors presented in this article is shown in the table below.

Type of bolt	**Sleeve**	**Wedge**	**Comp-ression**	**"U"**	**Eye**	**"P"**	**Mach-ine bolt**	**Thread-ed Rod**
Amount of drilling	SMALL-MEDIUM	SMALL	SMALL	MEDIUM (2 holes)	SMALL-MEDIUM	LARGE	SMALL-MEDIUM	SMALL-MEDIUM
Installation difficulty	LOW	LOW	LOW	HIGH	MEDIUM	HIGH	MEDIUM	MEDIUM
Biological Impact	LOW	LOW	LOW	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM
Tensile Strength	MEDIUM-HIGH	MEDIUM-HIGH	LOW-MEDIUM	HIGH	HIGH	HIGH	HIGH	HIGH
Shear Strength	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH
Expected Long-evity	MEDIUM	MEDIUM	SHORT-MEDIUM	LONG	LONG	LONG	MEDIUM-LONG	MEDIUM-LONG
Replace-able hanger	YES	YES	YES	NO	NO	NO	NO	YES
Remove-ability	PART-IALLY	NO (but can bash in)	YES	NO	NO	YES	NO	NO
Cost per anchor	MEDIUM	LOW	??	MEDIUM-HIGH	MEDIUM	HIGH	MEDIUM	MEDIUM
Approp-riate for limestone	MEDIUM	MEDIUM-HIGH (if 2 wedges)	LOW	HIGH	HIGH	HIGH	HIGH	HIGH
Overall Rating	**GOOD**	**GOOD**	**POOR**	**GOOD**	**GOOD**	**GOOD**	**GOOD**	**GOOD**

You can devise all sorts of rating schemes using the data above to try and work out which bolt is best, but to me it is not immediately obvious that any one method outshines the rest. However, there certainly is a case against continued use of the 8 mm spit in any cave that is going to have more than infrequent visitation.

Law et al. (1992) state that Glue-in bolts are at present the best answer to the all-round bolt; they are strongest in the widest range of rock and the integral stainless nature gives them high life expectancy.

In the UK, where they have significantly more cavers than here, the decision (based upon extensive research and testing by the NCA and the CNCC Technical Group) has been to go with the chemically fixed "P" hanger (DMM Eco hanger). Of all the glue-in bolts, the P hanger is the only one that is easily removable, which gives it the edge-i.e. it is replaceable when the time comes.

5. The Next Steps??

To me the following seems a logical sequence to follow:

- Ensure our knowledge of the options is complete and accurate,
- Gain some practical* experience; preferably hold a practical workshop* where we get some "experts" (e.g. company representatives, people with considerable practical experience etc.) to come along and provide sound instruction to people likely to be involved in installing bolts, (this is one proposal I have suggested for the Down To Earth Conference the VSA are running early next year; however it could equally be held at an ASF conference, or as a special event somewhere that interested cavers can get to). [*For the chemically set bolts there are quite a few points that need to be strictly adhered to (no pun intended) in order to achieve a high quality result.]
- Have a trial of some of the different bolting systems in a couple of different caves,
- **Plan out** a rebolting program; targeting the more popular caves (e.g. for Tasmania) such as Midnight Hole, Khazad Dum, Dwarrowdelf etc.

Any feedback from out there would be appreciated, contact details below. Thanks for the time and considerable space!

Contact: email: jeffbutt@netspace.net.au, or mail: 22 Clutha Place, South Hobart 7004.

Acknowledgements:
Nearly all diagrams were taken from the Internet, see the various Web addresses below.

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Dragon	http://www.dragon-speleo.co.uk/
Hilti	http://www.hilti.com
Inglesport	http://www.inglesport.co.uk/accessor/boltfixe.htm
Petzl	http://www.petzl.com/english/dir/climbacnhors.html
Ramset	http://www.itw-epcon.com
Rawl	http://www.rawl.com
REI	http://ww.rei.com/shopping/store3/climbing

Rappel Accident at Bridge Day 2002

By Tim White, Bruce Smith, and Wm Shrewsbury

On Oct. 20, 2002 Bridge Day saw its first rappelling accident in the 25 year history of the event. Below is the internal report from Bruce Smith, along with his follow-up. The first report appeared Monday, Oct. 21, 2002 in TAG-NET DIGEST #2989 and the follow-up was posted in DIGEST #2991- Oct. 23, 2002

Along with Bruce's report(s) is an archived post from Wm Shrewsbury submitted to TAG-NET #1262, back in Nov. 1997 and a follow-up titled "Belaying Long Drops" that posted in TAG-NET DIGEST #2991. Wm's testing, opinions and conclusions are not necessarily those of the Editor or Officers of the NSS Vertical Section. The reader should understand information presented here may be of an experimental nature. The reader should exercise good judgment and use common sense when attempting any vertical technique or using new equipment.

As Wm says, "If we had only learned from it..."

Tim White
Editor, Nylon Highway

Posted to TAG-NET on 10/22/02
Subject: Serious rappel accident at Bridge Day
By: Bruce Smith (onrope1@bigfoot.com)

It is regrettable, but as all those on the bridge over the New River (876' high) know, a rappeller from Washington, PA, Greg Clark, a paramedic firefighter, lost control of his rappel and landed on the railroad tracks at a great rate of descent. He was treated and transported by helicopter to Charleston Medical where he was diagnosed with Fractured Lumbar vertebrae, possible cracked pelvis, kidney damage, spleen damaged and liver failure.

It was his first rappel on the bridge and was observed having great difficulty from the start with six bars. Somewhere on down the rope he figured out to remove one of those bars and was able to descend at a controlled rate of speed. Just above tree line he was observed accelerating to a high rate of descent and landed on his back with his feet in the air. He was 220 lbs and his wife 115 was bottom belaying him ran with the rope sideways but as he fell, he simply pulled her off her feet and yanked her backwards. He was found clutching his rack with only 4 bars on the rope.

I am guessing when he dropped the sixth bar, 2 actually dropped and he was left with 4 engaged on the rope providing friction. This probably worked fine at the upper altitudes but as he got nearer the ground he was unable to reengage the necessary bars to provide the needed friction. He was also observed fighting his top heaviness, as he did not have a chest harness to keep him upright and again surmising that he was forced to fight not only the friction problem, but the upright problem at the same time, loosing both battles during the crisis.

This is the first rappelling accident at Bridge Day that has ever occurred.

This is all I know at this point.

Bruce Smith

Posted to the TAG-NET on 11/12/97
Subject: Deep Pit Belays
By: Wm Shrewsbury (taglite@bigfoot.com)

Before I begin, please note: Some of the following article contains practices that I do not condone. They were done under very controlled circumstances, and should not be repeated in your tree outside. They were done solely for the purpose of research, and trying to find an effective method of bottom belaying deep pits.

Send any "hate mail" to me directly at the above e-mail address. This is posted as research, not personal accomplishments. Anyone who knows me knows that I am a very responsible caver who has helped many people out of jams and dedicated years of my life to rescuing cavers and "locals".

A subscriber of TAG-NET writes:

>> Are bottom belays effective on vertical drops of 400+ feet? I was of the understanding that they were not. When I attended Bridge Day this year I was chuckling at people bottom belaying these 900+ foot drops theorizing that by the time you'd pulled all the stretch out of the rope to stop your out-of-control buddy he or she would land on you. Any answers? <<

Well, research will have to be more thorough than this, but here goes:

While doing Fantastic Pit with a group from Missouri once, I went down first. The rope was rigged to the new bolts in the ceiling, thus no lip debris. As each person got on rope, I waited about 2 minutes till they had cleared the upper chimney area, looked up to verify their light position, and then walked out into the pit.

My attempt was to bottom belay them with against the rope bounce/stretch from this virgin piece of PMI - 11mm (7/16) Max. I weigh about 175 pounds with full vertical/cave gear on, which I was wearing at the time.

What I discovered:

- Running out to the bottom of the rope (panic position) and pulling straight down on the rope had almost no effect. Too much stretch and bounce. The belay will cause the rope to 'zip' through their rack in short bursts. Yes, this may slow them down from "terminal velocity", but it was a far cry from preventing a crash&burn. It also prevented them from taking control of the rappel again. I would prefer that they didn't crash into me in the process....

- Taking the part of the rope currently at floor level (NOT the end of the rope) across the pit (about 50 feet) caused them to have a pretty nice rappel till about 100 feet up. If they were under control, this led to them rappelling diagonal near the bottom and slowed them somewhat.

- Repeating the above with someone who rappelled faster proved fruitless as they had way too much momentum and darn near made me into an impression in the wall.

- Taking the part of the rope currently at floor level and climbing up on top of the rock at the entrance to TAG Hall put me about 15 feet off the floor and about 50 feet to the side. I took some webbing and slung a couple of knobs on top of the rock, put in a figure 8, and clipped the rope into this. A normal rappel was stopped easily by the "loop" effect. I had to lower him to the ground.

- Repeating the above with a controlled 'speed rappel' did the same thing with one exception. As he came into the 'loop', his rate of descent pushed him closer to me. In effect, he was redirecting his downward force into a lateral force. This started about 30 feet off the floor for him. Since I was about 50 feet away, he did not swing all the way to me, and I had to lower him.

- One last 'test'. After conferring with a hefty guy I knew could be trusted to stay focused, I climbed back up and got on rope myself. Nothing like being on the other end of the rope....

I started with a descent rate that should have put me on bottom in about 30-45 seconds - five stainless bars spread on a 6 bar rack, with upper spacers. Bruce Smith calls this rate of descent "about 2 octaves above middle C". I would not call it an uncontrolled rappel, since this rate of descent has been done before without injury. It is, however, a pretty good way to get killed without a lot of years of caving under your seat. I do not recommend this rate of rappel to the smart caver. On to the report.

When I was about 50 feet off the floor, my downward descent started to turn into a diagonal Tyrolean. About 30 feet off the floor, I had reached the point where the top rope was stiff, and the slack was out of the rope from my belayer, creating this wide 'V', or maybe closer to an 'L'. At this point my momentum carried me toward him. As I swung closer, the rack moved along also. I got about 15 feet from the rock when I stopped. He had to lower me.

Now, all of the above stipulates that the bottom belayer remains alert, effective and does not get pulled off the rock. My belayer used the sling with the figure 8 in it. That way, he could feed out a little to keep me away from the rock should I come in too quick.

What does all this mean? Well, as I mentioned above, it means we need more testing - highly controlled!

- Pulling on the bottom straight down is not only ineffective, but dangerous - ask a guy who tried it in Ellison's a few years ago. His girlfriend (I don't think they were married, but forgive me if they were) came down on top of him. His body probably saved her. Sorry, but I will not throw my body under you so soften your fall....

- Pulling across the pit helps, but they will still 'touch-down', even in a controlled rappel. This will help slow descents though.

- Sitting up off the floor a short distance seems to be the most effective. You can stop a reasonably out of control rappel. Don't make yourself part of the system. Wrap the rope once around some knob or put in a sling and a use a hitch through a carabiner or a figure 8 (hey! great use for a figure 8 on a long drop!).

I pulled rope in on the straight down rappels. We did not try pulling in more rope on any of the diagonal rappels. We made the assumption that the belayer would not have effective control of the rope when the force finally hit. Also, had the rope been pulled in before the rappel began, it would have been one crummy rappel. We merely held the length constant, with the ability to feed out a little more on the "loop" belay.

More needs to be done. The difference between 200' and 400' is a lot. We often forget the difference in rope weight. We compensate for wet rope near the bottom of the drop from mist, and less rope weight. It becomes second nature for us.

Keep the less experienced in mind while caving. It will let a lot of us sleep that night...

Wm Shrewsbury
taglite@bigfoot.com

Posted to the TAG-NET on 10/22/02
Subject: Belaying Long Drops
By: Wm Shrewsbury (taglite@bigfoot.com)

More tests have been done since the first article appeared in Nov. 1997, and basically agree with its findings. In short, if you can't be above the landing area 20-25' and off to the side by around 1/10 of the drop it doesn't work very effectively.

What does this mean at Bridge Day? Well, some drops allow for a sideways pull, which helps, but few allow even that due to the trees in the way. Some drops allow for an uphill belay, but the other ropes, being strung along the same catwalk, are in the way. The 'clear' drops, which land on the railroad buffer zone and road, can be pulled sideways but have no height elevation.

There is an answer in the above, but it means more work on the part of the people attending Bridge Day, and probably some permission from the Park Service that owns the land down below (at least, I think it's the Park Service that owns it...)

1) Those who are in the 'tree zone' could climb a tree off to the side, set up a belay point, and park a belayer there. This would give them the elevation needed, the side distance needed, and

work.

2) Those on the 'hill zone' could walk uphill until they were the needed distance, and stagger themselves each way so that one walked East of the next rope, the next one West, etc. This would give them the needed height and side distance.

3) Those on the 'flat zone' don't have a lot of choice except to walk way off to the side. A long piece of rebar, driven into the ground off to the side and angled away from the drop, with a Figure-8 or similar belaying device attached, would assist in pulling the rope over. Not quite at good as the J-belay, but reasonably effective without worrying if the belayer weighs enough to be effective.

Of course, the most important part of belaying has not even been mentioned above - The rappeller should be capable of doing the drop in a 'reasonable' speed.

Bruce Smith, along with others, and myself noticed that quite a few people on the bridge this year had to be talked into doing the drop by their teammates. Once they got on rope, they inched their way down by feeding the rack until they were well below the superstructure of the bridge. By 'inched', I do mean inched! You could see that they were moving between two and 4 inches on each rope lift. One even fed till he was over 1/2 way down!

Folks, this is NOT rappelling. I have no problem with people being careful. And yes, the catwalk on the bridge is far different from walking up to the bluff at Whiteside Mtn. or the lip of Fantastic. But once someone is on the rope, taking 20-25 minutes to rappel an 876' drop (at the highest - it drops to 625' at the last rig!) means that they do not know how to control their rack. And no, they were not "taking pictures along the way" or "enjoying the view". Their vision was deadlocked onto their rack - no head turning side to side to view the gorge was observed by several of us for a couple of the rappellers.

There are some things that a person should know how to do on long drops. Dropping a bar, adding a bar and knowing how to spread your bars should be considered a minimal skill. It has also been argued that they need to know how to change over should a problem arise. Sitting for that amount of time in a harness can lead to blood pooling in the legs, along with lactic acid buildup. Not a good thing, as shown by several studies that the NCRC has seen and talked about during their week long sessions.

'Experienced' rappellers often shift around while going down, mainly as a way to shift our weight from one leg to the other to keep us comfortable. Our harnesses are also adjusted better since we simply know when it's too tight (or too loose). 'New' rappellers were observed to sit perfectly still, clutching the rope and rack as if they were trying to stop their descent into hell (no religious reference here, just a hot place...)

Now, back onto subject... Having someone who is not experienced in rappelling long drops means that they will take some time. Having someone who is not experienced in belaying long drops means that they probably wouldn't take the best method available to ensure maximum safety of the rappeller. Not to forget, a long rappel will also let the belayer's mind wander after a few minutes, thus adding to the problem since they would not be 'alert' at the moment of danger. Seconds count once a problem occurs, especially if it happens within the last 200' or so. 20+ minutes is a long time for someone to look up and watch for signs that the rappeller is out of control...

Setting up a J-Rappel doesn't give the belayer an OK to forget about the rappeller, but it does work even if they only catch the rope at the last second.

In summary, the best method of bottom belaying is to have the rappeller be able to control their rack. Kind of like having a seat belt in the car, but never needing it. However, if the rappeller should lose control, I would hope that some sort of J-belay would be in place to arrest their fall.

Food for thought...

Wm Shrewsbury
taglite@bigfoot.com

Posted to TAG-NET on 10/23/02
Subject: Bridge Day accident update.
By: Bruce Smith (onrope1@bigfoot.com)

In the final analysis, Greg Clark was not hurt as badly as previously thought. He is home now and was transported by ambulance from Charleston, WV to Washington, PA on Monday (I believe). His final injuries were a torn bladder and lumbar vertebra damage. All the other organs are fine.

The original report that the bottom belayer was his wife was incorrect; rather it was a member of his team. Many feel the little bit she did probably saved his life.

Some comments and thoughts about Bridge Day.

1. There were 115 people scheduled for 1st time bridge rappels on Saturday. About half of the total of all scheduled to do the bridge. This alone is not a concern. The concern arises from the incredible number of these folks that were more or less talked into rappelling, coerced, convinced they would regret not doing it on Monday, shamed into rappelling, etc., etc., etc. I feel we should provide positive encouragement, but allow folks to make up their own minds and give them an open out to walk off the bridge if they are not comfortable.

2. I saw more folks than usual pulling themselves down the rope 2-4 inches at a time. This is not rappelling... rather survival in a crisis. If I fall down a mountain or scoot down a mountain on my butt, am I going to brag later that I skied down the mountain? I am concerned that too many people were not trained or given the proper long rope experiences prior to Bridge Day.

3. Bar control: Start with a lot of bars and then remove them as you feel necessary; descend under control while sliding down the rope; spread out or push up bars as necessary; add bars as you need them. This skill is necessary and critical to long rappels.

4. If you cannot sit in a harness with your arms extended and remain upright, you need a chest harness on a rappel of this length to keep you upright. Attach a cord from that chest harness to the top of your rack. Horton Hobbs explained the Hobb Hole years ago and it is valid even today.

These are my thoughts and the thoughts of others shared during numerous discussions I have enjoyed lately.

Bruce Smith

NSS VERTICAL SECTION

SECRETARY'S REPORT

JUNE, 2002

By David Joaquim

NUMBER OF MEMBERSHIPS (After release of #46)	....	433
NUMBER OF MEMBERS PAID THROUGH #46	....	728
LIBRARIES	....	5
NYLON HIGHWAYS #47 TO BE MAILED	....	33

YEARS PAID:		ELECT.	PAPER
# 47	....	177	33
# 48	....	101	33
# 49	....	48	14
# 50	....	5	1
# 55	....	1	0

NSS VERTICAL SECTION

TREASURER'S REPORT

JUNE, 2002

By David Joaquim

INCOME:

NEW MEMBERSHIPS & RENEWALS	.... $ 241.00
2001 CONVENTION WORKSHOP INCOME	.... $1,225.00
BANK INTEREST (GMAC)July2001-May2002	.... $ 200.48
SYMBOLIC ITEM SALES TOTAL	.... $ 647.95
BACK ISSUE SALES	.... $ 81.13
DONATIONS	.... $ 1.00
TOTAL INCOME	**$2,396.56**

EXPENSES:

CLIMBING PRIZES & AWARDS	.... $ 283.25
PRINTING #45	.... $ 707.13
PRINTING #46	.... $ 983.50
REPRINT #45 (FOR REQUESTS)	.... $ 51.70
WORKSHOP MANUALS	.... $ 46.11
PRINTING COSTS @ 2001 CONVENTION	.... $ 43.50
VERTICAL SECTION COPIES (FOR BRUCE)	.... $ 71.19
POSTAGE & SHIPPING COSTS	.... $ 50.17
REFUND FOR OUT OF STOCK ITEM	.... $ 11.00
WORKSHOP GEAR	.... $ 103.82
TOTAL EXPENSES	**$2,351.37**

ACCOUNT BALANCES:

BANK ONE (AZ)	.... $1,309.88
GMAC	.... $7,236.57
TOTAL	.... **$8,546.45**