Nylon Highway Issue #52

... especially for the Vertical Caver

#52

Contents

Overleaf

NH #52

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Biner Blocks, Pull Cords, and All That Stuff

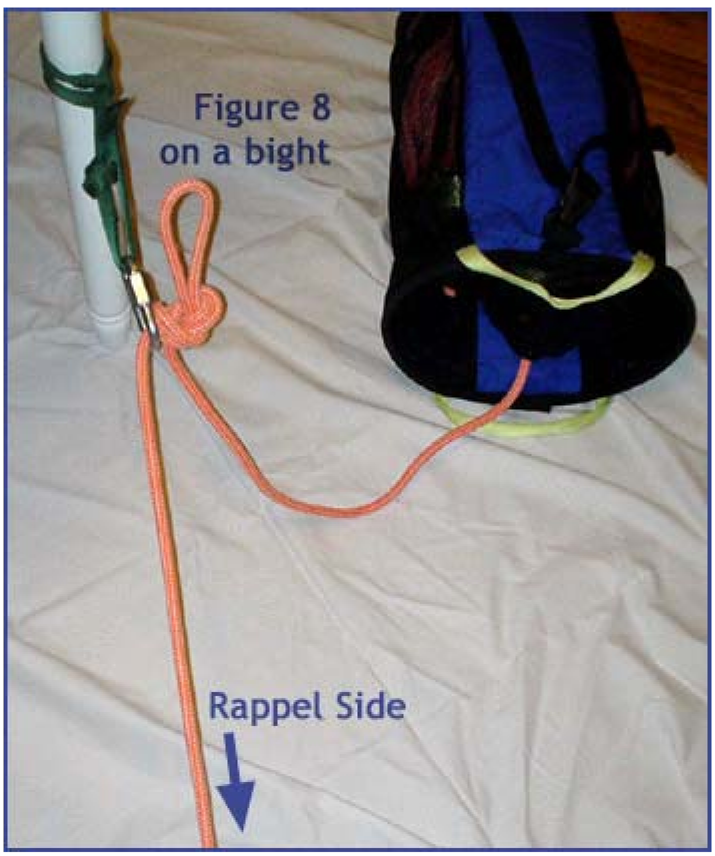
by Tom Jones

A **BLOCK** is a way of attaching the rope to an anchor so it can be retrieved.

The normal "climber" method of setting up a rappel is to thread the rope through the anchor and rappel on both strands. This is a simple, straightforward method, and works in a lot of cases.

Using a block, the canyoneer can rappel single strand on the rope, then pull using a lighter line, such as a 6mm pull cord. This saves weight and adds flexibility. Combined with use of a rope bag, this method can be quite a bit quicker than the "trad" method.

There are two normal ways to block the rope for rappelling - the knot block, and the biner block. In both cases, a block is placed against a metal ring, either a rappel ring or a rapid link. Many canyoneers carry a few rapid links (also known as "Rapides") to place on anchors as they descend canyons.

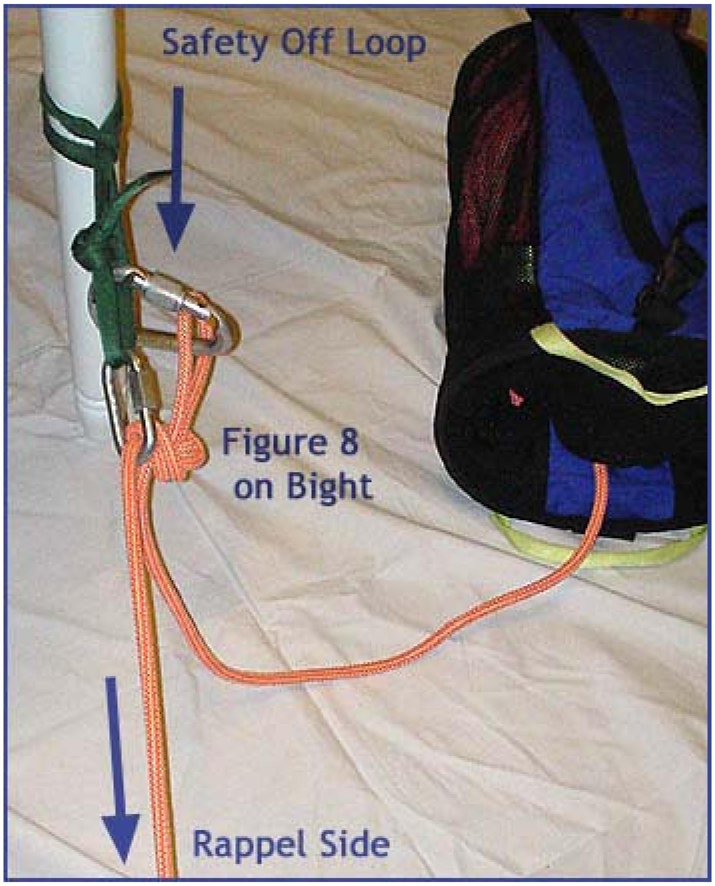


A Knot Block Against a Rapide.

Caution must be taken that:

A. the knot cannot pull through the rapid link or ring; and

B. the knot does not pull into the rapid link or ring and jam.

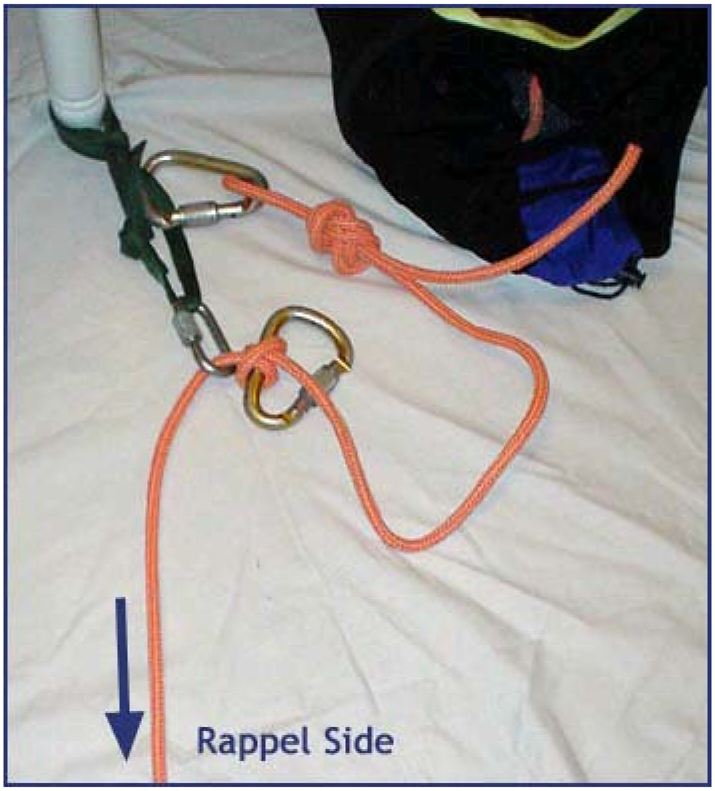


A Knot Block Against a Rapide, with the knot safetied off (clipped) to the anchor.

IF your group has more than a few people, or includes beginners, it is a good idea to clip the knot loop to the anchor, to **safety it off**. Sometimes in the confusion of getting people on rappel, beginners will hook up their rappel to the "wrong" side of the block, and try to rappel the un-blocked side. Sometimes experts will try the same trick.

To prevent this from being catastrophic, safety off the knot (for every person but the last). It also helps to NOT toss the rope bag down until the end, so there is only one strand of rope heading downward.

Because a knot block can be hard to untie after significant loading, I use a carabiner block more often. Tie a clove hitch around the spine of a locking carabiner as shown.



A Biner Block Against a Rapide

Again on this one, the ropebag side of the rope is safetied off to the anchor.

Using a Biner or Knot Block

How are these used? Here's a few examples.

A short rappel is any rappel that uses less than half the length of the rope. Let's say the rappel is 40 feet, and the bottom of the rappel can be seen.

Short Rappel Sequence:

1. Thread the rope through the rapid link.

2. Pull rope through the link until the rope hits the bottom of the rappel.

3. Block the rope against the Rapide. This is called **Setting the Rope Length.**

4. Safety off the other side of the rope.

5. Folks rappel. With the rope length set correctly, folks can rappel to the bottom, then pull the end of the rope through their device and walk or swim away.

6. Last person: clean (unclip) the safety. Toss the ropebag down, holding onto the rope so it cannot get away. Rappel single or double strand. (If the pull looks dodgy, clean the biner block and rappel double strand). Pull the rope, and stack it into the bag.

Two-Stage Short Rappel Sequence:

In this example, the rappel is done in two stages. Like the first rappel in Zion's Pine Creek, a two-stage rappel descends two drops that are close together off a single anchor. In Pine Creek, the first rappel is about 20 feet into a shallow pothole. Then the canyoneer walks 10 feet to the brink of the second rappel, goes back onto the rope and rappels 15 feet to the bottom of a second drop.

1. Thread the rope through the rapid link.

2. Pull rope through until you can see the rope hit the bottom of the rappel.

3. Block the rope against the Rapide, setting the rope length for the first stage.

4. The first person rappels into the first pothole, and walks to the edge of the second drop.

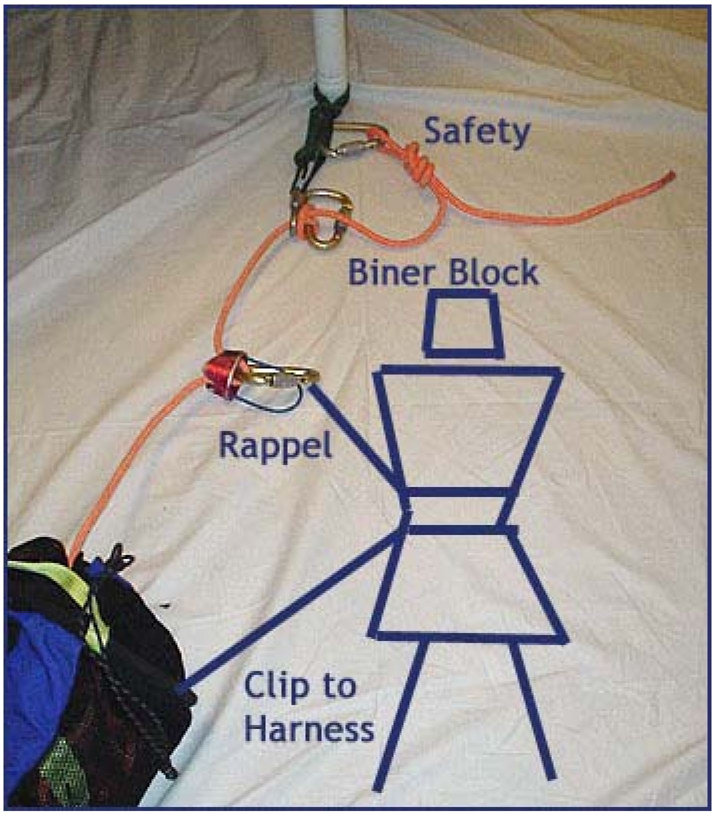
5. The rigger removes the biner block at the anchor, feeds through enough rope to set the length for the second drop (with the help of the first rappeller), and re-sets the biner block at the new length. Safety off the other side of the rope if appropriate.

6. Folks rappel. Into the first pothole, walk across, rap the second drop and pull the rope through the device.

6. Last person: clean the safety. Grab the rope, then toss the ropebag down (first and/or second drop). Rappel single or double strand. Pull the rope, stack into the bag.

Long Rappel

In this example, the rappel is long, and maybe goes through brush or trees. We will keep the ropebag with us, and use a pull cord to retrieve the rope.



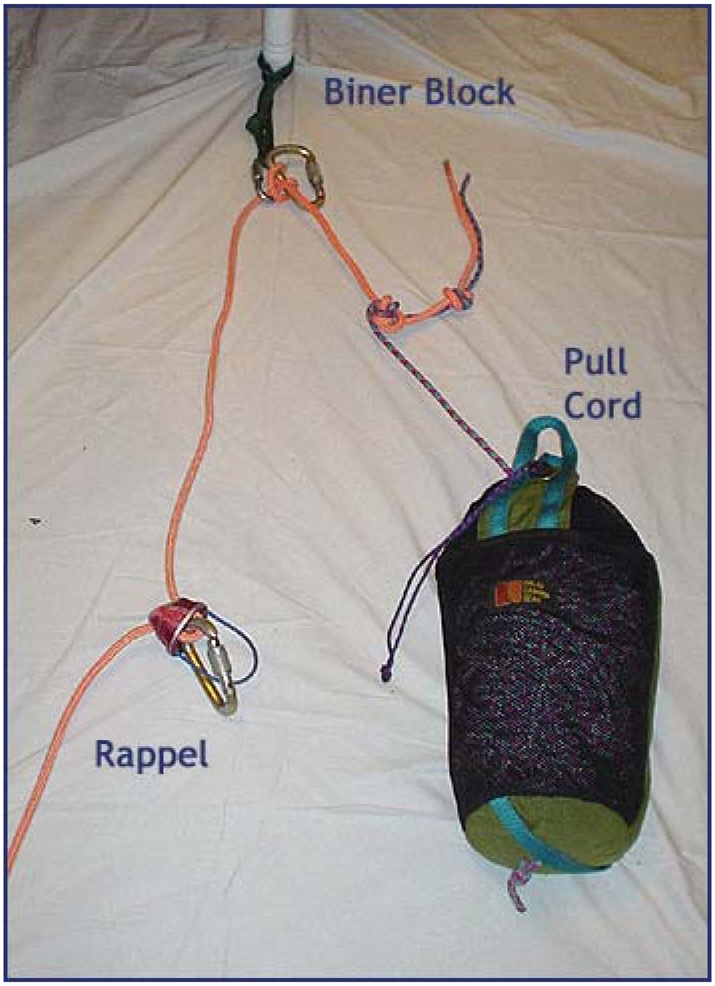
Long Rappel Sequence

1. Thread the rope through the rapid link.

2. Pull through 3 or 4 feet of rope and block the rope against the anchor. Safety off the short end.

3. Clip the ropebag to the side of your harness with a sling. Rappel, feeding rope out of the bag, through your device.

4. Send the other folks down.



5. Last Person: clean the safety. Tie the end of the pull cord to the end of the main rope. Clip the pull cord bag to your harness. Rappel, letting the pull cord deploy as you go. Pull on the pull cord to clean the rappel.

Comments: rappelling with the bag clipped to you is a pain. Kinks come out of the bag and try to hop out of your hand. **Be careful.** Once you get a clean shot to the bottom of the rappel, drop the bag, allowing the rope to deploy as it falls.

Same applies to the pull cord. Once you are in a position to get a clean drop, chuck it.

Tom's Utah Canyoneering Guide
http://canyoneeringusa.com/utah/tech/

SMC GUIDELINES FOR THE PERMANENT MARKING OF HARDWARE

Seattle Manufacturing Corporation (SMC) has released guidelines for the proper way to permanently mark their mountaineering, rescue, industrial and worksafety products. This information is intended to serve as a clear and simple guide concerning what is acceptable and conversely, what is not acceptable when permanently marking by engraving into the surface of various types of hardware.

It is only acceptable to use a hand held electric type engraver to place identifying marks on hardware. DO NOT strike with a hammer and stamps or ever use other similar methods. Once the marking process has been completed ALWAYS inspect the product for proper fit and function PRIOR to returning it to service. If you ever have concerns or questions you are advised to contact SMC directly at 18004266251 or info@smcgear.net.

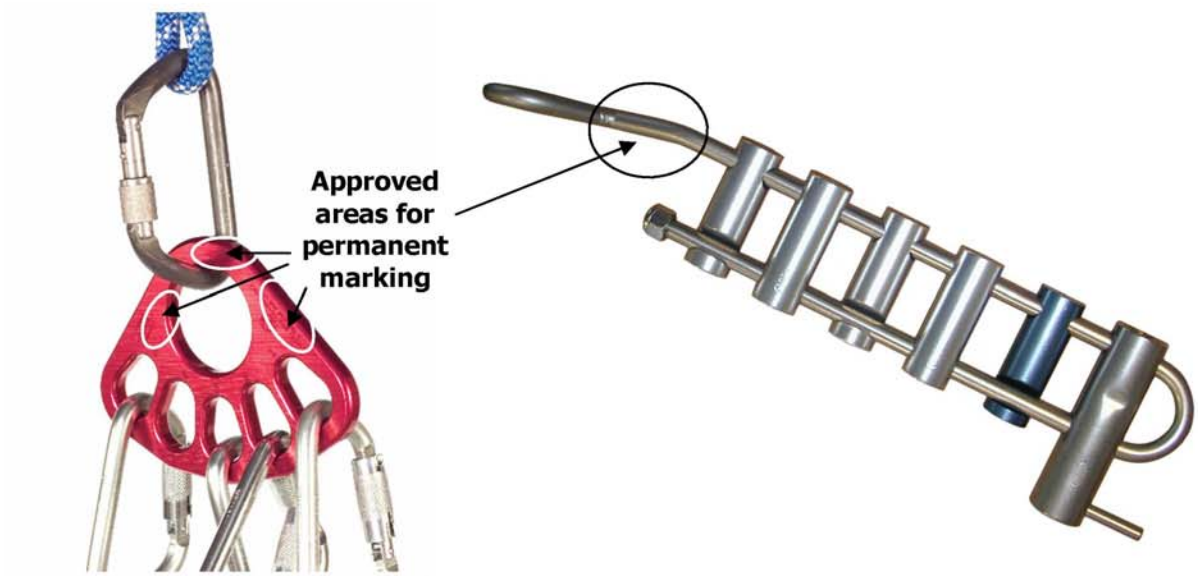
CARABINERS

For carabiners it is recommended to mark along the spine of the frame. DO NOT mark on or near the lock or pivot tabs of the frame and stay away from rope bearing areas. DO NOT mark on the gate. For steel and stainless products use a medium setting with medium to heavy pressure. For Aluminum products use a low setting with light to medium pressure. Depth of engraving equal to the thickness of a piece of paper should be enough to last the life of the product.

SMC GUIDELINES FOR THE PERMANENT MARKING OF HARDWARE
Page 2

PULLEYS

For pulleys it is recommended to mark on the flat outside surface around the axle. **DO NOT** mark **ON OR NEAR** the carabiner hole at the top of a pulley or anywhere on the beckett of a double pulley. Also, it is important to stay away from all rope bearing areas.



RAPPEL RACKS & BARS, RIGGING PLATES & ROPE PROTECTION

When marking any other hardware items always use caution and stay away from all carabiner holes, rope bearing surfaces and surrounding areas.

COATINGS

Most aluminum products are anodized. Some slight cosmetic oxidation may occur over time and this is a natural occurrence.

Alloy steel parts are typically zinc plated. Engraving these products will remove the zinc plating in that particular area. One advantage of zinc plating is that it will move over and protect the exposed base material (selfsacrificing). This however will eventually lead to the zinc in the area being consumed and may allow rust to begin to form. To help prevent corrosion, periodically wipe down plated products with LPS or a similar product.

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BUSHWALKERS WILDERNESS RESCUE

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The Confederation of Bushwalking Clubs NSW Inc PO Box 2090 GPO Sydney NSW 1043

PREFERRED KNOTS FOR USE IN CANYONS

David Drohan

Abstract

On behalf of the Bushwalker's Wilderness Rescue Squad (BWRS) Rock Squad, the author is conducting a series of tests in a voluntary capacity to determine the preferred knots that could be used in recreational canyoning. This paper will be of interest to all abseilers who have to retrieve their ropes. The project is planned for three stages. Stage one is now complete and this paper focuses on the tensile strength and slippage of various knots. Cyclic loading and rope pull down issues have also been investigated. 139 hours of actual testing has been conducted to date. This time does not include the considerable time to plan, analyse and write up the report.

This paper was presented at the Outdoor Recreation Industry Council NSW conference in Sept 2001.

For further information regarding BWRS visit the web site at http://www.bwrs.org.au

Introduction

Recreational canyoning groups are questioning the traditional knots to join tape or rope. It has been argued that the traditional Double Fisherman's Knot (Figure 1-a) to join ropes is very tight to undo after use and often catches on obstacles during rope pull down. The Tape Knot (Figure 1-b) can be difficult to adjust and now some groups have started using unconventional knots such as the Overhand Knot for joining rope or tape (Figure 1-c & d).

There is also evidence that some groups have been using smaller than usual size tape or cord for anchors, in order to reduce cost. This is done on the pretext that their group will only use the anchor sling once and they believe it is strong enough. It is commonly regarded that 50mm flat tape or 25mm tube tape is acceptable for use in anchor slings. The project will explore if smaller size slings could be used, such as flat 25mm or maybe even 19mm polyester tape.

The proposal for this project was outlined in March 2000. This paper discusses tests conducted to determine various knot strengths, slippage and ease of rope pull down for various rope/tape materials.

Literature Review

Existing Information on Ropes, Aging and Knot Strength/Slippage
The author has researched published information on the strength and slippage of knots in rope and webbing. There is significant data on the rated strength of new tape and rope as indicated in

the sample of catalogues and specifications (see references). However only a couple of references have been sighted that provide data on strength of knots tied in Kernmantle rope. Warild (1990 p33&34) provides information on recommended and non-recommended knots showing the static strength and falls taken for each knot. He states “the performance of most knots is variable and depends on many factors, rope diameter, wet or dry, knot packing and to a lesser extent temperature” (p33). He suggests the bulky knots appear to have a clear advantage especially in 8 or 9 mm rope and the Overhand Loop (knot) performs inconsistently. Whilst Warilds’ tables are very helpful, the current author has not been able to access the test data on which they were based, and there are no test results for knot slippage. Luebben (1996, p7) also provides some data on the strength of knots, but no supporting references are provided. Long (1993, p54), mentions that the Water (Tape) knot should be checked frequently, as it has the tendency to come untied.

Much testing has been conducted by the international organisation of alpine clubs, Union Internationale des Association d’Alpinisme, (UIAA) on falling climbers and the equipment that breaks their fall. It is important to understand what causes the severity of the fall and so understand what is called a fall factor. Benk & Bram (Edelrid) describe the fall factor (FF) as the proportion of fall and the length of rope run out. The fall factor describes the severity of the fall and determines the load on the entire system. The most serious fall a climber could take in normal circumstances is FF2, that is the length of free fall (say 20m) divided by the length of rope paid out being (say 10 m) therefore 20/10 = 2. This means 10m of rope must absorb the fall energy of a 20 m free fall. Abseilers do not take such extreme shock loads on their equipment. Warild (1990 p 15) argues that the worst fall factor a caver (abseiler) could take if one of the two anchor bolts snapped would only be FF0.6. The probability of a FF0.6 fall is extremely low and the most abseilers should ever expect for a well rigged rope is FF0.3. Warild states the most convincing evidence that caving (static) ropes are strong enough is the complete lack of accidents due to ropes failing under shock loads from caving (or abseiling in canyons).

Warild (1990, p 17) mentions ropes could be damaged by mechanical deterioration by 10 FF0.1 minor shock loads, caused by prusiking or rough abseiling and suggests this is an avenue for investigation. One of the future tests in Stage 2 will explore this issue, as old ropes (that are too stiff to abseil on) are often used as back up anchor ropes.

Polyamide static ropes used for canyoning can be old. There is no “use by date” based only on age. The Blue Water Technical Manual (2001) provides information on when to retire your static rope, such as damage from sharp edges, glazing from fast abseils or soft hollow or lumpy sections in the rope. Replacement is based on wear and tear. Age is not mentioned as a limiting criteria. What has been observed for ropes over 10 years old is that they often become too stiff to handle and abseil on. This is due to the mantle shrinking and so becomes less pliable. Blue Water recommends the shelf life for one of their unused dynamic ropes as five years. Blue Water admits there is no conclusive evidence from nylon manufacturers regarding aging of unused ropes. Warild argues on p 17 that age does affect used ropes and gives data for a 4.5 year old 9mm BWII rope that indicates it can only withstand four FF1 falls, where a new rope can take 41 such shocks. AS4142.3 (1993) requires new 11mm static ropes used for rescue to withstand two FF2 falls. Provided the abseiler does not intentionally shock load the rope the way a climber could, age is not an issue, as polyamide static ropes can withstand some shock loading. Even with the worst normal abseiling shock load of FF0.6 the old rope should survive one such shock load, as Warilds tests indicated the 4.5 year old rope could withstand four of the higher FF1 falls. It appears aging affects a ropes ability to survive shock. The five-year rule only apples to dynamic ropes as they are designed for high shock loads. Static ropes are not required to be condemned when they reach five years old as they are not intended to take high shock loads.

Many rope manufacturers treat their rope with a “dry treatment”. This involves coating the nylon fibres of the rope with either silicon or teflon. Details on the process are difficult to obtain from manufacturers. This process is done so the rope will absorb less water when wet and therefore maintain its strength. Warild (1990, p16) discusses that water absorption in nylon rope makes it less abrasion resistant and reducing its static and shock strength by up to 30%. Some of the Edelrid ropes tested in this study were “dry” treated.

For natural laid fibre rope Marks Engineering Handbook (1987, p88) states that the shorter the bend in standing rope, the weaker the knot (based on Millers experiments 1900). However it appears to be a different story for nylon ropes. A report (the author wishes to remain anonymous), discovered that knots in Kernmantle (polyamide) rope failed at the point of maximum compression due to the knot compressing one strand of the rope sufficiently that the heat generated by friction caused the strand to become plastic and then fail.

Petzl (2000) (an outdoor gear manufacturer) provides some information on alternative knots on their web page technical manual, such as recommending the Abnormal Figure 8 Knot to join two abseil ropes together. There is no supporting data for this recommendation. There is also useful data at this web site for UIAA limits and design criteria, such as that harnesses should not be loaded to more than 15kN.

Delaney (2000) from the Australian School of Mountaineering states he is not aware of any testing of aged tape and rope as typically found in canyons and suggests there is only limited information on knot slippage, but he could not provide any supporting test data.

Manufacturer’s Rated Strength

The rated strength given by the product manufacturer is the minimum strength that the material will fail at, normally given in kilonewtons (kN). Most of the older equipment was rated in kilograms force (kg).

To convert to kg, multiply by 1000 (newtons) then divide by 10 (gravity rounded up).
For example; a karabiner is marked as 22kN. 22kN x 1000 = 22000(N) /10 = 2200 kg. A quick simple rule is just multiply kN by 100 to get kg.

Adequate testing of the product has been conducted by the manufacturer to determine the mean breaking strength. Therefore the minimum or “rated” breaking strength can be determined. US and European companies that have extensive production undertake comprehensive testing of large samples from many batches. Therefore an accurate statistical figure can be determined. Some products like karabiners have a “Sigma 3” rating which is three standard deviations back from the mean. However many overseas companies only use two standard deviations back from the mean for rope and tape products.

To explain standard deviations (std dev), Freund (1988 p76) defines for the results that create a normal (bell shaped) distribution as follows:

> About 68% of the values will lie within one standard deviation of the mean, hence about 16% are outside the 1 std dev on the low side.
> About 95% of the values will lie within two standard deviation of the mean, hence only about 2.5% are outside the 2 std devs on the low side.
> 99.7% values will lie within three standard deviation of the mean, hence only about 0.15% are outside the 3 std devs on the low side.

Some Aust/NZ rope/tape manufacturers do not use statistical calculations to determine their rated strength for the materials used in this study. Toomer (2000) has clarified that the rated strength used by Australian rope manufactures is based on a number of batch tests, using the lowest breaking specimen. Usually the rated strength is rounded down to the nearest 100 kg. Small (2000) from Donaghys Industries (a New Zealand webbing manufacturer) stated the webbing (WPM25-OPG63 &WPM50-OA900) tested in this project is uncertified. The only testing conducted by the company on these products were by random sample and the "rated" load stated in the specification sheet is based on the minimum strength from the random testing. The random sample is based on three specimens from the end of a batch run. Batches were only tested when the company had altered a part of the manufacturing process or for some other reason. No statistical methods are employed to determine the minimum break load for random sample tests.

Working Load Limit

The working load limit (WLL), sometimes referred to as the safe working load, is the maximum static load that should be applied to a rated piece of equipment. Dividing the rated strength by the Safety Factor (SF) will give the WLL for that piece of equipment. Our example of a karabiner rated at 2200kg divided by SF5 for hardware will give a 440kg WLL.

Understanding Safety Factors

Most rope and hardware manufacturers give their product a rated strength. To determine the WLL a Safety Factor (SF) is used. Jensen (1974) describes safety factor as the ratio of ultimate stress (rated strength) to allowable stress (WLL). The safety factor is based on a number of considerations including risk to human life, wear and tear of the product, aging and the type of loading that may be encountered. To understand how SFs are determined, he gives examples ranging from 2 to 10 depending on the machine and application. Engineers have agreed that 5 is acceptable for lifting loads involving humans. SF5 has been adopted as the SF used for abseiling equipment hardware. Bateman & Toomer's (1990) Australian Lightweight Vertical Rescue Instructors (ALVRI) verbal advice during the course as recorded by the author, discuss that SF5 is acceptable for hardware, however rope and tape must include a factor to account for loss of strength due to the knot.

ALVRI use a strength loss of one-third (33%) for any knot used in rescue. That is 0.67 strength remaining in the rope. The original rope strength with no knot is divided by the strength remaining due to knot of 0.67. This gives a ratio of 1.49. Multiplying the SF5 by this ratio of
1.43 will give a figure of 7.46. This figure has been rounded up to give SF8.

Based on this rationale, AS 4142.3 (1993), notes the SF as not less than 8 is considered appropriate. It is noted that the American Blue Water (2000) catalogue use the US Fire department's SF15.

An appropriate SF is important. An excessive SF may add a significant weight or volume penalty to the equipment you have to carry if you wish to maintain the existing WLLs. A SF that is too low may lead to equipment failure with possible loss of life.

What else needs to be done?

From the literature review it is clear there is still a lot to learn about knot strength and slippage in rope and tape. The tests conducted in this study provide further data on these issues however are not exhaustive. Such a study would require access to research databases covering strength of rope materials to determine the extent of research already conducted on this subject and how best to build on this knowledge.

Project Design

This project aimed to determine the best possible knot for joining ropes and slings together in a canyon. A useful side benefit was to identify any hazards evident in alternative knots. A process of elimination determined the preferred knots. The knots being considered were eliminated in a step by step process based on the results from tests of A to E (listed below). The preferred knot (for each application) is the one that has the best results and has not been disregarded due to a safety issue.

The first stage of the process examined the static forces involved. The definition of “static” in this case, is load not subjected to dynamic forces.

Objectives: Stage One

A. To determine the tensile strength and slippage of standard knots in slings.

B. To determine the tensile strength and slippage of alternative knots that could be used to join tape and rope.

C. To determine the tensile strength of certain single strand ropes without knots.

D. To determine if knots used to join slings or ropes slip under normal (cyclic) loading.

E. To determine the ease of double rope pull down using various rope joining knots.

Section A is used as a baseline for the strength of standard knots. Section B compares the strength of the alternative knots to Section A. Section C attempted to confirm the strength of the rope/tape used in Sections A and B, without the influence of the knot on rope strength. Any knots that were found unsafe after completion of Sections A to C were deleted from the remainder of the tests. Sections D and E are the final set of tests to examine the preferred knots for canyon use.

A further two stages of the project are planned to consider the shock forces and aging process. More information on these topics is provided under “Further Research” latter in this paper.

Method

Testing Requirements

In order to maintain repeatability, reliability and validity of the tests the author has referred to appropriate Australian standards. No standard could be found that gave a procedure for tensile testing of endless loops, therefore the author has adopted the philosophy of AS 4143.1(1993) for endless loop tests and has described the procedures followed in a later section of this paper.

For single strand rope testing AS 4143.1 (1993) is directly applicable and requires a gauge length of one metre (the distance between bollards) at the required pre-tensioned load. This indicates a test bed with a stroke of two to three metres would be required. Toomer (2000) from Spelean (an Australian rope manufacturer) indicated that the one metre length is important in order to have enough material between the gauge lengths when compared with the material wrapped around the bollards. The machines that the author had access to only had a maximum stroke of one metre. In an attempt to solve this problem the author noted that in AS 2001.2.3 (1988) which is one of the standards for testing seat belts, the procedure only required a gauge length of 200mm. For this reason single strand tests using a gauge length of only 200mm were attempted.

There are no standards for conducting the cyclic and rope pull down tests in this project. Again the author has described the procedures followed in a later section of this paper.

Clem (2000) (former chairman of the Life Safety Section of the Cordage Institute, USA) provided useful advice on the testing requirements for tensile and dynamic testing of knots. His findings indicate apart from obvious criteria such as rope material and diameter, that more subjective issues can come into play. These include which side the tail comes out of the knot. ie if the knot is tied right or left hand. The author has noted these concerns and attempts have been made to record any unusual events during the tests by video recording a number of the tests and taking individual notes on test records. Clem advises the absolute minimum size of the sample would be six specimens of the same material. It is acknowledged that the sample should be larger, however due to resource constraints the author has chosen six specimens per sample based on Clem's advice. Although a sample of six is less than ideal, AS 4143.1 (1993) only requires a report based on two successful test specimens. Therefore the authors sample is three times greater than the relevant standard requires.

Units used.

The metric system of measurement has been used for this study.

Length measurements: millimetres (mm) are used for measurement up to one metre and metres (m) for measurements greater than one metre.

Force measurement: kilonewtons (kN) have been used for the tensile tests. For the cyclic and rope pull down tests kilograms (kg) were used. As manufacturers rate their equipment in kN it was decided the tensile tests would remain in that unit. Although Force (Newtons) equals mass (kg) times gravity, it was decided for the other tests that simulated the weight of people and arm strength required to pull ropes down, it would be simpler to express the results of measurements as kg mass units.

The Tests of stage One

A. Tensile Strength and Slippage of Standard Knots in Slings

A tensile test machine was used to test the rated strength of new tape and old rope made up into an endless sling by a knot. The slings were tested to failure. The joining knots were the Tape Knot for tape and the Double Fisherman's Knot for rope.

B. Tensile Strength and slippage of Alternative Knots in Slings

A tensile test machine was used to test the rated strength of alternative knots in tape and rope made up into endless slings.

C. Single Strand Tensile Strength

Single strand of rope is the terminology used by rope manufacturers to describe a single length of rope, it is not a single fibre of rope. The testing conducted in A & B was for endless slings, the rating given in the manufacturer's specification was doubled as a consequence. The doubled rating was compared to the second standard deviation back from the mean breaking strength from each sample. This is not ideal due to statistical differences in the size of the two samples being compared. To produce accurate values of strength loss due to a knot from the knot tests conducted in A& B, additional tests were conducted without a knot for the same material. This would make it possible to compare the results to determine a true strength loss due to a knot. Single strand tests are required for this. It is also reasonable to compare the breaking strength of the aged material without a knot to the rated strength to determine the strength loss due to age of the material.

D. Knot Slippage caused by Cyclic Loading

Knot slippage under cyclic loading may be a more serious problem than slipping under a constant load. Repeated predetermined loads were placed on the tape or rope slings. The knots were measured for any slippage after each load application.

E. Canyon Rope Pull Down

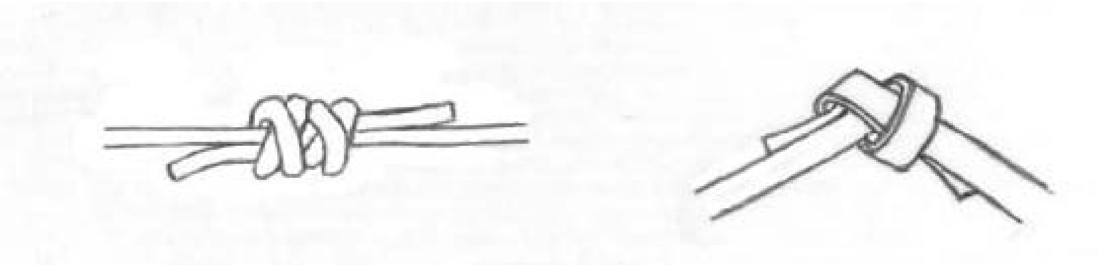
In canyon abseils a double rope is slung around the anchor point and one end is pulled down to retrieve the rope after use. Tests were conducted to measure the force to pull a knot joining two ropes over various edges.

Knots Selected for Testing

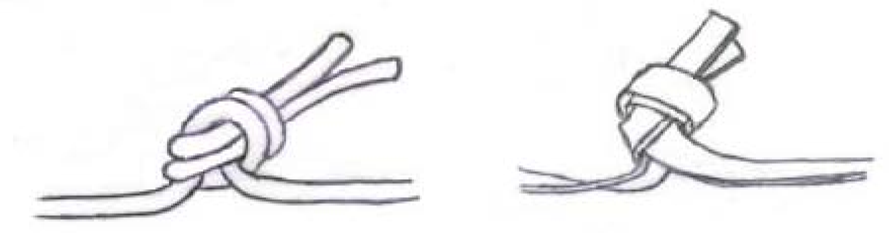
There are many knots capable of tying rope or tape together. A knot used in a canyon environment must be safe. Safety in this context can be broken down into four sub headings. 3 & 4 are considered safety issues due to the extra time to correct problems.

1. Acceptable strength and slippage
2. Easy to check
3. Easy to tie and untie
4. Suitable for the intended application. That is, the knot won't catch on an edge during pull down. These criteria were used to select the knots.

The following knots may meet the criteria. The project plan aimed to determine which knots met all of the above criteria.

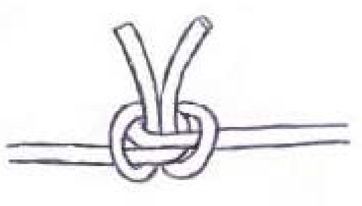


(a) Double Fisherman's Knot in rope (b) Tape Knot in tape



(c) Overhand Knot in rope (d) Overhand Knot in tape

(e) Rethreaded Figure Eight Knot (f) Abnormal Figure Eight Knot



(g) Alpine Butterfly Knot (to tie ropes together)
Figure 1

Where applicable the knots were tied right-handed. There is an exception for one of the Overhand Knot pull down tests that also included a left-handed knot.

The Single Fisherman's and Bowline to join ropes together were considered inappropriate due to known slippage issues. The Rethreaded Overhand knot (a Tape Knot for rope) did not have any obvious advantage over a Double Fisherman's and so was not considered. Obviously dangerous knots such as the Reef Knot or various slip knots were dismissed.

Other knots such as the Reef Knot backed up with a Double Fisherman's Knot and also the Double Fisherman's Knot to tie tape were eliminated before the testing began. The Reef backed up with a double fisherman's has been used by some groups to overcome the issue of the Double Fisherman's Knot being too tight to undo after use. It is considered this knot is too complicated and would be even more difficult due to its size to pull over a hard edge in rope pull down tests.

The author has heard of parties tying anchor tape with a Double fisherman's knot. It is assumed they consider this knot "fool proof" regarding slippage, however this knot uses a large amount of tape to tie and most canyoners do not distrust the Tape Knot enough to use this alternative knot. Therefore the author has decided not to test this knot.

Materials, Knot Packing, Preparation & Conditioning

Materials defined as new were purchased for the testing and were unused at the time of testing. Due to difficulties in accessing retailers purchase records, no attempt was made to determine the time lapse between actual manufacture date and purchase date. The actual manufacture date was not printed on the tape reels. Dates of known ropes/tape of known age are based on the purchase date.

Old rope is considered acceptable to use in these tests as this rope is sometimes used as canyon slings and always used as abseil ropes. A new rope can only be used new once! Variables were kept to a minimum to improve repeatability such as:

-Knowing the brand and age of the rope.
-Ensuring the 6 specimens per test are cut from the same piece of rope.
-Checking that any core or mantle damage is within the ALVRI guidelines.

Testing of some Sisal rope has been conducted, as canyoners may use this rope as slings in rarely visited canyons. This is done on environmental grounds, as it is believed sisal rope will rot and break down faster than nylon rope/tape when left in a canyon.

The material to be tested was formed into a sling (endless loop) by a joining knot. Figure 2 details the naming convention of the knot. The "Tails" are the rope/tape knot tail ends and the "Tension" is the section of rope/tape that form the sling.

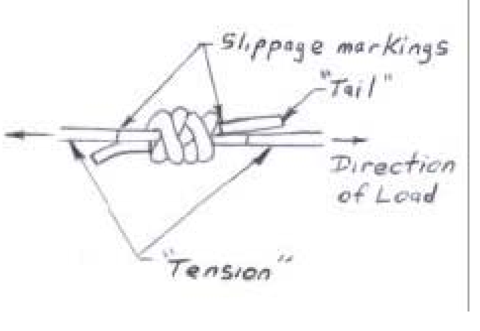


Figure 2 Knot Definitions

All knots in tape and rope were packed according to ALVRI guidelines. The guidelines recommend there shall be no cross overs in any part of the lay of the knot and the knot shall be pulled hand tight on each protruding section out of the knot to remove any rope slackness in the knot. The tails should be long enough to tie a thumb knot. When these procedures are followed, the knot should look neat in appearance and should not have any unnecessary slippage occurring under normal load.

Although the length of a sling does not influence the load at which it will break, the author considered it would still be useful to standardise sling length. This was achieved by the use of a bollard jig for each machine. Due to the physical dimensions of each machine a standard size sling was not possible for this stage of the project. The CIT machine sling length was 380 ±15mm. The ADFA machine sling length was 255 ±15mm.

Conditioning of dry samples to AS 4143.1 (1993) requires a standard atmosphere of 20 ±2 ^{o} C and a relative humidity of 65 ±2%. Whilst not all testing was conducted in an air conditioned facility, the temperature and relative humidity were monitored and testing was postponed if the relative humidity rose above 70% or the air temperature was less than 15 or greater than 30^{o} C

Conditioning for the tensile test wet samples was in water between 14 and 17^{o} C, for a duration of between 45 to 60 minutes which is considered appropriate to simulate a rope in a waterfall whilst people are abseiling. For the tensile tests refer to Annex B Sheet 2 to determine which wet samples were dry treated.

For the cyclic tests the rope/tape samples were not “dry” treated. Wet test specimens were tied into slings whilst dry, then placed into a bucket of cold water for approximately 10 minutes before the test. As each set of tests took 3 hours to conduct, cold water was poured onto the 6th and 10th cycle to prevent drying out. Dry tests were only conducted when the relative humidity was less then 67%, due to humidity possibly affecting the results by moisture tightening the knot and thus reducing slippage.

Equipment

Tensile Testing Machines
Two tensile testing machines were used to conduct the tensile tests. One is located at the Mechanical Test Laboratory; Bruce Canberra Institute of Technology (CIT) (ACT). The other is at the Civil Engineering Test Laboratory - Australian Defence Force Academy (ADFA) (ACT).

Bruce CIT The machine at Bruce CIT (Figure 3-a&b) is a Shimadzu universal tensile testing machine, rated to 25 tonne and is currently certified by the National Association of Testing Authorities (NATA) as a Class A machine for all loads in range. This machine can produce load elongation graphs, unfortunately they can not be scaled and are only to be used as a guide. On this machine the gauge length was measured between the cross heads on the machine. The author worked in collaboration with the technical officer responsible for the operation of the machine. The CIT laboratory is maintained to the necessary temperature and humidity requirements.

(a) The CIT tensile testing machine cross heads (b) Dial controls (The rope is to hold the pipe bollards in place when the specimen breaks)

Figure 3 Unfortunately the stroke of this machine was only 300mm. Due to the elongation of the material the machine often required a reset before the material broke (in some cases 2 or 3 times). This practice involved the hydraulic rams being reset whilst attempting the keep the cross heads in the current position. The specimen was unloaded about 10 to 20% for each reset. Fortunately nearly all specimens could have the elongation measured at 3.67kN before a reset was required. The author has been reassured this practice does not affect the accuracy of the final breaking load, however it did affect the measurement of elongation at failure. The reset issue was the primary reason why access to another tensile machine was sought.

ADFA The machine at ADFA was used to conduct the remainder of the tensile tests that could not be conducted using the Bruce CIT machine. This machine (Figure 4-a) is an Autograph tensile testing machine, rated to 10 tonne with a stroke of 950mm. It can be fitted with special bollards that are designed to minimise bollard stress concentration. For sling tests the 65mm outside diameter bollards (Figure 4-b) (which are free to rotate) have a 10mm machined radius to cradle the rope. The gauge length was measured between the bollard centres. For single strand tests the 65mm outside diameter fixed bollards (Figure 4-c) have a 10mm machined radius spiral into the bollard to cradle the rope for the required three wrap turns. This machine can produce scaled load elongation graphs. The machine has been certified by NATA as a Class A machine for all loads in range. Although not currently certified, the author has witnessed that the machine has been verified to within an accuracy of 100N to the requirements of the NATA certificate. The ADFA Lab is air-conditioned, but a roller door (located 20m away) to the outside was often open, which may have affected humidity.

(a) The ADFA Tensile Testing Machine (b) Sling bollard (c) Single strand bollard Figure 4

Knot Cyclic Testing Rig

A rig has been built to simulate the cyclic loads that occur when a rope is abseiled on, several times. The rig was set up to measure any slippage in knots caused by this type of cyclic loading. A sling tied with the knot to be tested was suspended from an overhead structure.(Figure 5-a) Each knot was marked so any slippage in the tail or out of the sling could be measured. Measurements were taken in the unloaded condition. Either 50 or 100kg of weight were hung from the sling. Any slippage was measured when the sling was loaded (Figure 5-b). The sling was then unloaded using appropriate mechanical advantage, and was shaken for five seconds to simulate possible knot loosening by wind or handling by an abseiler. The sling was then reloaded and another set of measurements taken. This process was repeated 15 times. The Figure of 15 was considered appropriate for a maximum number of people likely to be abseiling the pitch.

(a) (b)

(a) The cyclic testing rig showing the sling, the weight and the rope mechanical advantage for lifting the weight.
(b) Sling tape showing the slippage marks on the "Tension" side.

Figure 5

Rope Pull Down Friction Measurement Rig

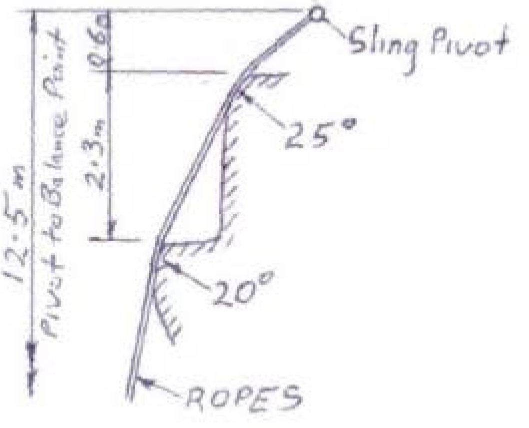
Any one who has been canyoning will know how varied the required force to pull down abseil ropes can be. Force can range from one hand for a 5m drop through to three people hanging off the rope under a waterfall to slowly move it down past 50m of friction points. Due to all the possible variables it was decided one standard cliff site would be used. Trial tests at Wee Jasper indicated a 15m cliff was acceptable to provide the required friction within the spring balance range.

Two sets of tests were planned using a natural and an artificial 90° hard edge for both dry and wet conditions. The first waterfall on Bungonia creek was selected as a good site to conduct the tests.

The 9mm static ropes used in this series of tests had no dry treatment applied.

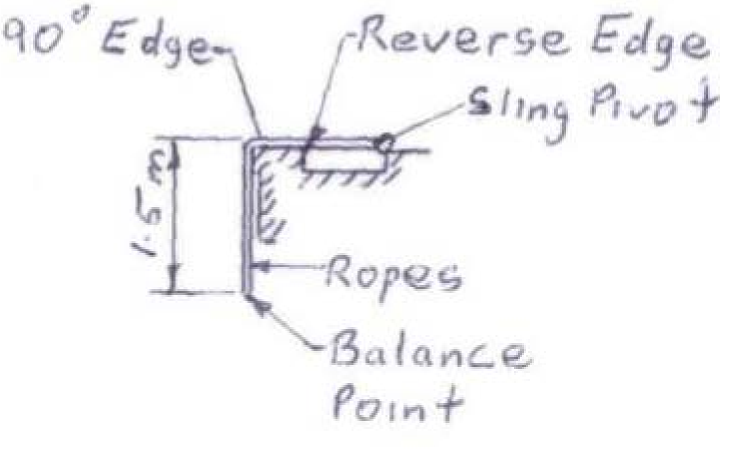
Permission was gained from the Bungonia NPWS ranger to conduct a BWRS Rock Squad testing day held at the first waterfall in Bungonia Creek. The cliff edge consisting of volcanic quartz has two points of contact for the rope with the edges at 25° and 20° off vertical. The anchor sling was angled at 40° above horizontal. The natural edge does not have a problem with excessive friction. As can be seen from Figure 6-a, a V shape groove could catch certain knots. There was a ledge 12.5m from the top edge to take load measurements from.

Two knot pull down tests were conducted, one on the natural cliff edge and for the second a Bessa block was used for the hard edge tests. Unfortunately the Bessa block could not be secured sufficiently to prevent movement, therefore the hard edge tests were invalid. Lack of time prevented the wet tests from being conducted.



(a) The Bungonia cliff detailing the knot going over the 25° edge (b) Profile of the Bungonia cliff edge. Figure 6

In order to complete valid hard edge tests, the authors garage roof (Figure 7-a) was selected. The roof is 2.7m high and 2x4m lengths of 9mm static ropes tied together with the knot to be tested were used. A concrete Bessa block was secured so it would not move under rope loads. A second block was used to position the anchor pivot point. The tests were standardised by using the block in the same position for all tests. A Spring balance has been used to measure the force required to start moving the knot over a 90° reverse edge and going over the 90° obtuse edge. Significant friction within the measurement range of the spring balance was obtained without the need to simulate the weight of hanging rope. Trial tests determined that the 1.5kg weights (to simulate 25m of free hanging rope) on each rope end were not required due to the 45kg spring balance exceeding its limit.



(a) The author using a spring balance to measure the load when pulling a knot over a 90° edge at his garage. (b) The profile of the edges used for the garage Figure 7

The rate of travel used in this series of tests was determined to be approximately 2 seconds per metre of rope pulled, ie 0.5m/s. This rate of travel was considered appropriate in order to read the spring scales. In actual canyon rope pull down situations the rate of travel of a person pulling down the ropes may be twice the speed for small pitches. There was evidence that fast rope pull downs sometimes required less load to pass over the edge. Unfortunately trial tests determined it was not possible to measure the load on the spring balance in the fast rope pull down tests, therefore the results obtained may be conservative.

The hard edge (Figure 7-b) is considered one of the harshest edges that could be encountered so it is a good edge to test the knots being examined. For the wet tests a garden hose was used to continually spray water over the Bessa block.

Loads & Test Weights
In simulating the loads that could be applied in canyoning, the load of two people abseiling at once on a double rope (twin person or assisted abseiling) is used, as this load is the heaviest load that should be applied in the recreational activity of canyoning. ALVRI use a standard weight of 100kg for one person. Therefore the load of 200kg (1.96kN) is used to simulate two people on the abseil rope. The 200kg weight should be the WLL of ropes and tape used for canyon abseiling.

AS 4142.3 (1993) states 3.67kN (375kg) is the WLL for a rescue rope. Collecting strength and slippage data at this load will be of use to the rescue community.

Slippage measurements have been recorded when the tensile test machine reached a load of 1.96kN and 3.67kN. A final set of records have been taken when the test specimens failed. Load verses elongation graphs have been produced by the tensile test machines.

For the Cyclic Loading tests, the aim was to determine if greater slippage at the knot would occur by the repeated application of a lighter load when compared to a standard 200 kg load applied only once. A load of 50kg representing a teenager and a load of 100kg representing an adult has been used in this series of tests. The cyclic loading test weights are made up of a cluster of calibrated 10kg and 20kg weights provided by Bruce CIT.

Test Apparatus and Measurement Equipment
The tensile test machines were pretensioned, as required by AS4143.1 (1993). For each 9mm rope and tape specimen pretensioning was set at 0.1kN. For 11mm rope specimens the setting was 0.15kN. With the specimen pretensioned between the bollards of the tensile test machine, the gauge mark length was measured with a tape measure. This was the zero load measurement. The gauge length is defined as a mark on each bollard structure to which measurements were taken to determine sling elongation. Elongation measurements were taken at zero load, 1.96 kN (200 kg), 3.6 kN (375 kg) and failure.

The tensile test machines crosshead rate of travel was set at 40mm per minute.

All tensile tests had the knot positioned mid away on the sling between the bollards. Refer to Figure 4-a, photograph of the ADFA machine that shows a typical sling set up.

Vernier callipers were used to measure knot slippage. The specimens were marked at the four protrusions from the knot with a suitable contrasting coloured pen (that would not affect the strength of the material). The tail lengths were measured at zero load, as it was expected the tails would shorten and the marks would move within the knot. Tail lengths were then measured at each predetermined load. The mean "Tail" slippage could then be calculated. The "Tension" slippage data provided is the summation of the two measurements taken between the mark and the knot. Measurements were taken at each predetermined load by stopping the tensile testing machine long enough to record the dimensions. Care was taken to place the vernier callipers on the same section of the test specimens for all the readings. Accuracy is believed to be within 1 mm.

A spirit level, adjustable protractor and a 30m tape measure were carried into the Bungonia waterfall site to survey the cliff edge (Figure 6b). A Bessa block was carried in (and out) for the hard edge tests.

Two spring balance scales rated to either 25kg or 45kg were available for the rope pull down tests. If loads were higher than 25kg then the 45kg scale was used. The load on the scale was noted as the knot moved each time. Reading accuracy was assessed to be within 1kg using this method. The 25kg spring balance was calibrated using test weights of 5kg 10kg & 20kg and was found to be accurate. The 45kg spring balance was calibrated using test weights of 5kg, 10kg, 20kg, 30kg & 40kg and found to require a correction for accuracy. A correcting factor has been applied to the results of the 45kg spring balance readings.

Results

Refer to the Annexes A to E for tables and graphs of the results of this study. Annex C is not used as this series of tests was not successful.

Discussion

The knot strength losses quoted in this report are for percentage strength loss due to a knot compared to the rope strength. Manufacturers tend to provide rated strength as percentage remaining in the material. Annexes A&B also tabulate the strength data as percentage strength remaining in the rope for reference only.

Statistical data is given for strength data to determine the lowest breaking strength based on 2 standard deviations (std devs) back from the mean. 2 std dev was chosen as the sample was too small for 3 std devs to give a meaningful number. Additional most overseas manufacturers use 2 std devs for their ratings.

The ramifications of relatively small samples and the approach to comparisons means there is some statistical uncertainty. It is therefore not possible to state the values for knot strength in absolute terms. However, the strength data provided can be used as a general guide.

Slippage data discussed in the paper is at the abseil working load of 1.96kN. The slippage data provided in Annex A & B is given at the loads of 1.96kN (200kg), 3.67kN (375kg) and failure. The slippage data is a guide only. Standard deviation calculations were completed for these measurements but have not been reported. There was significant scatter from the mean (up to 30%) and it is believed the sample would have to be much greater to provide conclusive statements about rope/tape slippage.

The slippage data presented in Annex A & B for the1.96 and 3,67kN loads could not be obtained for some materials when using the CIT machine. This was due to the large cross heads obstructing access to the specimens. Refer to Figure 3 (a) for a photograph of the cross heads.

The remaining factor of safety of the material is determined relative to a 1.96kN (200kg) load. Dividing the knot's 2 std dev breaking strength back from the mean by the 1.96kN load derives this safety factor. The equation for this is SF=(Mean breaking load –2 std devs)/Abseil WLL

For this case the breaking load includes the weakness of the knot. Therefore an additional knot factor is not included in this safety factor. As a result of this logic, the safety factor for any material should always be greater than 5. (SF5 is for loads involving humans)

Knot	Age & Material	Results Sling Breaking Strength 2 Std Dev back from Mean (kN)	Mean "Tail" slippage at 1.96 kN (mm)	Total "Tension" slippage at 1.96 kN (mm)	Analysis Loss of Strength due to knot
Tape	New 50mm flat tape	24.64	Not recorded	Not recorded	52%
Tape	New 25mm tube tape	21.52	Not recorded	Not recorded	42%
Double Fisherman's	1 year old 11mm static rope	36.43	5	48	42%
Rethreaded Figure 8	1 year old 11mm static rope	30.11	1	45	52%
Overhand	new 50 mm flat tape	17.94	25	Not recorded	65%
Overhand	1 year old 11mm static rope	22.05	12	51	65%
Abnormal Fig 8	15 year old 11mm static rope	24.10	16	203	62%
Alpine Butterfly	1 year old 11mm static rope	29.97	14	54	52%

Table 1
Summary of Strength Loss due to Knot & Slippage
For detailed information refer to Annex A & B

Table 1 provides an abridged summary of the strength loss due to knot & slippage data that is provided in Annex A and Annex B. The following discussion refers to these Annexes, this table is provided for quick reference.

A. Tensile Strength & Slippage of Standard Knots in Slings

Double Fisherman's Knot (Figure 1-a) (refer to sheet A-2)
One year old Blue Water 11mm rope had a strength loss due to the knot of 42%. The 18 year old Blue Water 11mm rope had a strength loss of 70%. The difference between the 1 and 18 year old rope tied with the same knot is 28%. It appears the aging of the old rope may account for a ≅30% strength loss.

Graph A-4 is typical of the slope of elongation verses load which was generally non-linear.

For new 10mm & 12mm Sisal rope the strength loss due to the knot was 36% & 9 %. The 9% may be explained, if the manufacturer's rated strength included a knot. It could also be explained if the manufacturers rated strength for the rope was 3 standard deviations below the mean rope breaking strength. Then a sample of rope well above the rated strength would give the low apparent strength reduction.

Graph A-5 is typical of the slope of elongation verses load which was very jagged due to the rope fibres in the knot beginning to fail, as well as minor slippage in the knot.

New 7mm & 9mm Riviory rope gave unexpected results of 2% & 6 % strength loss due to the knot.

The abseil working load "Tension" slippage averaged out at 49mm for both 9mm and 11mm rope. The "Tail" creep was 6mm at this load. The sisal rope slipped less than the kermantle rope. Its "Tension" slippage was only 30mm due to the laid strands locking and thus reducing slippage.

The remaining SF for 10mm Sisal rope was only 4. All other materials tested had SF s in excess of 5

Tape Knot (Figure 1-b) (refer to sheet A-1)
These results indicate new Polyester flat tape (19 & 50mm) had a strength loss due to the knot of around 50%. The 25mm flat had the greatest strength loss due to knot of 58%.

New Polyamide 25mm tube tape, had a strength loss due to of the knot of 42%. Graph A-3 is typical of the slope of elongation verses load which was generally linear until failure, however their were noticeable dips in the graphs believed to be due to slippage in the knot as it became tight.

Slippage data was not recorded for most of this series of tests. However, the cyclic tests on tape do provide further data on slippage.

The remaining SF when using 19mm or 25mm slings tied with a tape knot is only 3. The remaining SF for 50mm flat and 25mm tube was good at 13 and 11.

B Tensile Strength & Slippage of Alternative Knots

Overhand Knot for rope (Figure 1-c) (refer to Annex B sheet B-1)
One year old Blue Water 11mm rope had a strength loss due to the knot of 65%. Graph B-4 is typical of the slope elongation verses load which was generally exponential until failure. At near failure it was noted one specimen displayed a partial roll back in the knot. (Similar to the abnormal Figure 8 Knot) This was an unusual event and should be examined with further testing.

The strength loss due to knot for the six year old 9mm rope was high at 75%. It is unclear whether rope age is affecting the results here. The remaining SF when using a 1.96kN load was acceptable at 5. The remaining Factor of Safety for one year old Blue Water II 11mm rope was good at 11.

There was only a 5% difference in strength or slippage between the wet and dry tests for the 6 year old Edelrid 9mm static rope. The Edelrid “dry” treatment is likely to have protected the rope from moisture and so loss of strength.

The abseil working limit “Tension” slippage averaged 65mm for both the 9mm and 11mm rope. “Tail” slippage was 10mm.

The Overhand Knot had acceptable standard deviation figures for strength. This goes against Warild’s (1990) observations that reported the strength of this knot as being inconsistent.

For new 12mm Sisal rope the strength loss due to the knot was low at 41 %. Graph B-5 is typical of the slope of elongation verses load, which was jagged as the rope fibres began to fail, as well as minor knot slippage.

Of the Overhand Knot samples tested on the tensile testing machines, the majority appeared to fail at the point of maximum compression inside the knot. The knots geometry uses a chocking effect for gripping the two ropes which may be the reason why it is not as strong as the other knots tested. The chocking action may concentrate all the load onto a small area thus causing a compression point which leads to failure. The Double Fisherman’s Knot, which also failed at the point of maximum compression just inside the knot, was not affected by a chocking action but rather a gripping action over a greater proportion of the knot. Hence the Double Fisherman’s Knot is stronger than the Overhand Knot.

Overhand Knot for tape (Figure 1-d) (refer to sheet B-1)
For new Polyester flat tape (25mm & 50mm), the strength loss due to the Overhand Knot was between 61 to 65%. The remaining SF when using a 1.96kN load for the 25mm flat and 25mm tube tape was only 3. For the wet and dry 50mm flat samples, the remaining SF was between 9 and 10. There was no major difference in strength or slippage between wet and dry tests for 25 or 50mm flat polyester tape.

The result for the three-year-old Polyamide 25mm tube tape, which had a strength loss due to the knot of 82%, was alarming. Mean breaking strength was only 7.16kN and the standard deviation of the sample tested was very small at 0.42 (indicating very repeatable results). If the material were new, it is estimated the breaking strength would be 12.6kN. The results give a breakage 56% less then what was expected. It seems unlikely the ageing effect would be this bad for tape that was only bought in June 97. The sample had been used as a club hand line during that time and had been stored appropriately when not in use. Although the sample tape was dirty (It was washed and dried before testing) no serious abrasion was detected apart from some minor fluffing.

Graph B-3 is typical of the slope of elongation verses load which was generally linear until failure.

Rethreaded Figure Eight Knot (Figure 1-e) (refer to Annex B sheet B-2)
One year old BW 11mm rope had a strength loss due to the knot of 52%. The new 7mm and 9mm Rivory rope had a low strength loss due to the knot of 24% and 30% respectively. The remaining SF with the 1.96kN load for the 9mm and 11mm ropes were excellent at 13 and 15 respectfully and acceptable for the 7mm cord at 8.

The abseil working limit “Tension” slippage averaged at 44mm. Average “Tail” slippage was only 1mm. This knot had the least slippage (especially tail) when compared to the other knots of the same material.

Abnormal Figure Eight Knot (Figure 1-f) (refer to Annex B sheet B-2)
Breaking strength was similar averaged at 14.8kN between the two Edelrid wet and dry samples. This was probably due to the “dry” treatment on this rope. Strength loss due to knot was between 62% to 64%, however this rope was aged. The breaking strength of the older Blue water 9mm rope sample was a lot stronger at 24.1kN compared to the two Edelrid samples that were not as old.

All 9mm rope specimens tested had at least one roll back, four rolled back twice and one specimen rolled back three times. The lowest first roll back occurred at 2.1kN (the weight of two abseilers) Graph B-6 is typical of the slope on the graph of elongation verses load, which was dramatic, as the knot displayed either partial or complete roll-backs.

Significant “Tension” slippage was already occurring at the abseil-working load, with an average “Tension” slippage of 165mm. “Tail” slippage was only an average of 10mm.

Average “Tension” slippage at failure for the 3 sets of tests conducted was 410mm. On one specimen the “Tail” had slid in 120mm to the point where the tail was flush with the knot before it broke. Another specimen had a “Tension” slippage of 633mm at failure. No significant slippage difference was noted between wet and dry samples.

Another example of how dangerous this knot can be is to tie the knot with inappropriate tail lengths and have the knot poorly packed. In this configuration, it is possible for two people pulling in a tug of war fashion (which equates to approximately a 50kg load) to pull the knot completely apart. For the reason of roll back and knot failure this knot was deleted from further testing.

Alpine Butterfly Knot (Figure 1-g) (refer to Annex B sheet B-2)

One year old 11mm rope had a strength loss due to the knot of 52%. The six year old rope was between 59 and 66%. Remaining SF with the 1.96kN load was very good, being between 12 and 16. From a strength point of view, this knot performed very well. The large majority of the specimens broke at the top or bottom bollard indicating the knot was very strong. The lower strength of the older rope may be due to an aging factor.

It was interesting to note the difference between the dry and wet samples. All specimens from the dry sample had uniform slippage as load was applied and there was still some slippage as load approached failure. The wet sample was interesting in that the knot would hold then slip all of a sudden, hold then slip again. Graph B-7 is typical of this noted occurrence.

The abseil working limit “Tension” slippage averaged at 74mm. Average “Tail” slippage was 14mm.

Horrocks (2000) discovered this knot (when used to tie two ropes together) could easily be tied the wrong way resulting in the knot possibly undoing under load with obvious deadly results for any abseiler on the rope. This fact was pointed out to the author soon after this set of tests was completed. Two people pulling on the rope in a tug of war fashion can demonstrate this. It is not apparent to casual visual inspection that the knot is tied incorrectly. Due to this issue, the Alpine butterfly knot was deleted from further testing.

Knot Strength Comparisons

The results of Section A and B have been summarised into Table 2 as sourced by the author. This table also compares the present data to other published sources.

	TYPE OF ROPE JOINING KNOT					
Source	TAPE	OVERHAND IN TAPE	DOUBLE FISHERMAN'S	RETHREADED FIGURE 8	OVERHAND	ALPINE BUTTERFLY
DROHAN	42% & 52%	65%	42%	52%	65%	52%
Wild Sports (11 & 9mm)	-	-	12% & 22%	-	-	24% & 34%
Luebben	30-40%	-	30-35%	-	35-40%	-
Warlid (mainly 10mm)	55%	-	45%	50%	55%	53%

Table 2
Knot Strength Comparisons
Percentages given are for strength loss due to a knot
Drohan's results are for New Donaghys 50mm tape and 1 year old BWII 11mm rope

The present results compare well to Luebben (1996) and Warild (1990). While this appears to validate the current results, it must be remembered the current study’s method of testing is not considered statistically accurate because of the small sample size and inability to test single strands. The accuracy and statistical significance of Luebben and Warild’s results are not known.

Wild Sports (1996) knot strength loss figures are far less than the other quoted sources. For example, the Double Fisherman’s knot has a strength loss due to knot of only 12% for 11mm and

22% for 9mm, whereas the other sources state between 30 and 45%. Luebben and Warlid may have compared breaking strength to manufacturer's rated rope strength, as has the present study.

A report has been sighted that the author requests not to be quoted, that suggests Wild Sports testing procedures compared knot breaking strengths to single strand test results for the same rope. This method provides a more useful measure of strength, therefore these results should be more accurate.

Safety Factor Concerns for Knots

Table 2 indicates many of these knots are weaker than the standard 33% allowed for strength loss due to a knot. Currently SF8 is applied to tape and rope by many outdoor and rescue organisations. Whilst SF8 is considered appropriate for the Double Fisherman's knot due to its adequate strength, these results indicate SF8 may not adequate for some of the other knots.

Using the logic discussed in the "Introduction - Understanding Safety Factors" (on p4), Sheet B8 calculated the required SF for the knot strength loss from the data in Table 1. From these results only the Double Fisherman's Knot from three of the four sources of test data support SF8 as appropriate. All the other knots require a greater safety factor.

The Tape Knot and Overhand Knots, are of interest to the author. Table 3 provides a summary of their safety factors based on Drohan, Luebben and Warild's results

	Tape Knot	Overhand Knot
Drohan	8.6 & 10.4	14.3
Luebban	8.3	8.3
Warild	11.1	11.1

Table 3: Summary of Knot Safety Factors

Table 3 indicates only Luebban results are approaching SF8. Until absolute values can be determined, it would be wise to consider the other figures. The Tape knot ranges from SF8.3 to SF11.1. Noting the range of data SF10 is considering a good compromise for this knot. SF10 is also a good figure for field calculations to determine the WLL. As Warild's data is unclear on how the figures were determined, less importance has been placed on that figure. The Overhand Knot using Drohan's higher figure of SF14.1 should be rounded up to SF15. Considering the other Overhand knot test data on aged rope presented in this paper, SF15 is considered appropriate until more comprehensive testing can confirm the issue.

A SF15 will have impact on the WLL, for example: A 9mm BWII static rope rated at 1820kg tied with an Overhand Knot is divided by SF15. This will give a WLL of only ≅120kg (ie no more than two 60kg people are to be on the rope at any one time). This would rule out planned double loadings such as assisted or twin person abseiling. In a self rescue situation where a leader has to rescue a jammed abseiler by the use of prussiks, the safety factor will be compromised. For this reason 9mm ropes used in canyoning must be in good condition.

Knot Slippage graphs

Sheet B-9 graphs the comparison of the slippage of various knots at 3 different loads. All knots were acceptable at the two limit loads except the Abnormal Figure 8 Knot. The Double Fisherman's does slip up to 50mm in tension at a 1.96kN load. The Abnormal Figure 8 had alarming slippage in tension of 203mm at the 1.96kN load. The Rethreaded Figure 8 had the least slippage and the Overhand knot (Graph 12) slippage was acceptable.

Anchor Sling Knots & Minimum Size

In attempting to use smaller size rope or tape for abseil anchor slings, it is important that the strongest knots are used in order to maintain sling strength. Therefore the Double Fisherman's Knot should be used for rope and the Tape Knot for tape. Of the tests performed on non standard sling material, only the 12mm Zenith brand Sisal rope and 7mm Riviory brand cord are satisfactory, provided they are not shock loaded and are used only once by the party who placed them.

Single Strand Tests

Due to lack of access to a tensile test machine with a stroke of over two metres, the single strand tests could not be successfully conducted.

This series of tests was very disappointing. Only one series of tests with new 25mm tube tape was conducted where the specimens broke before the machine reached the limit of stroke. This was due to tape not stretching as much as rope, however all the specimens broke at the bollard which according to AS 4143.1 (1993) indicates a failure of the test.

The single strand testing conducted on rope was a failure, due to lack of stroke on the tensile test machines available. The special spiral bollards on the ADFA machine did improve the situation by reducing stress concentrations in the rope, but the specimens still did not break prior to maximum stroke extension.

AS4143.1 (1993) requires three wrap turns of rope around each fixed bollard and then locking off by clamping. Throughout the tests the clamping arrangement did not move more than a few millimetres. The problem was the rope in the three wrap turns between the clamp point and the gauge mark began to stretch out as load was applied. This occurred to the point where the machine was out of travel.

The procedure from AS4143.1 (1993) was followed, except for gauge length of specimen. The standard requires the gauge length to be 1m. With the specimen pretensioned, the machine allowed only a 250mm gauge length in order to attempt breakage before the maximum stroke of the machine was reached.

Due to the unsuccessful single strand tests, the author is of the opinion that further statistical analysis to determine the precision of the strength of knots is not warranted.

D Cyclic Tests

50 kg cyclic load	Tape knot	Overhand knot in tape	Double Fisherman's	Rethreaded Figure 8	Overhand in rope
Mean Tail slippage (mm)	-6	40	9	3	26
Total Tension slippage (mm)	55	117	27	34	50
100 kg cyclic load					
Mean Tail slippage (mm)	-	31	15	10	14
Total Tension slippage (mm)	-	90	41	63	40

Table 4: Summary of Cyclic loading data for various knots
Slippage data is after 15 cycles of loadings have been completed.

Table 4 provides an abridged summary of the cyclic loading data that is provided in Annex D. The following discussion refers to these Annexes, this table is provided for quick reference.

Refer to Annex D1 to D11 for graphs of the cyclic loading. “Acceptable slippage” is defined as not being noticed or causing alarm to the user.

50kg cyclic loads on knots in dry 9mm static rope
All knots tested had acceptable slippage in the range of the tests especially in the critical area of “Tail” slippage.

The Rethreaded Figure Eight Knot (Graph D3) had the least “Tail” slippage of only 3mm after 15 cycles. The Double Fisherman’s Knot (Graph D1) had acceptable “Tail” slippage of 9mm after 15 cycles. The Overhand Knot (Graph D5) had the most “Tail” slippage at 26mm after 15 cycles. “Tension” slippage was acceptable for the knots tested, with the most being the Double Fisherman’s (Graph D1) at 27mm after 15 cycles.

100kg cyclic loads on knots in dry 9mm static rope
All knots tested had acceptable slippage in the range of the tests especially in the critical area of tail slippage. Again the Rethreaded Figure Eight Knot (Graph D4) had the least “Tail” slippage of only 10mm after 15 cycles but it had the most “Tension” slippage of 63mm.

The overhand knot performed the opposite way to the other two knots tested, in that the 100 kg load slipped less than the 50 kg load (Graphs D5 & D7) (“Tension” slippage 14mm verses 26mm). From this it appears the Overhand Knot can slip more if there is not adequate weight to lock up the rope.

Wet tests on rope knots
The wet tests (Graph D6) undertaken in both load ranges had significantly less slippage. The rope specimens had no “dry” treatment. It appears that when wet, the ropes expand about 0.5mm in rope diameter in the knot and so lock up more tightly.

50kg cyclic loads on knots in dry 50mm flat tape
The Tape Knot (Graph D8) was interesting in that after 15 cycles the “Tail” had increased by 6mm in length as the knot tightened up. This is due to the construction of the Tape Knot, in that as the knot tightens the tail does not move from its existing position and so actually gets longer simply as a result of the knot becoming more compact. All other knots tested had a decrease in tail length.

The Overhand Knot in tape (Graph D9) had significantly more “Tension” slippage than the same knot in rope. “Tail” slippage was 40 and 31mm for the two load tests. The “Tension” slippage was also significant at 117mm with the 50kg load. It is expected that continued slippage would occur with additional load cycles.

Wet test with overhand knot on tape
The wet test undertaken with the 50kg load (Graph D10) had significantly less “Tension” slippage than the dry (69mm verses 117mm). It appears the polyester tape may expand when wet and so lock the knot more tightly.

100kg cyclic loads on knots in dry 50mm flat tape
As with the rope the Overhand Knot in tape (Graph D11) “Tension” slippage was slightly less with the 100 kg load than the 50 kg load (“Tension” slippage was 90mm verses 117mm). The overhand knot in tape can slip if there is not adequate weight to lock up the tape.

E Rope Pull Down tests

Comparison of Sites

Annex E Sheet E-1 provides the results for the simulated 90° edge. Sheet E-2 provides the results for the Bungonia cliff edge. The graphs depicting the commencing rope pull and 200mm movement show little difference between the three knots tested, for the simulated cliff edge against the Bungonia waterfall. This shows the simulated edge appears to accurately model the starting inertia and rolling friction. There was significant difference in edge knot pull over results between the two series of tests. This was expected due to the vastly different shape of the two edges.

Results from actual and simulated cliff edges

Sheet E-1 indicated that the Double Fisherman's Knot did get caught on all hard edges especially the reverse edge. (Figure 12 depicts a reverse edge). This is due to the cylindrical shape of the knot where the knot jams against the hard edges. This knot required significantly more force (nearly 40kg) than the other knots to move over a 90° reverse edge.

It was noted on sheet E-2 for the natural edge the Rethreaded Figure 8 Knot required slightly more load than the Double Fisherman's Knot to move over the edge. This may be due to the Rethreaded Figure 8 Knot jamming more in the natural groove (refer to Figure 6a) than the Double Fisherman's knot. However the Double Fisherman's Knot did jam (Figure 8) and needed far greater force to move over all the simulated edges than the Rethreaded Figure 8 Knot. Based on this evidence, further rope pull down tests on the Double Fisherman's Knot were discontinued.

The Double Fisherman's Knot jamming on the edge. The arrow indicates the direction of pull.
Figure 8

Comparison of the Rethreaded Figure to the Overhand knot

Two series of rope pull down tests were conducted on the Rethreaded Figure Eight Knot (Figure 9) and the Overhand knot (Figure 10). Graphs E-3 & E-4 indicated that the Overhand Knot required less force than the Rethreaded Figure Eight Knot on all the edges tested. In all cases the Overhand Knot required about 50% less force to pull down over the edge.

Figure 9 Rethreaded Figure 8 knot jamming Figure 10 Overhand knot clearing Knots

being pulled down over an edge. The arrow indicates the direction of pull.

As a result of this test the Rethreaded Figure Eight Knot was deleted from further pull down tests.

Focus on the Overhand Knot

With the Overhand Knot appearing to be the preferred knot, a more intensive series of tests was conducted.

Starting Inertia loads: It was observed the Overhand knot required more force than any other knot if the knot is against the sling. Graph E-5 comparing a Rethreaded Fig 8 to the Overhand Knot, indicates that the starting break free load of the overhand knot can be around three times higher if the knot is against an anchor sling. This is due to the knot clasping itself around the sling (Figure 11-a). Only the Overhand knot of the knots tested had this issue. If the knot is away from the sling this does not occur (Figure 11-b).

(a) The Overhand knot against the sling (b) away from the sling
The arrow indicates the direction of pull. Figure 11

Comparison of the Tail direction: Tail orientation can make a difference for the overhand knot. Figures 12-a& b below depict knot tails leading and trailing

(a) Tails leading (b) Tails trailing
Knot tails on the reverse edge. The arrow indicates the direction of pull. Figure 12

*Reverse edg*e-Graph E-6 shows there is little difference for the tails up position for leading or trailing, but as expected it is a different story for the level or down position. Refer to the photos below for a definition of tails up (Figure 13-a), level (Figure 13-b), or down. (Figure 13-c). For the down position, the tails leading required significant less force to pass the reverse edge than tails trailing. Surprisingly the tails level made more of a difference between the leading to trailing position than the tails down position.

(a) Tails up (b) Tails level (c) Tails down
Knot tails on the reverse edge. The arrow indicates the direction of pull. Figure 13

It appears the geometry of the knot against the edge comes into play. Figure 14 is a profile view of the Overhand Knot with tails leading in a down position when the knot first comes into contact with the 90° reverse edge.

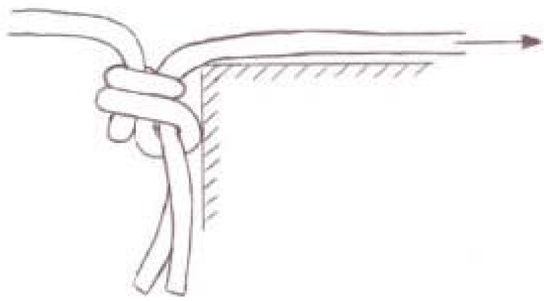


Figure 14 Overhand Knot with tails leading in a down position against the reverse edge Arrow indicates direction of pull.

First Test
For one set of tests with tails leading the knot pivoted about the corner of the reverse edge. This took reasonable force to pull over, a mean of 25kg, before the knot cleared by lifting itself over the edge as shown in Figure 15.

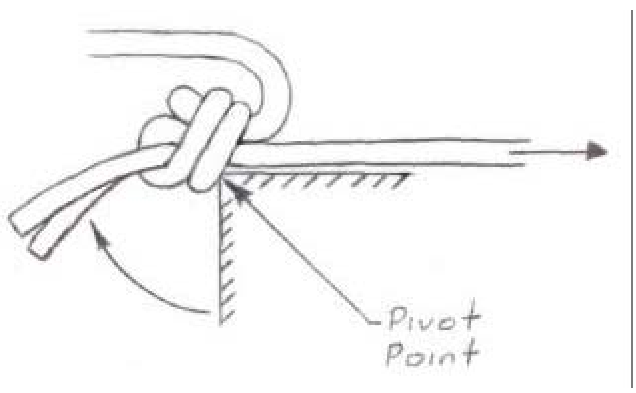


Figure 15 Overhand Knot with tails leading against the reverse edge being pulled over Arrows indicates direction of pull and knot lifting.

Second test
Another set of sets with tails leading in a down position gave a surprising result for how the knot cleared the reverse edge. When under load the tails righted themselves to an upright position, which required less force to pull past the reverse edge. Only a mean of 11kg was required to clear the edge. Figure 16 of the end view of the knot with an arrow indicating how the tails

rotate themselves to an upright position. The bulk of the knot against the edge is diagonal in shape, this appears to give a turning moment so the tails can right themselves.

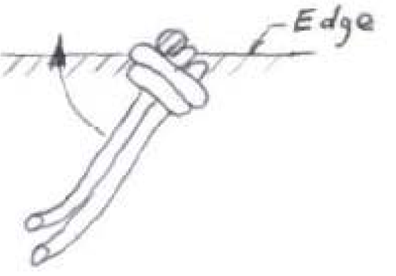
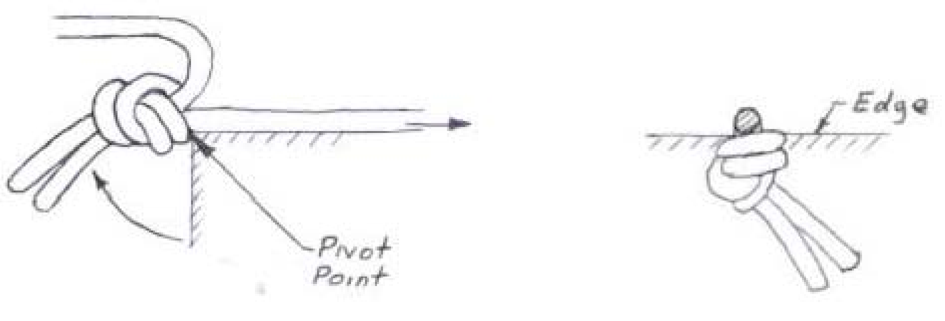


Figure 16 End view of the Overhand Knot Tails leading against a reverse edge with tails down. Arrow indicates direction of knot lifting.

The comparison of this first and second set of tests was not planned, it was only by chance. In order to conduct a left hand test, (tying the knot left handed) the second set of right hand tests was also conducted for comparison. It was noted the first set of tests were different to the second. No reason is known as to why the two sets of tests, gave the two types of response. Tail lengths were similar, at approximately 100mm. The only suggestion could be that as the two tests were done over a week apart, it is possible the rate of travel in the rope pulling was not constant.

Third Test

For tails trailing in a down position (Figure 17-a) the mechanism that the knot cleared the edge was by pivoting over the edge. It was also observed (Figure 17-b) the bulk of the knot against the edge is symmetrical when against the reverse edge. This square on abutment with the tails down required similar force (mean of 19kg) to the first set of tests (tails down and leading) to clear the edge as the knot can not so easily right itself by rotating as in the second set of tests.



(a) Profile (b) End view
Overhand Knot with tails trailing against a reverse edge with tails down
Figure 17

90° Edge Graph E-7 shows that even going over the edge, the tail leading position required less force than the tails trailing. The tails up leading position required 24% less force than the tails trailing. Observation indicated the last section of the knot (labelled as the tripping point) on Figures 18 & 19 caused the load build up before the knot slipped over. But why the difference between tails leading to trailing?

For tails leading: (Figure18) perhaps the distance between the knots tripping point and the edge which was measured at 7mm may have allowed the knot to slip over the edge with less force.

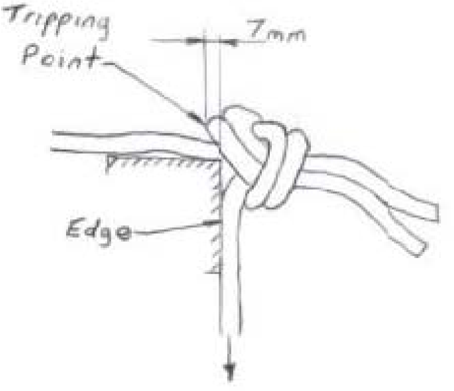


Figure 18 Profile of the Overhand Knot with tails leading going over a 90° edge. Arrow indicates direction of pull.

For tails trailing: (Figure 19) the distance between the knots tripping point and the edge was measured at 9mm. Although only 2mm greater than for tails leading, it may explain why this knots configuration requires more force to slip over the edge.

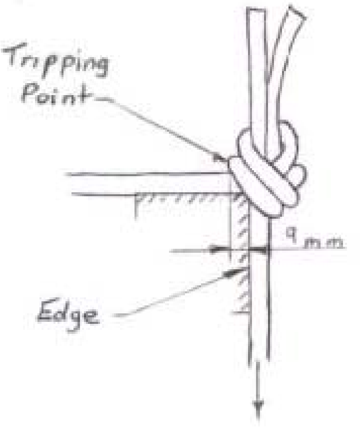


Figure 19 Profile of the Overhand knot with tails trailing going over a 90° edge. Arrow indicates direction of pull

Comparison of Left Hand to Right Hand Tying of the Overhand Knot

Two sets of tests were conducted to observe if the hand the knot was tied would make any difference on the edges. The results were generally within 2kg of each other, therefore it appears it does not matter if the knot is tied right or left handed.

Comparison of the Overhand knot between Wet and Dry Conditions

The final test was to determine if flowing water acted as a lubricant for the ropes being pulled down. Graph E-8 indicated the opposite was true. Wet ropes with no “dry” treatment require about double the load to pull over the edges than the dry ropes for the two tail positions tested. It appears the weight of the sodden tails makes the knot harder to right itself. The weight of the entire rope is also heavier when wet, which also adds to the force to pull over the edges.

Conclusions and Recommendations

Disclaimer
Conclusive strength or slippage statements can not be made for this project, as the sample size of testing conducted was not large enough. However, an indication of what to expect can be drawn from these results. The results in this paper are not a substitute for proper training.

Knot Strength
The Double Fisherman's was the strongest knot tested for joining rope. The Rethreaded Figure 8 knot was the second strongest knot tested. All knots tested had acceptable strength for recreational abseiling. There may be an issue with the strength of the Overhand Knot when used on older rope.

It appears very old rope strength is affected by age, as one set of tests indicated a 30% strength loss when compared to the same tests using a newer rope.

More testing is required to confirm if there may be a safety issue when the Overhand Knot is subjected to a shock load.

Due to the wide range of published data on the strength of knots, the author recommends a more in depth literature review of knot strength, together with additional research on knot strengths.

Safety Factor Concerns
Due to the weaker strength of some knots, it is recommended the safety factor for the Tape knot should be increased from SF 8 to SF 10 and the Overhand Knot should be increased from SF8 to SF15. SF8 for the Double Fisherman's knot is acceptable, as it is a strong knot

Slippage
The Rethreaded Figure 8 Knot had the least slippage of the knots tested. The second best was the Double Fisherman's Knot. The Overhand Knot is acceptable.

Smallest Size Material for Anchor Sling
Of the tests conducted on non standard sling material, the smallest size anchor sling that is safe for one off use in a canyon provided it is not shock loaded is 12mm Zenith Sisal rope and 7mm Riviory cord.

Knots for Anchor Slings
The Tape Knot for tape and the Double Fisherman's for rope are still considered the preferred knots for tying anchor slings together due to strength and slippage considerations.

Unsafe Slings
From the results of this study, 19mm or 25mm flat tape are not recommended to use for sole abseil anchor slings, as these loops have only SF3 at the maximum abseiling load, which is not adequate.

Unsafe Knots for Joining Two Ropes/tapes
The Abnormal Figure Eight Knot is unsafe. The tensile tests confirmed that this knot rolls back on its self when loaded. It is possible that a rope joined with a poorly packed Abnormal Figure Eight Knot with small tails can completely undo with loads as low as 50kg as demonstrated by two people pulling either end of the rope.

The Alpine Butterfly Knot used to tie rope together can be tied incorrectly in a way that is not apparent to casual visual inspection. When incorrectly tied it is possible the knot may result in complete separation of the two ropes when loaded as low as 50kg. This can be demonstrated by 2 people pulling in a tug of war fashion. Therefore this knot is considered too risky to use for joining rope.

The Overhand Knot should not be used on tape due to the progressive slippage when loaded.

Preferred Knot for Tying Canyon Ropes Together
The Overhand Knot appears to be the best knot to join two canyon ropes together when considering cliff friction issues. However canyoners should ensure knot tails are leading towards the edge and do not drop down on reverse edges as this increases the load required to pull the knot over the edge. When setting up a canyon abseil rope ensure the Overhand Knot never engages the anchor sling or link, otherwise it will take greater load to start pulling.

If the ropes are wet, the rope pull down load can be doubled.

The Double Fisherman's Knot has traditionally been the knot used to join two ropes. Whilst the strength of this knot can not be questioned, its performance in rope pull down tests was poor and for that reason this knot is not recommend for joining ropes in canyoning where rope jam could be an issue.

Overhand Knot Hypotheses
A hypothesis is proposed that the knot geometry of the Overhand Knot is responsible for the issues of rope pull down ease, as well as strength and slippage. The author understands that a number of reports state knot geometry is responsible for strength and slippage. Unfortunately none have been sighted due to the limitations on the literature review undertaken in this study. Based on the work in this paper, the overhand knot appears to be the most suitable knot that abseilers can use for joining their ropes together in recreational canyoning. The geometry appears to be the reason why the Overhand Knot performed so well on edges where as other knots performed poorly.

Further Research

To prove the hypothesis put forward in this paper, an in depth study is required to explore the Overhand Knot in greater detail. This will prove if the geometry of the knot is responsible for its performance and should provide conclusive strength and slippage data.

Due to the premature failure of the Edelrid 25mm tube tape with an Overhand Knot, further tests are required to determine the strength of aged tape.

Additional rope pull down tests could be conducted in wet conditions to determine if a dry treated rope would require less load to pull down than a non dry treated rope when using the Overhand Knot.

A question should be put to Riviory in France as to how the rated strength of their rope is determined.

Additional research could be conducted on tape and rope. If suitable test machines are available, then stage two of this project plans to investigate shock forces and stage three plans to investigate the aging process. The objectives in detail are listed below:

Stage Two
- To determine how many cycles an old static rope can take using a FF0.1 and FF0.3 fall and a 200 kg load.

- To determine the dynamic strength of alternative knots that could be used to join rope.
- To determine the dynamic load required to damage tape and rope over a 90° edge. In addition to the tests planned for stage two, additional testing of the Overhand Knot should be conducted especially on old 9mm ropes using shock loads that could be generated by abseilers.

Stage Three

- To determine over a three year period the effect of ageing on the tensile strength of tape and rope when left in a simulated canyon environment.

Future of the Project

BWRS has raised some funds for next stage of the project, however for donations would be gratefully accepted. Due to other commitments, the author will not be able to commence work on further research until the year 2003. A tensile testing machine with a stroke of at least two metres will be required if the project is to continue. The author is not aware of such a machine being available in Canberra. It may be possible to build a machine using a suitable hydraulic ram with two to three metres of stroke and a load cell mounted on the cross head. A suitable structure that can mount an appropriate load cell will also be required for the shock tests planed. ADFA have given tentative support to use their testing equipment, provided the tests can be scheduled around their other planned work.

Acknowledgments

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First Caving World Games – Seville, Spain 2006

In 2006 The Association for the Overseas Promotion of Seville (Spain), in collaboration with the Seville Local Council and the Spanish Federations, created what was promoted as the first World Games and caving was included.

For the first time in the city's history, Seville hosted large-scale games where the sports included are recognized by the "Consejo Superior de Deportes" (Sports Advisory Council) were not those included in the Olympic program.

These Games took place during the summer months (July, August and September 2006) with both national and international participants, who competed in the distinct sporting categories established by each federation, the locations of which were based throughout Seville and its province.

The World Games of Sevilla EuroSpeleo Forum ran from the 14th to 17th of September and was an opportunity for all European cavers to meet there, enjoy the activities and debate about Speleology in Europe during the public informal meeting that was held on the 16th of September. The caving events were held in Tomares (a southern suburb of Seville). A dozen countries were represented at these games.

Results from the 1st World Speleological Games in Seville 2006.

SPEED - 30 METERS (FROG)

MEN:
(1) Gold Medal: Zhdanovych Leksiy (Ukraine, 00:46.38)
(2) Silver Medal: Cheridnichenko Daniil (Russia, 00:50.94)
(3) Bronze Medal: Pinheiro Ribeiro Samuel Tomas (Portugal, 00:55.86)

WOMEN:
(1) Gold Medal: Medvedyeva Kateryna (Ukraine, 00:54.05)
(2) Silver Medal: Pozdnyakova Larisa (Russia, 01:16.74)
(3) Bronze Medal: Medvedyeva Galyna (Ukraine, 01:17.70)

RESISTANCE - 120 METERS (FROG)

MEN:
(1) Gold Medal: Provalov Denis (Russia, 05:35.46)
(2) Silver Medal: Zhdanovych Oleksiy (Ukraine, 05:39.85)
(3) Bronze Medal: Pinheiro Ribeiro Samuel Tomas (Portugal, 06:43.88)

WOMEN:
(1) Gold Medal: Medvedyeva Kateryna (Ukraine, 06:34.30)
(2) Silver Medal: Medvedyeva Galyna (Ukraine, 07:35.97)
(3) Bronze Medal: Pozdnyakova Larisa (Russia, 07:50.42)

CIRCUIT (REBELAY)

MEN:
(1) Gold Medal: Cheridnichenko Daniil (Russia)
(2) Silver Medal: Zhdanovych Oleksiy (Ukraine)
(3) Bronze Medal: Provalov Denis (Russia)

WOMEN:
(1) Gold Medal: Pozdnyakova Larisa (Russia)
(2) Silver Medal: Medvedyeva Kateryna (Ukraine)
(3) Bronze Medal: Stepanova Sretlana (Russia)


Finis Ellians


Finis Ellians

Photos of the Circuit (Rebelay) Event.

Federación Española de Espeleologia

I JUEGOS MUNDIALES DE ESPELEOLOGIA - SEVILLA 2006

1st CAVING WORLD GAMES - SEVILLA 2006

Tomares, 15-17 septiembre 2006 — **Tomares, September 15th-17th, 2006**

Resultados oficiales: medallero — **Official Results: Medals**

Medalla / Medal	Apellidos, nombre / Surname, Name	País / Country	Tiempo / Time
Velocidad 30 m - masculino			**Speed (30 m) - men**
oro / gold	Zhdanovych, Oleksiy	Ucrania / Ukraine	00:46,38
plata / silver	Cherednichenko, Daniil	Rusia / Russia	00:50,94
bronce / bronze	Pinheiro Ribeiro, Samuel Tomas	Portugal	00:55,86
Velocidad 30 m - femenino			**Speed (30 m) - women**
oro / gold	Medvedyeva, Kateryna	Ucrania / Ukraine	00:54,05
plata / silver	Pozdnyakova, Larisa	Rusia / Russia	01:16,74
bronce / bronze	Medvedyeva, Galyna	Ucrania / Ukraine	01:17,70
Resistencia 120 m - masculino			**Stamina (120 m) - men**
oro / gold	Provalov, Denis	Rusia / Russia	05:35,46
plata / silver	Zhdanovych, Oleksiy	Ucrania / Ukraine	05:39,85
bronce / bronze	Pinheiro Ribeiro, Samuel Tomas	Portugal	06:43,88
Resistencia 120 m - femenino			**Stamina (120 m) - women**
oro / gold	Medvedyeva, Kateryna	Ucrania / Ukraine	06:34,30
plata / silver	Medvedyeva, Galyna	Ucrania / Ukraine	07:35,97
bronce / bronze	Pozdnyakova, Larisa	Rusia / Russia	07:50,42
Circuito SRT - masculino			**SRT Track - men**
oro / gold	Cherednichenko, Daniil	Rusia / Russia	
plata / silver	Zhdanovych, Oleksiy	Ucrania / Ukraine	
bronce / bronze	Provalov, Denis	Rusia / Russia	
Circuito SRT - femenino			**SRT Track - women**
oro / gold	Pozdnyakova, Larisa	Rusia / Russia	
plata / silver	Medvedyeva, Kateryna	Ucrania / Ukraine	
bronce / bronze	Stepanova, Svetlana	Rusia / Russia	

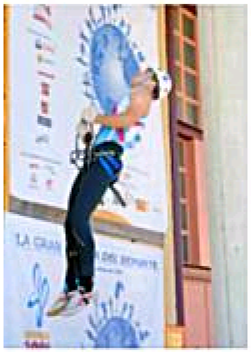
Sevilla, 19 de septiembre de 2006 — **Seville, September 19th, 2006**

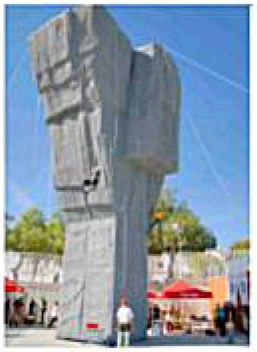
Serg

FEDERACION ESPAÑOLA DE ESPELEOLOGIA

Sergio García-Dils de la Vega
Coordinador General Juegos Espeleológicos - Sevilla 2006
General Coordinator "Caving World Games - Sevilla 2006"

Photos from the first Speleological World Games in Seville 2006


Zhdanovych Leksiy (Ukraine)

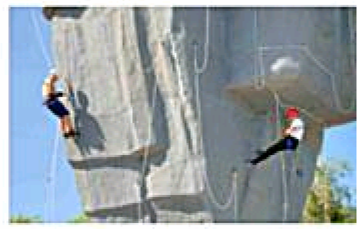

rocodromo (circuit)


Jose Ayrton Labegallini X - UIS President


George Veni 15th ICS presentation


Sergio Garcia Dils & Denis Provalov (Voronia presentation)

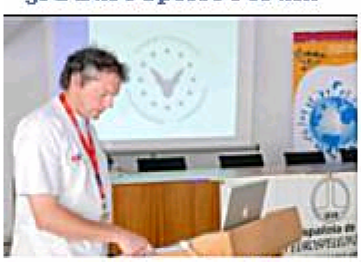

Stamina 120 meters

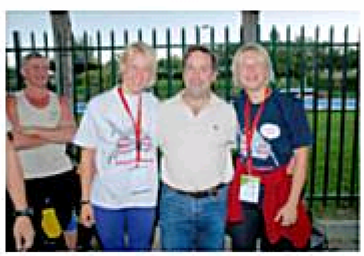

circuit


Olivier Vidal & Bernard Tomaschot 3rd Euro Speleo Forum

Euro Speleo Forum


Viewers


Jean Claude Thiess FSUE presentation


Juan Carlos Lopez Casas Medvedyeva Kateryna Medvedyeva Galyna


Sergio Garcia Dils Juan Carlos Lopez Casas

Worldwide Caving News - http://www.zenas.gr/wcn

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A Simulation of Climbing and Rescue Belays

Tom Moyer

This simulation was written to try to understand the gripping requirements for "manual" belay techniques in both rescue and climbing situations.

Previous studies of human grip strength have shown a wide range of gripping ability.

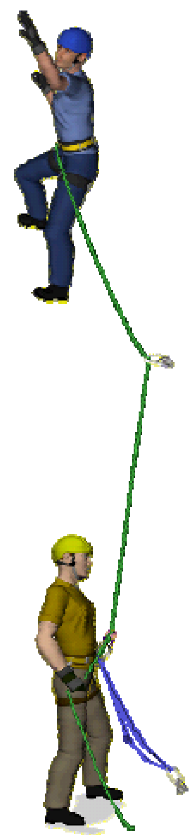
This simulation includes nonlinear rope, knots, damping, carabiner and belay device friction, slipping in the belayer's hand, and lifting of the belayer.

SALT LAKE COUNTY
SHERIFF'S OFFICE
SEARCH RESCUE

2006 International Technical Rescue Symposium

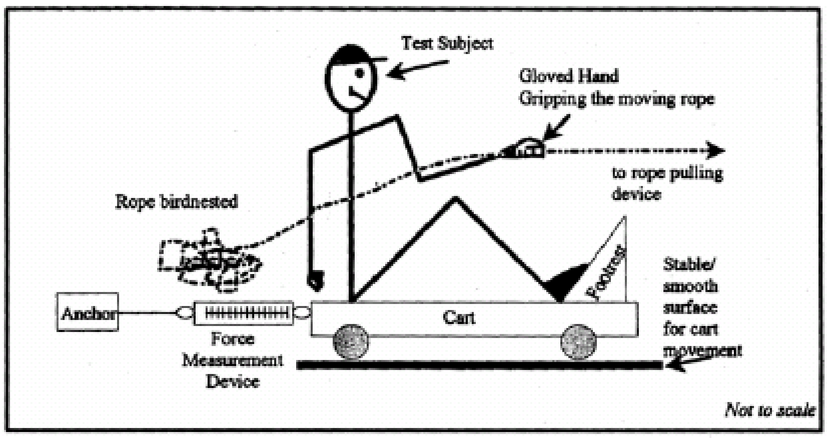
This presentation and the associated model can be downloaded at http://www.xmission.com/~tmoyer/testing (© Tom Moyer) All images in this presentation were generated with RescueRigger (rescuerigger.com)

How do TTRL* belays compare to climbing belays?

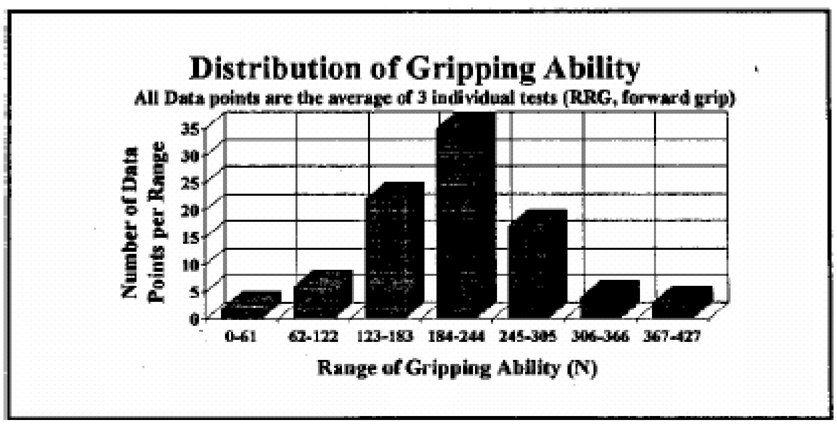


* Twin Tension Rope Lower

Mauthner –
Gripping Ability on Rope in Motion study

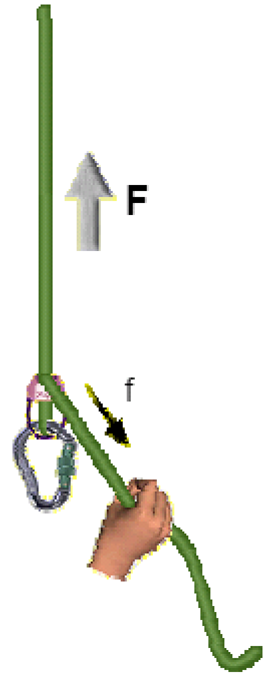


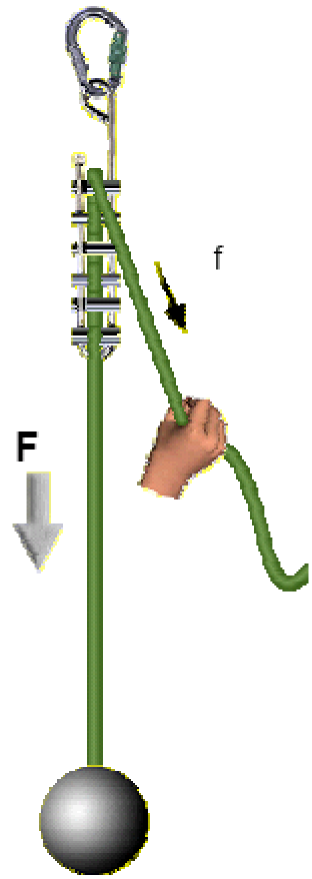
46 N min
209 N average
425 N max



No load above which 100% of the population can grip

Force Multiplication Factors of Friction Devices





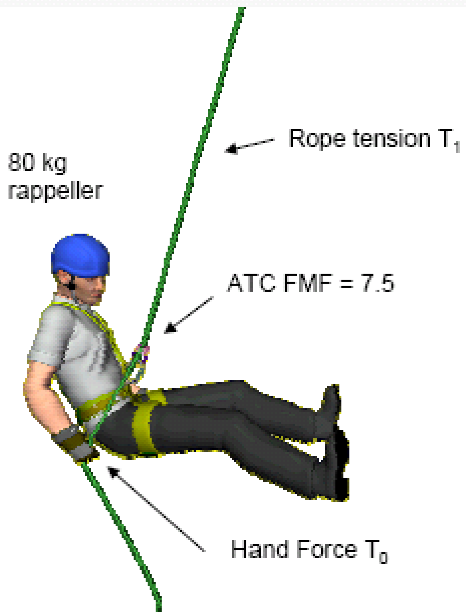
F / f = force multiplication factor (FMF)

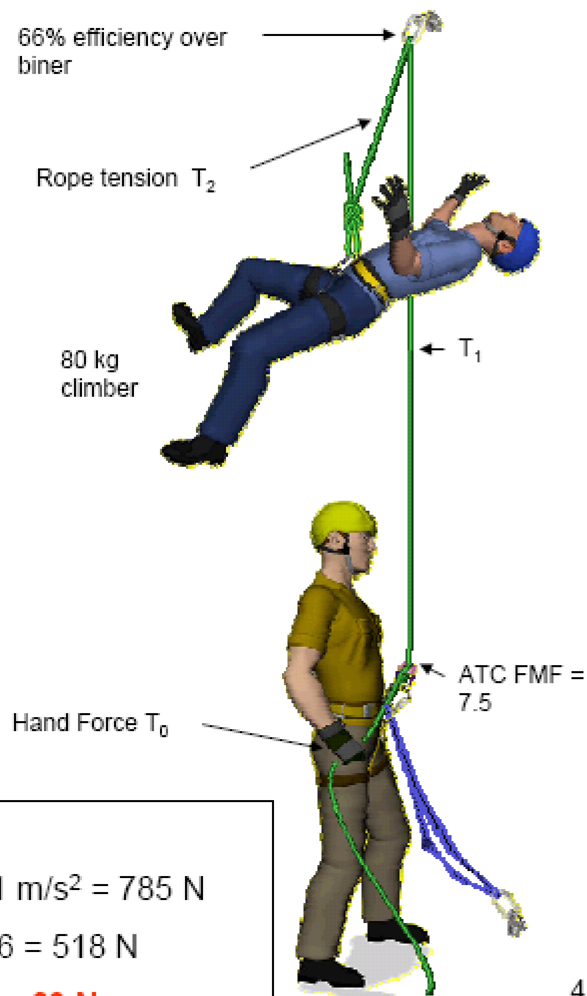
For a brake bar rack with 5 bars, FMF ≈ 20 with 6 bars, FMF ≈ 25

For an ATC, FMF ≈ 7.5

What gripping ability is required to hold the load statically?

Climbing Scenarios – Static Loads





Rappelling

T_1 = 80 kg * 9.81 m/s^2 = 785 N

T_0 = 785 N / 7.5 = **105 N**

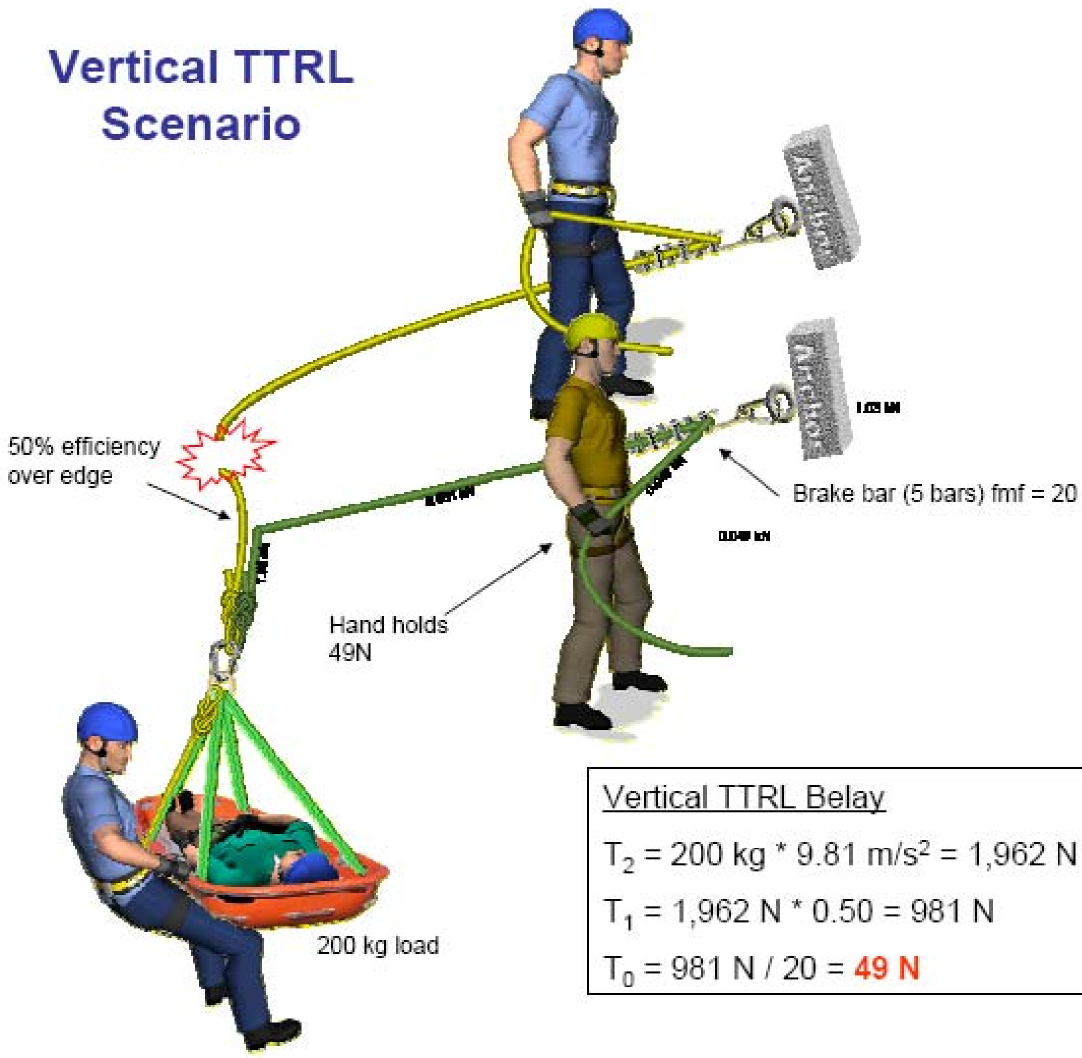
Belaying

T_2 = 80 kg * 9.81 m/s^2 = 785 N

T_1 = 785 N * 0.66 = 518 N

T_0 = 518 N / 7.5 = **69 N**

Vertical TTRL Scenario

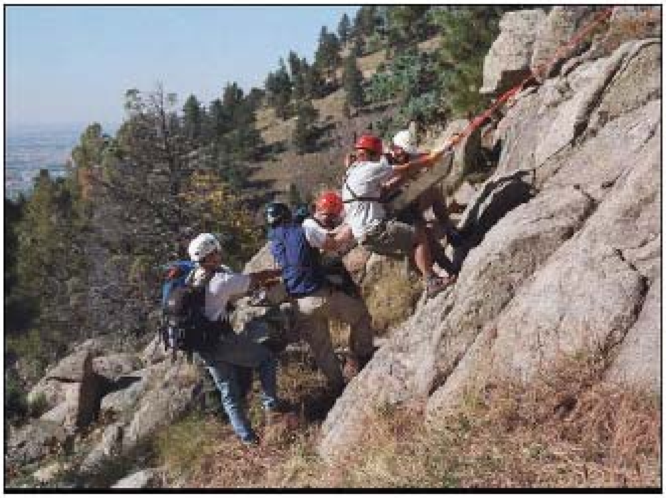


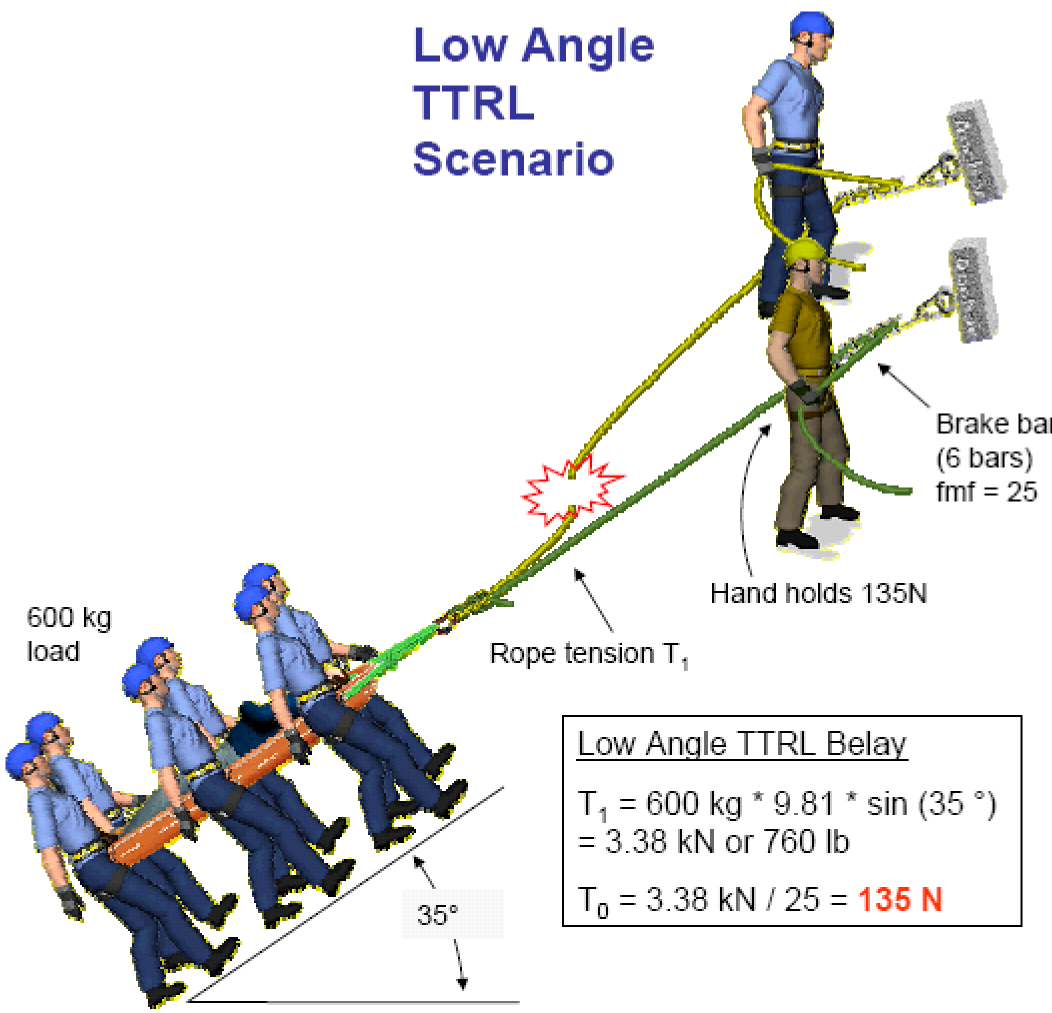
Vertical TTRL Belay

T_2 = 200 kg * 9.81 m/s^2 = 1,962 N

T_1 = 1,962 N * 0.50 = 981 N

T_0 = 981 N / 20 = **49 N**




Low Angle TTRL Scenario
Brake bar (6 bars) fmf = 25
Hand holds 135N
600 kg load
Rope tension T_1
35°
Low Angle TTRL Belay
T_1 = 600 kg * 9.81 * sin (35 °) = 3.38 kN or 760 lb
T_0 = 3.38 kN / 25 = **135 N**

Dynamic Models

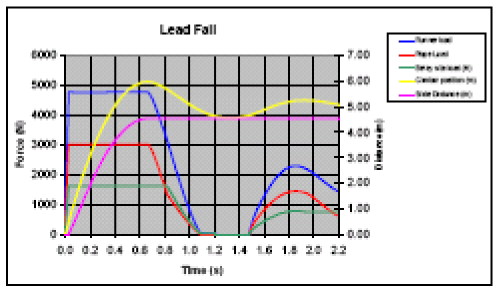
Model dynamic events and compare to test data

Why model?

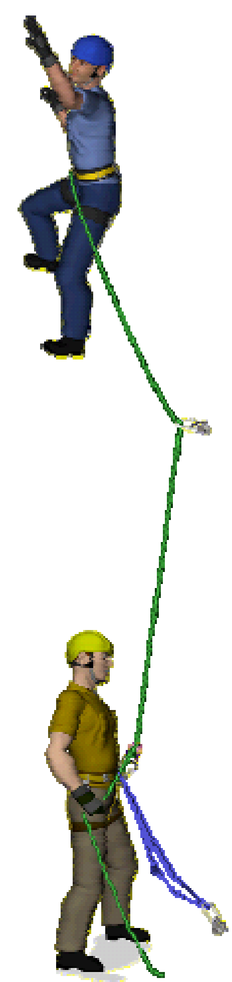
- Repeatable
- Cheaper than testing
- Can study one variable at a time
- Can study parameters that are difficult to test

Comparison Data

- No Hand
  - Weber - PMI drop tests
  - Moyer - cordelette tests
  - Manufacturer's ratings



- With Hand
  - Petzl fall simulator
  - CMT test data & simulation (live belayers)
  - Rigging for Rescue TTRL tests (mechanical hand)



Simple Linear Model

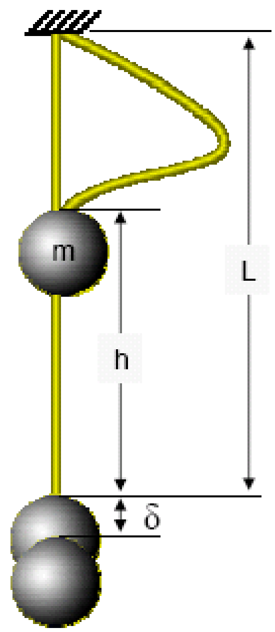
Conservation of Energy

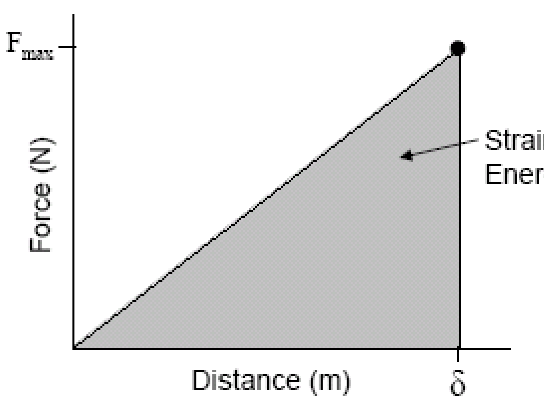
Gravitational potential energy
= strain energy in the rope

Rope Modulus $M = T/strain$ or TL/δ
Potential Energy = $mg(h+\delta)$
Strain Energy = $\frac{1}{2} T\,\delta$

$$T_{\max} = mg + mg\sqrt{1+\frac{2M}{mg}F}$$

where fall factor $F = h/L$



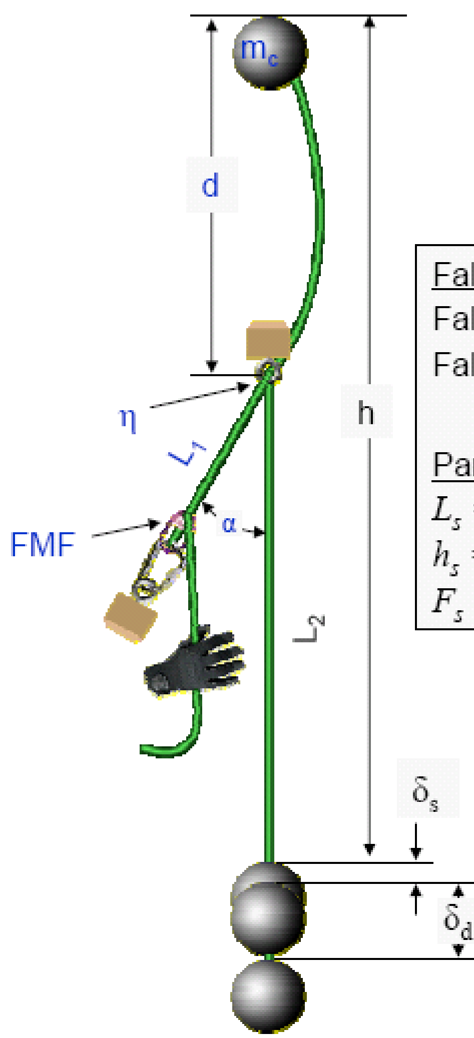


Detailed Model

Iterative Dynamic Motion Equations

Includes:
- Nonlinear rope elasticity
- Knots
- Rope damping
- Carabiner friction
- Belay device friction
- Slipping in belayer's hand
- Lifting of belayer

Iterative solution approach:
- From current rope tension, calculate $a = T/m + g$
- Calculate $\Delta v = a\,dt$ and $\Delta x = v\,dt$
- From new positions, calculate new rope strains $\varepsilon = \Delta L/L$
- From new strains, calculate rope tensions
- Calculate slip distances at friction devices to limit tension ratios to allowed values
- Calculate new rope strains and new rope tensions



Fall equations

Fall height $h = d + L_2$

Fall factor $F = h / L$

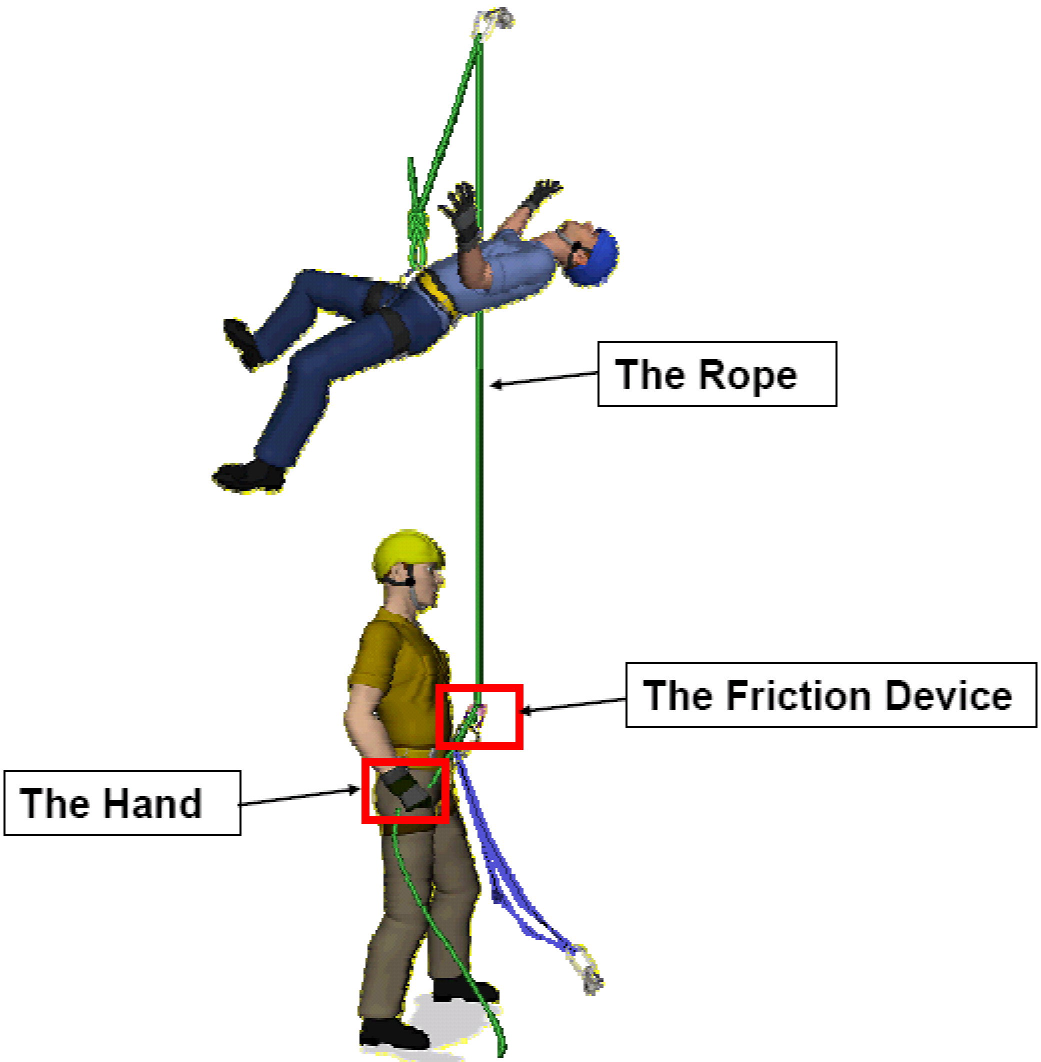
Parameters at static load

$L_s = L + \delta_s$

$h_s = h + \delta_s$

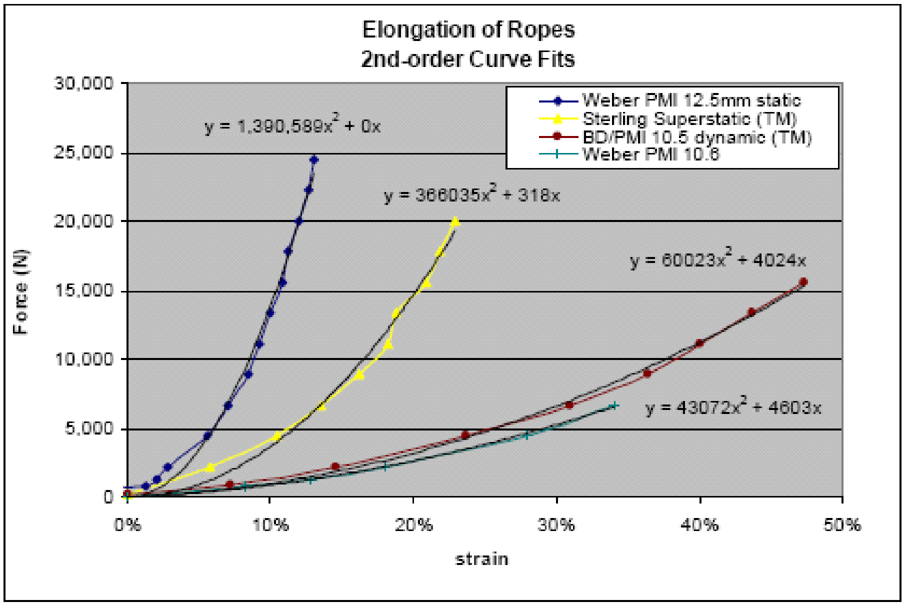
$F_s = h_s / L_s$

Three Components are Critical to Understand



Rope Properties

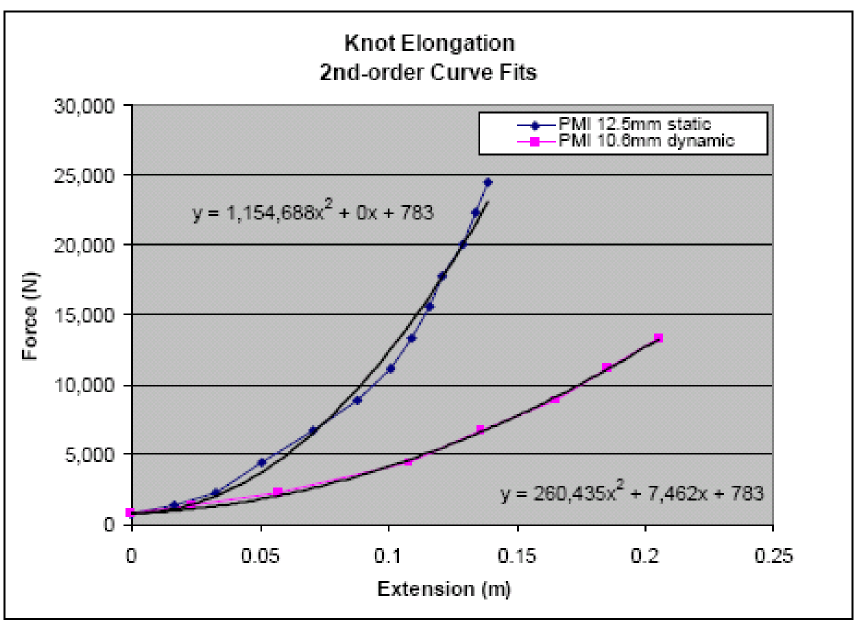
2nd order curve fits – Weber PMI Data



- Model results with nonlinear properties match Attaway's analytical predictions
- Nonlinear rope still obeys fall factor rule. Impact force is a function of fall factor.
- Impact force for a zero ff drop on nonlinear rope is 3 x weight instead of 2 x weight.

Knot Properties

2nd order curve fits – Weber PMI Data



- Knots modeled as rope sources rather than compliance terms
- Knots are much more significant on short ropes

Rope Properties - Damping

What is damping?

• Elastic force is proportional to deflection (strain)

• Damping, or viscous force is proportional to velocity (strain rate)

• Elastic energy is returned on rebound.

• Damping energy is lost to heating in the rope.

• Damping causes oscillations to die out.

C. Zanantoni - CMT

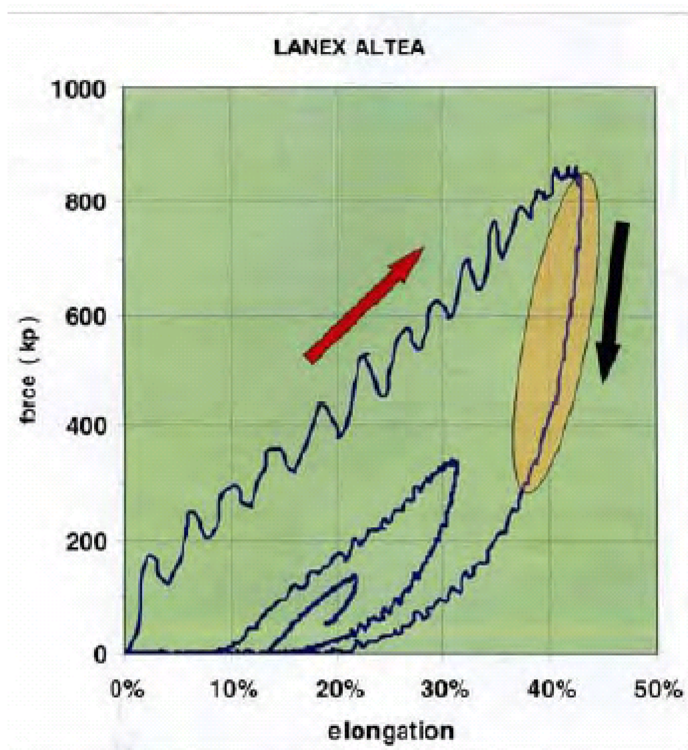


Fig. 3 - Recorded force during a classical Dodero test (no rupture).
Note the sudden reduction of the force during the return phase

Pavier Damping Model

- Spring in series with a spring/dashpot combination

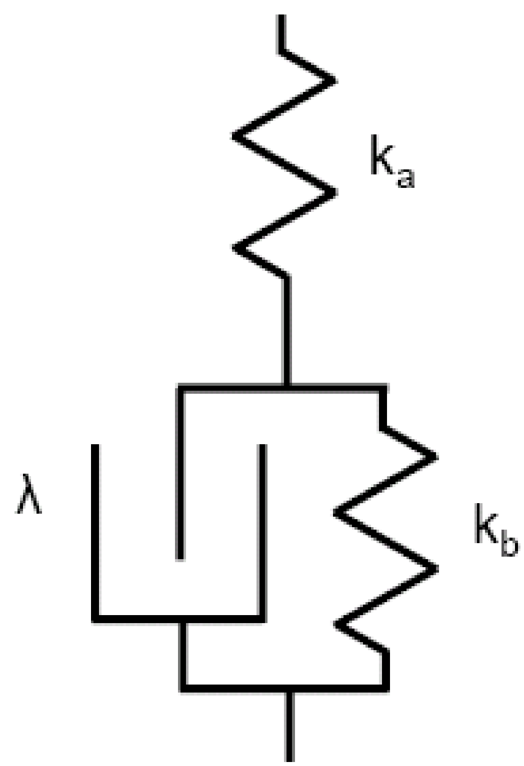
- Simple spring/dashpot combo produces unrealistic results.
  Initial impact forces too high.
  Damping values too low (too underdamped)

- Real ropes are close to critically damped.

- Damping values k_a/k_b and λ determined by trial and error to produce reasonable model behavior.

- Overall spring rate k from slow-pull testing

- Damping values could be determined experimentally with good force/deflection measurements in drop tests or fast pull-tests.



Comparison to Weber PMI Data

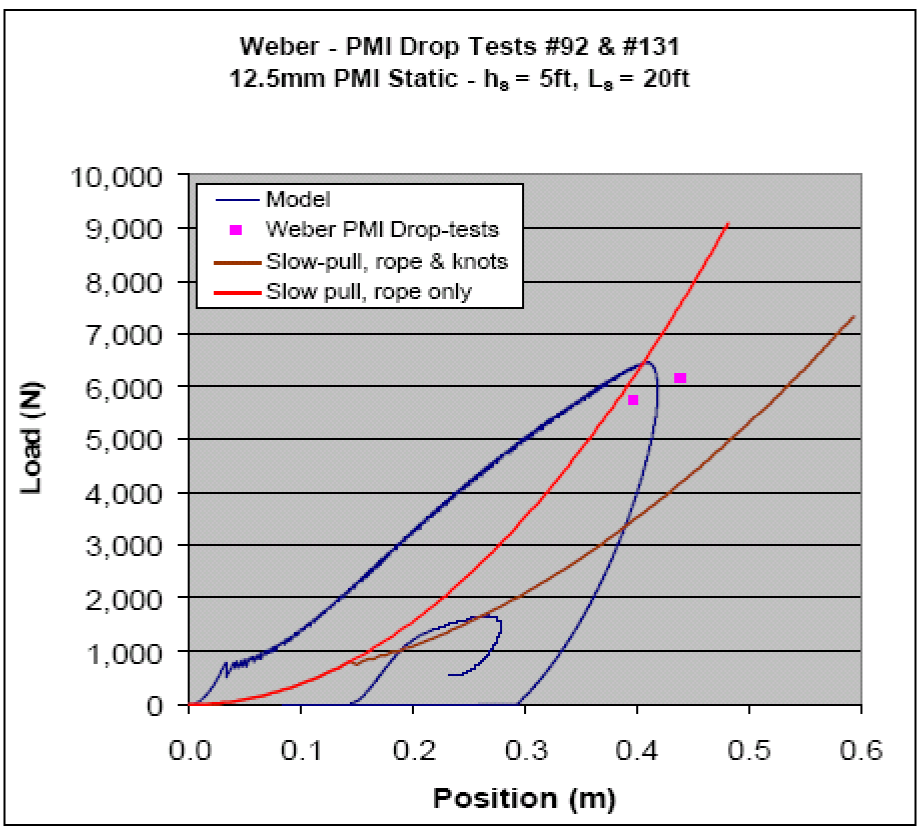
Example Load Profile

- Drop-test values give maximum force, elongation, and *energy.*

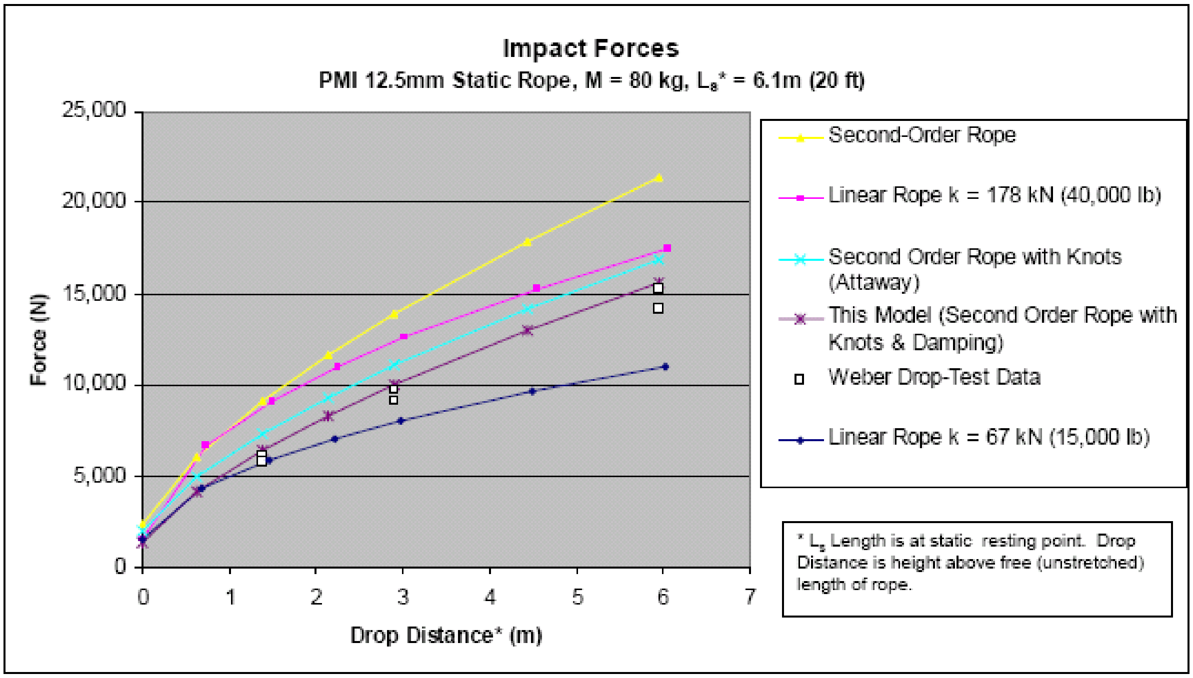
- Data points are very close to the rope-only curve.

- Without damping, rope and rope + knots curves do not store sufficient strain energy.

- Therefore they over-predict both force and elongation.



Comparison to Weber PMI Data



Comparison to Moyer Cordelette Testing

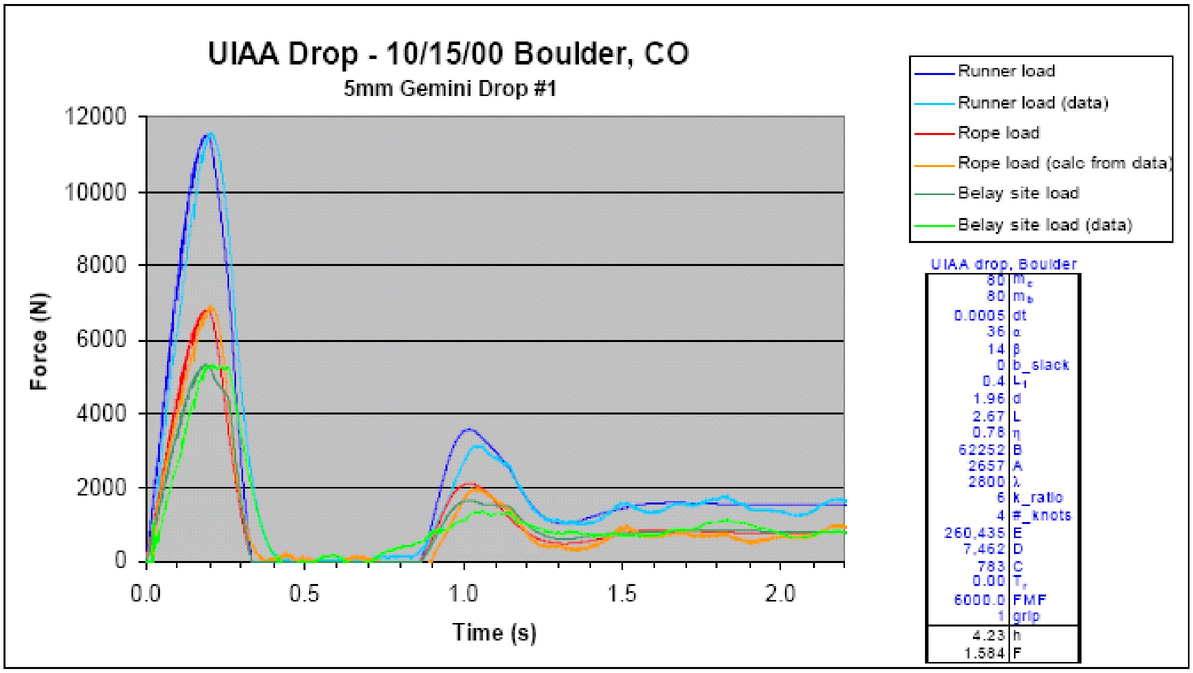
UIAA Test

80 kg weight
Fall Factor 1.71
2.8 meter rope

Cordelette is at the direction change anchor

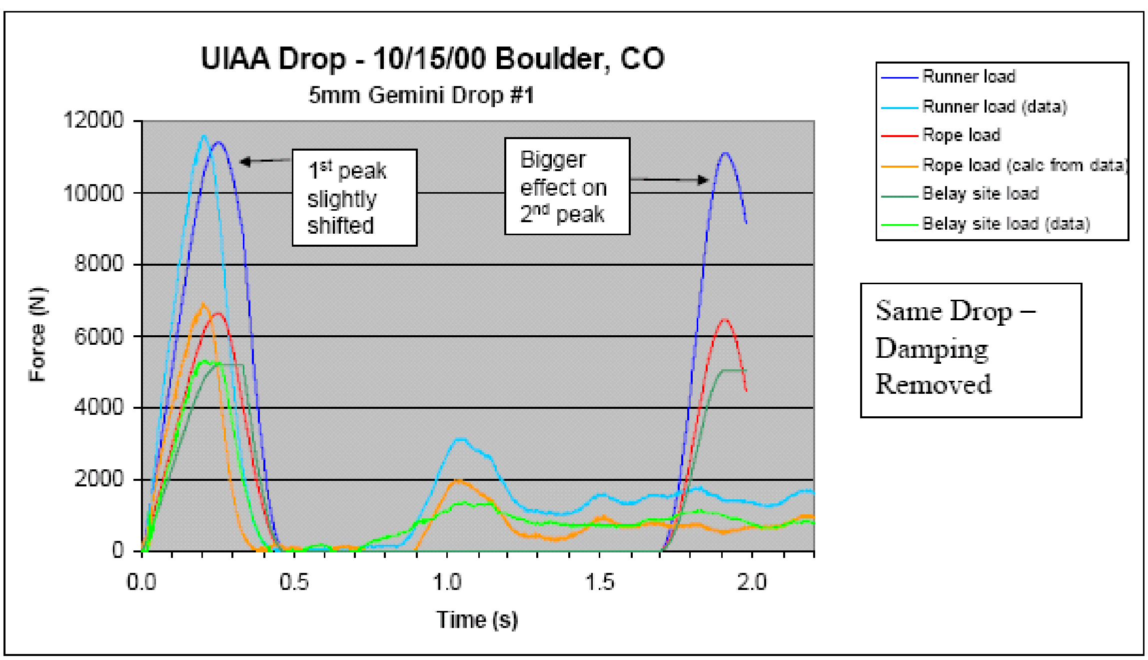
Black Diamond 10.5mm rope - rated impact force of 8.4 kN (1888 lb)

Comparison to Moyer Cordelette Testing

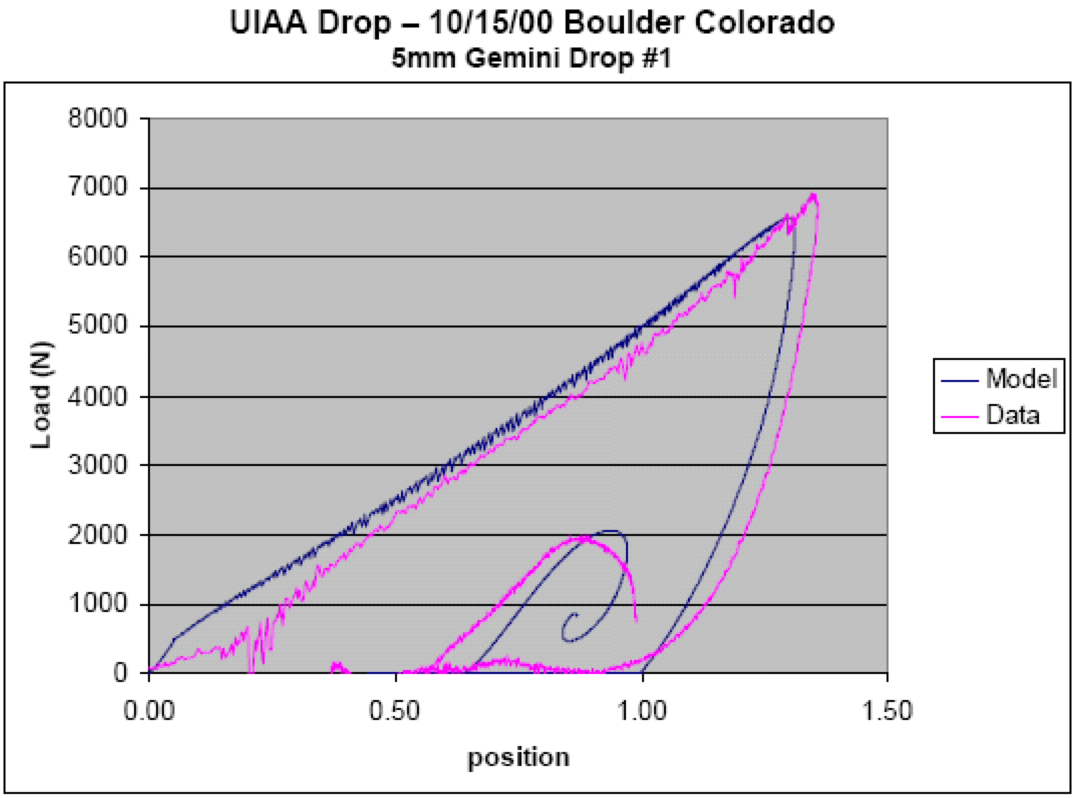


80	m_c
80	m_b
0.0005	dt
36	α
14	β
0	b_slack
0.4	L_l
1.96	d
2.67	L
0.78	η
62252	B
2657	A
2800	λ
6	k_ratio
4	#_knots
260,435	E
7,462	D
783	C
0.00	T_r
6000.0	FMF
1	grip
4.23	h
1.584	F

The Effect of Damping



Comparison to Moyer Cordelette Testing



Drops with a Hand in the System

- Hand slipping makes rope properties relatively unimportant

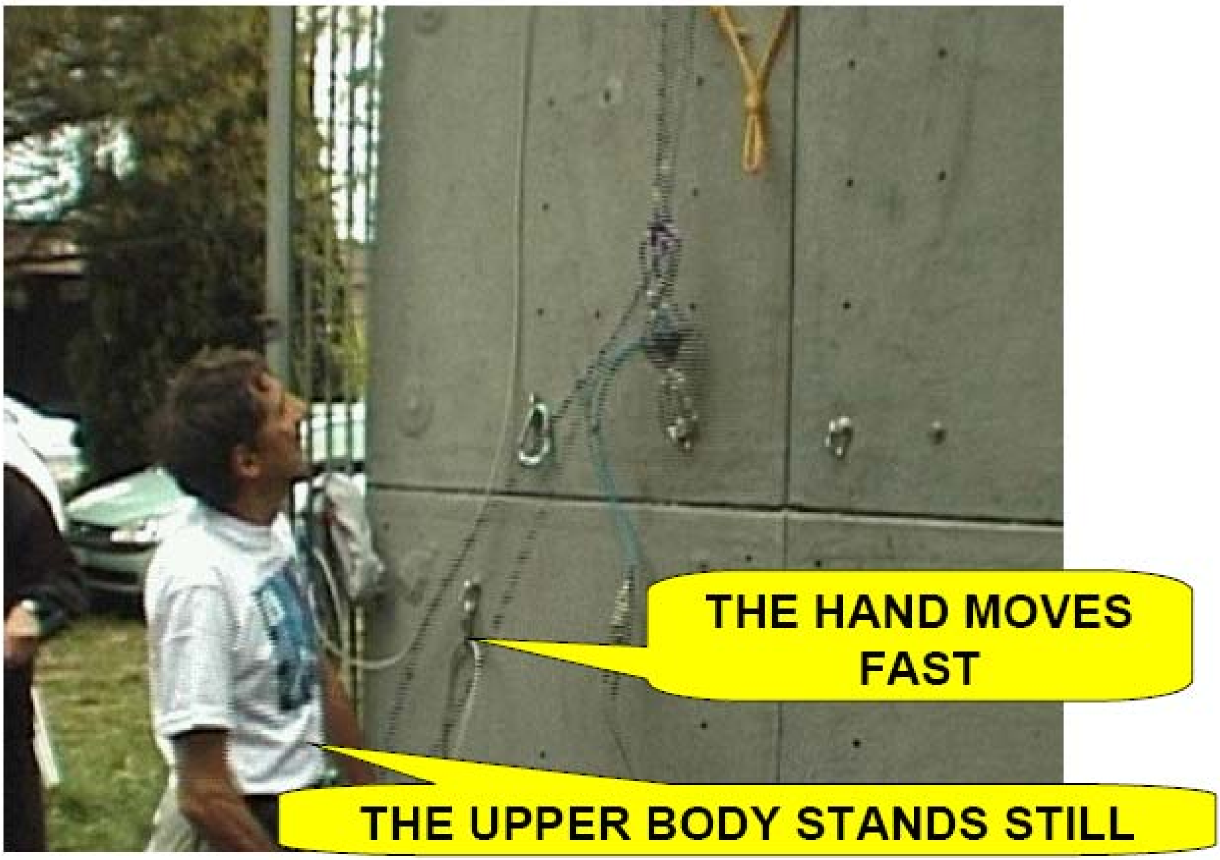
Italian CMT has done extensive study of the behavior of the belay hand in climbing falls

- Force measurements in falls compared to slow-motion video of the belayer

- Three phases of belay-hand behavior identified
  - Inertial Phase
  - Muscular Phase
  - Slipping Phase

“INERTIAL” PHASE

The hand moves fast



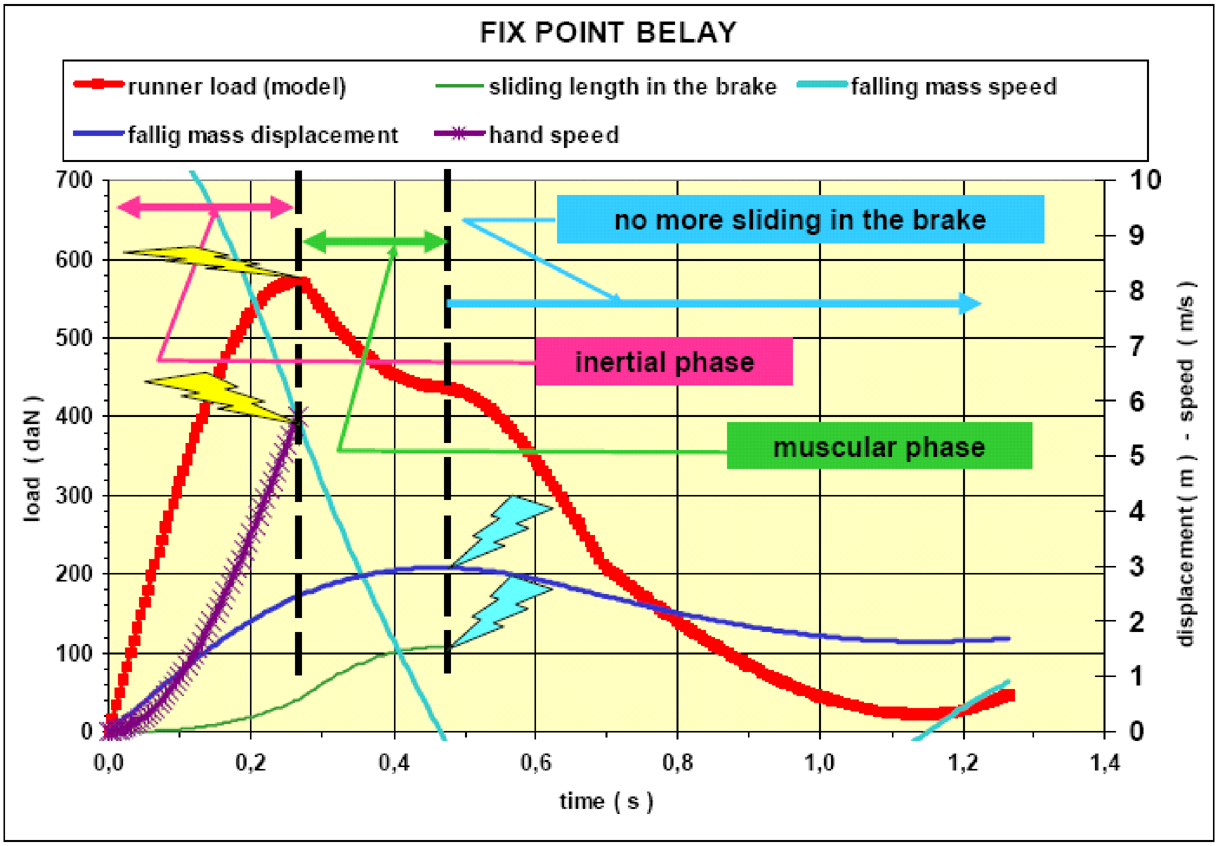
“MUSCULAR” PHASE

The hand moves slowly

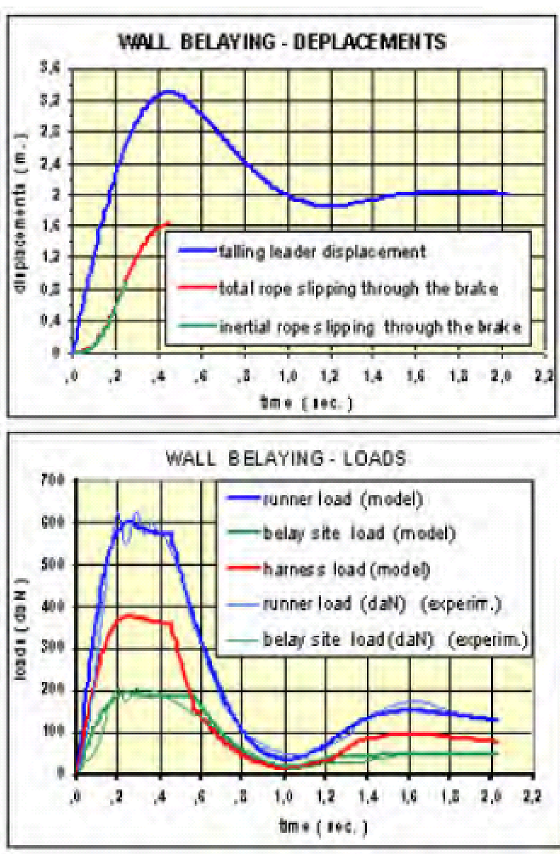
“HAND SLIPPING” PHASE

Possible rope slipping in the operator’s hand

FIX POINT BELAY



Comparison to CMT Belay Simulation and Data

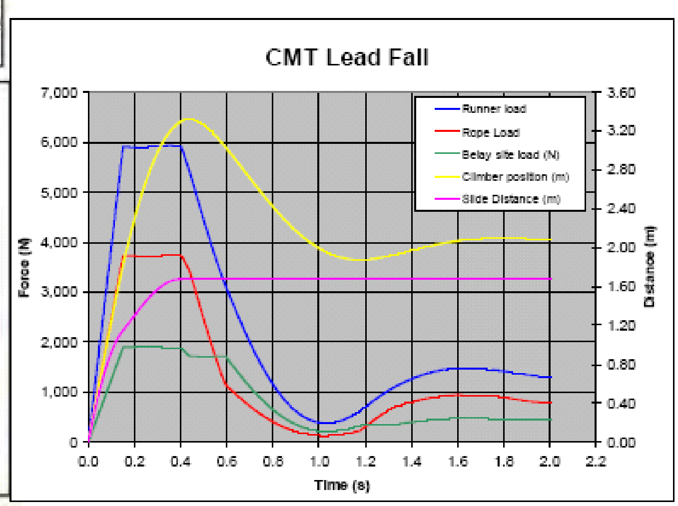


CMT Fall Parameters given:

- Mass m = 80 kg
- Fall height h = 8 m
- L_1 = 7.15 m
- Belay Device FMF = 7.5
- Hand mass = 2.5 kg

CMT Lead Fall

80	m_c
0.0005	dt
7.15	L_1
4	d
11.15	L
0.58	η
0	B
20920	A
3000	λ
50	k_ratio
0.15	l_r
7.5	FMF
290	grip
8	h
0.717	F



CMT Conclusions on Belaying

• Hand acts as an inertial load for the first few hundred milliseconds.

• Slip distance is proportional to fall height, not fall factor. *Confirmed.*

• Peak force occurs at maximum hand acceleration, not at lowest climber position.

• Only a small amount of belayer lifting is helpful (~20 cm). More lifting increases fall distance and does not decrease peak force. *Confirmed.*

Comparison to Petzl Fall Simulator

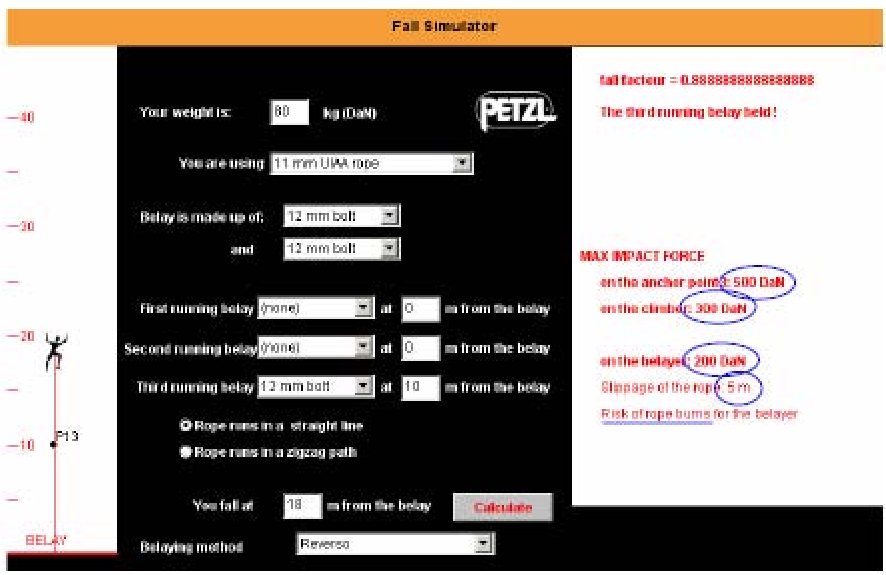
<u>Petzl Simulator values:</u>

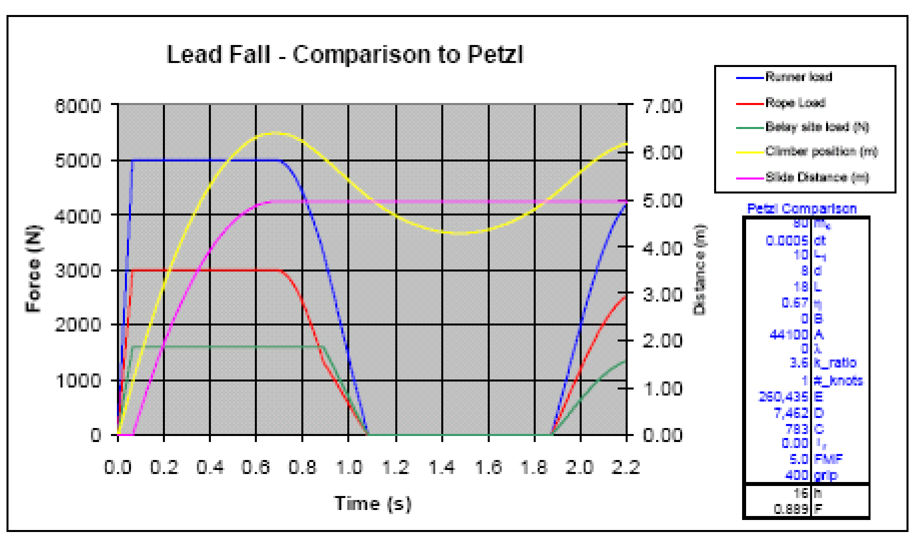
- Hand Grip = 400N
- Rope Burn Warning = 1800J
- Reverso FMF = 5.0
- Munter Hitch FMF = 7.5
- Grigri FMF = ∞ (no slipping)

- 11mm rope modulus ≈ 44.1 kN
- Carabiner efficiency = 66.6%
- Knot elongation included

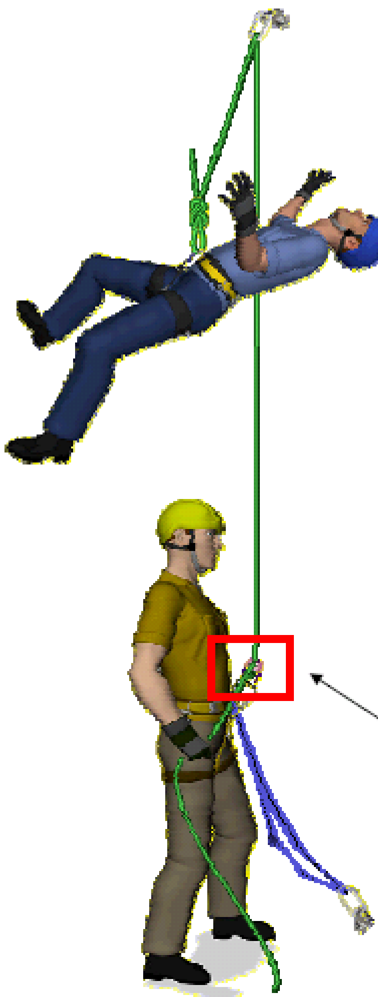
- No rope damping
- No lifting of belayer

Peak Force		
- on rope	3000	N
- on anchor	5000	N
- on belayer	2000	N
- on belayer's hand	400	N
Slide distance	4.95	m

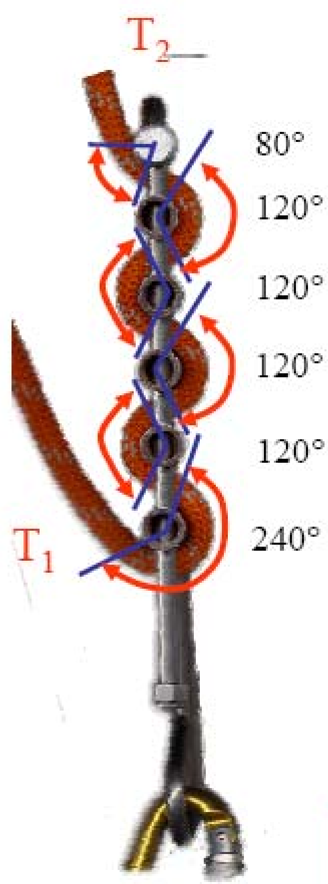




Belay Device Details - FMF Values



Friction device properties are very important to the model predictions



Attaway Friction Analysis

$T_2/T_1 = e^{\mu\beta}$

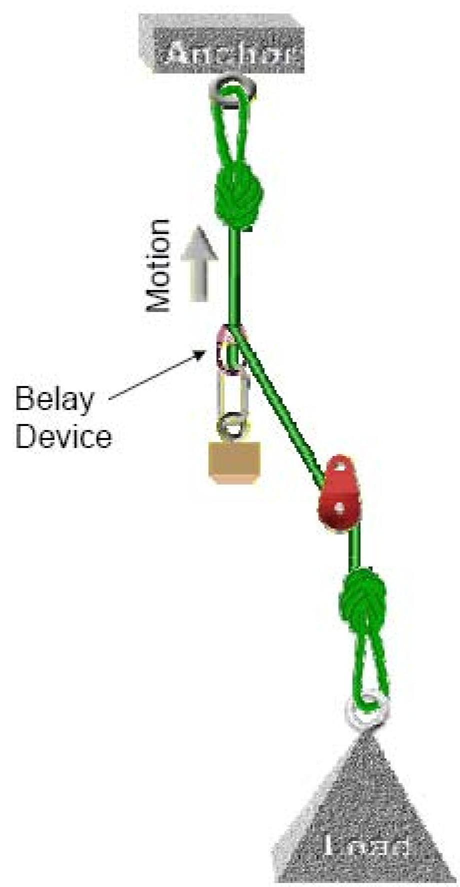
Total = 800°

4.4π

$T_1 = T_2/31$

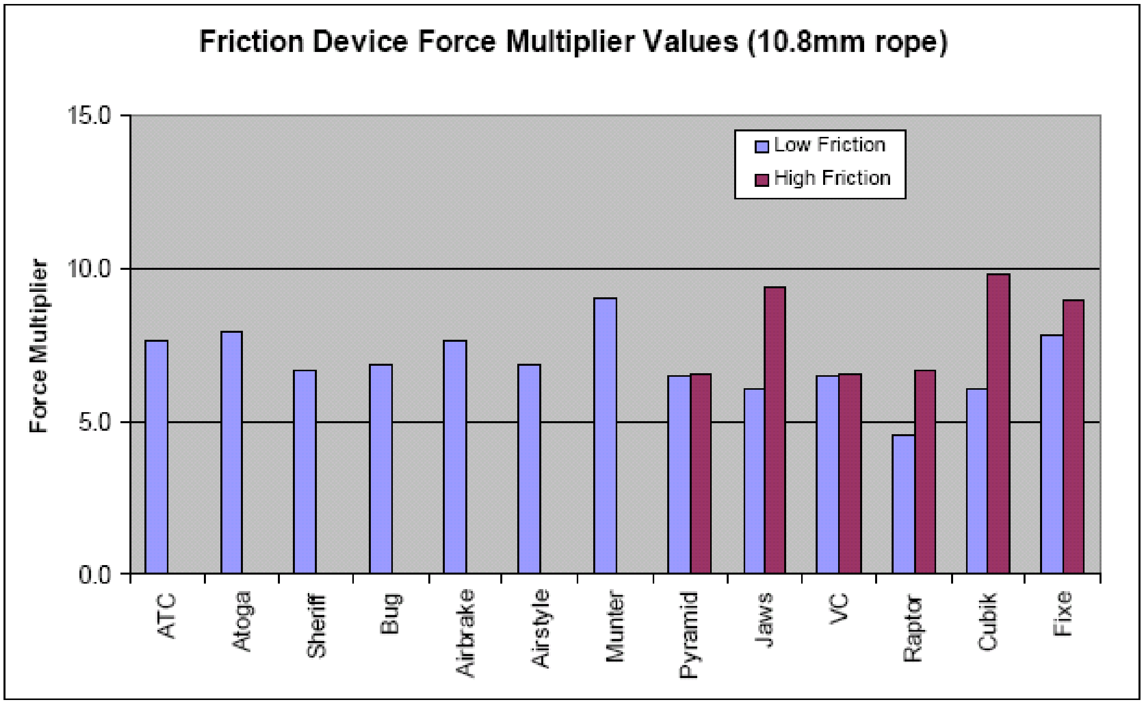
Belay Device FMF Values

Black Diamond Testing



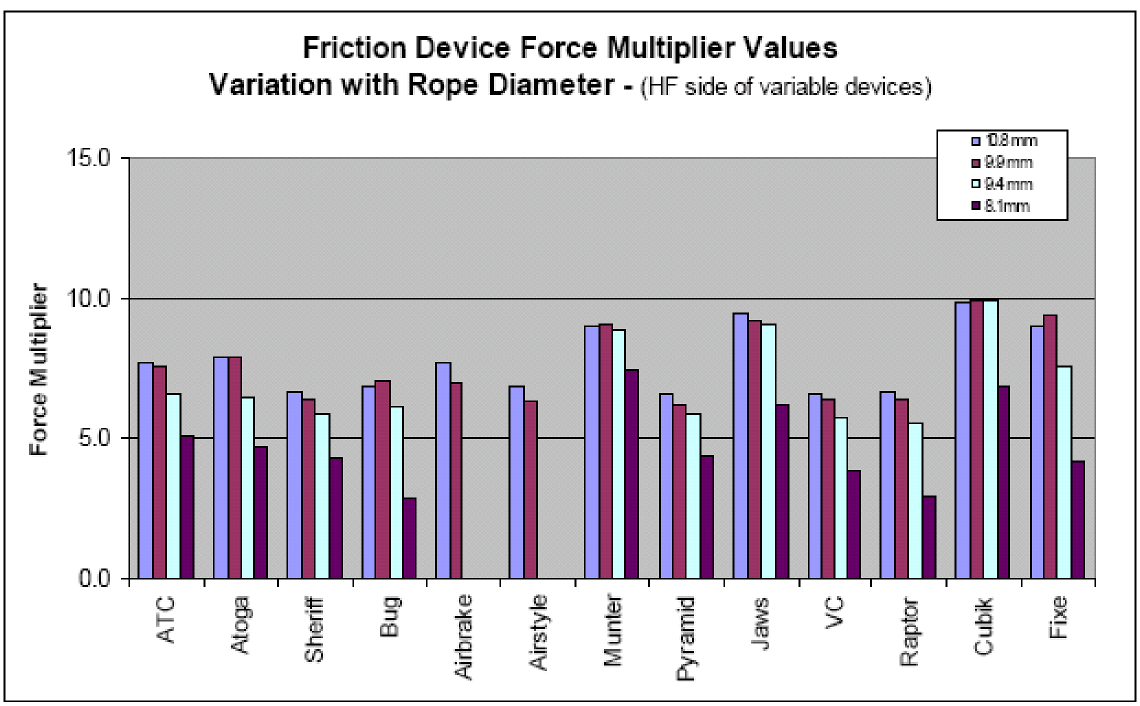
Belay Device FMF Values

Black Diamond Test Data



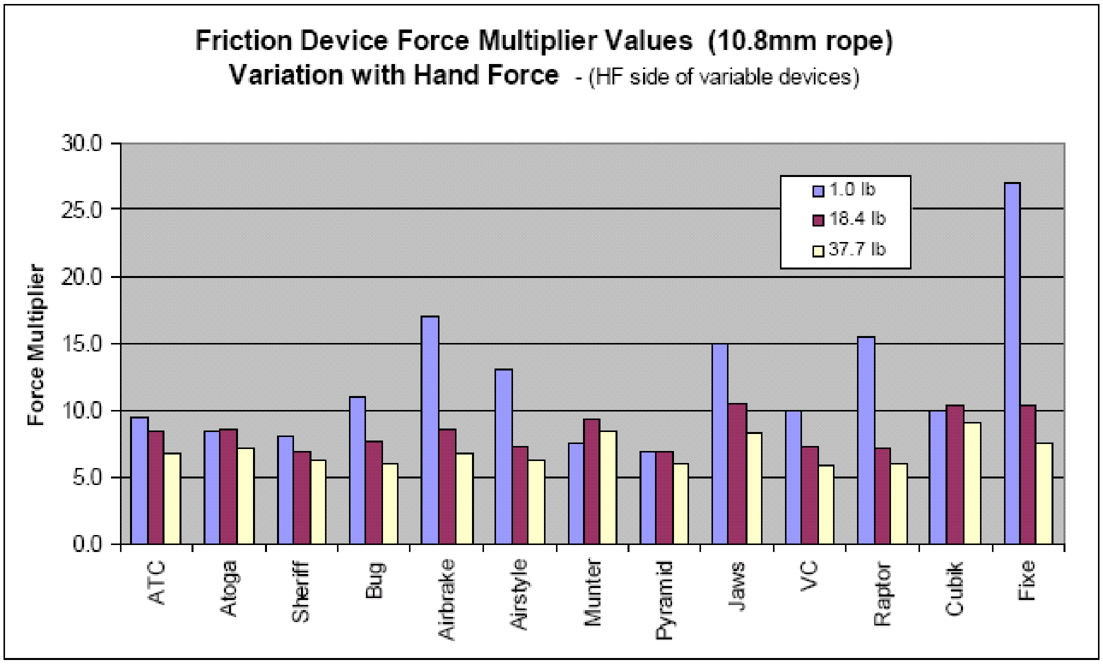
Belay Device FMF Values

Black Diamond Test Data



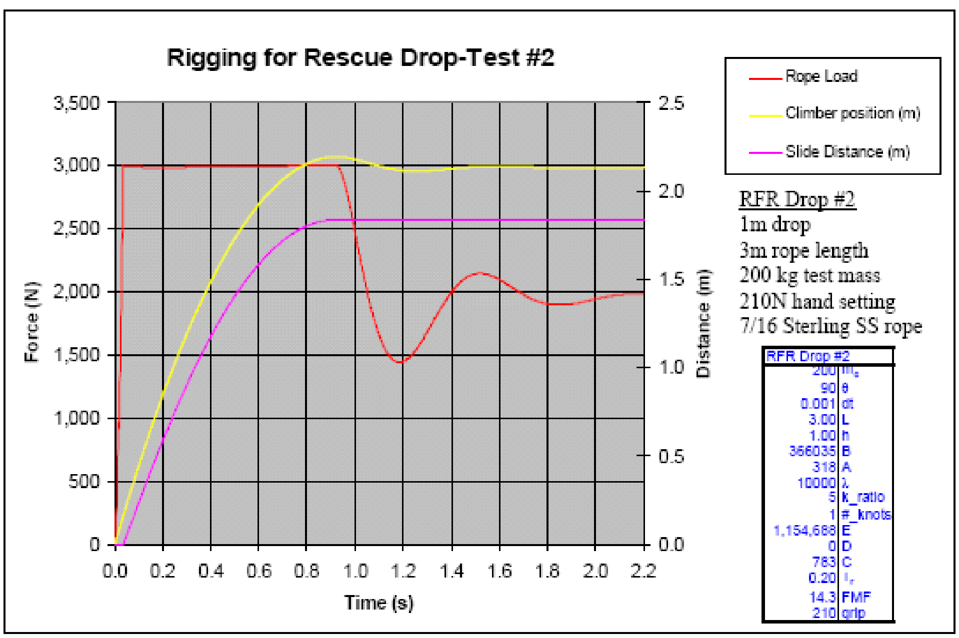
Belay Device FMF Values

Black Diamond Test Data



Comparison to Rigging for Rescue Drop-Test Data

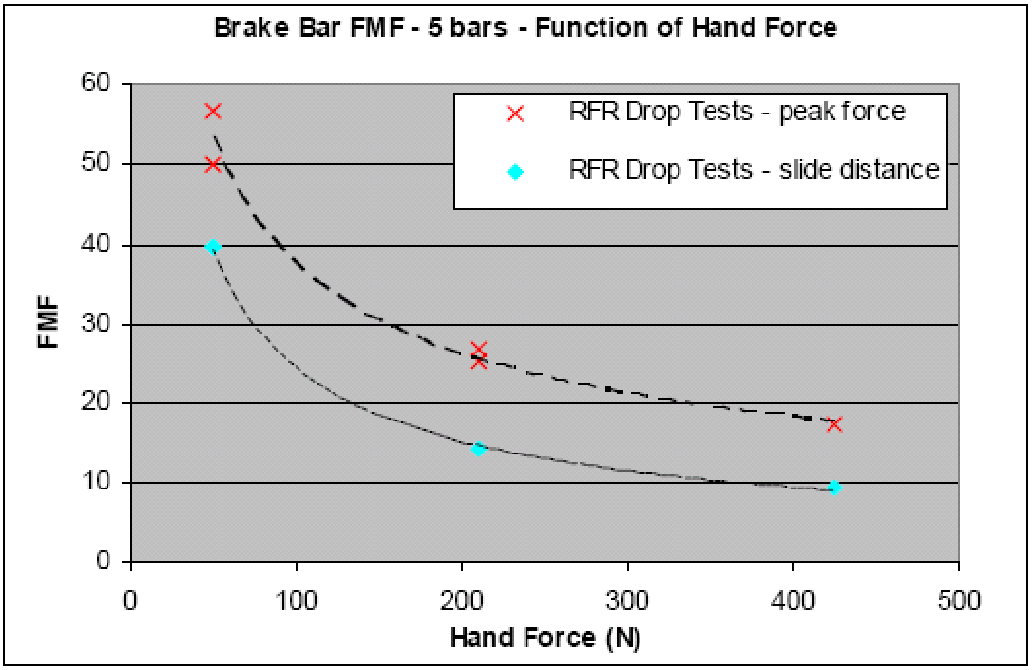
- Brake Bar FMF determined by trial and error.
- FMF = 14.3 gives a slide distance equal to the measured value
- This underpredicts the measured peak force



- Measured values:
  5,626 N Peak Force, 184 cm slide distance, 231 cm FAS Extension
- Model values:
  3003 N Peak Force, 184 cm slide distance, 219 cm FAS extension

Comparison to Rigging for Rescue Drop-Test Data

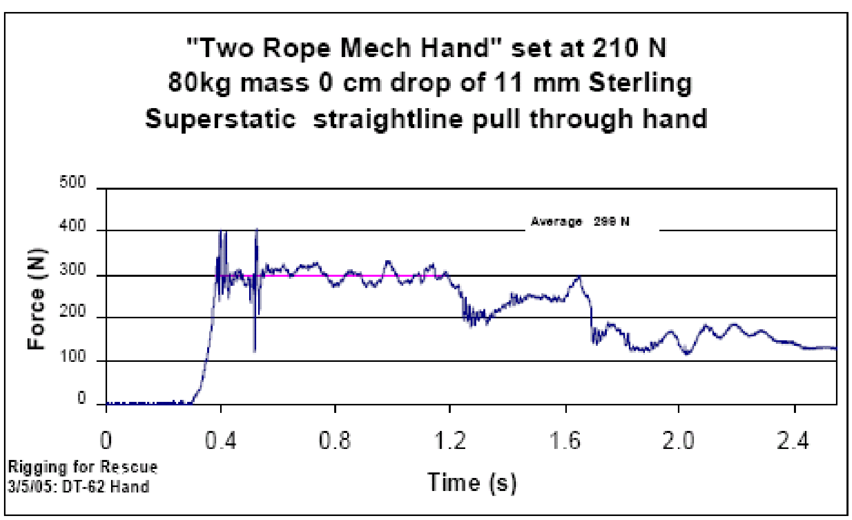
Brake Bar FMF varies with Hand Force



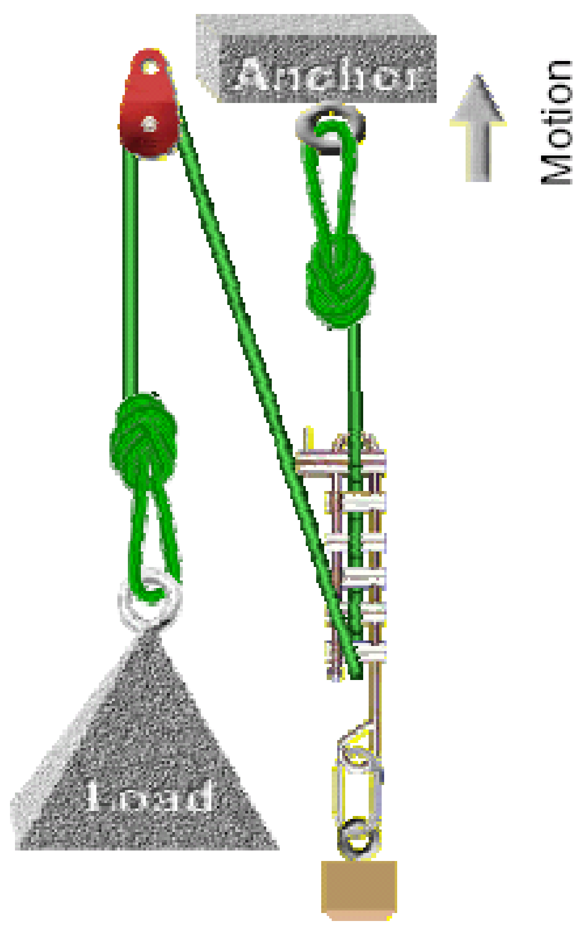
Comparison to Rigging for Rescue Drop-Test Data

Rigging for Rescue Data – ITRS 2005

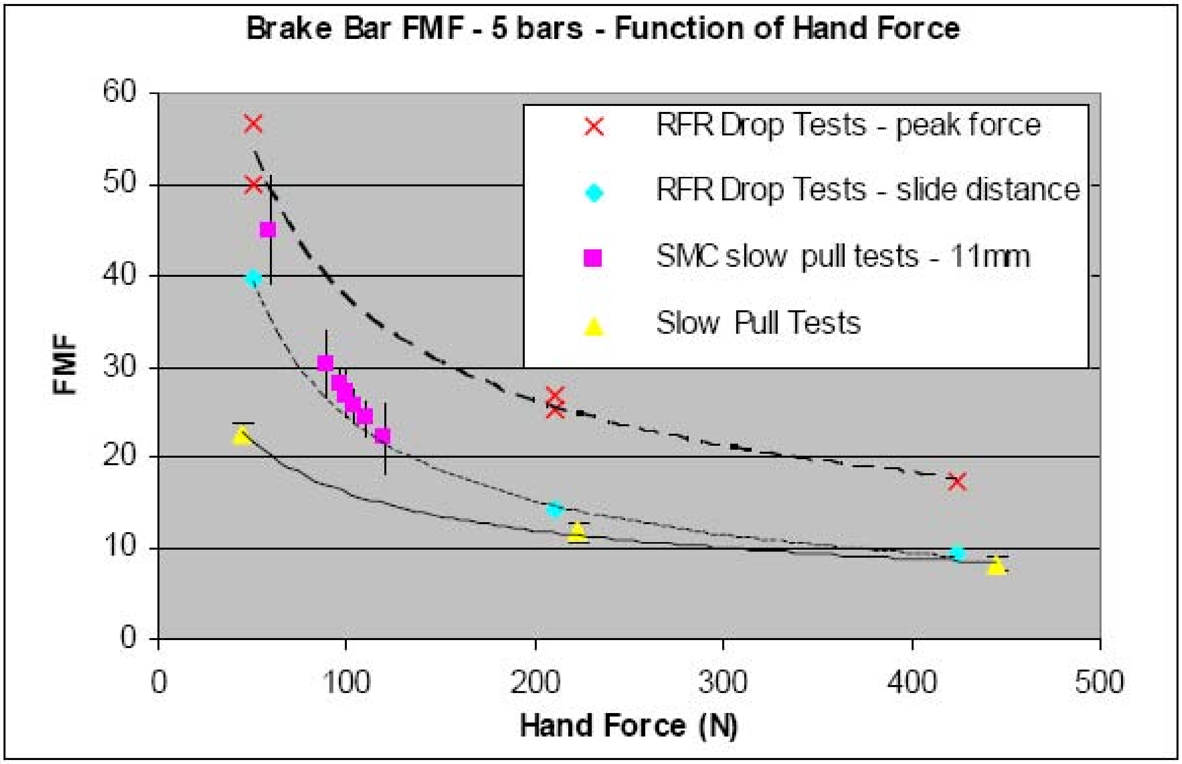
- Slide distance is a function of the average mechanical hand force.
- Peak rope tension is a function of the peak mechanical hand force.
- Any spikes in the mechanical hand force will cause higher measured peak force values.



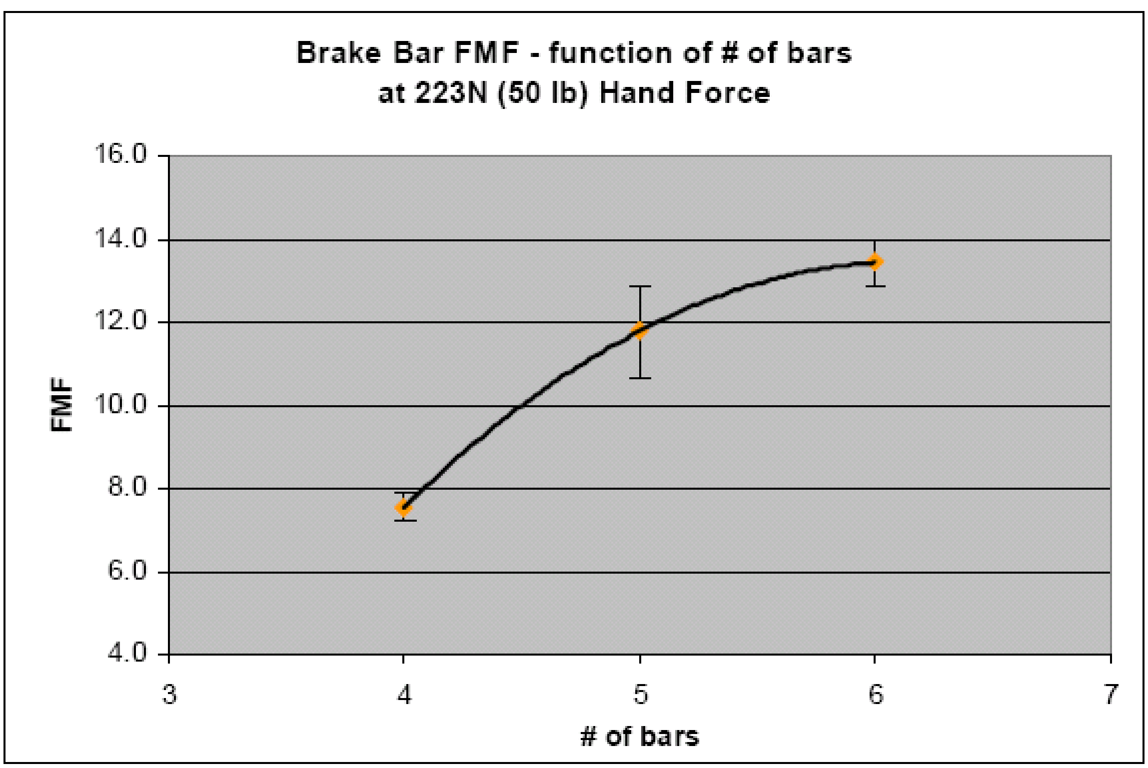
Brake Bar FMF Testing at Black Diamond



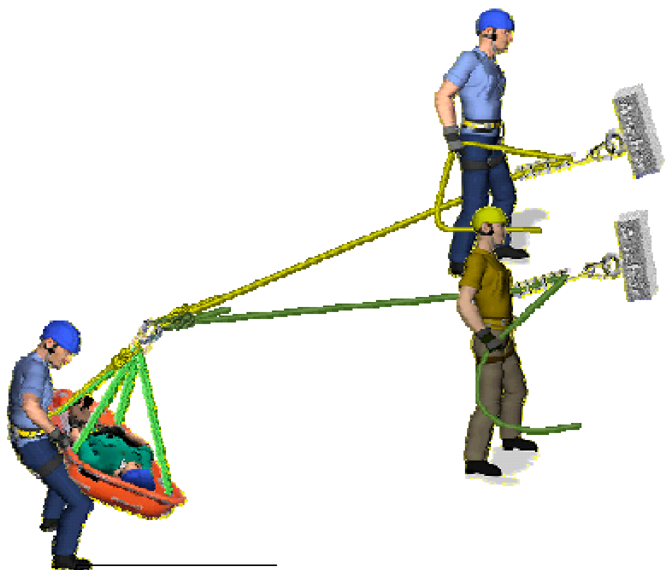
Brake Bar FMF Testing at Black Diamond



Brake Bar FMF Testing at Black Diamond



Back to the Original Question



How do TTRL belays compare to climbing belays?

Gripping Ability Required for Climbing and Rescue Scenarios

How much slip is too much?

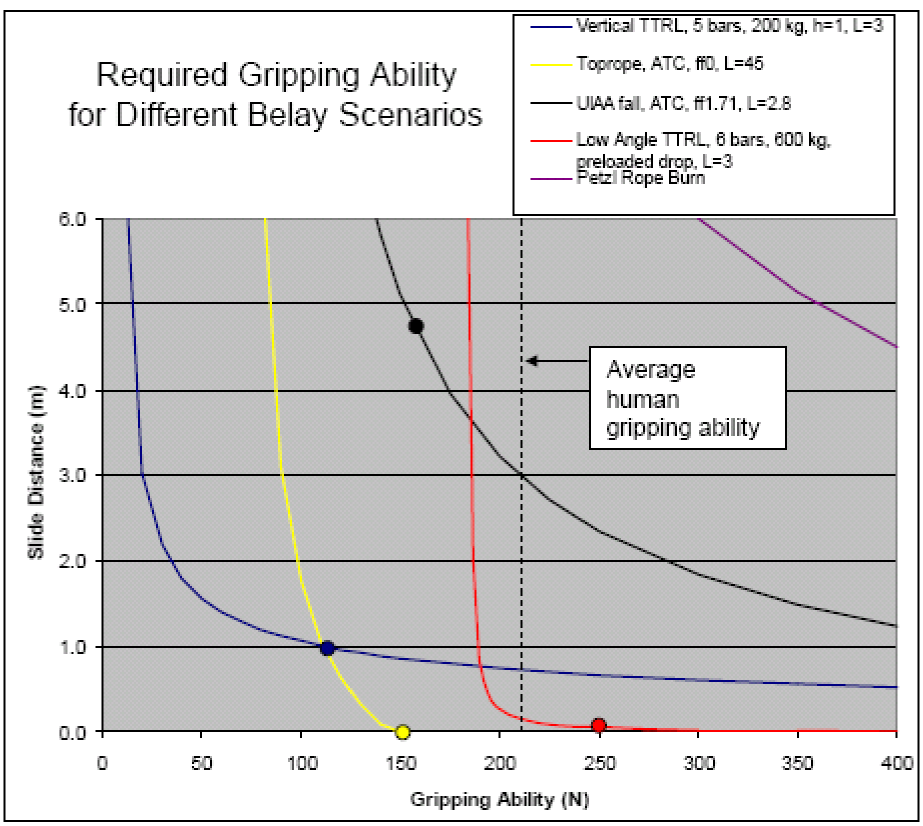
• BCCTR belay standard, 1m maximum total extension.

• Petzl rope burn warning, 1800J

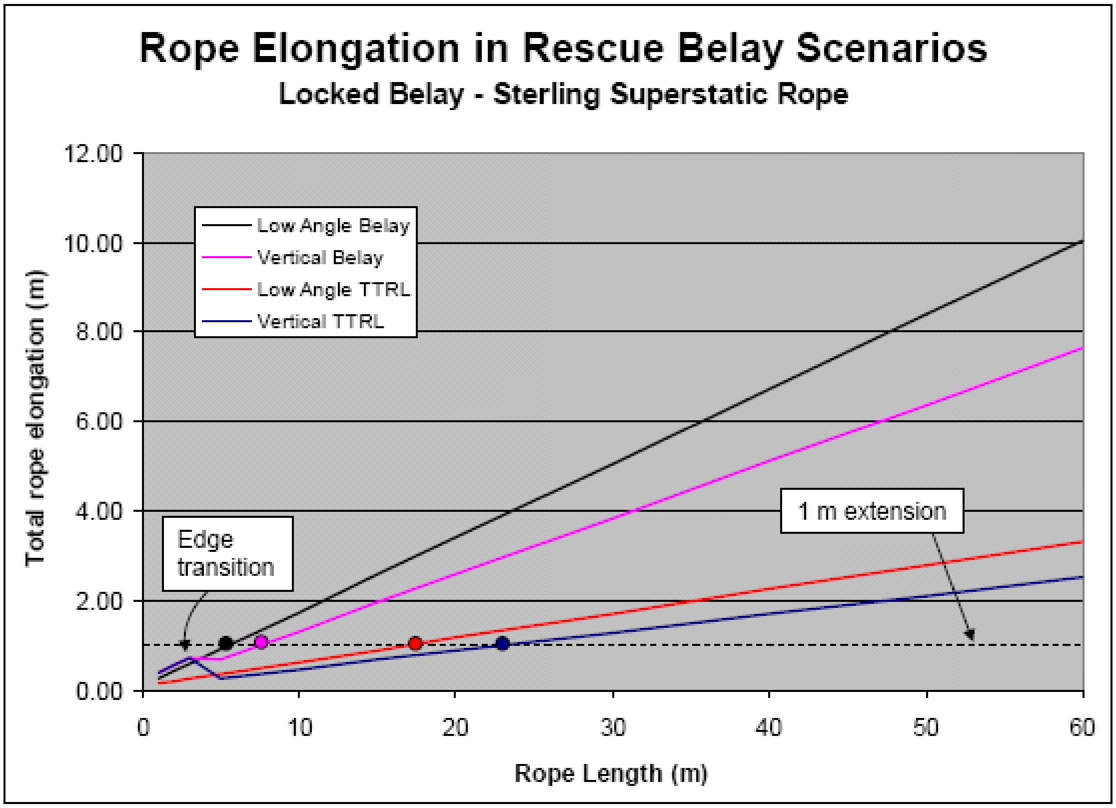
• Some belay device slip is good - reduces peak force.

• Too much sliding increases chance of collisions.

• A reasonable limit might be slide distance less than fall height.



Rope Stretch



- Rope stretch is very important at longer rope lengths
- A preloaded rope is much better

Differences Between Rescue Belays and Climbing Belays

- The hand is preloaded in a TTRL belay
- A TTRL belayer can optimize brake bar setup

- Reaction time may be longer for a TTRL belay.
- TTRL belay may already be sliding.
- TTRL belayers typically wear gloves.
- TTRL belayers are not expecting to catch falls.

Conclusions

- TTRL grip requirements are similar to climbing.
- Teams who prohibit manual devices should also prohibit them for lead climbing and rappelling.
- Brake bars are not very high friction devices.
- Unlikely that TTRL belay would ever meet 1m extension limit in the BCCTR test.

- The ideal rescue belay would be autolocking, force limiting and preloaded.

Thank You

- Chuck Weber – PMI
- Paul Tusting and Kolin Powick – Black Diamond Equipment
- Carlo Zanantoni - CMT
- Mike Gibbs – Rigging for Rescue
- Dave Custer – UIAA
- Steve Achelis – RescueRigger
- Garin Wallace – SMC
- Marc Beverly and Steve Attaway

Rope Breakage

Ref incident of May 20th, 2006
At Pipeworks Climbing Gym
Sacramento, California

Kolin Powick, Quality Assurance Manager
Black Diamond Equipment, Ltd
August 2006

THE INCIDENT (from posts on supertopo.com and rockclimbing.com)

Posted by a member of the gym
At approximately 1:15 pm, Saturday, May 20, 2006, at an indoor climbing gym in California, a climber was taking his "lead" test, which consisted of lead-climbing an indoor, slightly overhanging route of about 35 or so feet, clipping the pre-placed quickdraws, and then, taking a short fall from the top of the climb.

The climber, a young male, in the vicinity of 6 feet tall, of relatively thin build (weighing an estimated 155 lbs), had successfully climbed the route to its top, and had his hands on the top hold of the climb. His rope was clipped through a steel, key lock carabiner approximately 3.5 to 4 feet below his waist tie in point. The rope appeared to be properly clipped. The quick draw, and the clipped carabiner (that was about to take the load from his fall) hung out from the gently overhanging wall so that the carabiner did not come into contact with the wall. The climber, and his partner, were being observed by a gym staff-person who was evaluating the climber to determine whether the climber would pass his lead-test. In addition, several other climbers had gathered to observe the test.

Pursuant to the requirements of the lead test, the climber intentionally let go of his holds and proceeded to fall. It was not clear from my vantage point exactly how much slack the belayer had fed out at the time of the fall, but it appeared the climber fell perhaps 6-7 plus feet before the rope tightened and began to catch his fall. The climber had fallen approximately 2 clip points (perhaps approximately 10 or so feet) below the loaded carabiner, and his fall appeared to be substantially arrested, when the rope ruptured, and the climber plummeted to the deck. From a (very rough calculation), this appeared to be a very "low-load" fall. With the climber falling (including rope stretch before the break) about 10 feet (and perhaps up to 12 feet), before the break, it would appear that by an equally rough estimate that this 10-12 foot fall occurred on about 35 feet of rope (between the belay and climber). This fall would appear to produce a modest "fall factor" of say, around .333 (compared to the UIAA fall test of "fall factor" 2.)

I performed (an exceedingly) informal examination of the severed rope. According to the rope's owner, who was the partner, and belayer of the climber who fell, his rope was about three years old. He reported the rope had previously experienced several "light" falls, and, additionally, one 20 foot fall, which, according to the rope's owner, had occurred with much of the rope "out" to absorb the shock of the fall.

The rope appeared to be in good shape. The rope's sheath had almost no wear. I pulled the length of the rope through my hands: no obvious core irregularities were detectable. There were no detectable stains or other markings on the rope. In short, if the information reported from the rope owner was true, and there were no significant omissions, this appeared to be a rope that many climbers, including myself, would lead on, and indeed, had experienced less wear and tear than many gym lead ropes that I see employed on a daily basis. Of course, clearly, I am not in a position to know the whether the history of this rope was accurately reported.

Posted by the climber

I am the one that fell. It was at Pipeworks. The rope was flaked out twice before we began. The above story is correct. The rope was not caught in the gate of the carabiner. I saw it break as I fell. I was taken to UC Davis med center. After several test I was released. I am sore but ok. Link to a picture of the rope is below.

The rope belongs to my partner. I believe the history in the first post is correct. I will add that the rope was stored inside and he does not have pets that could have pissed on it. Furthermore, he has a lot of climbing experience, is a friend, and is someone I trust. The rope looks a lot better than most gym ropes. There is no damage anywhere to it except at the break. I believe it is going to be sent back to BD.

And I think they are going to make me take the test again.hahahaha.

posted by the climber

Hello everyone, I just joined the site. I have a question and I'll throw a couple more facts out.

When preparing the rope it somehow got pretty tangled. After untangling it the belayer/rope owner ran the entire thing through his hands, twice. I was not tied in while he was doing this. Once tied in the point where the rope would eventually fail was only ~5 ft from me. We are both human, but I think it is pretty unlikely we missed a cut in the rope.

As for the biner. After I clipped it I made one move above it. Then I looked down at the draw, and realized I was not very far above it. I made another move up, then looked down at the draw again and then proceeded to take the intentional fall. Given that the route was slightly overhanging, the biner was in good shape, the biner was designed so that the rope would not get stuck in the gate, and the fact that I looked down at the draw twice after I clipped it leads me to believe the rope was not cut here. But again, I am human and it is certainly possible that I missed something. Also, there was some slack in the rope when I fell so a couple of feet of rope ran through the *biner, it seems like there would be damage elsewhere on the rope if it was indeed cut at this point.*

Last thing, having had the rope on my desk for a couple days, I can say from a purely observational stand point, the rope looked cut. It looked cleanly sliced about half way through. The other half looked like it was ripped apart. This does not match the pictures of acid induced failures that I have seen. I am really interested in the testing results, I have no idea what they are going to be.

Take it easy everyone,

Brian Voyles

Posted by the Climber
The biner was removed from the draw and examined. I was told there was nothing at all wrong with it, no sharp edges, no deformation, etc. I never saw it after the incident and do not know if Pipeworks still has it or if it was sent elsewhere to be tested. I do not know the exact length of the draws, but they appear to be the standard length.

I think it is unlikely that the rope caught on the hanger or sharp holds. None of the holds were real large or sharp. It is only slightly overhanging, but enough that I think the rope would have just slipped off a hold. Also, when I fell I pushed away from the wall with my legs, so that should have helped pull the rope away and keep it from snagging something on the wall. While climbing up I never felt like the rope caught on anything. Because of the shape of the wall and the location of the draws I really do not see how it could have been cut by anything but the biner.

The break in the rope was about 5 feet from me while tied in. I was tied in with a figure eight with a roughly 6 inch tail. So I guess that puts it 8ish feet from the end of the rope. I had an atc and locker on my harness, but it was clipped to rear gear loop, so I'm sure it is innocent.

Brian Voyles

DISCUSSIONS WITH PARTICIPANTS/WITNESSES

Some general information after discussing the event with the belayer (Dan Sobieski)

- It was the belayer’s (Sobieski’s) rope
- It was their first climb of the day.
- When the climber fell, the belayer lost his balance but did not fall to the ground.
- The belayer was using an ATC.
- The belayer gave a slightly dynamic belay. He did not give a big ‘jump’ as many people do when climbing outside during a sport climbing fall.
- There was ‘some’ slack in the rope at the time the climber jumped.

Rope History

- Bought in 2002.
- Used fairly regularly (weekends and road trips) for a year.
- Then used periodically (odd weekends) for the next few years.
- Had not been used for a year prior to incident.
- Always stored in a rope bag.
- Washed two times with warm water in a tub (no soap, bleach or detergent), hanged to dry in a cool shaded environment.

INITIAL IMPRESSIONS

When I first heard of this incident, my initial reaction was that there had to be some outside circumstances that caused this rope to fail – because ropes just don't break. I've done a substantial amount of testing of very old weathered quickdraws and my own personal climbing ropes that have been beaten and abused, as well as new slings and ropes. Though I've learned that these nylon products definitely degrade with time, weathering and use, and I have seen some instances where rope products do start getting close to what I would call "the danger zone", I have yet to see a sample that would fail under the relatively low forces generated in a fall as in this case. My guess is that the rope was most likely cut somehow: on a sharp biner, sharp edge, a climbing hold, etc. I wasn't, however, ruling out some extremely peculiar manufacturer's defect, some form of contamination of the rope (improper care, exposure to chemicals, etc), or a pre-distressed area of the rope that finally saw its limit in this instance.

When I was first asked to look at this incident, I read the posts on Supertopo.com and Rockclimbing.com. Upon learning more about the circumstances, and once I saw the photos of the rope, I was more convinced that the rope had been cut. The core strands looked very different than a broken rope after typical drop tower testing. Some of the strands had very clean ends with little unraveling from the core strands, while others were more frayed and significantly unraveled. See photos below.

The belayer sent me the rope, I received it on May 25th.

THE FACTS

- Rope – the rope is a 10.5mm Black Diamond rope – circa 2001. It appears to be a "Cirque" – at this time Black Diamond ropes were manufactured by PMI, with Nylon supplied by Beal.
- Carabiner – Kong steel key-lock carabiner
- Quickdraw – was a Petzl 'logo-ed' draw with Petzl rubber "keeper" – attached to the bolt with a Quicklink
- The climber was approx 4ft above the last quickdraw when he jumped falling approximately 10 feet. There was approximately 35 ft of rope out at this time – equaling a fall factor of about .29. The rope came tight, then broke sending the climber another 20ft to the padded floor where luckily he was not seriously injured.

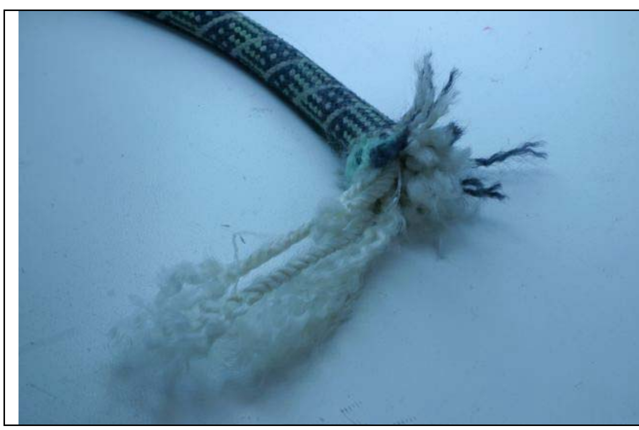
ANALYSIS

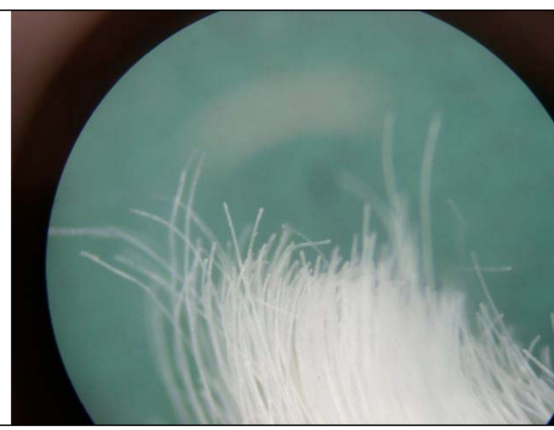
Carabiner

- The carabiner is a steel keylock. It is not worn significantly. (note: it's steel). There are no sharp edges.

Rope

- The rope broke 8ft from the end at which the climber was tied in. Using a figure eight with a back-up knot, this would equate to approximately 5ft from the climber's harness.
- Some of the strands at the point of breakage had clean ends, others were unraveled and frayed.





Comparative Rope Testing

Background

- Typical sport climbing falls, with a dynamic belay, generate forces at the top piece of protection anywhere from 1-4kN.

Lab Testing

- Several sections of the Sobieski rope were pulled to ultimate strength in a tensile testing machine. All failure loads and modes were consistent with a rope of this diameter. There was nothing unusual discovered in the sections of the ropes tested.
- Severe drop tower tests were performed on the remaining sections of the Sobieski rope, as well as a comparable new 10.5mm dynamic rope. These tests included factor 2 falls generating upwards of 10kN. Test configurations included the rope with falls:
    - over standard carabiners
    - pinched in the gate of a similar steel carabiner
    - running across the back edge of the gate of similar steel carabiners
    - over the edge of an extremely sharp and worn carabiner
    - through a bolt hanger (simulating a very sharp edge)
    - over the sharp back edge of a climbing hold
- The summary of the results is that the remaining sections of the Sobieski rope did not cut even under these extreme circumstances until multiple severe falls in the same location occurred. Even then, the failure mode was not consistent with the failed rope in this case. (ie. There was substantial melting of the strands in the drop tested ropes).
- The remaining portions of the Sobieski rope fared only slightly worse than the brand new rope in the same tests.
- Based on the results of this testing it was obvious that the entire rope was not suspect and the likelihood of a 'normal' rope being cut under the circumstances given in this case was very low.

On Site Re-creation of the Fall

The staff at Pipeworks, a representative from PMI ropes and I visited Pipeworks to examine the route and try to re-create the fall. The staff at Pipeworks had kept the route intact, changed nothing and were there to answer questions and assist in the analysis. As well, the climber and the belayer were there to answer questions and help in the investigation and analysis.

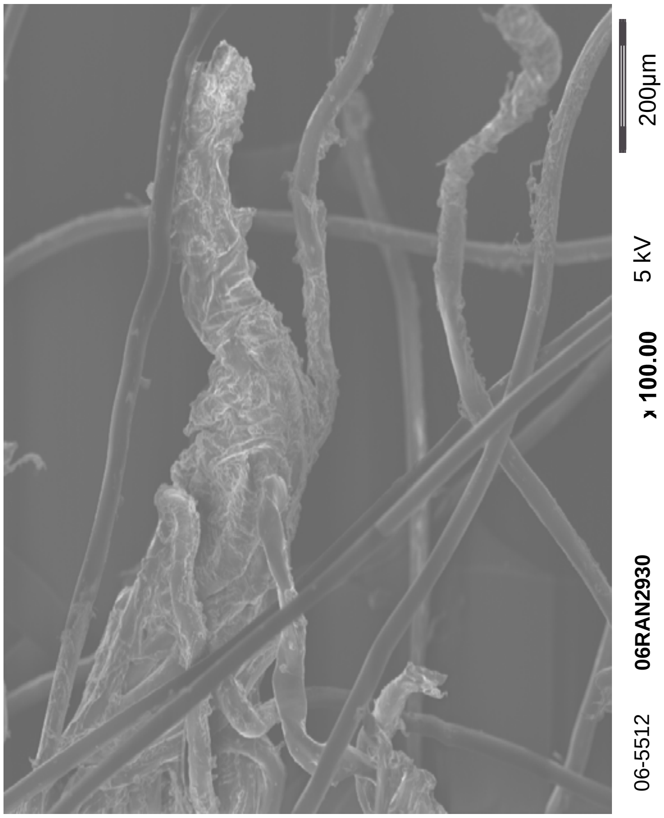
We climbed the actual route which the incident occurred, taking the identical fall using remaining sections of the Sobieski rope. We attempted to have the rope cut by forcing it behind nearby climbing holds, behind bolt hangers, being pinched in the carabiner gate, etc. The results from this test were that we could not get the rope to even come close to cutting in the terrain where the incident occurred.

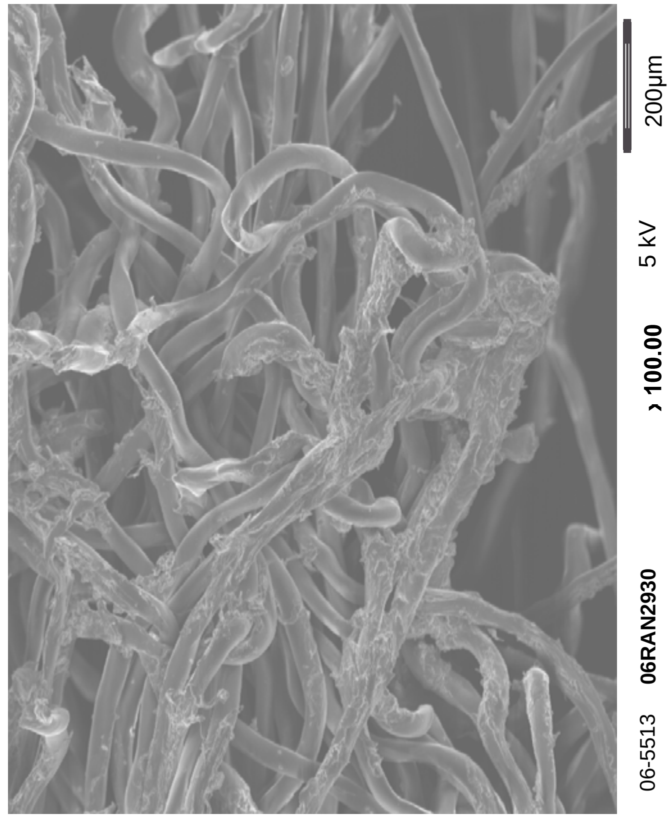
Chemical Analysis

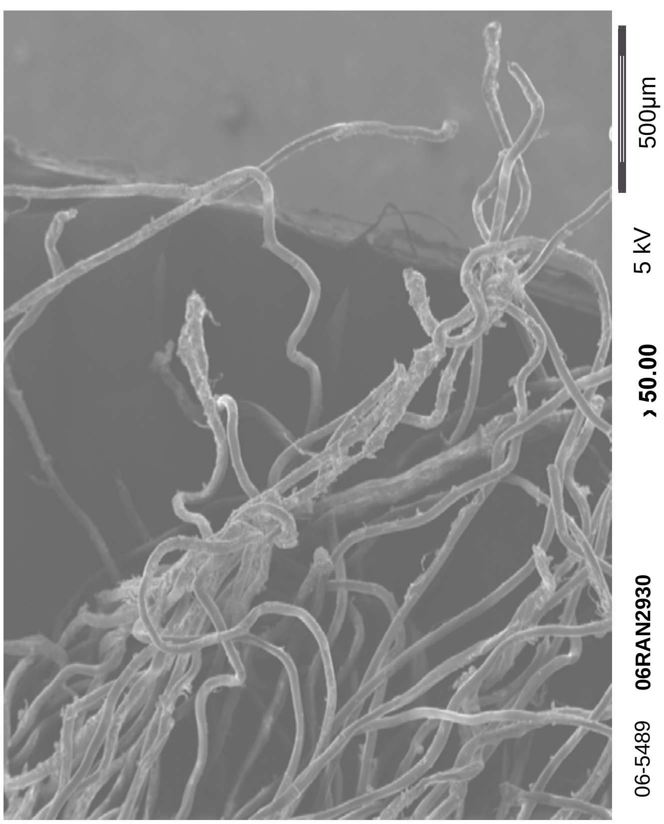
The section of the rope where the original failure occurred was sent to a Nylon manufacturer and chemical laboratory for analysis. **The results came back showing traces of sulfuric acid on the rope in the location of the rupture**. The photos on the following pages show the strands from the Sobieski rope (clean ends) compared to photos of a comparative rope when tested to ultimate failure in a UIAA drop test.

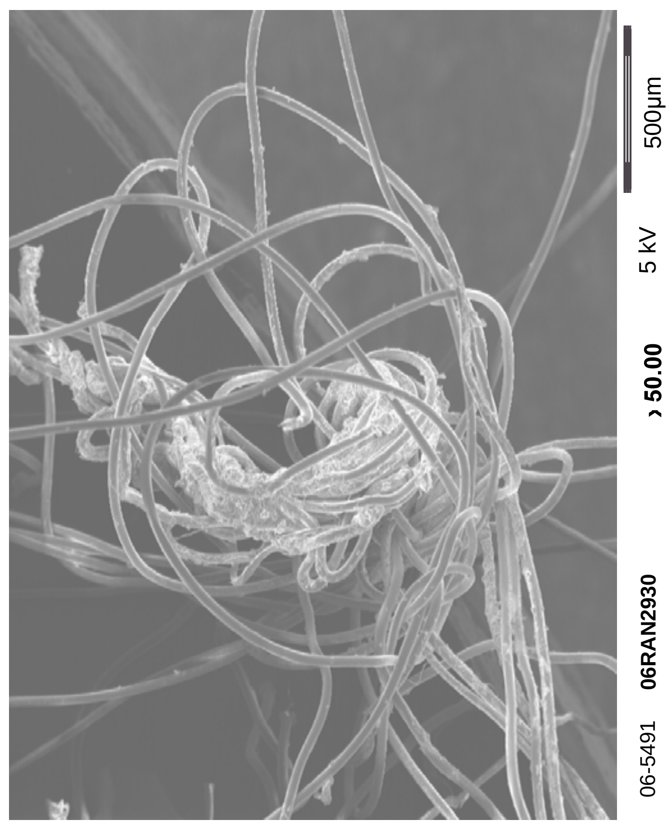
As can be seen in the photos, the strands of a standard tested rope are extremely melted whereas in the Sobieski rope in this case, there are very clean-cut strands. Note that there is no 'bulb' of melted section on the fiber ends. This too is consistent with nylon affected by acid. The acid weakens the nylon and even under low load the strands pull apart easily rather than generating heat while being pulled apart which exhibits signs of melting.

Comparative Rope

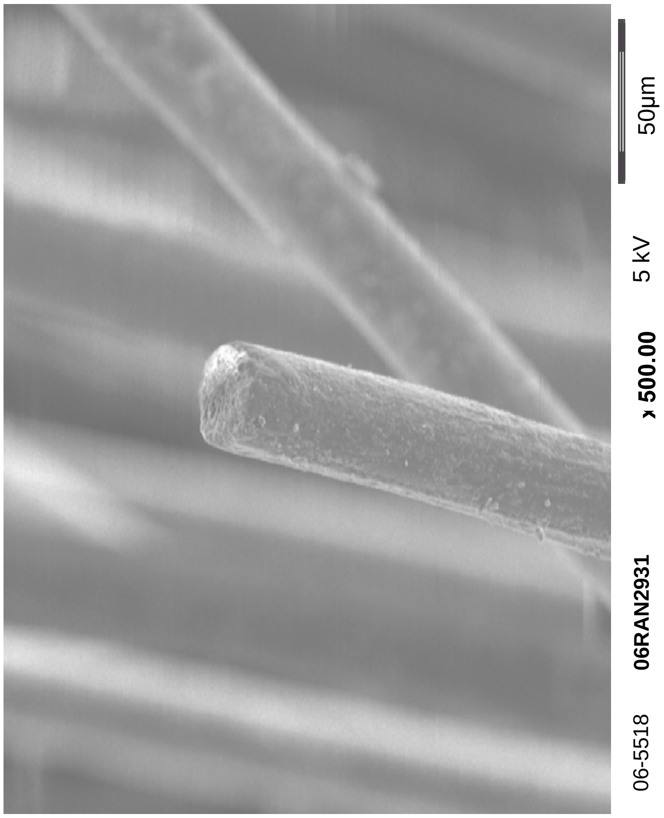








Failed Rope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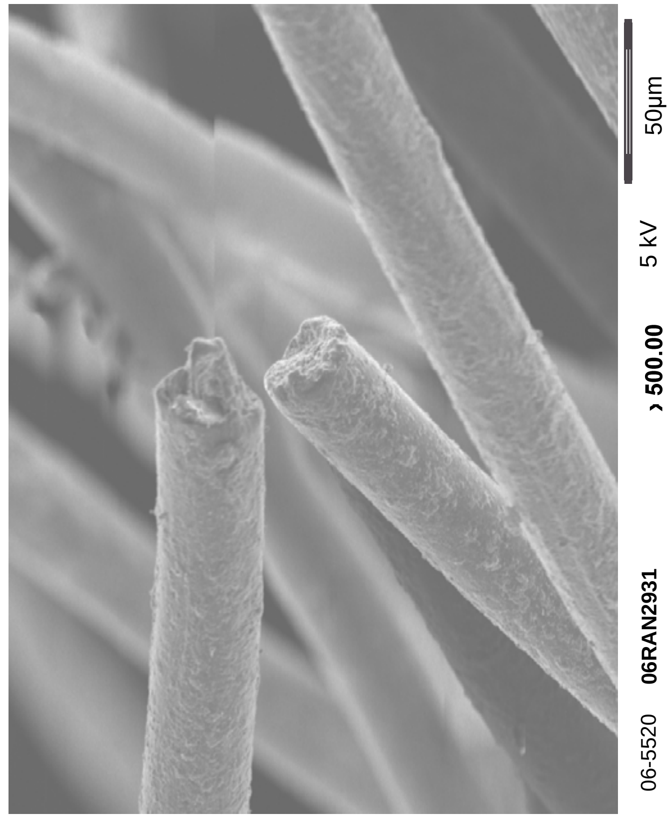
50µm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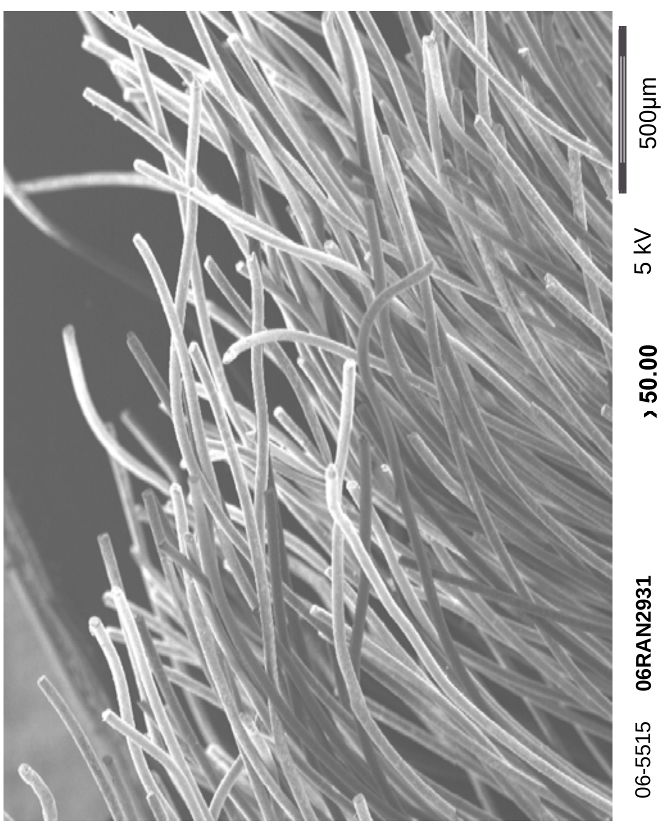
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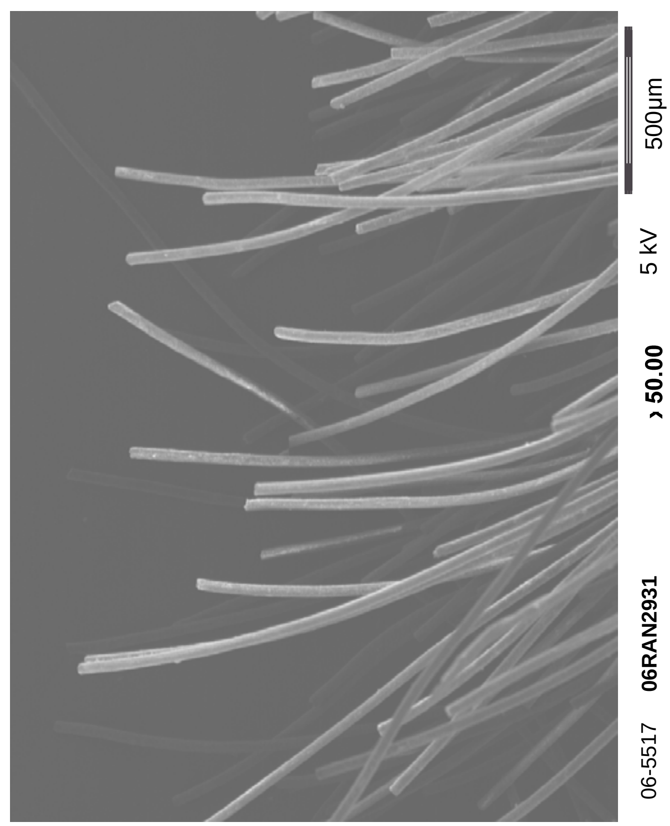
06-5517
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x50.00
5 kV
500µm

CONCLUSIONS

Based on the following:

- Typical ultimate strength of other sections of rope in tensile tests.
- Typical behavior of other sections of the Sobieski rope during extremely aggressive drop tests over biners, sharp edges, etc.
- Inability to recreate the breakage in the drop tower.
- Inability to recreate the failure on the exact route (human testing).
- Findings of the chemical analysis showing traces of sulfuric acid on the section of the rope where failure occurred.

It is apparent that **the rope was locally contaminated by sulfuric acid**. This contamination led to a weak location in the rope which ultimately failed when loaded even to a low load during the mild fall of the lead test.

FURTHER THOUGHTS

What is unknown:

1) How did the rope get contaminated with sulfuric acid?
2) How did ONLY the location in question get contaminated?

Sulfuric acid is the electrolyte found in lead-acid batteries (ie. Car batteries). It is also found in fertilizer, high powered drain cleaner, glue and some other household products. Even the vapors alone can destroy nylon.

There have been at least three other cases of ropes breaking due to sulfuric acid contamination. Details can be found in the German Language book by Pit Schubert *Sicherheit und Risiko,* as well as a short article written here: http://www.uiaa.ch/article.aspx?c=231&a=147

After discussions with the owner of the rope (belayer Dan Sobieski), it is still uncertain how the rope could have possibly come in contact with sulfuric acid. He reports that it never came in contact with a car battery and was always stored in a rope bag away from any of the other possible sources of sulfuric acid. He recalls during one of the ropes last usages prior to the incident, laying it coiled in a parking lot while racking-up – could a car battery have leaked there? Would it have been enough to cause this rope failure? And how did only the section of rope which would run over the carabiner in this particular fall get contaminated? These are answers which may never be known.

FINAL COMMENTS

I'm still a firm believer of the age old climbing adage that 'ropes just don't break'. Proper care and storage of your rope is paramount. Always use a clean rope bag and never let your rope get in contact with items which may contain sulphuric acid or other chemicals which may harm nylon. Be conscious of where you put your rope. Never throw it in the back of a pickup truck or trunk of a car that may have been used to transport old batteries or other potentially harmful chemicals.

ACKNOWLEDGEMENTS

Thanks to those who assisted in the investigation and analysis:

- Pipeworks Rock Gym
- PMI Ropes
- Beal Ropes
- Sterling Ropes
- Rhodia
- Dan Sobieski (belayer/rope owner)
- Brian Voyles (climber)

Minutes of the
2007 NSS Vertical Section Meeting
July 25, 2007

The 2007 NSS Vertical Section meeting was held Wednesday, July 25, 2007 at the Crawford County High School in Marengo, Indiana. Executive Board members present were Chair Miriam Cuddington, Secretary-Treasurer Bill Boehle, At-Large Executive Members John Woods, Brice Williams, and Ed Sira, Vertical Techniques Workshop Coordinator Terry Clark, Education/Training Coordinator Bruce Smith, and Contest Coordinator Bill Cuddington. Approximately 15 additional Vertical Section members were in attendance.

I. **Meeting opened at 1:10 PM by Chair Miriam Cuddington**
Announcements - Thank you to all who helped at the climbing contest on Monday and Tuesday. Special thank you to John Woods for coordinating and conducting the climbing gear "tune-up" discussed at last year's convention. It was very successful and productive. See additional discussion under old business below.

II. **Minutes of the Last Meeting** - were published on the website and read at the meeting. Minutes were accepted as published.

III. **Officer Reports:**
   - **Secretary's Report** - Bill Boehle. See attached. Accepted as presented.

   - **Treasurer's Report** - Bill Boehle. See attached. Accepted as presented. Regarding getting paid for the Workshop registrations collected by the conventions for us, it was suggested that it would speed things up if a bill were given to the convention treasurer right after the workshop. Lynn Fielding handles the registrations for the Vertical Workshop for Terry Clark. Terry was present and agreed that this was a good idea and would pass this suggestion along to Lynn.

   - **VS Symbolic Items** - Bill Boehle. See Treasurer's Report for sales numbers. We restocked the sizes and colors of sweats and T-shirts that we were out of. I can't fill orders if we don't have what the members want. Still thinking of producing a bandanna with vertical devices and equipment on it. Need to finalize a design and get a production estimate. A volunteer good at computer graphic design to assist in producing the photo-ready artwork needed for this project would be appreciated. The single silkscreen artwork of the section logo that was produced for the Instructor T-shirts is now available for any other projects that we may have in the future. Members have also inquired about the possibility of hats with our logo. I am looking into costs either using our patch or directly embroidering the logo on the hat. Costs will dictate if that becomes available. The new Vertical Instructor T-shirts (36) were given to Terry Clark. He and his committee will determine how and to whom they will be distributed. They are intended to both identify the instructors at the workshop as well as to reward those instructors who have provided long time service to this section activity. Section logo pins are also in short supply. Costs for production still need to be investigated. Will look into the traditional triangular pin as well as a variation with the yellow triangular design set into a red circular background. This may be cheaper to produce as well as making the logo "pop" out of the background. This will be run by the Executive Board before finalizing any purchase.

- **Nylon Highway Editor's Report:** -
  Information from Tim White (not present) relayed by Miriam. Tim is willing to continue as Nylon Highway editor.

IV. **Committee Reports:**

- **Contest:** Bill Cuddington -
  When setting up the ropes in the gym, we need to get the contest ropes done first. This will allow us to start the contest on time, including early climbs by contest staff and workers. Thanks to all who help during the vertical contest. We can always use more help. Whether you can only spend a little time or a lot, it all adds up. Without help it would be impossible to run the contest. We appreciate any help from section members and others with timing, pulling rope, running the rack (the racketteers), etc. This year we had 8 Age Group Records set in the contest. We need more younger climbers entering the contest. They are the future of the section. The contest is a race, but it functions as a workshop as well. People come in with new rigs and get to work out any problems they may have with their setup. If you can't use your rig under ideal conditions, it probably won't work in a cave. Thanks to PMI for donating 1200 feet of rope for the contest. The ropes will be cut up for use as prizes. Awards will be given out on Friday at 1:00 PM.

- **Vertical Workshop:** Terry Clark -
  The Vertical Workshop may not have happened without the tremendous help of Mike Rusin. Mike spent a lot of time with Terry rigging the workshop ropes. Terry must have more help with this big job. More helping hands would make this tough job easier. Rigging is always done Monday morning starting about 8:00 to 8:30 am. Rigging needs to be done quickly and efficiently so that the climbing contest, gear tune-up, and rebelay course can all start on schedule. This can't be accomplished without help. It was suggested that help could be requested from the convention volunteer coordinators for people that could assist with moving all the heavy equipment needed into the gym. This would free up trained riggers to have more time to do the actual rigging. Terry and Lynn have decided on their criteria for giving out the new Vertical Instructor T-shirts. Instructors with three or more years of service to the section in this activity will earn their T-shirt in recognition of their continuing support. The workshop continues to be a big success. This is due in no small part to Lynn Fielding's work with registration and coordination, and to all the instructors who volunteer their time to ensure that people learn good vertical technique. Terry also noted that we have been spending some time at convention teaching vertical technique specifically to the JSS. He believes this is time well spent instructing the next generation on proper vertical caving technique.

- **Education:** Bruce Smith -
  This convention marks the 20th anniversary of the release of "On Rope". There have been 10 reprints in that time, with an 11th reprint scheduled (there are less than 300 copies remaining in stock). It has been the largest selling book for the NSS in every year for the last 20 years. It is also being reprinted now in Spanish. This success has been due to all the efforts of the section members who have participated in the many phases of this project over the years. Allan and Bruce were asked to review the book, once again, for a possible Version 3. They don't think that may be necessary, since no major revisions/updates appear to be needed. A bunch of minor "tweaks" of some information could be handled before a 12th printing would take place.

  Basic Training Course - There have been a lot of requests for this course. We are cleaning up the procedures for the ordering, invoicing, and mailing of these manuals. This will allow better communication and coordination between the Editor and Treasurer. Bill Boehle noted that similar procedures need to be followed regarding the production and distribution of the Nylon Highway annual volumes for those who have paid for them.

Intermediate Training Course - Much time has been invested up to this point on what skills should be included in this course. Bruce continues to have a problem with "HOW" to teach this course. This is not an NCRC course and some types of skills are better handled there. This course is intended for leaders so that they can properly teach many complex skills that they must be able to demonstrate as part of the course. These are laid out in Chapter 12 of On Rope. This involves a lot of time and expensive equipment and raises many logistical problems that Bruce has no easy solutions to. Bruce is stuck and out of ideas. Section ideas are desperately needed and feedback is requested. This may be something that is does not lend itself to a single course, but is learned through time and practice. Perhaps acquired skills could be demonstrated/certified in some to-be-determined forum. Certification could result in liability issues. Various ideas were kicked around. Different grottoes do different things regarding vertical training. The creation and use of instructional videos/DVDs was raised. Bruce stated that is under consideration, with some recent discussion with Dave Socky. These would be helpful to convey demonstrations of complex skills.

- **Rebelay Course:** Gary Bush and John Woods -
  This year there were about 15 people signed up for the rope course, although many spectators sat in and observed during the orientation/demonstration portion. It was well received by all who participated.

- **Web Page:** Gary Bush, webmaster - No report submitted this year.

V. **Old Business:**

- John Woods reports that 40 to 50 people showed up for the vertical gear tune-up prior to the re-belay course. Unfortunately they kept trickling in and this was not efficient for the instructors who helped, and resulted in delays in getting the re-belay training started in a timely manner. It might be better to establish a cutoff time to avoid backups that effect the rest of the schedule of activities. Thanks to the 8 or so instructors who pitched in to help with this. Initially John thought they were okay with the 3 to 4 precommitted instructors, but they were soon overwhelmed with the crowds that showed up. Additional instructors stepped in to help. The consensus was that people have a lot of problems with their gear, especially with "frog" systems. Much improper gear needed to be replaced or upgraded. John noted the the speleo-venders who provided this gear were VERY happy. There was much positive feedback from the participants and confirmed the need for this type of activity. However, we need to be sure we are not over-extending ourselves. In the future we need better scheduling, more available ropes (at least 3), and more precommitted instructors. Although we don't want to turn people away, maybe we need to limit students if we can't resolve the manpower and other issues.

- No other old business from the floor.

VI. **New Business:**

- Bob Thrun raised issues related to the Nylon Highway on the web. Issues are in HTML and are difficult to download and print. Also complained that the early out-of-print issues that are posted as PDFs are of low or poor quality. He thinks that Adobe Acrobat could be used to produce a higher quality PDF file. Gary Bush responded that he generally agreed with Bob. However, when the web issues were first produced starting with the post 43 issue, many members were still using dial-up connections to access the internet. Producing the issues in HTML allowed users with slow connections to more easily access the information. Now that Gary is retired, he intends to recompile the post 43 issues as high quality PDFs for those with high speed connections.

- Gary Storrick reminded people that he brought his vertical equipment collection to this years convention and invited all to stop by and look at it. He thanked those who helped him set it up.

- Ed Sira suggested that we should enter the new Vertical Instructors T-shirt in next conventions Symbolic Items contest. [Note: Since Terry Clark has all the shirts, he would need to submit the entry.]

VII. **Elections:**

- **Secretary/Treasurer** (1-year term) - Bill Boehle was nominated and reelected by acclamation.

- **Editor** (1-year term) - Tim White was nominated and reelected by acclamation.

- **At-Large Board Members** (2-year term, 2 to be elected) - Miriam Cuddington and Brice Williams were nominated. A ballot of the section members present was not required. Miriam Cuddington and Brice Williams were elected by acclamation. [Note: Current At-Large members Ed Sira and John Woods have 1 year remaining in their terms.]

VIII. **Motion to Adjourn:**

Motion to adjourn was made and carried. Time of adjournment was approximately 2:40 PM.

[Additional note: Subsequent to the Meeting, the Board Members elected Brice Williams as Chair. The three appointed members were re-appointed to serve for another year. They are:

- Contest Committee - Bill Cuddington
- Vertical Techniques Workshop Committee - Terry Clark
- Education Committee - Bruce Smith]

Respectfully Submitted,
Bill Boehle

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NSS VERTICAL SECTION

SECRETARY'S REPORT

JULY, 2007

By Bill Boehle

Number of Members (current/expired)	....	163
Number of Members Current as of 2007	....	76
Number of Subscribers Current as of 2007	....	5
Number of Annual Volumes Paid for 2007	....	12
Number of Complementary Subscriptions	....	3

YEARS PAID:	MEMBER	SUBSCRIBER	ANNUAL VOLUME
Comps	--	--	3
2007	38	1	7
2008	23	2	3
2009	11	1	2
2010	1	0	0
2011	1	0	0
2012	2	0	0
2007 TOTALS:	76	5	15
Expired 2006:	87	10	
TOTALS:	163		

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NSS VERTICAL SECTION
TREASURER'S REPORT
JULY, 2007
By Bill Boehle

INCOME:

New Memberships, Subscriptions, & Renewals	.... $ 231.00
Nylon Highway Annual Volume Sales	.... $ 180.00
2006 Convention Workshop Registrations (not received)	.... $ 0.00
Vertical Training Course Sales	.... $ 127.00
Symbolic Item Sales	.... $ 271.00
Nylon Highway Back Issue Sales	.... $ 14.25
Shipping/Postage Charges	.... $ 10.98
Donations	.... $ 0.00
Bank Interest (GMAC) July 2006 - June 2007	.... $ 495.52
Reserved	.... $ 0.00
TOTAL INCOME	**$1,329.75**

EXPENSES:

Shipping/Postage Costs	.... $ 10.97
2006 VTW Transportation Subsidy (Terry Clark)	.... $ 580.00
2006 Climbing Contest prizes	.... $ 82.50
NH Annual Volume Production & Mailing Costs (1)	.... $ 0.00
Symbolic Items Restocking (T-shirts, Sweats)	.... $1,182.10
Vertical Instructor T-shirts	.... $ 315.60
New Vertical Contest Record Boards	.... $ 97.60
Vertical Workshop Supplies (Howie's Harnesses)	.... $ 20.00
Printing - Climbing Contest Certificates	.... $ 126.85
Photocopying for NSS Convention paperwork	.... $ 5.78
Reserved	.... $ 0.00
TOTAL EXPENSES	**$2,421.40**

ACCOUNT BALANCES:

Commerce Bank (NJ)	.... $3,424.68
GMAC	.... $8,821.56
BALANCE ON HAND:	.... **$12,246.24**

(1) Not Yet Billed by Nylon Highway Editor

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