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Industrial rope access - Investigation into items of personal protective equipment

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Industrial rope access - Investigation into items of personal protective equipment

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An investigation into items of equipment used for work at height in industrial rope access and arboriculture. Techniques and equipment used in these areas have evolved rapidly in the last 15 years, opening up new working methods which are being deployed in equally rapidly expanding areas. The investigation comprises tests and evaluations of ropes and associated items such as lanyards, cow's tails, termination and other knots, and rope protectors. It proceeds to look at items of equipment which are attached to working and safety ropes to allow movement in all directions along them. These so-called rope adjustment devices include back-up devices, ascenders and descenders.

Testing included worst-case scenario dynamic loadings, some fall factor 2, and others fall factor 1. Evaluation includes discussion on how rope access and work-positioning may be effected using the items tested to minimise or eliminate falls.

Reference has been made to existing and draft European standards, in particular, prEN 12841 (May 2000) Personal protective equipment for the prevention of falls from a height: Rope Access Work positioning systems – Rope adjustment devices, BS EN 1891:1998 Personal protective equipment for the prevention of falls from a height – Low stretch kernmantel ropes and BS EN 353-2:1993 Personal protective equipment for the prevention of falls from a height: guided type fall arresters.

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HSE BOOKS

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1 PRINCIPLES

1.1 INTRODUCTION

Developments in equipment and techniques for climbing and potholing during the 1970's led to new, faster and lighter ways of moving around in vertical environments. These sporting developments were adopted for use in the workplace after appropriate modifications and development of the techniques, including the addition of extra safety measures. This method of work became known as rope access.

Rope access has taken the last decade to become generally accepted as a valid way to work at height. Initial reservations were fuelled by a perceived danger of workers dangling from insubstantial ropes and by the employment of cavers and climbers without specific industrial training. Perhaps the (now archaic) French term for rope access – travaux acrobatiques – sums up these old perceptions.

The approach adopted by the United Kingdom's Industrial Rope Access Trade Association (IRATA)[1] may be summed up as the integration of rigorous work procedures and operator training. This, coupled with a growing statistical record of safe work, has led to a gradual re-assessment of rope access in the workplace. It enables workers undertaking temporary work to access difficult places quickly and relatively cheaply, and to undertake inspections and a wide range of stabilising and other works.

Because this is a relatively new field of work, there has been little co-ordinated research into the equipment employed, which is presently governed largely by standards for fall arrest and for mountaineering equipment. This research, undertaken for the Health & Safety Executive (HSE), is designed to shed light into the characteristics, capabilities and limitations of some of the main components in the work system.

In addition to rope access, the versatility of the new methods and equipment is influencing the techniques used by arboriculturalists, steeplejacks, theatre riggers and others. The results of this research will thus also have some relevance to work at height in general, however it is performed.

A vital concept in understanding the equipment used in rope access is that of the 'safety chain', whereby no one component is more important than the others in the system. Like any work system, the rope access work system must be inspected, at regular intervals, for weak links in the chain so that any problems can then be eliminated.

To make all the equipment used in work at height intrinsically foolproof would be to make work methods impractically slow, cumbersome and expensive, and would inhibit innovation and development. As a result, all the equipment is open to misuse, making proper training vital. With the right training work situations, perceived to be potentially dangerous, can be tackled with minimal risk.

A key feature of equipment for rope access is versatility. Almost all rope adjustment devices will have secondary uses, especially during rigging for rescues, etc. This reduces the amount of hardware an operative has to carry and increases their operational abilities and safety margin.

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[1] INDUSTRIAL ROPE ACCESS TRADE ASSOCIATION
Association House, 235 Ash Road, Aldershot, Hampshire, GU12 4DD

1.2 AIMS, OBJECTIVES AND SCOPE

1.2.1 Aim

The aim of the research was to examine the characteristics and behaviour of certain items of Personal Protective Equipment (PPE).

1.2.2 Objectives

The objective was to obtain knowledge of the performance of the equipment and to comment on ways that it might be improved.

1.2.3 Scope

The research covered equipment used in the following areas of work:

- Rope access
- Work positioning
- Fall arrest
- Arboriculture

1.2.4 Equipment

The following types of equipment were tested:

- Ropes
- Back-up devices
- Ascenders
- Descenders
- Lanyards: fall arrest and cow's tails
- Knots: termination and prusik
- Anchorage loadings
- Rope protectors

Equipment beyond this core section of the safety chain (e.g. harnesses and helmets) was not covered. Similarly the connectors (e.g. karabiners and screw link connectors), used as links within the chain, were also beyond the remit of the project. Although these areas were not investigated, this does not imply there is no scope for work on them. Anchorages themselves were not tested, although the forces applied to them in a typical work situation were studied.

The criteria used in selecting equipment for test were as follows:

- products currently in use (Deduced by circulation of a questionnaire, see Appendix 2 for a summary of the replies)
- new or soon to be available products
- products available on the United Kingdom market and working on different principles to those in the two categories above.

1.3 QUESTIONNAIRE

A questionnaire was circulated to industrial users of rope access equipment. This included arboriculturalists and theatre riggers as well as rope access technicians.

The objective was to gain an insight into what equipment was being used in the workplace, how it was being used and why.

Within rope access the techniques are fairly standard, although variations exist. In the worlds of arboriculture and theatre rigging, however, techniques are far more varied.

A summary of the replies is provided in the Appendix. The summary includes both statistics and comments provided by the respondents. The questionnaire was circulated primarily to rope access workers. The comments are particularly useful as technicians often use equipment provided and chosen by their employers. Hence, data on what equipment is in use do not necessarily reflect user choice. It was not possible to circulate the questionnaire more widely.

1.4 TESTING

1.4.1 General

A variety of tests was used to assess the performance of the equipment. Where appropriate these were taken from either established or provisional standards. However, in some circumstances new tests had to be devised. The aim was always to produce results that were both relevant and impartial, i.e. the tests must not have been designed to favour a particular device.

1.4.2 Criteria

It was clearly important to test items of PPE against standards. It also seemed prudent to 'road-test' them in the manner in which they would be used.

Items that produce impressive test results on paper may well prove to be impractical and ultimately unusable in a work situation. This is due to a number of factors. Firstly, standards do not specify a method of use. In order to produce comparable results, all items were tested in the same manner irrespective of their recommended method of use. Clearly, this would not allow some items to perform as well as they might. Therefore, both the tests and the results had to be carefully assessed in accordance with the relevant method of use.

Secondly, the ease of use of the item had to be considered. Irrespective of test performance and methods of use, a key measure of the value of a piece of equipment is its acceptability by the user: the device will not be used if it is not user-friendly. It is therefore inevitable that this aspect of the test programme was to some extent a product review from the user's point of view. While this type of test will always be less objective than scientific tests, and preferences will always vary from person to person, impartiality was of paramount importance and every attempt was made to limit subjectivity.

To give new products a chance against established favourites, all devices were used by both IRATA level 3 and level 1 Rope Access Technicians. While the level 3 Technicians' expertise and experience were invaluable in such a test, the level 1 Technician is likely to be less familiar with all the equipment, and therefore, hopefully, less biased against unfamiliar equipment and will be more open to change.

While in some circumstances the practical performance will outweigh the test results, ideally items of equipment needed to excel in both practical and technical areas.

1.4.3 Verification

For the tests to be valid, it was essential to make them reproducible, allowing for verification of results, either by the test team or by anyone with similar test facilities.

To achieve this all test set-ups were made to be as simple as possible. Replicating tests (usually 3 times) highlighted tests where variations were likely. Where initial tests indicated that the results would not vary, such replication was curtailed.

1.4.4 Methods

In the device testing programme, the Provisional European Standard (prEN) 12841 (May 2000)[2] was used as the starting point for the test methods. Results were not correlated directly to the requirements of what is, at the time of writing, a draft standard. The concern was with relative performance rather than the simple pass or fail criteria of the draft standard.

Only tests that dealt directly with the function of the devices were attempted. All the tests were performed on new equipment with no attempts made to replicate wear or contamination by mud, dust, etc. Tests specified in prEN 12841, but beyond the scope of the project, for example, conditioning to oil, were not attempted. During the tests, monitoring included not only the performance of the devices but also that of the test itself. This allowed assessment of the suitability of the tests for the devices concerned.

During the test programme the rationale behind some of the specified test parameters from prEN 12841 was unclear. Attempts were made in these cases to discover the original justifications behind them. In the report, therefore, every attempt is made to explain the purpose of each test.

Additional tests were then designed to address areas not covered by prEN 12841. In most cases a document search revealed applicable tests in previous standards, but in a few cases, notably edge protection, new tests had to be designed.

For a detailed description of test methods, machines and locations see the Appendix.

1.4.5 Limitations of results

All tests suffer from attempts to standardise real situations. Practical deployment of the types of equipment to be tested involves differing weights, directions of loading, combinations of items, etc. No two operatives are exactly the same size and weight, and no two falls will load the equipment in exactly the same manner. On the other hand, the tests performed have to isolate the component in question, be standardised, and be repeatable. In order to address this the aim was to examine only the worst-case scenario. The unavoidable result of this is that the tests were, by necessity, harsh. In addition, worst-case scenarios often occur when equipment is subject to slight misuse. The magnitude of this was carefully examined when designing the tests. The level of misuse had to be conceivable during normal operation, arising for example, from carelessness or haste. More serious levels of misuse could not be addressed, since they become irrelevant in normal operation by trained personnel. In some cases, the final tests may represent more-than worst-case scenarios – for example where all elasticity is taken out of a test, but would always be present to dampen peak forces in a real situation. Thus the results from these tests reflect the harshest of possible regimes.

In all cases, results are presented in the report in an interpreted form. Raw data is available in the Appendices. However, without an exhaustive understanding of the test methods and recording equipment used interpretation can be difficult.

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[2] BRITISH STANDARDS INSTITUTION (BSI),
prEN 12841: May 2000 Personal protective equipment for prevention of falls from a height: Rope Access Work positioning systems - Rope adjustment devices

All the results are strictly comparative: i.e. 'good' results and 'bad' results relate only to better or worse performance when compared to other devices. 'Bad' results do not, therefore, necessarily mean a device is dangerous, but that other devices will be more effective in a similar situation. Where devices do perform in a manner that could prove dangerous this is clearly indicated.

Good test performance is only part of what makes a safe device. If the device is not user-friendly, experience has shown that it will not be used.

2 ROPES

2.1 INTRODUCTION

Ropes are the primary element in a rope access system. They are the highway along which the operative travels, up, down, and even sideways. They are the core of the progression and the safety systems. They must be selected - and used - with care.

Ropes used for the suspension of persons require a significant degree of shock-load absorbency. In this respect, rope technology has reached a plateau, with no fundamental changes, in the textiles or constructions used, in the past two decades. In fact, just one polymer predominates – polyamide. Other materials may be used in particular circumstances (polyester, steel) but only with special safeguards due to their lack of appropriate elasticity and ability to absorb energy.

It was beyond the scope of this project to conduct exhaustive tests of ropes in isolation. Rope technology and standards are well developed and understood. Rope, representative of the types used in rope access, was used in conjunction with all the rope adjustment devices, and with knotted terminations. The performance of the ***combination*** of rope and device together is of key importance.

2.2 ROPE TYPES

There are two standards relevant to ropes for use in climbing and the suspension of personnel. Both are of 'kernmantel' sheath and core constructions.

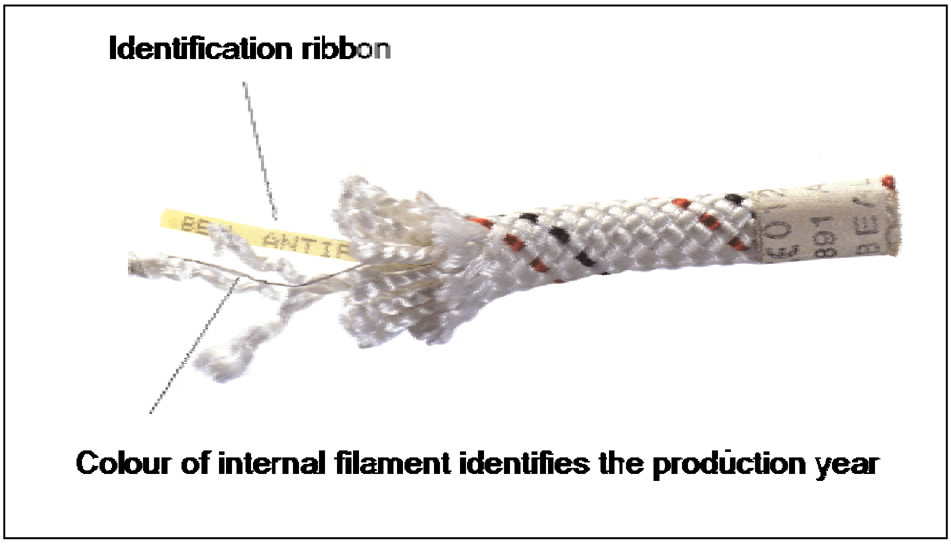

Figure 1
Kernmantel rope showing sheath and core construction of low stretch rope

For most rope access purposes, the appropriate Standard is BS EN 1891.[3]

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[3] BRITISH STANDARDS INSTITUTION
BS EN 1891: 1998 Personal protective equipment for the prevention of falls from a height - Low stretch kernmantel ropes

This standard has two categories, or types, A and B. Only type A ropes are recommended for work purposes. Both types of rope have low extension during normal working procedures, but they have sufficient stretch to dissipate the type of forces likely to be generated by the progression of operatives along them, up to those generated by a fall from the anchor point. (This severity of fall, where the distance travelled before arrest equals the length of rope arresting the fall, is known as fall factor 1).

The sheath on low-stretch ropes is generally thicker than that of dynamic ropes, specifically to withstand the wear and tear of rope adjustment devices.

Type A ropes, to BS EN 1891, can be from 10 mm to 16 mm in diameter. However, the industry ‘norm’ is 10.5 mm, and so three different ropes of this diameter were chosen for the tests:

Table 1
Details of the Type A low stretch ropes used in the tests

Manufacturer	Rope name	Diameter (mm) (nominal)	Weight (gm/m)	Static strength (kN)	Sheath/core ratio (%)
Beal	*Antipodes*	10.5	65.0	27.0	38/ 62
Edelrid	*Softstatic*	10.5	67.0	29.9	41/ 59
Marlow	*Static*	10.5	69.7	32.9	37/ 63*

All figures are from manufacturer’s data sheets except where marked- this was measured during the project.*

All were soaked in tap water and dried (conditioned) before use, according to the manufacturers’ instructions.

In certain applications, where greater elasticity is required, the appropriate rope will be a dynamic rope complying with BS EN 892[4]. This standard specifies single, half and twin ropes. Only single dynamic rope is generally applicable to work purposes. It should be deployed in circumstances where a fall greater than Factor 1 could be encountered – in simple terms a fall from above the position of the anchor. In practical terms this means where ropes are used for lead climbing or to make cow’s tails, a type of attachment lanyard or link.

Single dynamic ropes on the market vary in diameter from 9.4 mm to 11 mm. A rope at the upper end of this size range is recommended for work use. The following table shows the rope which was chosen as being reasonably representative of this type of rope:

Table 2
Details of dynamic rope used during the tests

Manufacturer	Rope name	Diameter (mm) (nominal)	Weight (gm/m)	Impact force (FF2, 80 kg mass) (kN)	Sheath/core ratio (%)
Beal	*Apollo*	11	78	7.4	30/ 70*

All figures are manufacturer’s stated except where marked- measured during the project.*
(FF2 means fall factor 2)

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[4] BRITISH STANDARDS INSTITUTION
BS EN 892: 1997 Mountaineering equipment - Dynamic mountaineering ropes - Safety requirements and test methods

The ropes are all fundamentally of the same construction. Parameters that vary slightly between manufacturers include sheath thickness (expressed as a percentage of the total rope mass), the tightness of the sheath, the tightness of the sheath on to the core, and core construction. These combine to give the rope its feel and character.

To create dynamic rope similar original fibres are used, but they are heat-treated before construction of the rope. This makes them retract (shrink) and become more elastic, giving them better ability to absorb dynamic shock loads.

Different uses require ropes of different constructions: for heavy-duty use, e.g. in arboriculture, a thicker sheath may be required to counter the high levels of abrasion.

All the tests (except on prusik knots) were carried out with new, unused ropes, which were conditioned before testing. The behaviour of ropes may be expected to change during their lifetime. Investigation of the performance of used ropes will require further research.

During the test programme attempts were made to investigate the effect that various environmental factors have on rope strength. One sample of ropes was subjected to weathering, one to rust, and one to both weathering and bird droppings. Ideally, these ropes should then have had the worst sections subjected to an ultimate static strength test. However, due to the difficulty of achieving this (see section 2.3) the ropes were tested as short lanyards consisting of two overhand knots. A full description of the method is included under the heading of Knots (see Chapter 3). As the method was then identical for the termination knots, the results could be directly compared.

2.3 ULTIMATE STATIC STRENGTH

By using Beal's static test rig in Vienne, France, it was possible to test ropes to their ultimate static breaking strength.

Obtaining the ultimate static strength of a low stretch rope requires a special arrangement for gripping the ends of the rope. Each end of the rope is wrapped around a capstan before being fixed in a clamp. In this way the load in the rope at the clamp is reduced and slippage at the clamps is avoided.

Due to time restraints only a small number of samples were tested, however these were sufficient to gain a representative result.

The aim was to test both new samples of rope and some that had been damaged during the dynamic tests.

The ropes that had been used in the dynamic tests on the Petzl Microcender rope adjustment device were chosen, as they showed localised damage to the sheath, which appeared to be severe. By placing the damaged section between the test capstans, it was possible to ascertain whether the damage affected the ultimate strength of the rope.

Two initial tests carried out on new Edelrid 10.5 mm rope gave peak forces of 28.4 kN and 28.9 kN. A sample that had suffered light glazing showed no decrease in strength, while the sample that had been damaged in the Microcender tests showed a very slight strength decrease, breaking at 27 kN. Tests on a Microcender-damaged section of Beal 10.5 mm showed a lower strength of 24.5 kN.

In the final test a piece of lightly glazed Marlow 10.5 mm rope was tested, which gave a high peak force of 31 kN. As all these figures are higher than even the strongest knot, it is reasonable to assume that even heavy glazing will not cause weakening of the rope to a point where it becomes dangerous.

These figures may be compared to the manufacturers' stated breaking strengths given in Table 1.

Table 3
Ultimate strength of low stretch ropes

Manufacturer	Diameter (mm)	Force (kN)	Condition of rope (all low stretch)
Edelrid	10.5	28.4 – 28.9	New, unused
Edelrid	10.5	28.0 – 30.0	Light glazing
Edelrid	10.5	27.0	Nominal damage (Microcender dynamic test)
Beal	10.5	24.5	Nominal damage (Microcender dynamic test)
Marlow	10.5	31.0	Light glazing

2.4 ROPES: SUMMARY

Throughout the device testing programme clear differences were observed between the low stretch ropes.

The Edelrid rope was the supplest and the most slick, while the Marlow rope was much stiffer. Devices on the latter tended to slip less. In dynamic tests on Type A and Type C rope adjustment devices, the greatest slippage was seen on Edelrid, the least on Marlow and with intermediate slippage on Beal.

These differences can be explained by differences in manufacture. The main difference is that Edelrid ropes are, in effect, dry treated during their manufacture, although they are not marketed as such. This treatment reduces the effect of the conditioning that was given to all the ropes before testing. This is reflected in the manufacturers' figures for shrinkage in water: Edelrid 2.3%, Beal 4%, Marlow 3.2%.

When the ropes are soaked, the sheath shrinks and tightens around the core resulting in a stiffer rope. In the case of the Edelrid rope, this does not occur to the same extent and the rope remains supple, allowing easier slippage of devices. It can be surmised that slippage is likely to decrease with use, although this remains to be tested.

As only one dynamic rope was used in the test programme, comparative testing was not possible. The main use was to test the strength and energy-absorbing abilities of knots. The other use was to test the performance of back-up devices if used on such a rope.

3 KNOTS

3.1 INTRODUCTION

Termination knots enable a termination to be made at any point along the rope's length. Most create loops, which are then used to attach the rope to anchors.

Exceptions are: firstly, rope-connecting knots which do just that! The double fisherman's was the only knot of this type tested. Secondly, hitching knots, for hitching to a post. The post can be anything from a tree trunk to the 10 mm bar of a karabiner. Again, only one knot of this type was tested, the clove hitch.

Different knots are used in different situations. The tests produced ultimate force strength figures for each knot. By comparing these figures to the ultimate breaking force of the rope itself, a percentage figure can also be presented for the strength of the knot.

Slight variations above and below a knot's average strength are inevitable. These may or may not be related to how the knot is tied.

In a simple knot, such as a bowline, it is difficult to see any difference between one knot and another, whereas in a figure-of-eight subtle differences can be identified. These are largely due to slight twists imparted as the rope is tied. These may even be present in a well 'dressed' knot.

A knot's strength depends largely on the radius of the first bend as the loaded end of the rope enters the knot. A very tight bend will result in a weaker knot than one with a more gradual bend.

In the more complex knots, several parameters can be altered, within the internal geometry of the knot, by tying them slightly differently. Preliminary tests were carried out to identify how these variations affect strength. In the main tests these variations were considered (see section 3.2 Methods, paragraph 3).

3.2 METHODS

The knots were tested by making up a short lanyard with approximately 200 mm length of rope between two near identical knots at each end. This was then pre-tensioned on the test rig to a force of 2 kN. It was then left to relax for a minimum of thirty minutes.

No standard exists for testing knots: the standard for slings, BS EN 566: 1997[5], specifies an extension rate of 500 mm per minute. This rate was used to test the knots. The lanyard was then tested to destruction and the maximum force sustained was recorded. This was repeated three times, for each knot and rope combination, to illustrate the potential for varying strengths, and to reduce the risk of aberration-derived inaccuracies.

Where knots are complex enough to allow slight permutations this set-up enables them to be tested against each other to find the weakest. By using the strongest permutation at both ends the maximum possible strength for the knot can be found, and vice-versa for the weakest. As each test consisted of three samples, a representative cross-section of results could then be produced for each knot.

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[5] BRITISH STANDARDS INSTITUTION
BS EN 566:1997 Mountaineering equipment – Slings – Safety requirements and test methods

3.3 RESULTS

The main body of results is presented in graphical form, as both absolute and percentage figures (see Figures 12 & 13). Numerical results can be found in the Appendix. The principal conclusion of the tests is that there is no cause for concern over knots. No knot was found to reduce rope strength to less than 55% of its absolute strength, with the majority being considerably stronger.

While one knot's average strength may be greater than that of another's there is considerable variation between individual test values. For example, it cannot be guaranteed that a figure-of-nine knot will always be stronger than an overhand knot. Larger variations are generally due to the permutations mentioned above: in the simpler knots, the reasons are less obvious.

3.3.1 Double overhand knot

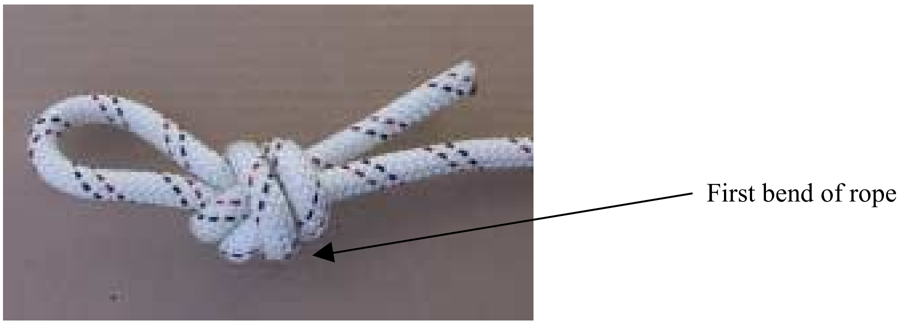

Figure 2
Double overhand knot

This is the simplest knot that forms a secure loop in the rope. It is very easy to tie but very difficult to undo after loading.

In all cases, failure occurs in the same place: where the loaded rope first rounds the loop. Whether it rounds the loop above or below the loose end can affect strength by up to 10%. In the overhand knot, it is stronger if the working rope lies above the rope end.

In the tests, overhand knots retained between 58% and 68% of the rope full strength.

3.3.2 Double figure-of-eight knot

Figure 3
Double figure-of-eight knot

Adding an extra half-turn to a double overhand knot creates a double figure-of-eight knot, a very common knot in both rope access and mountaineering. It is both stronger and easier to undo than the double-overhand knot while still being of fairly low bulk.

Unlike the double overhand and double figure-of-nine knots the rope positions in the first bend do not appear to have a marked effect on diminution of strength.

In the tests, the double figure-of-eight knot retained between 66% and 77% of the rope's full strength.

3.3.3 Double figure-of-nine knot

Figure 4
Double figure-of-nine knot

Another half-turn to the double figure-of-eight creates the double figure-of-nine. It is slightly stronger again and even easier to undo. Again it is very common in rope access, particularly for securing to anchors, where ease of undoing is more important than bulk.

Unlike the double overhand, it is stronger if the loaded end lies underneath the loose end in the knot.

In the tests, it had the widest range of test values of all the knots tested, with values ranging from 68% to 84% of the rope's full strength.

3.3.4 Double figure-of-ten knot

Figure 5
Double figure-of-ten knot

Adding another half-turn to a double figure-of-nine, making two full turns in total creates this very bulky knot. Although it is slightly stronger than a double figure-of-nine, its bulk and the amount of rope needed to tie it, mean that it is not commonly used in either industry or sport.

As with the double figure-of-nine, it is stronger if the loaded end lies below the loose end in the knot.

It produced only one test value higher than the figure-of-nine, but averages were higher with variations from 73% to 87%.

3.3.5 Double figure-of-eight on the bight

Figure 6
Double figure-of-eight on a bight

Often called a bunny knot, this knot is useful as it creates two loops that can be used to equalise anchors. As the name suggests, it is based on a double figure-of-eight with an adaptation to create two loops.

These can be easily adjusted and it is widely used in both industry and caving to make loads equal when a rope is secured to two anchors. The knot can be dressed in a variety of ways: some of which compromise strength. In the tests, the loops were tested individually. This established that the loop closest to the loaded end tends to be slightly stronger than the other. The knot is also stronger if the bight between the two loops is dressed towards the top of the knot.

In the tests, the double figure-of-eight on the bight retained between 61% and 77% of the rope's full strength.

Further work on its ability to equalise forces between the two loops would be interesting.

3.3.6 Bowline

Figure 7
Bowline knot

A common, versatile knot, quick to tie and very easy to undo, which is useful for tying around large anchors. It is very common in many areas, particularly sailing.

It is unique in that it can be easily untied even after very large forces have been applied. For example, during the tests, one knot will always break before the other in the lanyard. This means the other has withstood a force very close to its breaking force. Despite this, the unbroken knot can be easily untied.

This knot showed the greatest variation in strength between the different ropes, 55% to 74%.

3.3.7 Alpine butterfly

Figure 8
Alpine butterfly knot

This knot is frequently used as it can be used to create a loop in the middle of a rope that, unlike the 'double figure-of-knots', can accept loading in any orientation without deformation.

It is commonly used in industry to create a mid-rope belay, or to isolate damaged portions of the rope.

It was tested for loop strength as with the other termination knots. Loop strengths were comparable to the overhand knot.

In the tests, it retained between 61% and 72% of the rope's full strength. Further work on its effect on mid-rope strength would be of interest.

3.3.8 Barrel knot

Figure 9
Barrel knot

This is commonly used in cow's tails as it is small and forms a slip loop that tightens around the karabiner, holding it in the correct orientation.

It can also be tied while under slight tension, although the clove hitch is better for this purpose.

Due to its slipknot nature, it has good energy absorbing abilities, and gave the lowest impact forces in the knotted cow's tails dynamic tests.

In the static tests, breaking strength was found to be high, comparable with a figure-of-eight, at between 67% and 77% of the rope's full strength.

3.3.9 Double fisherman's

Figure 10
Double fisherman's knot

This knot is used to join two rope ends, either to extend a rope or to create a rope sling.

It is very difficult to untie if it has been heavily loaded.

Due to the amount of stretch when knots are heavily loaded, it was only possible to test the double fisherman's as part of a rope sling. On all the tests, the rope broke before the knot, at forces of around 40 kN. This is most likely due to the friction created around the pins at each end of the sling. As the force is applied, the knot tightens, releasing rope into that side of the sling and hence reducing the force. This extra rope must slip around the pins to equalise the forces on either side. Inevitably, friction impedes this process and the side of the sling without the knot is subjected to higher forces.

As the pins used have a very low coefficient of surface roughness, this process would be exaggerated in a real situation. Although the knot did not break, it was subjected to very high forces and was one of the strongest tested. By halving the maximum force reached during the test on the loop, it can be stated that 20 kN will be the minimum figure that the double fisherman's knot will hold, on the particular rope tested.

3.3.10 Clove hitch

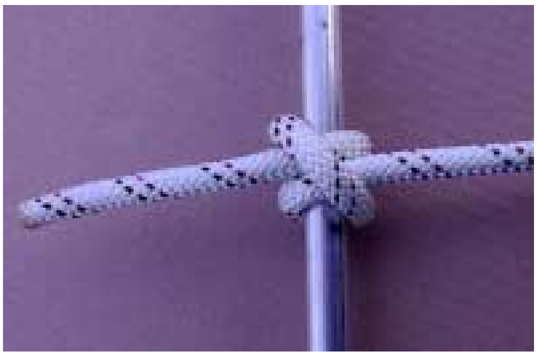

Figure 11
Clove hitch knot

Used to secure a rope directly to a post or bar, it does not create a termination loop but instead grips the anchor directly.

Unlike any of the other knots tested, it can be tied while the rope is loaded.

On most of the tests with low-stretch rope, the clove hitches slipped without breaking, at widely varying forces only partly dependent on the manufacturing process.

Interestingly, with the dynamic rope the knots broke on every test at forces comparable with the overhand knot.

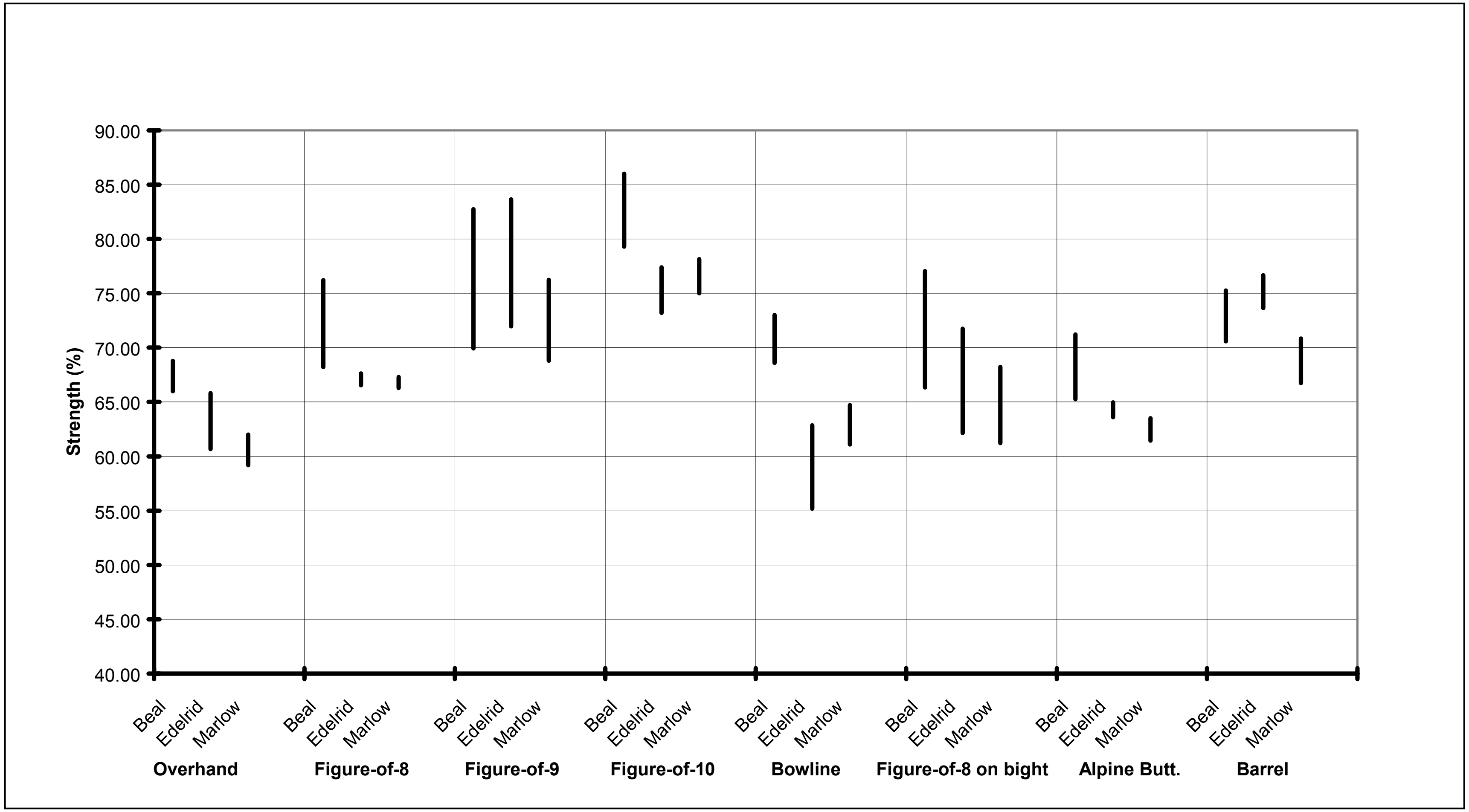

Figure 12

Knot strengths (percent of manufacturers' stated strength)

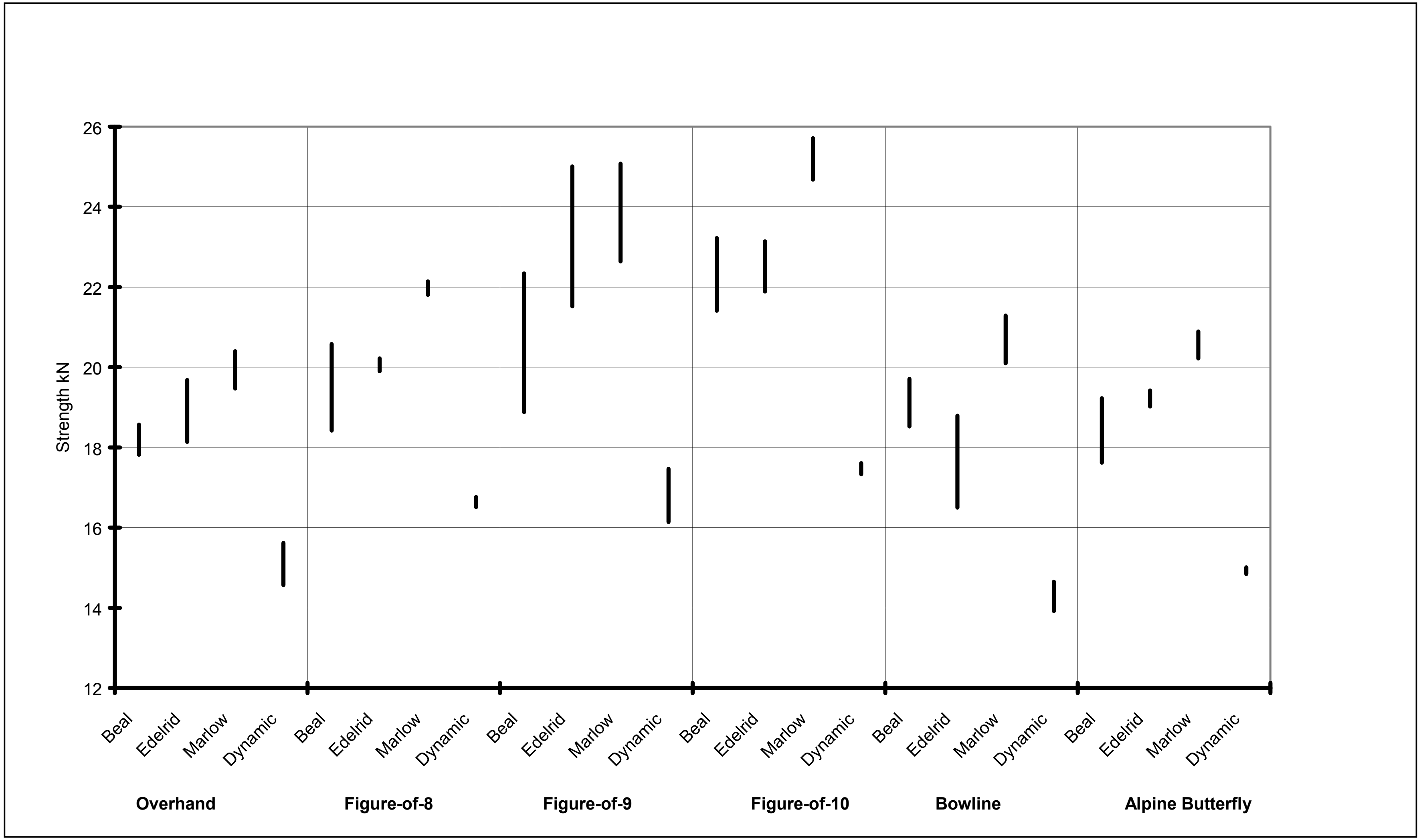

Figure 13

Knot strength (absolute)

3.4 CONTAMINATED ROPE TESTS

A limited number of tests were carried out on sections of rope that had been exposed to contaminants. The choice of contaminants was based on those which are likely to be routinely encountered on a work site. Direct contamination such as chemical spills, battery acid and engine oil were not considered as they are, firstly, easily avoidable and recognisable, and secondly, already subject to published data. Two contaminants likely to be found on an industrial work site, and on which little data was available, were studied: rust and bird droppings.

3.4.1 Rust

Sections of rope were left in a bucket filled with water along with around 1 kg of steel swarf (metal shavings). After about six months the sections were removed and left to dry. Rust staining was seen on all the sections. The worst affected parts were then tied up into lanyards using double overhand knots. These were then tested in the same way as the other knots described previously. When compared to the double overhand knot tests, tied in new rope, no additional reduction in strength was found. This does not necessarily mean rust has no effect on polyamide ropes. The amount of rusting that occurred was limited by the amount of oxygen dissolved in the water. After some time this was used up and rusting slowed considerably. Periodically removing the rope, allowing it to dry and then re-immersing it would have resulted in far worse degrees of rusting. This would also be a more accurate simulation of the conditions likely to be encountered in rope access. Also, whilst the rust itself may not cause damage, the iron would form chelates[6] with the organic acids that are likely to be formed in such wetting and drying scenario. Both the chelates and the organic acids would be very likely to cause weakening of the nylon fibres. More research in this complex area would be necessary before any definite conclusions could be drawn.

Table 4
Strength of rope contaminated by rust

Rope brand	Type	Diameter (mm)	New rope Average breaking force (kN)	Rust contaminated rope Average breaking force (kN)
Beal	Low-stretch	10.5	18.28	18.34
Edelrid	Low-stretch	10.5	19.05	19.47
Marlow	Low-stretch	10.5	19.79	19.83
Beal	Dynamic	11.0	14.92	14.57

[6] CHELATE - a chemical compound whose molecules contain a closed ring of atoms of which one is a metal atom

3.4.2 Bird droppings

Sections of rope were left hanging on a tower where large numbers of birds roost. To check that any effects where caused by the droppings rather than simply weathering, more sections of rope were hung on an adjacent fence where no birds roost. After about three months all the sections were examined. The sections from the roost area showed staining and smelt strongly. The sections from the fence were in good condition, and were little different from new. Again the worst affected sections were tied up into lanyards with double overhand knots and tested in the same manner as the other knots.

When compared to tests on new rope the excrement-covered rope showed a slight reduction in strength of around 2%. This is most likely to be caused by the rope fibres being damaged by the organic acids in the bird droppings. Again, it would be interesting to investigate this further.

When compared to the tests on new rope, both the weathered and the rusted Edelrid rope actually showed a slight increase in strength. This is not as unlikely as it sounds: the rope is not necessarily in its strongest form directly after it has been made. A period of hanging or soaking is ideal to allow rope to relax and for any differential tensions created in the manufacturing process to be resolved. This is one of the reasons why manufacturers suggest soaking and drying the rope before use: the shrinking helping the rope to find its natural shape. Whilst this is adequate for the other ropes, the Edelrid's waterproof coating means longer periods of relaxation and soaking are necessary.

Table 5
Strength of rope contaminated by bird droppings

Rope brand	New rope Average breaking force (kN)	Weathered rope Average breaking force (kN)	Bird dropping contaminated rope Average breaking force (kN)
Edelrid 10.5 mm low-stretch	19.05	19.34	17.74

3.4.3 Knots summary

The knotted strength of a new polyamide (nylon) low-stretch kernmantel rope may be taken to be at least 55% of its ultimate breaking force. This investigation therefore confirms that calculating the practical breaking load of a rope to be 50% of the ultimate breaking load will give a good margin of safety in all cases.

The overhand knot and the bowline are the least strong of the single loop knots.

The figure-of-eight is probably the best compromise between strength and complexity, both in its double form (simple loop) and on a bight (double loop).

In all the knot tests, the dynamic rope was significantly weaker than the low-stretch rope. This was to be expected, as the treatment of the yarn to give greater elasticity also reduces its tensile strength. However, at the same time it also showed less variation between similar knots and gave more consistent results across different knots.

The static breaking load of knots in dynamic rope requires a different interpretation. Single dynamic ropes complying with BS EN 892[7] do not have a stated static breaking load. The relevant measurement is the maximum dynamic load sustained by the rope given a fall-factor 2 drop with a mass of 80 kg. The knots in dynamic rope all held more than 150% of this figure.

Dynamic ropes, carrying the weight of one person, are never liable to break at the knot, nor are they liable to break at the knot when used for raising or lowering with the weight of two persons on a rescue. However their elasticity and resultant 'bounce' limit their suitability for load hauling.

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[7] BRITISH STANDARDS INSTITUTION
BS EN 892: 1997 Mountaineering equipment - Dynamic mountaineering ropes - Safety requirements and test methods

4 ANCHOR FORCES

4.1 INTRODUCTION

The object of these tests was to investigate the forces that anchors receive during a typical day's access work. Although the tests were of limited scope, they gave a valuable insight into the loads involved. While these tests are labelled 'anchor forces', they also represent the forces that pass into the user's harness.

Work was carried out at Firbank Viaduct, Sedbergh, Cumbria. A portable load cell was installed on the working rope where it held the full weight of the technician. A level 3 IRATA technician then performed a variety of operations and a laptop computer was used to continuously record the forces. The operations and peak forces were as follows.

4.2 ABSEILING

From the anchor point the technician abseiled approximately 10 metres at a speed of 1 metre per second. The average force was 0.75 kN, the weight of the operative. Slight jerks meant the force varied from 0.65 kN to 0.90 kN.

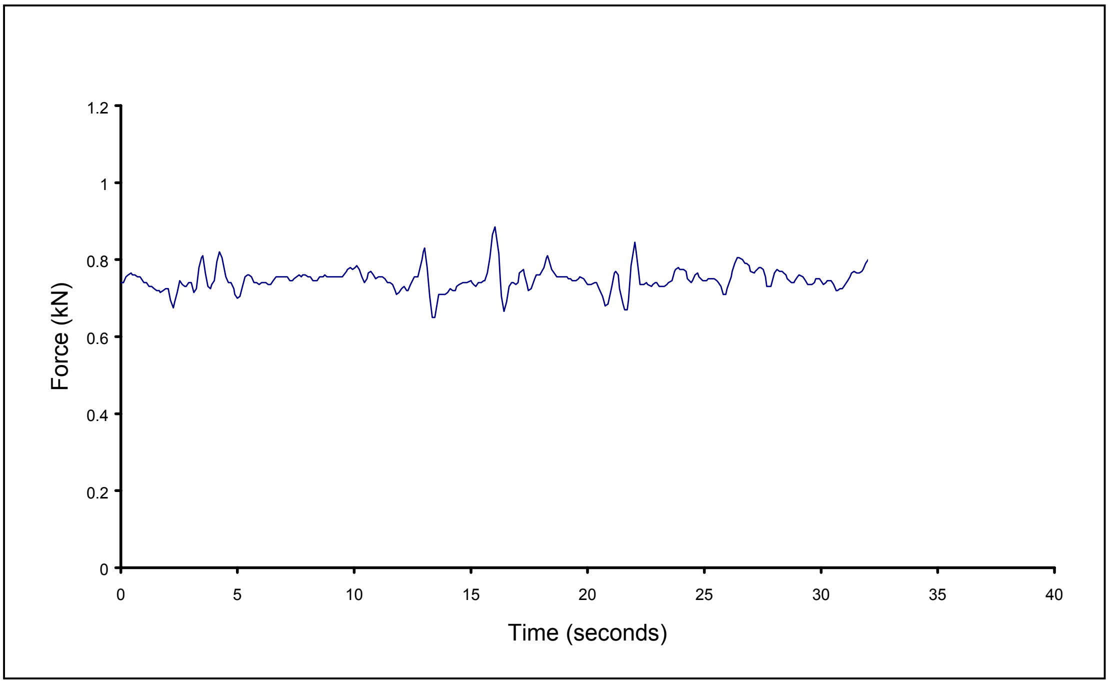

Figure 14
Graph showing forces generated when abseiling

4.3 ASCENDING

The technician ascended back to the anchor point using the normal technique of hand and chest ascenders. Again, the average force was 0.75 kN, but the maximum and minimum forces covered a greater range: from 0.35 kN to 1.05 kN.

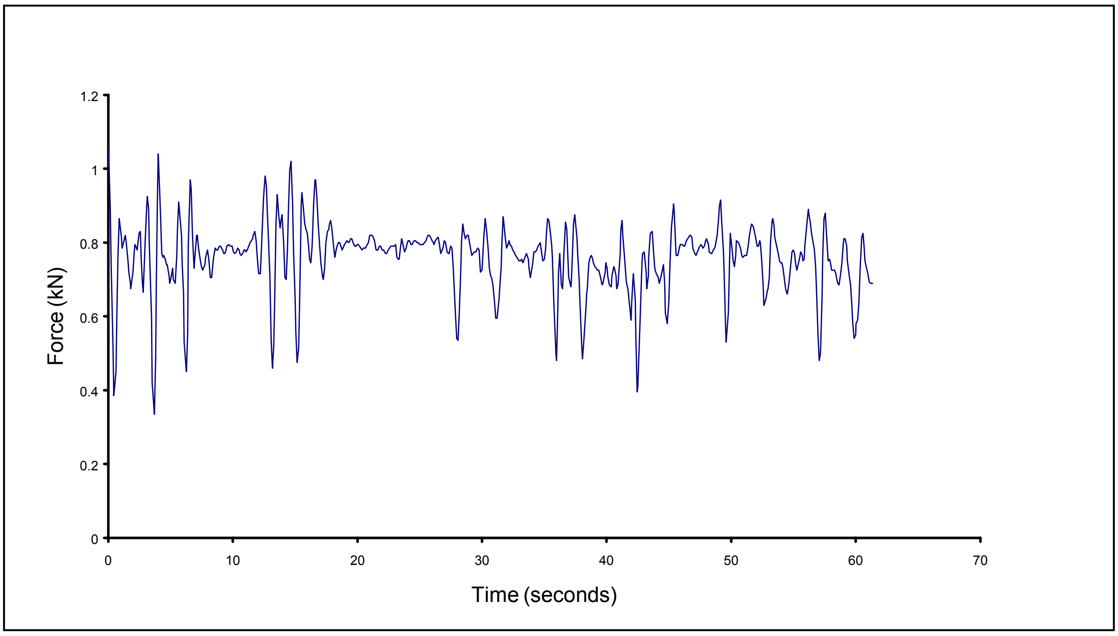

Figure 15
Graph showing forces generated when ascending

The sequence of climbing is - put weight onto footloop and stand up, sit down to transfer the weight onto the chest jammer and finally bend leg whilst moving the hand ascender up the rope. The peaks and troughs coincide with these movements which were then repeated.

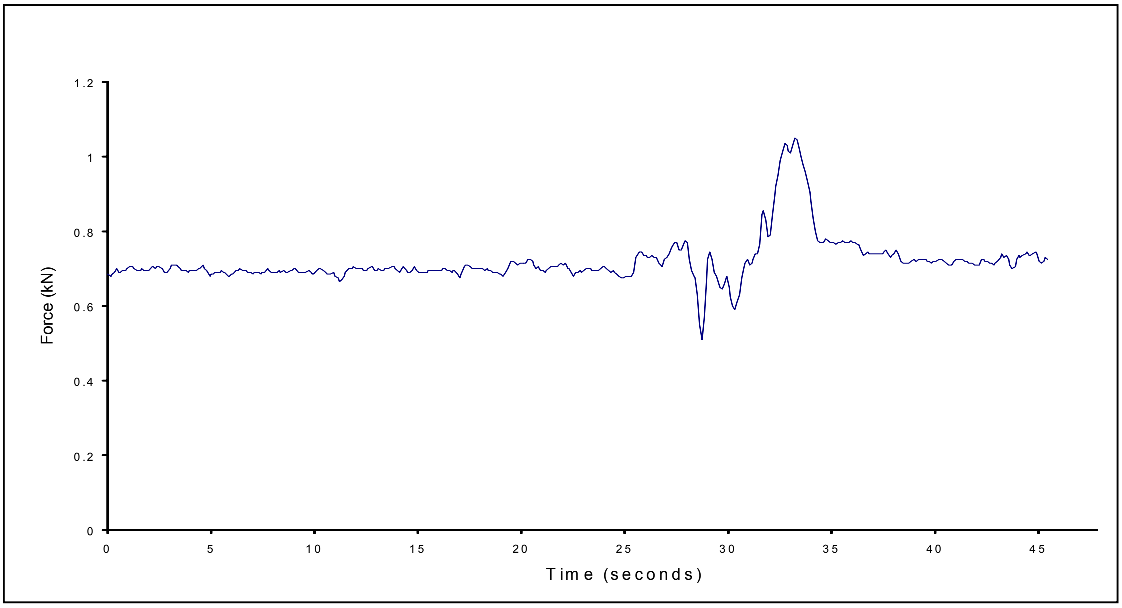

Figure 16
Graph showing forces generated when changing from ascent to descent

4.4 WORK POSITIONING

A combination of hand ascender and descender were used to ascend the rope: a not unusual work positioning technique. Forces were similar to those produced by normal ascent but slightly wider ranging: from 0.30 kN to 1.10 kN.

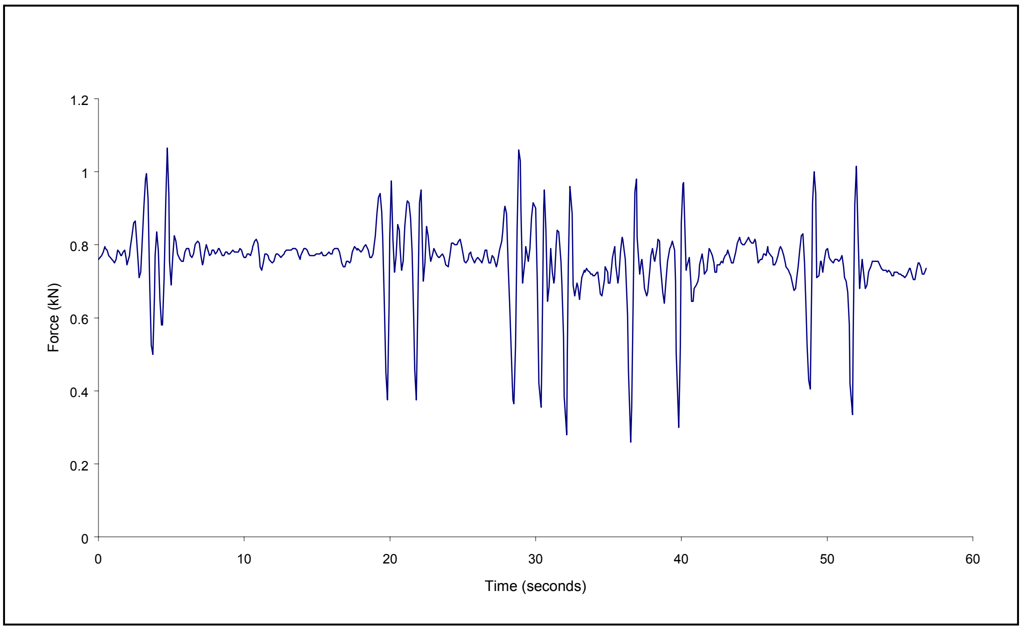

Figure 17

Graph showing forces generated when ascending using a combination of ascender and descender

The sequence of climbing was the same as in Figure 15, Ascending, except that a hand ascender was not used. In this case the footloop was attached to a descender and to move this upwards the slack rope was pulled through the descender.

4.5 WORKING

The technician remained at one point on the rope, around 5 m below the anchor, and performed a variety of simple work operations. Again, average forces were 0.75 kN, with values ranging from 0.45 kN to 1.00 kN.

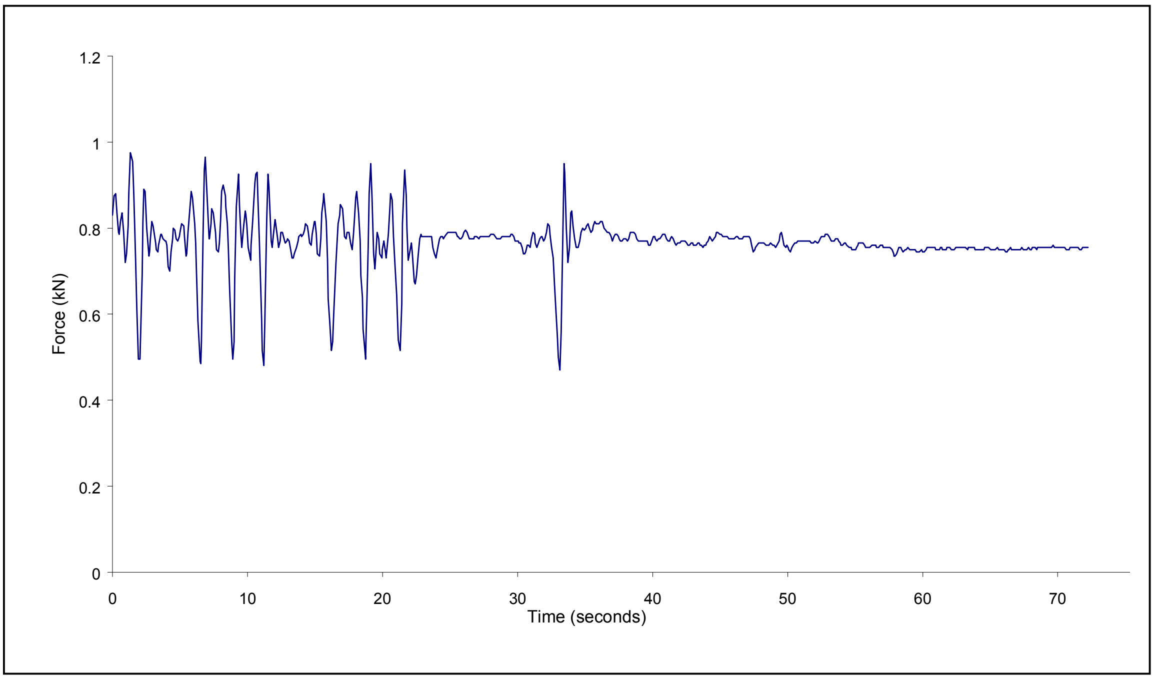

Figure 18
Graph showing forces generated whilst working at a single point

4.6 RIGGING

The technician remained stationary in one position, around 5 m below the anchor, while carrying out a variety of rigging procedures such as tying knots and placing strops and slings around the structure. The forces varied very little, from 0.72 kN to 0.78 kN.

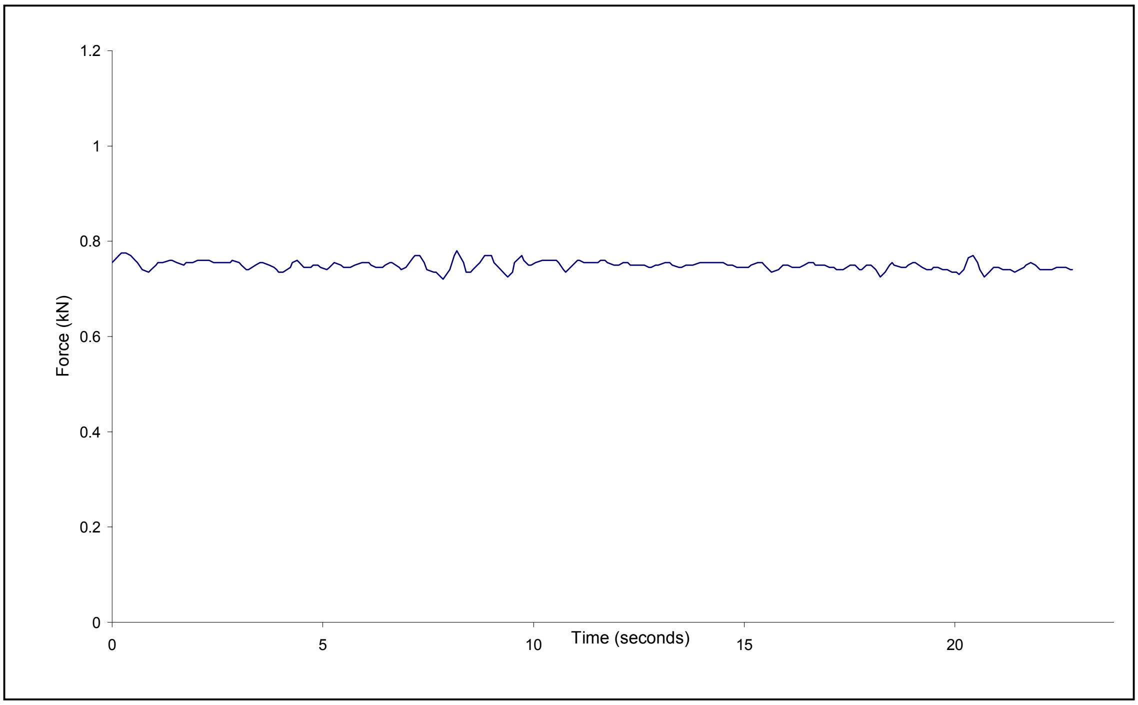

Figure 19
Graph showing forces generated when tying knots in one place (operative stationary on rope)

4.7 ASCENDING/DESCENDING RAPIDLY

Attempts were made to generate higher forces by carrying out conceivable poor practices, such as abseiling jerkily and ascending as fast as possible. Higher forces and correspondingly low forces representing bounces were seen, ranging from 0.35 kN to 1.60 kN.

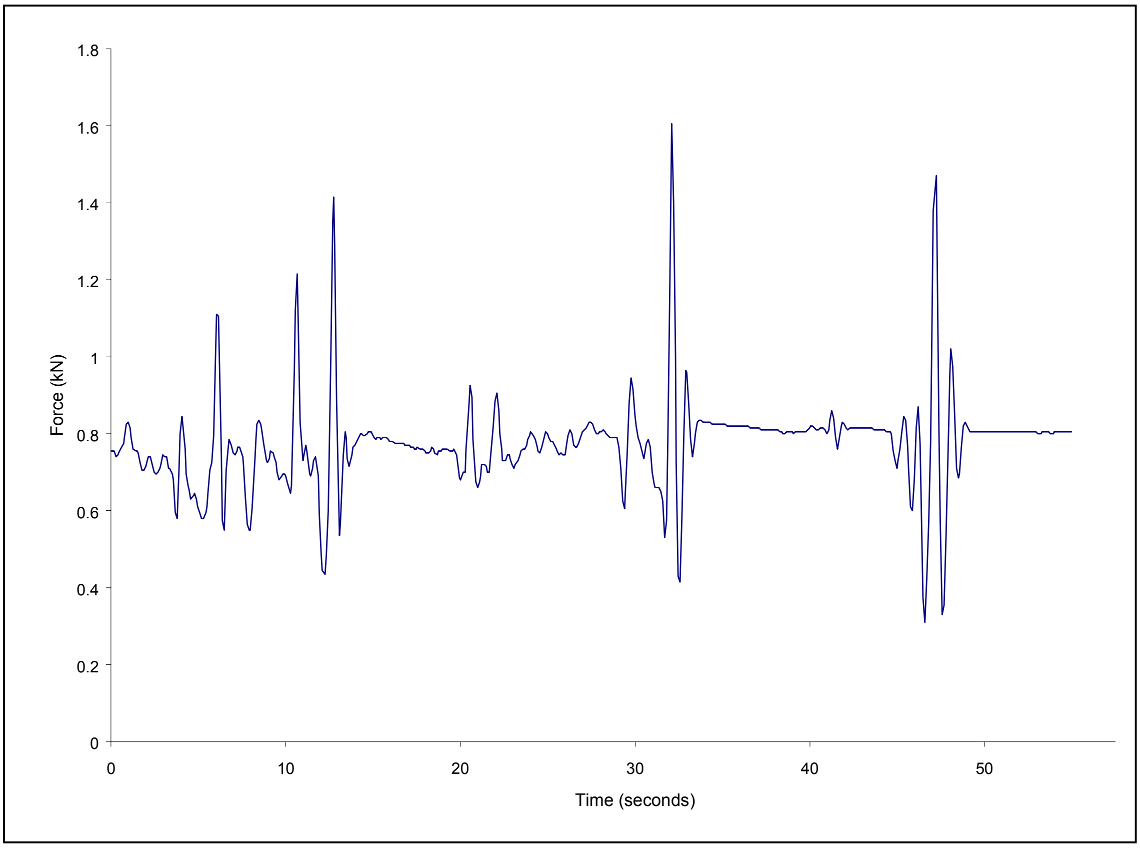

Figure 20
Graph showing forces generated when ascending and descending rapidly

4.8 SUMMARY

In normal operations loads on anchors should not exceed 150% of the gross weight of the operative, i.e. the weight of the operative and his/her equipment. It is possible to increase peak forces to 200% of the gross weight of the operative by moving abruptly or braking. Rescue procedures, where static loading may be doubled, should always be carried out as smoothly as possible.

The further down the rope from the anchor the operations were carried out, the more rope was available to stretch and absorb peaks and troughs in the loading, thus reducing force fluctuations.

5 ROPE PROTECTORS

5.1 INTRODUCTION

Textile ropes are softer than virtually any building or structural material, with the exception of wood. Therefore, it is essential to protect ropes against abrasion wherever they run over a hard surface. (In the case of arboriculturists the protection is equally important, but here it is to protect the tree's cambium layer from the rope). A variety of materials and devices are used in an attempt at edge-protection. These are often improvised, for example, rope bags, scraps of carpet, etc.. Purpose made protection devices range from metal rollers to simple canvas sleeves.

Test results will certainly vary if repeated with different ropes, edges, forces, reciprocation times and speeds, and different protectors. It would be impossible to test all possible combinations. However, the results obtained give a sufficiently clear picture for good, indifferent, and poor protectors to be identified with some degree of certainty.

Before detailing the test methods and results it should be stated that the first line of rope protection should be to avoid all contact with sharp or abrasive edges, whenever possible.

5.2 METHODS

Because all ropes commonly used in rope access are made from similar yarn, and are of similar construction, all the tests were conducted using the same type of low stretch rope - Beal 10.5 mm Antipodes.

Three edges were used:

- A rounded concrete edge (coping stone, radius approximately 10 mm)
- A 90^0 concrete edge (paving slab, cut edge)
- A 90^0 steel edge (50 mm by 50 mm steel angle, radius <1 mm)

A mass of 87.5 kg was suspended from the rope. This was cycled vertically, through 50 mm over the edge, at a speed of 500 mm per minute, at a rate of 5 cycles per minute. The machine was left to cycle and the rope was inspected at intervals for damage. The levels of damage were classed as follows:

- Slight damage: any visible damage to the sheath such as cut or melted fibres. Damage of this type often developed very slowly.
- Severe damage: cut bunches of sheath fibres or large melted areas. While slight damage could slowly progress into severe damage, beyond a certain point things would progress more quickly. This was due to parts of the sheath beginning to catch on the edge, causing rapidly escalating damage to the sheath. When the test was continued beyond this point the sheath was usually quickly cut to the extent that it no longer protected the core. If ropes reached this state, the tests were stopped.

5.3 UNPROTECTED

Over an unprotected right-angled edge the rate of abrasion was, in all cases, rapid.

Over the sharp concrete edge, it took 8 cycles to destroy the sheath.

Over the steel edge, it took 15 cycles to destroy the sheath.

The results over the rounded concrete coping, however, were very different. After approximately 600 cycles, taking 2 hours, only slight sheath damage was seen. The rope slowly polished the concrete and abrasion only occurred because of a small bubble imperfection in the edge.

This was particularly surprising because in some subsequent tests, with an edge-protector in place, far worse damage was seen over this same edge. The only conclusion that could be drawn was that the protectors themselves were causing the damage!

5.4 ROLL MODULE (PETZL)

This device consists of a series of "U" shaped roller cages linked by screw link connectors (maillon rapides).

Within the cages, the rope is prevented from touching the abrasive surface by aluminium rollers, with side rollers to prevent lateral movement. By linking the appropriate number of cages together, any variety of abrasive edge can be traversed safely by the rope. (Just two cages in the case of a right-angled edge, more for gradual edges.)

Although the test was performed on all three of the edges, the edge material is largely irrelevant, as the rope does not touch it. In the tests, the only effects on the rope were flattening and black marks from the aluminium rollers. The longest test was run for two hours, a total of 600 cycles.

This result may be taken as representative of the use of any type of smooth rollers – the only difference may be in practicability of use, not in the (total) degree of protection given.

5.5 CANVAS SHEATH

A rectangular double-thickness strip of 15 oz. natural shrunk canvas, secured as a tube by means of velcro strips, fixed around the rope.

Compared to other types of fabric protectors performance was impressive, taking 270 cycles (54 minutes) over the steel edge to wear through both the protector and the rope sheath. Over the sharp concrete edge only slight wear was seen after 450 cycles (90 minutes).

5.6 POLYVINYL CHLORIDE (PVC) COATED FABRIC SHEATH

Identical in construction to the canvas rope protector, except that it was made out of a PVC coated polyester fabric (6 oz. CAFLEX FP600FREN71).

Performance, however, was nowhere near as good as plain canvas, with severe rope damage occurring after only 75 cycles on the steel edge.

It fared little better on the sharp concrete edge, wearing through after 75 cycles, with sheath failure occurring after 100 cycles.

Over the rounded concrete edge the protector did not wear through, but the PVC coating rubbed off, leaving stains on the rope and increasing friction and hence heat. Damage then occurred due to melting rather than abrasion. After 300 cycles, the protector was not in a reusable state and the rope was both stained and glazed.

5.7 COMPRESSED AIR FLEXIBLE HOSE PIPE

This was chosen as being representative of the kind of improvised protector that could be made from materials commonly found on construction sites.

Although appearances suggest the pipe to be very robust, it actually fared very badly in the tests.

Over the sharp edges, the pipe wore through within the first 25 cycles (5 minutes) and on the rounded edge within 50 cycles (10 minutes). During these periods the rope suffered much damage, becoming coated in rubber and abraded. Over the rounded concrete edge, these constituted far worse effects than those caused by an unprotected edge.

5.8 CARPET

This is a form of improvised protector commonly used in the workplace.

There are many combinations of carpet construction and material mixes, e.g. Axminster 80% wool/20% polyamide, Tufted 50% wool/50% polypropylene. Naturally, performance as a rope protector will vary, depending on the combination. In this test programme, only two types were tested. The first was foam-backed with nylon pile. The second was a stiffer hessian backed type, again with nylon pile. Neither had particularly deep pile and they were obtained from active level three IRATA technicians as being typical of those in use. However they were not felt to represent the height of durability.

5.8.1 Carpet 1 (Foam-backed)

This performed very badly.

Over the steel edge, it took a mere 25 cycles (5 minutes) to wear through both the carpet and the rope sheath.

Over the concrete edges, it was a little better, surviving around 50 cycles (10 minutes) before sheath damage began.

A point worth noting is that over the rounded concrete edge the rope suffered more abrasive damage than if it had been left unprotected.

5.8.2 Carpet 2 (Hessian-backed)

This performed slightly differently.

Over the steel angle it deteriorated very quickly, taking less than 10 cycles to wear through both the carpet and sheath of the rope. This was particularly surprising as the deterioration appears to be quicker than on the unprotected edge. This could be due to the edge being slightly sharper at that particular point, or it could be due to friction caused by the carpet heating the rope and allowing the edge to cut the fibres more easily. Further investigation would be necessary to determine exactly what occurred.

Over the rounded concrete edge the hessian backed carpet lasted much longer than the foam backed variety, wearing through after about 130 cycles. As with the foam-backed carpet, slightly more damage was seen to the rope than with the same edge and no protection.

Over the sharper concrete edge sheath damage began after about 70 cycles.

Although the carpets were tested in single layers, the providers of the samples suggested that in doubtful situations the carpet would always be used folded at least once.

5.9 PVC COATED FABRIC SCRAPS (SIMULATED ROPE BAG)

These were used to simulate a rope bag, or similar, being used for protection, which the questionnaire highlighted as being commonly used. The material used was the same as that used to make the PVC sheaths.

Using several layers of material was beneficial: even on the steel edge no holes were created even after 300 cycles (60 minutes). However, as with the PVC sheath, the coating rubbed off at an alarming rate. Eventually a state was reached where the rope ran directly over the fibres of the fabric. This increased friction and the rope did not run smoothly.

It seems the thickness of the four layers increases the edge radius sufficiently to prevent wear at a single point. The condition of the material at the end of the tests was, however, poor. The layers were fused together, losing all their PVC, at the wear point. If this were a rope bag, several uses as a rope protector would soon render it unusable.

5.10 ROPE PROTECTORS - SUMMARY

Two types of damage were seen. Firstly, abrasion damage consisting of rope fibres cut by a sharp edge. Secondly, heat damage consisting of melting of rope fibres caused by friction between the rope and the rope protector.

The first conclusion is that protection is vital over any sharp edge.

While the roll module provides the highest level of rope protection, canvas sheaths provide superb protection for their price. A double layer of these would provide peace of mind in almost any situation.

From the tests it is also apparent that even a slight smoothing of an edge will dramatically reduce abrasion effects. Any type of rope protection over these edges will appear to be working, even though the protection is not actually required.

Over rounded edges some protectors will actually increase the risk of damage, due to friction between the rope and the protector.

The PVC protectors provide little protection but are still better than nothing over a sharp edge. Similarly the improvised protectors - pipes, carpet or rope bags, will all provide some degree of protection in an emergency, but are far from ideal. In properly planned rope access work this situation should never arise.

Movement over edges is dependent on the relative positions of the anchors, edge and load. Where both the load and edge are far from the anchor point, rope stretch will cause exaggerated movement over the edge. Where the edge is close to the anchors, but the load well below, the majority of the stretch will occur below the edge, causing limited movement over the edge. What is less obvious is that large amounts of movement may be preferable as wear is spread over a longer section of rope.

Due to time constraints, only parapet-edge situations were investigated, where movement is perpendicular to the edge. Projections from the wall, partway down the rope, would need to be protected differently, as would any situation where a sawing action across the edge was possible. These areas would benefit from further study.

Another point to recognise is that any protector is only as good as the method used to hold it in place. The PVC protectors, in particular, do not allow the rope to slide smoothly over them, but instead adhere to the rope and move up and down with it, gradually creeping out of position.

In rope access, prevention is always better than cure. In situations where ropes run over sharp edges, the initial reaction should be an attempt to re-rig the ropes to avoid them. If this fails, a rope protector may then be used. Re-rigging or deviations should always remain the preferred option. On the basis of the tests carried out this would ideally be a roll module for a parapet edge and quality canvas sheaths for protection lower down the rope. Other types of protectors, such as 100% wool carpet and 50 mm diameter scaffold tubes, may provide protection equal to, if not better than, canvas. These could be the subject of further investigation.

6 ROPE ADJUSTMENT DEVICES

6.1 INTRODUCTION

There is an increasing range of devices on the market, some originating in sport, some designed specifically for industry. As in prEN 12841, rope adjustment devices are divided into three categories:

- Type A - Back-up devices
- Type B - Ascenders
- Type C - Descenders

A key feature of equipment for rope access is versatility. Almost all rope adjustment devices will have secondary uses, especially during rigging for rescues etc. This reduces the amount of hardware an operative has to carry and increases their operational abilities and safety margin.

Some newer devices are not as versatile as those currently in use and this must detract from their suitability for rope access. Their specialist nature may, however, make them more suitable for certain specific purposes.

The line diagrams in the following sections are intended to show the principles of operation of the devices, they are not intended to illustrate the entire device. The diagrams are partial sections and have been reproduced at approximately 35% full size.

6.2 TYPE A – BACK-UP DEVICES

6.2.1 Introduction

The adoption of two-rope systems, one for progression (the working rope), and one for security (the back-up or safety rope) requires that a third device be installed on the safety rope. It must slide when required, and lock on to the rope when required. This is the origin and the function of the back-up device. The adopted definition of back-up devices differs slightly from that in the standard prEN 12841, where they are called "Type A Rope adjustment devices". For the purposes of this report the definition adopted is:

> ***"A rope adjustment device, for a safety line, which accompanies the user during changes of position, allows adjustment of the safety line, and which locks automatically to the safety line under static or dynamic loading and which can be intentionally released while under load."***

The performance and limitations of the back-up device were one of the HSE's main concerns when commissioning this project. Over the years, the Petzl Shunt has become almost universally accepted as the industry standard and was stated as meriting particular attention.

At present, the back-up system incorporating the Petzl Shunt is effectively standardised by the IRATA Guidelines[8]. The Shunt is connected to the harness with a cow's tail made from dynamic rope tied to the user's required length. The Shunt remains where it is placed on the secondary (safety) rope and must be repositioned whenever the user moves upwards or downwards. When ascending, this is done by pushing it up the rope ahead of the user. When descending, users fit the Shunt with a short cord to enable it to be towed downwards.

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[8] INDUSTRIAL ROPE ACCESS TRADE ASSOCIATION
General requirements for the certification of personnel engaged in industrial rope access methods: Edition 2, 1998

The IRATA Guidelines state that the Shunt should be maintained above waist level at all times to prevent fall factors above one. The system works well and when used in ***accordance with the training*** has a good safety record.

However, the Shunt has four potential drawbacks, some of which may be shared by all of the devices.

A. The principal concern is that grabbing the body of the Shunt itself negates the cam action and prevents it arresting a fall. As a grabbing action is a known reflex in fall situations, this constitutes a potential danger in the Shunt's performance. However, in normal use the ability to release a loaded Shunt, by the same action, is a very useful feature. It adds to the versatility of the device and encourages the user to keep the Shunt in a safe, high position, without him/her having to worry about whether it will become unintentionally clamped to the rope and thus prevent descent when required. The question is whether users can be trained to overcome the grabbing reflex in a fall incident.

B. The second concern is the use of a cord to tow the Shunt when descending. If this is either caught in the user's equipment, or simply remains held by the user during a fall the cam action is again negated. IRATA members use various methods of holding the cord that are designed to prevent this, but it remains a significant risk.

C. The third concern is over the Shunt's relatively weak body strength. The Shunt is designed to slip when overloaded and can be used on double or single ropes. The slipping function negates the need for a strong body, as high forces should be impossible to reach. However, if the Shunt is loaded when it is only a short distance above a knot on the rope, it will be prevented from slipping by the knot and high forces could be achieved. This situation is possible in rope access, and could result in the Shunt releasing the rope at forces as low as 4 kN. The problem is exacerbated when the device is used on a single rope, as would be the case in rope access.

D. The fourth concern is the low force required to cause the Shunt to slip. While this reduces the need for a very strong body, it has one of the lowest sliding force of all the devices tested. In a dynamic loading situation the Shunt could slip well in excess of 2 metres. When combined with rope stretch, the risk of a falling operative hitting the ground or structure during the fall is greatly increased.

These problems are largely the result of the adoption of a device that was not specifically designed for the purpose. So, what are the alternatives to the Shunt? At present the alternatives can be split into two groups. The first group is work positioning devices which are used in the same manner as the Shunt. The second group replaces the work positioning-style back-up system with a fall arrest system, which consists of a free-running device that accompanies the user during changes of position. Both alternatives have their advantages and disadvantages and require devices to fulfil different requirements.

6.2.2 Back-up devices – What they must do or must not do - general

The back-up device used in rope access is just as much a work tool as any other part of the system. It must be under the control of the operator for proper effectiveness. It should be possible to deploy it as a spare ascender should the need arise. This means that a fall-arrester device, which simply follows the movements of the vertical worker, reacting only to gravity – or the removal of the effect of gravity by a free-fall – is not entirely appropriate for the job. (It may well be possible for free-running fall-arresters to incorporate features which allow them to switch to back-up function).

Some fall-arrest systems and techniques require the deployment of a guided type fall arrester for a flexible anchorage line. This type of fall arrester, defined in BS EN 353-2[9], has to travel along the anchorage line, accompanying the user without requiring manual adjustment during upward or downward changes of position, but locking onto the line when a fall occurs.

The main advantage of a fall arrest system over a work positioning system is that it allows faster movement both up and down the rope. Some devices can also work independently with no input from the user. The back-up system device can be ignored while the user changes position. However, as it hangs below the user, and may not 'grab' until the user has fallen some distance, fall factors related to the device can be greater than two, and the device must be able to handle the resultant forces safely. To limit the length of the fall, the link (or cow's tail) to the harness should be as short as possible. This system has the following drawbacks:

The back-up device should be positioned to minimise any fall which may be incurred. To this end, it should always be positioned at, or above, the attachment point of the connecting link, or cow's tail, to the operative. To allow for this positioning the back-up device must have a positive hold on the rope, so that the operative can slide it up or down the rope, position it, and know that it will stay there until he or she moves it. The force necessary to tow the device, or to dislodge it from its position, should be known. With a work positioning system, movement may not be as simple but the user should always be in a safer position, particularly if the user remains in one place for any length of time. The back-up system can then be adjusted so that an actual fall is prevented.

Some manufacturers have recognised these issues and have attempted to create fall arrest devices that can be locked in position when required. One of these is the Komet 'Stick Run', which features a catch that adds or removes the cam's sprung action. Without the spring, the device runs very freely: when it is installed it will not. Similarly, the instructions for the Troll 'Rocker' illustrate how a second karabiner can be used to prevent the device moving freely on the rope.

To be able to slide up and down the rope, without snagging, it is virtually certain that a device without aggressive teeth will be needed. This is also a factor in considering what effect the device might have on the rope should a limited fall occur. The device should be such that no possible fall could damage the rope to the point of stripping the sheath.

It is essential that the device can be attached to, and removed from, the rope at any point. It then follows that this method of attachment should be practical in everyday use, and that it should be secure.

It is highly desirable that the device should be deliberately releasable while under load. This makes it far more practical as back-up during descent, so that if the device does become loaded, it can be recovered without the user having to climb back up the rope. At the same time, it must be certain that, either by product design or by operator training, any possibility of the device slipping, because of panic grabbing, is eliminated.

There may be reasons to deploy the back-up device on a link, or cow's tail (lanyard), of any length from a few centimetres, e.g. a connecter, up to the 'reach' of the individual operator. It is highly desirable that the back-up device can be deployed at the end of lanyards covering this range. (Say 10 cm to 100 cm.)

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[9] BRITISH STANDARDS INSTITUTION
BS EN 353-2: 1993 Personal protective equipment against falls from a height: guided type fall arresters Part 2 Specification for guided type fall arresters on a flexible anchorage line

Devices certified to BS EN 567[10] (Ascenders), and others certified to BS EN 353-2, are currently being used as back-up devices in rope access.

The disadvantages of some BS EN 567 ascenders are that they cannot be released while loaded, and even when unloaded they are difficult to move down the rope. This makes them particularly difficult to use during descent.

The disadvantages of some BS EN 353-2 fall arresters are that, by definition, they cannot be positioned on the rope by the user as they only grab the rope in a free-fall situation. They cannot be used for fall-prevention or work positioning without modification.

It is clear that neither standard is totally appropriate. It is hoped that when prEN 12841 is finalised it will become the definitive standard for back-up devices.

The devices tested fall into two groups:

'Work positioning':	Petzl Microcender, Petzl Rescucender, Petzl Shunt, and Wild Country Ropeman. (All of which are certified to BS EN 567, mountaineering ascenders)
'Fall arrest':	Ushba Stop-Lock, Komet Stick Run, SSE Stop & Go, Tractel Stopfor D, Troll Rocker. (All of which are certified to BS EN 353-2, guided type fall arresters, except the Ushba Stop-Lock which does not carry the Certificate European (CE) mark)

The devices come from a wide range of design backgrounds. These vary from purpose designed mobile fall arrest devices to mountaineering ascenders. Despite this, the range of design principles is small.

The majority of devices (Komet Stick Run, Petzl Microcender and Rescucender, Petzl Shunt, Tractel Stopfor D) are cam loaded rope clamps. Force applied to the attachment point is transmitted via a pivot to a cam that traps the rope against the body of the device. In all but the Petzl Shunt the pivot lies between the applied force and the cam. In the Petzl Shunt the cam lies between the pivot and the applied force. This design principle has been used for both work positioning and fall arrest devices.

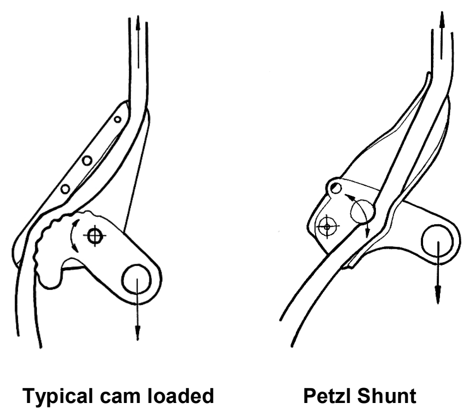

Figure 21
Typical cam loaded and Petzl Shunt back-up devices

[10] BRITISH STANDARDS INSTITUTION

BS EN 567: 1997 Mountaineering equipment – Rope clamps – Safety requirements and test methods

In the other main principle (Ushba Stop-Lock, SSE Stop & Go, Troll Rocker) the force is applied to the body of the device. This features a fixed smooth block that traps the rope against a second pivoting block. The upper end of the block is forced upwards by the rope attempting to straighten under load. This force is transmitted through the pivot to the lower end of the block, trapping the rope. These three devices all run fairly freely on the rope.

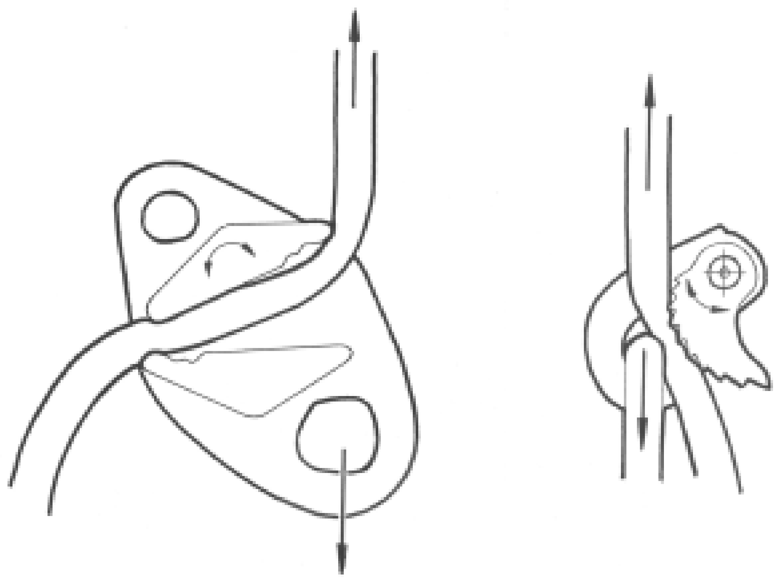

Figure 22
Troll Rocker (left) and Ropeman from Wild Country back-up devices (latter shown with karabiner attached)

The Wild Country Ropeman is different again, working on a body-loaded principle most common in Type B devices (ascenders). A sprung toothed cam contacts the rope that lies in a channel. When force is applied to the body of the device the ridged-style teeth bite into the rope, pulling the cam into the channel and trapping the rope. This device will only work when it has a karabiner attached, as the rope is trapped between the cam and the karabiner. It is worth noting that the Ropeman would not ordinarily be included in a list of back-up devices: it was added because it was found to be in use as such when the questionnaire was returned.

6.2.3 Tests

The nine devices each underwent four tests, as specified in prEN 12841 (see 3.2 of this standard).

- **Minimum working strength** (section 4.2.3 prEN 12841)

  Device to hold a force of 4 kN for 3 minutes.

  This test is designed to check that the device can comfortably exceed its safe working load without deformation or damage to the rope.

  The test originated in BS EN 567, an ascender standard, where 4 kN represents a force at the limit of what could be achieved in normal usage, but below the forces at which toothed cam ascenders will inevitably damage the rope.

  When applied to back-up devices, which are designed to slide before high forces are reached, it is less suitable. Pass/fail results related to this test may simply indicate the need for a different test.

In practice this type of test is useful to determine the static force at which slippage begins.

The working strength tests were performed on four different ropes: Beal 'Antipodes' 10.5 mm low stretch, Edelrid 10.5 mm low stretch, Marlow 10.5 mm low stretch and Beal 'Apollo' 11 mm dynamic.

Table 6
Back-up devices and forces to initiate sliding on the rope

Device Rope >	Force to slip under static load (kN)			
	Beal	Edelrid	Marlow	Dynamic
Komet Stick Run	3.1	2.5	2.7	2.3
Petzl Microcender	3.5	2.2	3.2	3.4
Petzl Rescucender	(>4)	6.7	(>4)	(>4)
Petzl Shunt	2.3	2.5	2.5	2.7
SSE Stop & Go	2.1	2.8	2.4	3.4
Tractel Stopfor D	2.5	2.2	2.7	2.5
Troll Rocker	(>4)	3.4	(>4)	(>4)
Wild Country Ropeman	No slippage: cuts sheath at approximately 4 kN			

The Ushba Stop-Lock was not tested: see later comment in section 6.2.4

- **Dynamic performance** (section 4.2.5 prEN 12841 May 2000)

  Peak impact force and slippage with a fall factor 2 drop with a 100 kg mass.

  The tests were carried out using the 'catch plate' rig at Petzl. See section 14.4.5, in the Appendix, for details.

  Perhaps the most relevant test, this test investigates the energy absorbing abilities of the devices in a worst-case scenario: a fall factor 2 with an inelastic lanyard.

  100 kg represents the likely upper mass limit of an operative plus equipment. A large operative might also be tall and therefore require long cow's tails. The total lanyard length was therefore simulated as being one metre including connectors: giving a factor 2 fall of 2 metres. A catch plate method was used for these tests. This eliminates an actual lanyard from having to be used and results in more consistent results.

  The dynamic tests were performed on four different ropes: Beal 'Antipodes' 10.5 mm low stretch, Edelrid 10.5 mm low-stretch, Marlow 10.5 mm low-stretch and Beal 'Apollo' 11 mm dynamic. Three replications were carried out on each rope type, giving twelve tests on each device.

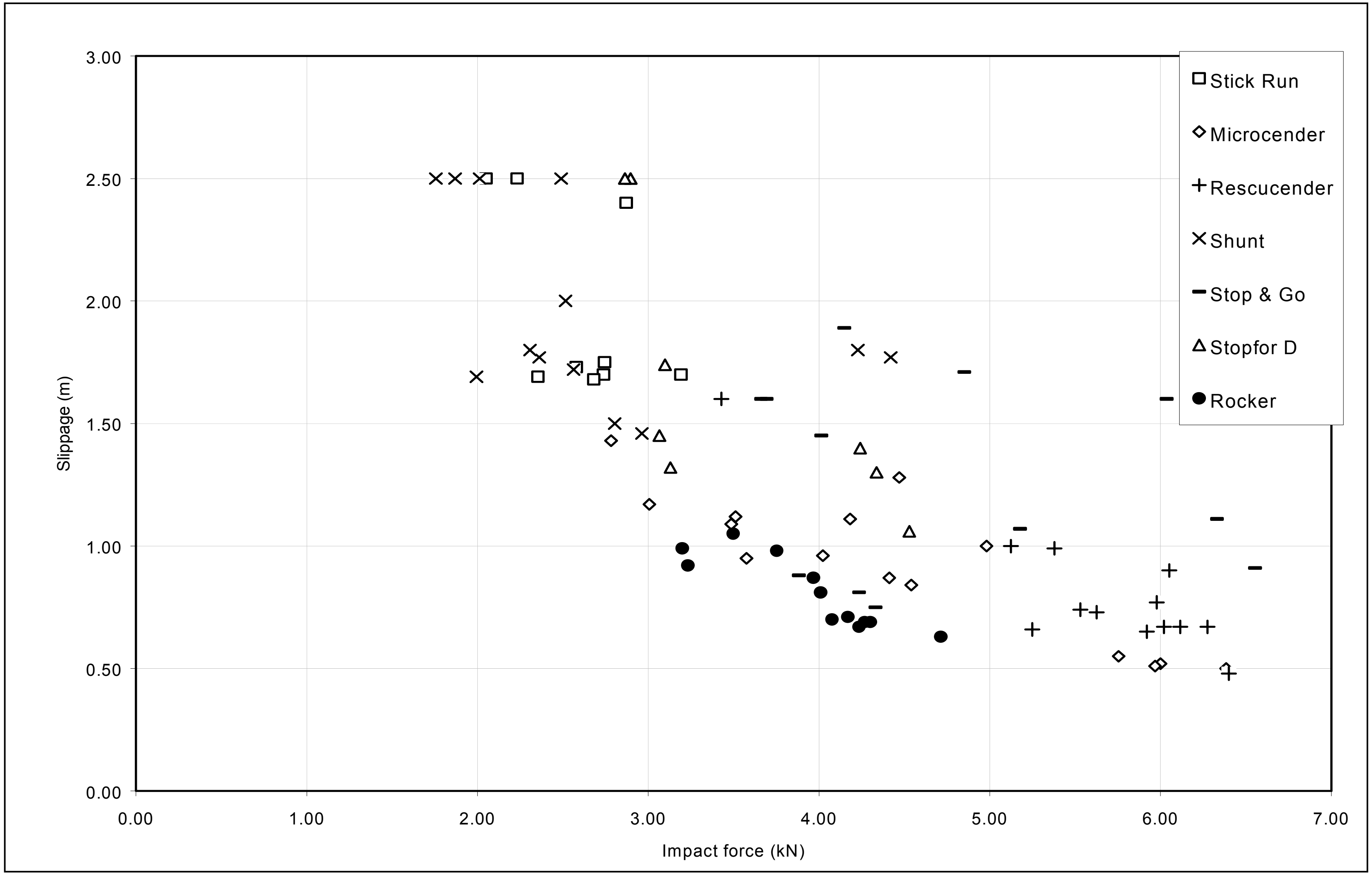

Figure 23
Type A Back-up devices – dynamic performance

Note: Maximum slip limited to 2.5 m by test rig.

- **Minimum static strength** (section 4.2.4 pr EN12841 May 2000)

  Hold a force of 12 kN for three minutes.

  The relationship between the minimum working and minimum static strength test is based on factors of safety.

  With a minimum working strength of 4 kN the 12 kN static test gives a safety factor of 3.

  The severity of this test is dependent on the amount of damage the device is allowed to sustain. All devices require a stop on the anchor line, usually a knot, to prevent slippage at such high forces, and this causes abnormal loadings that can damage the device.

  As long as the device does not release or damage the rope it is argued that some deformation here is acceptable. Any evidence of fracture, however, should constitute a fail. A device should also be considered as 'failed' if it becomes unusable.

  In the minimum static strength only one test, on Edelrid rope, was performed due to the expense (and availability) of destroying up to four of each device. The rope is irrelevant in this test as it simply acts as a stop against which the device can be pulled.

- **Ultimate static strength**

  Initially it was intended as a final test to load all the devices to destruction.

  However the severity of the minimum static strength test meant that most devices had already reached their limits during this test.

  The devices which were apparently still usable were those with a machined aluminium body. It was deemed not necessary to test these devices to their ultimate strength for two reasons:

  - it is extremely unlikely, even with abuse, that forces will exceed 12 kN in the workplace
  - the devices would have been tested on a knotted rope and knot strength would have limited the maximum force which could have been applied to the devices.

6.2.4 Ushba Stop-Lock

Material: Titanium

Weight: 132 gm

Design principle: Body loaded

Method of use: Fall arrest

Figure 24

Ushba 'Stop-Lock' back-up device

Markings: Front face "EN567" AND "UIAA" on the rear. The device does not show the Certificate European (CE) mark.

Performance in use: Installation on the rope is easy, although the device must be unclipped momentarily. It runs quite freely both up and down 10.5 mm rope, although occasionally sticks when descending. It can be tensioned onto the back-up rope easily, but if unloaded briefly it may drop down the rope. It can be released from the loaded position easily, and is generally easy to use and very compact.

Test performance: The Ushba 'Stop-Lock' fared very badly in the dynamic tests. Only two devices were available for the dynamic tests and both of these cut the rope completely, without any slippage, at a peak force of 5.5 kN. The devices were too distorted and damaged to test again. This would appear to be a serious design fault and the Stop-Lock cannot be recommended for use as a back-up device. No further tests were carried out.

6.2.5 Komet Stick Run

Material: Steel

Weight: 474 gm

Design principle: Cam loaded

Method of use: Fall arrest

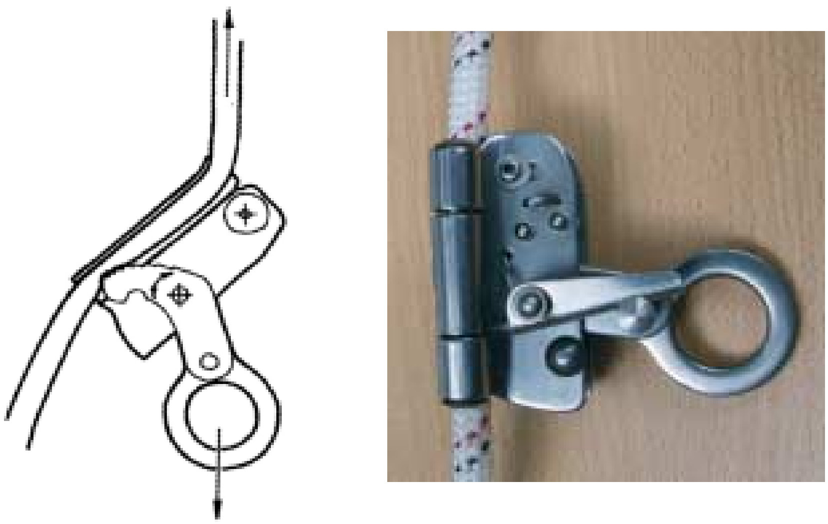

Figure 25
Komet Stick Run back-up device

Markings: On the spine, “KOMET STICK RUN646000 DRISSE D10.5 EN 353-2 OU CORDAGE 3T PA D12mm”. There is also an ‘up’ arrow.

Performance in use: To attach and remove it from the rope requires a bolt to be screwed and unscrewed. This is a little fiddly but, as the device remains attached to the operative it cannot be dropped. The Stick Run has two different settings - it will 'stick' or 'run'. It runs freely on the rope, with a small brake wheel, in one position for descending, and will only move up the rope in the other, for ascending. Simply adding, or removing, a spring action from the cam achieves this change of action. Effectively this means the user can choose whether to have a fall arrest or a work-positioning device. However, as such it is a compromise and does not excel in either situation. When used with a lanyard the active 'run' position is a little too free on 10.5 mm rope, and relies mainly on the device's weight, meaning the device may take time to deploy in some situations. This could possibly be remedied by modifying the brake wheel. However, when used attached directly to the harness the free action is appreciated. When in the ‘Stick’ position it can easily be tensioned onto the back-up rope for safety or to aid positioning. It is very difficult to release when loaded.

Note: - Since the tests, the Stick Run has been slightly redesigned with a smaller, completely smooth brake wheel, and an additional light spring in the cam.

Test performance: The Komet Stick Run failed to hold the 4 kN minimum working strength test, slipping at approximately 3 kN. It passed the 12 kN hold test but was severely distorted.

In the dynamic tests long slippage distances reflected the low slippage force. On two tests on Edelrid rope the device hit the buffer at the end of the test rig. On ten out of twelve tests the peak impact force was less than 3 kN. The two tests that exceeded this were on Marlow rope. Despite the higher impact forces, over 4 kN, slippage was comparable to the other tests, at approximately 1.75 metres.

6.2.6 Petzl Microcender

Material: Aluminium

Weight: 162 gm

Design principle: Cam loaded

Method of use: Work positioning

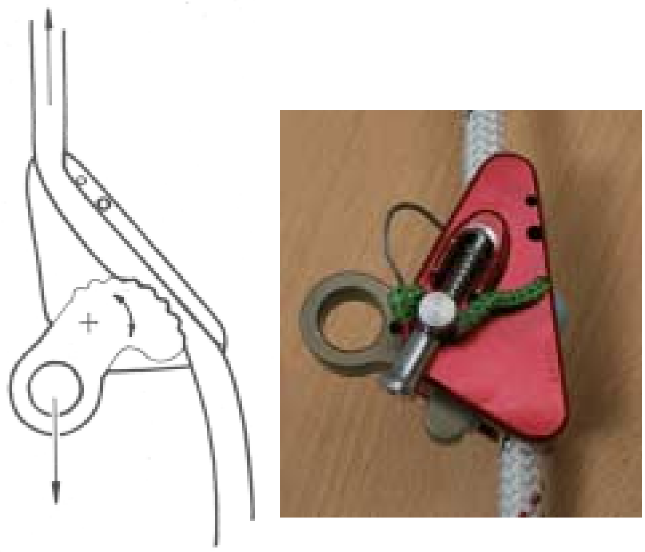

Figure 26
Petzl Microcender back-up device

Markings: "UP" at the top, “EN567 CE 0197” plus characters showing rope diameters from 9 to 13 mm and 3/8 to 1/2 inches inclusive. There is also a small “!” instructions symbol (outline of a book).

Performance in use: The device is installed on the rope after removing the axle by means of a small catch. The device remains clipped in and cannot be dropped. It stays wherever it is placed and can easily be moved up and down. There is a hole in the device that will accept a cord for towing downwards. It can easily be tensioned onto the back-up rope to aid positioning. Release when loaded is very difficult.

Test performance: In the working strength test it was found to slip at approximately 3 kN. Despite the 12 kN force applied, in the minimum static strength test, the device showed no sign of any damage.

In the dynamic tests it performed well on the Edelrid and Marlow ropes. On the Beal rope, however, the results were not consistent showing a steady increase in slippage as the test progressed. As the same device was used for all the tests, on Beal rope, this could be attributed to polishing of the cam surfaces. However the same did not occur with any of the other ropes.

The relationship between slippage and maximum impact force was, however, very consistent.

6.2.7 Petzl Rescucender

Material: Aluminium

Weight: 250 gm

Design principle: Cam loaded

Method of use: Work positioning

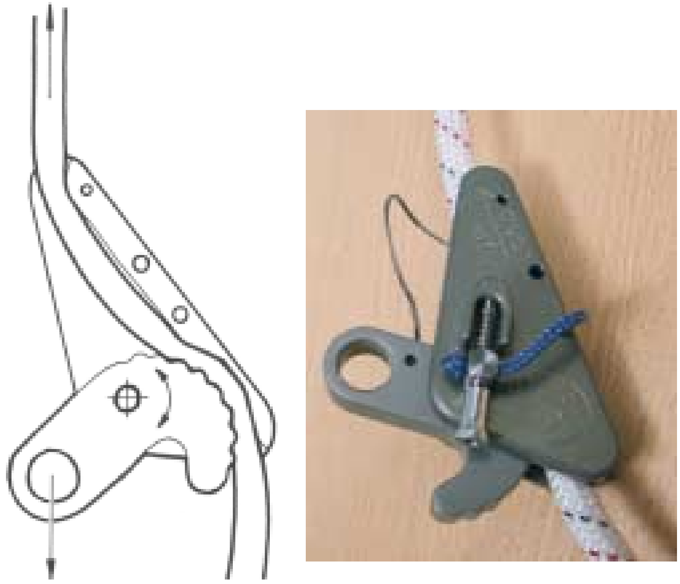

Figure 27
Petzl Rescucender back-up device

Markings: On one side of the body, 'UP' arrow "EN567 CE 0197".plus characters showing rope diameters from 9 mm to 13 mm and 3/8 to 1/2 inches inclusive. and an "!" symbol with a pictograph of an instruction book. On the reverse there is a large engraved arrow with the words "UP" and "LOAD".

Performance in use: This is a larger version of the Microcender and functions as such. It is perfectly usable as a work positioning device, although the spring is a little weak and the device may fall down the rope instead of staying where it is placed. It can easily be tensioned onto the back-up rope to aid positioning. Release when loaded is very difficult.

Test performance: In the working strength test it did not slip. During the minimum static strength test it was seen to slip at approximately 7 kN. After the 12 kN force was applied in this test the device showed no sign of any damage.

In the dynamic tests it performed fairly well, in grabbing the rope, although impact forces were a little high compared to other devices: approximately 6 kN on most of the tests. Slippage, however, was consistently low, 1 m or less on 12 out of 13 tests. One test was something of an anomaly with a low impact force of 3.4 kN, and a correspondingly large slippage of 1.6 m. Unsurprisingly this was on Edelrid rope[11]. However, an extra test was carried out and this proved consistent with the other figures. The only feasible explanation is that the device was not installed on the rope quite as firmly on this test.

[11] Throughout the test programme the Edelrid 10.5 mm low stretch rope was found to be the supplest and 'slippiest' rope tested. See section 2.4 'Ropes: summary' for more explanation.

6.2.8 Petzl Shunt

Material: Aluminium

Weight: 186 gm

Design principle: Cam loaded

Method of use: Work positioning

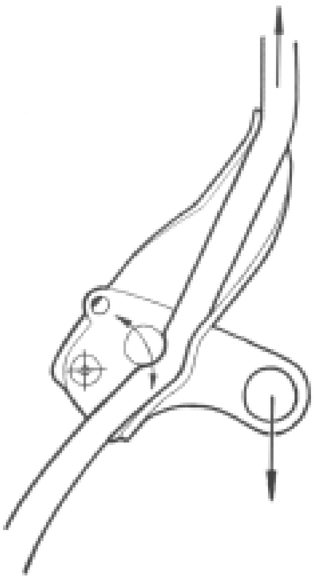

Figure 28
Petzl Shunt back-up device

Markings: On one side of the body, "DOUBLE ROPE" with characters to show rope diameter 8 mm to 11 mm inclusive, "SINGLE ROPE" with characters to show rope diameter 10 mm to 11 mm inclusive, "CE0197" and an "!" with the outline of an instruction book. On the other side there is an outline of a figure with raised hand and "WARNING DANGER PROPER TRAINING IS ESSENTIAL BEFORE USE".

Performance in use: Installation on the rope requires it to be unclipped with the attendant risk of dropping. The method is easy, however, and the device remains where it is placed. It is easily moved both upwards and downwards by hand. A hole in the back of the cam allows a cord to be attached for towing downwards. It can easily be tensioned onto the back-up rope to aid positioning. Release when loaded is straight forward.

Test performance: The working strength test simply served to demonstrate the low force at which the shunt will slip (~2.3 kN to 2.5 kN): however when prevented from slipping in the minimum static strength test the frame bent, releasing the rope at only 5.5 kN. This force is a little too low for comfort, giving a very small margin of safety.

In the dynamic tests it performed poorly. Slippage figures were high, the shortest being 1.5 m, while the longest slips hit the buffer - over 2.5 m below. On most of the tests impact forces were below 2.5 kN, although on two of the tests on dynamic rope, higher figures were achieved when the device snagged and severed the sheath. On all tests, the corner of the frame left a mark down the sheath as it slipped.

6.2.9 SSE Stop & Go

Material:	Aluminium
Weight:	484 gm
Design principle:	Body loaded
Method of use:	Fall arrest

Figure 29
SSE Stop & Go Back-up device
(shown with side plate swivelled through 180^0)

Markings: On the front there is an ‘up’ arrow and “EDELRID USE ONLY ROPE ø 12”. On the rear face an ‘up’ arrow and “CE 0335 01962”.

Performance in use: The device must be unclipped momentarily for installation. The cam is not sprung, instead a small brake helps prevents downwards movement. Raising the device by raising the attachment releases the brake and the device moves freely upwards. Careful positioning also allows it to follow the worker down the rope. When the user falls the upward force on the karabiner is removed and the brake is activated, speeding up the arrest of the fall.

The body and cams of the Stop & Go are significantly larger than the other devices working on the same principle, resulting in a device that is very kind to the rope.

An additional handle is supplied to release the cam when loaded: this does not work well and would be ignored by most users. The handle is separate and has to be fitted to the device for each use.

Test performance: In the working strength test it was found to slip at between 2 kN and 3.5 kN, depending on the rope used. In the minimum static strength test the device distorted badly at approximately 11 kN, although the device did not release the rope.

In the dynamic test conditions the device performs quite well, although not too consistently. On dynamic ropes it gives excellent results comparable to the Rocker. However, on other ropes the results vary widely.

The highest impact force was achieved on Marlow rope - 6.5 kN, although on many of the tests it was approximately 4 kN. Although a wide range of results was obtained, all were within acceptable margins.

6.2.10 Tractel Stopfor D

Material: Steel

Weight: 616 gm

Design principle: Cam loaded

Method of use: Fall arrest

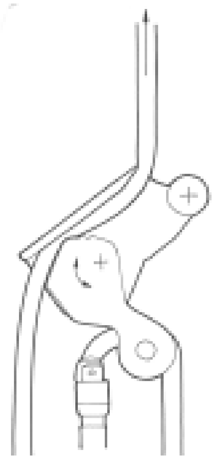


Figure 30
Tractel Stopfor D
(shown without the supplied lanyard)

Markings: On the side, "Drisse Ø 11 Kernmantel rope EN 353-2 CE0082". There is an 'up' arrow on the operating mechanism.

Performance in use: This new device has been designed specifically for industrial fall arrest and has a couple of unique features. Like the Stick Run it can be installed on the rope without unclipping, but it also has the advantage of simply clicking on the rope without the need for any screws to be tightened. A small catch arrangement also prevents the device from being installed upside down on the rope.

The device comes complete with a 0.3 m tape or 0.6 m static rope lanyard already installed. The instructions suggest the 30 cm tape lanyard is used for fall arrest applications, and the 60 cm static rope lanyard for rope access. These lengths do not allow for all variations in user size and technique. For the purpose of the tests the lanyard provided was removed (as would have been required in prEN 12841). However, it was made of very inelastic tape which is unlikely to have absorbed any appreciable fall energy. On the other hand, the modification to the test discussed in 6.2.13 would have allowed the device to be tested with the lanyard as supplied.

With the only sample available for test, concern was raised about the durability of the spring arrangement in the latch. It is understood that the manufacturer has since modified this spring arrangement.

The high weight is noticeable when the device is used. The supplied lanyard was completely static in nature, always a concern in a fall arrest system as it will absorb little energy.

The device moves up the rope well and, if adjusted correctly, will also run down the rope very freely as the operative moves down the rope. Due to the length of the lanyard, and the device's weight and design, it may allow a long drop before it deploys.

Test performance: In the working strength test it was found to slip at approximately 2.5 kN. It survived the minimum static strength test undamaged.

In the dynamic tests it did not perform too well: slip distances were excessive, hitting the buffers on four occasions and never slipping less than 1.4 metres. When the weight and free-running capabilities of the device are taken into account some very long falls are conceivable. As this device seems most suitable for the fall arrest market this gives cause for concern

6.2.11 Troll Rocker

Material: Aluminium

Weight: 162 gm

Design principle: Body loaded

Method of use: Fall arrest

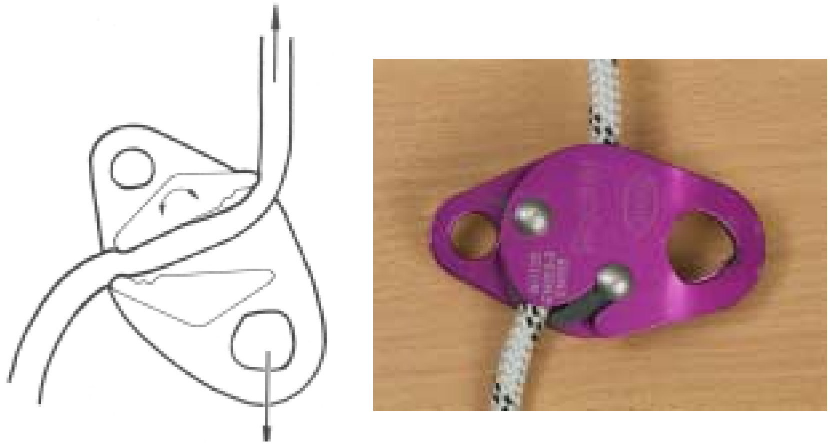

Figure 31
Troll Rocker back-up device

Markings: On the opening plate, "CE0120 EN353-2 EN358" and the name "Rocker" and the Troll trade mark. On the main plate there is the outline of a figure with an upraised arm to show which way up to use the device.

Performance in use: In appearance, the Rocker is very similar to the Ushba Stop Lock, although its aluminium construction makes it a little bulkier than the titanium device.

In use it feels very similar, although a weaker spring means it runs a little more freely. As is recommended in the instructions it was found best to keep it on a short link (15 cm to 25 cm): the Rocker will then run freely up and down the rope, as the operative moves. Some sticking was encountered during descent, however the short link and easy release meant it did not cause a problem. With practice and careful positioning this occurred less often.

The attachment hole is also large enough to allow a second karabiner to be fitted to prevent free movement on the rope, as shown in the instructions. However, in normal use the Rocker had a tendency to catch on the screw-gate of the karabiner, making cross-loadings possible.

Test performance: In the static tests it was found to slip at approximately 3.5 kN to 4.5 kN, depending on the rope. At high forces (over 10 kN), the side plate distorted and cut the rope.

In the dynamic tests it produced extremely good results. The results not only show the best impact force and slippage relationship but also the greatest consistency of any of the devices tested.

Slippage remained under a metre on all but one test, with impact forces between 3.2 kN and 4.8 kN. The light weight and moderately free action mean the device will arrest falls quickly without long drops.

6.2.12 Wild Country Ropeman

Material: Aluminium

Weight: 60 gm

Design principle: Body loaded, toothed cam

Method of use: Work positioning

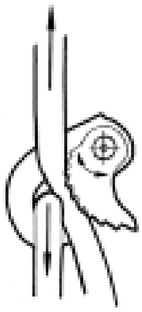

Figure 32
Wild Country Ropeman back-up device
(shown with karabiner attached, in diagram)

Markings: On one side plate, "CE960120 Ø10-11mm ENGLAND". On the other plate "WILD COUNTRY Ropeman" and the outline of a figure with raised hand.

Performance in use: This tiny device was originally intended as an emergency ascender for mountaineering. Compared to the other devices it will not move freely on the rope, particularly downwards, making it difficult and time consuming to use. To descend the cam must be pulled away from the rope and held while the device is moved. This device is extremely difficult to remove under load.

Test performance: In all the tests the results reflect the design of the device. As a small body-loaded, toothed-cam ascender experience has shown a likelihood that the sheath of the rope would be stripped rather than the device slip. In a static pull this occurred at approximately 6 kN. In the dynamic tests this occurred at impact forces as low as 3.5 kN, although on Beal rope a maximum of 6.3 kN was reached. On the third test with Beal the Ropeman actually severed the core as well, breaking the rope. These results are clearly unacceptable for a back-up device. While correct use of a passive back-up device can render only marginally suitable devices safe, in this case the design principles may have been pushed too far.

The only advantage the Ropeman offers is that it will operate correctly and safely, even if grabbed by the user. This is a function of its body-loaded design principle rather than a unique feature. It is however, the principle reason why the company concerned adopted it. The reason that the Ropeman was adopted, rather than other devices, is due to the cam design.

The cam has teeth too large to penetrate the rope sheath, allowing it to be dragged down the rope by a cord attached to the cam.

N.B. During the test programme, Wild Country released the Ropeman MkII. This has a redesigned cam. The cam design has been significantly altered to a design closer to those of other ascenders. This includes the addition of teeth too sharp to allow it to be dragged down the rope. Correspondence with the industrial users of the Ropeman confirmed that they had discontinued its use.

6.2.13 Summary of test performances

The minimum working strength test was not found to be particularly useful in relation to back-up devices. A modified static test would be useful, but the sliding force would have to fall within a stated range rather simply ‘above 4 kN’ as required by the present test. There is no need for the back-up device to withstand a force of 4 kN before slipping, indeed this could be disadvantageous in some cases. A suggested range for a static slippage test is between 2.5 kN and 6 kN.

It can be argued that the dynamic performance test is even more severe than the worst-case scenario. It allows for the back-up device to be connected to the operative by a rigid strop or lanyard – which is something that would never be recommended. The only two ways that the energy of the test fall can be absorbed are through the stretch of the rope on which the back-up device is mounted, and the slippage of the device on that rope. In reality, the back-up device should always be attached to the user by a dynamic lanyard, thereby providing a third energy-absorbing element.

There is therefore a good argument for allowing the manufacturer to provide, as a sub-system, both back-up device and connecting lanyard, and for the dynamic test to be conducted as a fall factor 2 drop onto the integral connecting lanyard.

In the dynamic performance test, the degree of slippage is, broadly, inversely proportional to the peak forces achieved (see the Appendix 9). This is expected from the physics involved: low slip distances resulted in high impact forces and vice-versa.

Within this relationship, the different devices display a wide range of slippage/impact force characteristics. Interestingly the fall-arrest/work-positioning nature of the device is not reflected in the results, which bear little relationship to the design or principle of the devices.

It is suggested that the 'best' results lie in the central area of the distribution, see figure 23, where both extreme impact forces and long slip distances have been eliminated. Of these results, the very best are those closest to the origin, where the lowest combination of both impact forces and slippages lie.

Ideally, devices should perform consistently. Almost all the devices proved disappointingly inconsistent.

Using the slippage/force criteria described above, the Troll Rocker was the best performer and showed the highest degree of consistency. The Petzl Microcender and the SSE Stop & Go also performed well but of the two, neither showed any reasonable degree of consistency, the Stop & Go being the more inconsistent.

The Petzl Rescucender is the next most consistent performer, showing a similar range of slippage figures to the Rocker, but with impact forces in a range approximately 2 kN higher.

Three devices slipped 2.5 m, such that they hit the buffers on the test rig. These were the Petzl Shunt, Komet Stick Run, and the Tractel Stopfor D. A secondary factor to take into account is the state of the rope following the test. Opinion was that slight sheath damage may be acceptable, although not ideal, but severe sheath damage should invalidate even excellent test values.

The kindest device on the rope was the SSE Stop & Go. Following the test, it was almost impossible to tell if the rope had been used. Conversely, two devices succeeded in cutting the rope completely: the Ushba Stop Lock and the Wild Country Ropeman. The Petzl Shunt and the Komet Stick Run both stripped the sheath when tested on dynamic rope, although not on every test. Beyond this, the damage was more difficult to quantify. Devices such as the Petzl Microcender and the Troll Rocker left a short length of rope heavily glazed and furred on one side. The Petzl Shunt left a single long cut down the side of the rope sheath. It is not possible to say which is worst. Tests on damaged sections of rope suggested that ultimate strength is not reduced to a level where it becomes dangerous.

6.2.14 Summary of Back-up devices

Despite identical test set-ups inconsistent results were the norm rather than the exception. One reason for these inconsistencies is rope type. Some devices perform better with certain makes of rope. How this relationship changes with worn rope is uncertain. For a device to be recommended as 'compatible' with a specific rope, a study would have to be made with ropes of varying age and condition.

Fall arrest type devices had a contrived advantage in the dynamic tests by being already locked on to the rope by the weight of the catch plate. (See Appendix 4 for a description of the test equipment of which the catch plate was part.) In a real situation this might not occur until the user and the device were falling. There is concern that with a downward acceleration less than 'g', for example in rapid abseils, the device might not lock onto the rope at all. A very short link to the harness may help locking on to the rope to occur as quickly as possible. A short link does, however, increase the chance of the device locking when this is not wanted. As they operate largely by themselves, for example on the rear attachment of a harness, predictable performance is, therefore, essential. Only one device, the Tractel Stopfor D, comes with a non-adjustable and non-removable lanyard attached. There is scope for further research into the effect on performance when these devices are used with different length lanyards.

With the work positioning devices, operator attention is required at all times. The degree of safety provided is dependent on sensible positioning of the device by the user. With very careful use almost any device can be kept in a position where the impact of a fall would be negligible. Despite this, it cannot be recommended that any cam, toothed or aggressively ribbed, body-loaded ascender be used for back-up. At the time of the tests, only a limited number of operatives were using such a device (the Wild Country Ropeman). Only ascenders with smooth cams should be considered.

None of the devices stood out as being the ideal back-up device. All suffered from shortfalls somewhere in their performance. However, much has been learned. While fall arrest devices can work well, and may be applicable to many situations, they are not suitable for rope access without modification to allow them to remain in position on the rope. (Such modification could, for example, be by the application of a spring, or additional karabiner loading as shown by two of the devices tested). Correct operation of a back up device, as recommended by the IRATA 'Guidelines on the use of rope access methods for industrial purposes',[12] results in a very safe system where the possibility of a fall factor greater than 1 is eliminated. This has allowed trained operatives to use devices whose performance and strength may not be ideal, effectively and safely. The shortfalls of the Petzl Shunt have been clearly seen and the industry should now be developing devices which fulfil the requirements discussed above. One serious concern remaining is the 'grabbing' reflex, of the operator, in a fall situation. With many devices there is a good chance that performance will be impaired if anything is in contact with the device. The consequences of the user actually grabbing the device in a fall are potentially catastrophic: many devices will be completely disabled by this action. Ideally this should be designed out of the device. However, at present all devices suffer to some degree from this problem. Training users to overcome this reflex is essential, at least until a device is available which will pull down the rope when required, but remain secure if grabbed in panic.

[12] INDUSTRIAL ROPE ACCESS TRADE ASSOCIATION

Guidelines on the use of rope access methods for industrial purposes, Edition 2 Revision 1 01/00

6.3 TYPE B - ASCENDER DEVICES

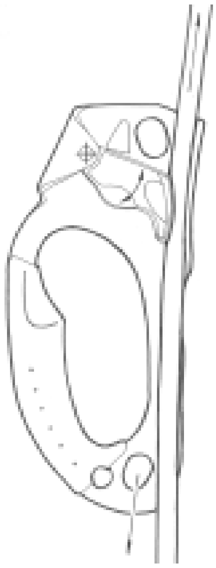

Figure 33
Typical hand ascender Type B device
(chest ascenders similar but with smaller body and no handle)

Rope clamps (Type B) are principally used for ascending the rope, and hence are generally called 'ascenders' or 'jammers'.

All type B devices clamp onto the rope, but may be connected to the user in different ways. For industrial use they are usually either, fastened into the suspension point of the user’s harness, or they are fitted with a foot-loop so that the user’s weight is transmitted to the device when he stands in the loop. In the first case the device is held vertically against the chest by a second attachment point on the device, which connects to the upper torso part of the harness. An ascender used like this is known as a ***chest ascender***. This chest ascender arrangement allows automatic body movement when ascending, while the ascender with a foot-loop is pushed up the rope manually. The latter may therefore be referred to as a ***hand ascender***. Ascenders may be attached in other ways, for example to the knee or ankle, but this is not common practice on the work-site.

To ascend the rope, the operator stands up in the foot-loop, keeping himself upright by holding the hand ascender, while the chest ascender slides up the rope. Sitting down in the harness, suspended by the chest ascender, then allows the hand ascender to be slid further up the rope.

In the workplace, ascenders used for upward progression are of the toothed-cam, body loaded type. The questionnaire confirmed that there were no exceptions to this. The only ascender standard currently in existence is BS EN 567. There are other ascenders that meet this standard, but some are unsuitable for any work application. Others may be more suitable as Type A – back-up devices.

The reasons for the use of body-loaded, toothed cam ascenders are that they:

- slide easily and directly up the rope,
- hold immediately and positively when subject to a downward force,
- do not cause the user to lose any height gain as they are loaded,
- are easy to install and remove from the rope.

All these devices work on the same body-loaded, toothed-cam principle and differ only in detail. All consist of a channel in which the rope is trapped by a toothed eccentric cam. Only a light locating spring and the teeth initiate the gripping action: no force is directly applied to the cam. For this reason extremely dirty or icy ropes can cause problems with the operation of the device. The cams of two manufacturers incorporate cam-cleaning devices (slots) to counter this. Six ascenders in total were tested: three hand and three chest types.

These device were tested against three of the tests specified for Type B devices in prEN 12841 (see 3.3 in this standard):

A. Minimum working strength (see section 4.4.6 prEN 12841)

Device to hold a force of 4 kN for 3 minutes. (Test originally from BS EN 567.)
All the ascenders on test had been previously tested to this standard prior to their release onto the market, and unsurprisingly all passed.

B. Dynamic performance. (see section 4.4.8 prEN 12841)

Peak impact force and slippage were measured with a fall factor 1 drop of a 100 kg mass. The device was located on the rope 1 metre below a rigid anchor, and the weight released from the height of the anchor.

The tests were carried out using the 'catch plate' rig at Petzl. See section 14.4.5, in the Appendix, for details.

Given that this type of ascender is designed to grip the rope without slippage, the only way that the energy of the fall can be absorbed is by the stretch of the rope and sliding of the sheath down the core if, or when, it is severed. It is, therefore, as much a test of the rope used as of the device itself. All devices of this type will cut the sheath in an impact of this severity. The fall is only arrested when the sheath bunches and grips the core, usually after about a metre of slippage.

It should be noted that the ends of all the test ropes had been cut with a hot knife and thus the sheath and the core were bonded together at this point. If the ends of the sheath and core are not bonded then the ascender can run off the end of the rope. A knot will prevent this.

The impact forces sustained in these tests are summarised in Appendix 12.

There is a strong argument to say that this test is irrelevant. The action of these devices on kernmantel rope is such that the sheath of the rope is held without slippage by the toothed cam. When the dynamic force reaches a figure at which the sheath breaks, the severed sheath slides down the rope core. This test adds very little to the minimum working strength test. This could be extended, so that first the device would be loaded to 4 kN for three minutes, as normal, then it could be pulled to sheath failure, and the figure recorded.

C. Component body test. (see section 4.1.6 prEN 12841)

Device to hold a force of 15 kN for 3 minutes, across attachment points.
Although in prEN 12841 this test is aimed at all rope adjustment devices, not all have the two attachment points necessary for the test.
Type B devices all have at least two attachment points and therefore qualify.
The test is designed to safeguard against the unlikely risk of the ascender being used as a link between two connectors, for example in a rescue, and does not apply to the normal operation of the device at all.

6.3.1 Camp Pilot

Material: Aluminium (Sheet)

Weight: 222 gm

Design principle: Body loaded

Method of use: Hand ascender

Figure 34
Camp Pilot Type B ascender device

Description: The cast steel cam has a relatively small concave contact face ~35 mm long. This has 17 small teeth distributed in pairs either side of a plain central strip. This strip appears to have been designed as a slot but not actually manufactured as one. The conical teeth are ~2 mm long with fairly sharp points. The axes of all the teeth are roughly parallel with the top surface of the cam.

Markings: Next to the rope channel includes: outline of man indicating correct way up. "EN 567.CE0123 ROPE min Ø 8 max Ø 13". The marks are lightly etched and painted.

Performance in use: The push-button catch design works well and has a good positive action. The rubber handle is comfortable with plenty of room for large hands. However, the broad handle means the load is some distance from the rope and the device rotates slightly when loaded. Installation on the rope is more difficult than with the other ascenders as the slot is narrow and curved. However, once on the rope it moves up and down well, although the sharp teeth will snag the sheath if care is not taken when moving down the rope.

Test performance: Both the static tests were passed. Following the 15 kN component body test some distortion was seen. This was visible around the top attachment hole where the thin metal, forming the top of the hole, had stretched slightly.

In the dynamic tests, the Camp Pilot cut the sheath at slightly lower impact forces (4.1 kN to 5.2 kN) than the other devices. See the Appendix. This is possibly due to the small area of the cam's contact face and the nature of the teeth. These are quite sharp and protrude almost horizontally. Following the dynamic tests it was quite difficult to remove the Camp Pilot from the rope. This is because the rope channel opens up slightly when the rope is forced into it under high forces. When the load is released the channel springs back, trapping the rope against the cam.

6.3.2 ISC ascender

Material: Aluminium (Extruded and then machined)

Weight: 364 gm

Design principle: Body loaded

Method of use: Hand ascender

Figure 35
ISC Type B Hand ascender device

Description: This ascender has been milled from an extruded aluminium section. The cam has a concave contact face, ~45 mm long, uniformly covered with 46 teeth arranged in alternating rows of 3 and 4 teeth. The teeth are short (1 mm) and stumpy, with rounded points. The teeth's axes are perpendicular to the cam face.

The plastic handle is not as comfortable as the others, particularly for large hands. The device is not particularly broad and so sits well when vertically loaded. Installation on the rope is very easy and it moves up and down the rope well. The teeth are not sharp enough to snag on the sheath.

Markings: On the front of the handle, a rather ambiguous arrow pointing upwards, and a small "0120CE" mark. On the rear of the handle, "Ø ROPE MIN 9mm - 13mm MAX". The marks are lightly etched on a painted background. On the rear of the body is a machine stamped batch number. In use it is noticeably heavier than the other devices but is not detrimental to performance, or ease of use. The extruded section is clearly very strong and gives a reassuring solidity to the device. In contrast with the rest of the device the catch, an aluminium lever, feels slightly flimsy.

Test performance: In the static tests it was the only device to show no distortion whatsoever. Following all the tests the cam released easily no matter what force had been applied. The 15 kN component body test was passed without any distortion. The rope channel is sufficiently strong to prevent it opening, even slightly, when under load.

In the dynamic tests it cut the rope sheath at forces comparable to other devices (4.8 kN to 6.6 kN). However, in contrast with the other devices it could be removed easily following the test.

6.3.3 Petzl Ascension

Material: Aluminium (Sheet)

Weight: 198g

Design principle: Body loaded

Method of use: Hand ascender

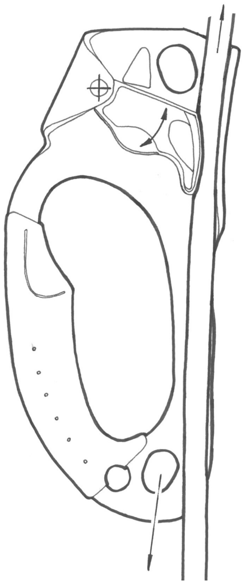

Figure 36
Petzl Ascension Type B hand ascender

Description: The contact face of the cam is 32 mm long with a central vertical slot to assist the removal of mud from the rope and cam interface. The face is covered with 26 teeth arranged in rows. The teeth's axes are angled downwards at an angle constant to the cam face, i.e. they are not all parallel. The teeth are short (~1 mm long) but fairly sharp. In the body there is a pressed stop, above the cam, to help stop the cam pulling through the channel when under extreme forces.

Markings: (stamped): next to the rope channel, outline of man indicating correct way up, and characters to show rope diameter from 8 to 11 inclusive. On the front base, "CE0197", and on the rear base, "EN567". On the rear of the body there is a small "!" instructions symbol (outline of a book).

Performance in use: The rubber handle is comfortable and the plastic catch easy to use although strongly sprung. Installation on the rope is easy and the device moves up and down the rope easily. Care must be taken when moving downwards to ensure the sharp teeth do not snag the sheath. There are two attachment holes at the bottom of the handle. The handle is canted slightly to allow these to lie in line with the rope, with the result that it seats well when loaded.

Test performance: Both the static tests were passed, although some distortion was seen following the component body test. This was visible as distortion and crazing of the thin metal forming the top of the upper attachment hole.

Dynamic performance was on a par with the others tested, stripping the sheath at between 4.5 kN and 6.5 kN. As with other stamped aluminium devices, an impact of this severity results in a slight opening up of the rope channel, visible as crazing of the anodising on the rear of the device. Following the test the rope was difficult to remove as the channel tried to spring back, trapping the rope.

6.3.4 Anthron AC30

Material: Aluminium (Sheet)

Weight: 146 gm

Design principle: Body loaded

Method of use: Chest ascender

Figure 37
Anthron AC30 Type B Chest ascender

Description: The cast steel cam has a fairly small contact face ~33 mm long. The face is covered with 18 small teeth with a large lug at the base. The purpose of the lug appears to be to prevent the teeth scratching the inside of the rope channel. The teeth are 1 mm to 2 mm long, fairly sharp, and are set at a slightly downward angle constant to the cam surface. The sides of the cam are grooved to aid the removal of mud from the rope/cam interface.

Markings: (stamped): on the top of the rope channel, an ambiguous double-headed arrow, and “ROPES Ø8-13mm”, on the back of the body, “CE0123”.

Performance in use: When the cam is open the wide slot accepts the rope easily. The top hole is slightly smaller than on other chest ascenders, but easily accepts a 10 mm karabiner. Once installed it moves up and down well. Care must be taken when moving downwards to ensure the sharp teeth do not snag the sheath. The very strong catch spring can make releasing the rope difficult.

Test performance: Both the static tests were passed, although some distortion was seen following the component body test. This was visible as stretching and crazing of the anodising surrounding the upper hole. However, it was the only one of the three chest ascenders to pass this test.

In the dynamic test it produced slightly higher peak impact forces (5 kN to 7 kN) than any other device. In contrast with the type A and type C devices this is a good sign, as it shows the toothed cam does not cut the rope sheath as readily as other devices. The reasons for this are unclear, however it may be due to the action of the small lug at the base of the cam's contact face.

6.3.5 Kong Cam Clean

Material: Aluminium (Sheet)

Weight: 156 gm

Design principle: Body loaded

Method of use: Chest ascender

Figure 38
Kong Cam Clean Type B ascender (chest)

Description: The cast steel cam has a large contact face ~42 mm long with four transverse slots to assist the removal of mud from the cam and rope interface. 24 teeth are arranged in rows across the face. Both the teeth and slots are contained within a concave groove in the face of the ascender. This groove decreases in radius from top to bottom to accommodate different rope sizes. The teeth are small (~1 mm to 1.5 mm long) with rounded ends, and are all aligned parallel with the top surface of the cam.

Markings: On the rope channel, diagram of device and rope with arrow pointing up. On the back of the device, "CE0426 UIAA Ø 8 - 12 mm". The marks are lightly etched.

Performance in use: The device is easy to install on the rope as a result of the wide slot and curved rope channel. It moves up and down the rope reasonably easily, although care must be taken when descending to ensure the sharp teeth do not snag the sheath. When ascending, with little weight of rope below the device, it does not always run smoothly, as the rope catches in the channel. The release catch can be easily operated with either finger or thumb to release the rope.

Test performance: The minimum working strength test was passed without incident. However, the device failed the component body test when the upper hole failed at approximately 8.5 kN. This occurred where the metal is thinnest to the side of the upper hole.

In the dynamic test the device cut the rope sheath at forces comparable to the other devices: between 4.6 kN and 6.4 kN.

6.3.6 Petzl Croll (chest)

Material: Aluminium (Sheet)

Weight: 132 gm

Design principle: Body loaded

Method of use: Chest ascender

Figure 39
Petzl Croll Type B chest ascender

Description: The cam is identical to the one in the Petzl Ascension and is formed from cast steel. The contact face of the cam is 32 mm long with a central vertical slot to assist the removal of mud from the rope and cam interface. The face is covered with 26 teeth arranged in rows. The axes of the teeth are angled downwards at an angle constant to the cam face, i.e. they are not all parallel. The teeth are short (~1 mm long) but fairly sharp. The catch is a sprung plastic lever with hollows within it for the finger and thumb. There is a pressed stop in the body, above the cam, to help prevent the cam pulling through the channel when under extreme forces.

Markings: (stamped): On rope channel, outline of man indicating correct way up and characters to show rope diameter from 8 to 13 inclusive. On the back of the body, "CE0197 EN567", a UIAA symbol and an “!” instructions symbol (outline of a book).

Performance in use: The rope slot when the cam is open is not as wide as on the other devices: however 10.5 mm rope is accepted easily. Larger ropes may be more difficult. It moves up and down the rope well, although care must be taken when descending to ensure the sharp teeth do not snag the sheath. When releasing the rope, the plastic catch can be quite awkward to operate and, ideally, must be pinched between finger and thumb.

Test performance: The Petzl Croll passed the minimum working strength test but failed the component body test. The failure occurred when the metal surrounding the upper attachment hole fractured. This occurred at 12.2 kN on the first test and 10.9 kN on the second. The failure appeared to start at the pressed cam stop, next to the upper hole.

In the dynamic tests it cut the sheath at impact forces between 4.7 kN and 6 kN.

6.3.7 Summary

At present, most of the Type B ascender devices on the market have been designed for sport use, whether for caving, climbing or both. As a result, the designs are centred on producing lightweight products that are not really intended for intensive daily use in a working environment.

The exception here is the International Safety Components (ISC) ascender that would be ignored for sport use due to its excessive weight. However, in an industrial environment this is less of an issue and its bulky strength will be much appreciated by some users. The usual damage scenario for handled ascenders is when they are bent over edges. This can occur on a variety of scenarios some of which are fairly common. For example, at the top of a pitch when the parapet is reached. The ascender is pushed so it lies across the edge and the operative then stands in the foot-loop. This applies considerable force to the device where it is weakest: between the cam and the handle. The stamped aluminium devices are particularly prone to this, although both the Camp Pilot and the Petzl Ascension have strengthening ridges in the most susceptible areas. The ISC ascender would appear to be less vulnerable to this kind of damage.

Despite the differences in cam and body design the devices all performed well in use, with little to choose between them. Again the ISC device was the only one to stand out: this was due to its blunt teeth allowing easy downward movement. This could, however, mean it would perform less well on very dirty ropes (not tested). The only other obvious differences between the devices were the strength of the catch springs. This affects the ease of removing the device and very strong springs can prove troublesome.

The obvious point not addressed by these tests is that of wear. Devices will perform differently as they wear: springs will weaken, teeth will become blunted, etc. The only way to test this is by continuous use over long periods, something which was not possible during this project. Similarly, device performance on worn or dirty ropes was not tested. Both of these points are important when choosing an ascender, and hence there may be scope for further work on these subjects. At present users must rely on experience.

Most of the devices passed the static tests, the only failures being the Kong Cam Clean and Petzl Croll chest ascenders. On both of these the top hole failed at high forces during the component body test. While high forces would not be applied to this hole during normal operations it is just about feasible during rescues. It is not suggested that these devices are avoided on this basis alone, but that manufacturers should perhaps address the problem in the next version of their device. The Anthron chest ascender shows this is not too difficult to achieve.

In comparison with the other types of equipment, ascenders are relatively weak. This is because their strength, when installed on the rope, is limited by the strength of the rope sheath. Because of this the devices should only be used for progression when only low (single body weight) static forces are applied. They are not suitable for rescue loadings with two people. Dynamic forces should be avoided in all situations.

Another point to consider is the markings on the devices. While some are clear and useful others are at best vague. Some standardisation would be useful here. However some users do make the point that as the devices require training to use, a trained user should know which way up to use them. Similarly, if used as part of a haul system, the 'this way up' markings become incorrect.

6.4 TYPE C - DESCENDER DEVICES

6.4.1 Introduction

Type C devices are friction-inducing devices used for descending the rope. They are commonly known as 'descenders'. The principle of these is fairly simple. The rope is wound round a series of posts, or bobbins, which create sufficient friction such that, under body load, a controlled descent can be performed. While countless designs exist, not all are applicable to a working situation. For the purposes of this project a descender was defined as:

> ***"A manually operated, friction-inducing rope adjustment device which allows the user to achieve a controlled downward motion and to stop, with hands off, anywhere on the anchor line. In addition these actions should not cause twisting of the rope."***

The idea of this is to discount the many devices, such as figure-of-eights and racks, which are used widely in the sport world but are not as suitable for industrial use because they do not have an auto-lock facility.

They should also have a hands-free auto-lock or speed limiting function. Auto-locks come in two types: single action and double action.

A single action auto-lock (e.g. Petzl Stop, Troll pro Allp tech) requires a handle to be continuously squeezed to maintain descent. If it is released the device stops, or at least slows significantly. This prevents an accident if the operator is knocked unconscious. However, in a situation where the user remains conscious the panic reflex is often to grip the device harder, resulting in uncontrolled descent.

In the double action devices (e.g. Anthron Double Stop, Petzl I'D, etc.) descent is also stopped if the handle is squeezed too hard, preventing uncontrolled descent. In practice the auto-locks on some devices work far better than on others: this is highlighted in the individual product reviews.

A third class of device has a function for continuously varying friction. In the minimum friction position the device will not slip down the rope. The applied friction is then steadily reduced, by the user, to allow descent at a set speed. Descent continues at this speed unless the applied friction is adjusted by the user: preventing the danger of a ‘grab and drop’.

Despite the name, descenders are used for a variety of purposes in rope access. The versatility of a descender will affect its suitability in the workplace as the fewer devices a worker has to carry, the better. One common secondary use for a descender is as a locking pulley, while in conjunction with a handled ascender and foot-loop, an effective work positioning system can be created using the descender for both ascent and descent. The design of some devices makes them unsuitable for such secondary uses, nevertheless these less adjustable devices may be more suitable for some rescue and escape purposes.

Seven devices were tested. The variety of devices on the market means this can only be a representative sample. However, most types likely to be encountered by industrial users have been covered.

6.4.2 Tests

All devices underwent four tests, as specified in prEN 12841 (see 3.4 in this standard), with only three devices undergoing the Descent performance test:

A. Minimum working strength. (see section 4.4.6 prEN 12841)

Hold 3 kN for 3 minutes.

This is a static test simply intended to check the device's ability to hold normal forces without slipping or distorting. Although the weight of an operator is unlikely to exceed 100 kg, sudden braking during descending or lowering will create larger forces. This test gives a factor of safety of 3 to accommodate these forces. The device must pass this test using only the manufacturer's recommended lock, whether by a cam action or with an additional rope lock**.**

B. Minimum static strength (see section 4.4.7 prEN 12841)

Hold 6 kN for 3 minutes.

Again, this is a simple test to check the device's ability to tolerate high forces without damage. The figure of 6 kN gives a comfortable factor of safety for loadings that exceed the norm. This test is aimed at testing the device's structural integrity rather than their resistance to slippage. Hence, for devices that do slip under such forces, a knot is permitted below the device in order to allow the test. It should be noted that this may impart forces into the device in a way not envisaged by the manufacturer, but it is a credible situation, for example, when the device is halted by a knot in the rope.

C. Dynamic performance. (see section 4.4.8 prEN 12841)

Peak impact force and slippage with a fall factor 1, 100 kg mass.

Although dynamic loadings on descenders may seem unlikely they are not impossible to achieve. A likely situation would be a slip while clambering over a parapet wall. Slowing fast descents quickly will also impose dynamic-type forces on the device. Neither of these situations is likely to produce falls greater than the length of rope deployed, hence the fall-factor in the test is limited to 1.

The results for this test were particularly interesting, as they did not conform to the expected relationship between impact force and slippage. (See the Appendix). At first it is difficult to reconcile a spread of results, such as these, with what is expected from the physics involved. That is, a reasonable linear relationship between impact forces and slippages. This is clearly not the case here. For identical test set-ups, and similar resulting slippages, the impact forces may vary from 2 kN to as high as 8.5 kN. Examination of the charts produced by the recording instruments provides the answer. Some devices produce a short rising curve followed by a flat peak maintained for up to half a second. These devices are absorbing the energy steadily by slipping, if only for a short distance, without generating large peak forces. Others show a long rising curve followed by a sharp peak maintained for as little as an eighth of a second. Slight judders on the rising limb indicate slippage down the rope before the cam mechanism 'bites' and arrests the fall suddenly.

The devices with the more aggressive cam actions, e.g. Anthron Doublestop, Petzl I'D, therefore achieved the highest impact forces. The lowest impacts resulted from tests on the least aggressive devices, e.g. Troll Allp.

D. Descent performance (see section 4.4.4 and 4.4.5 prEN 12841)

This test was not conducted in accordance with prEN 12841. The standard requires that a 20 kg mass is supported by the device as the line is drawn through the device for 50 m. In order to more accurately replicate the workplace, the test was conducted with a 100 kg mass and the line was drawn through the device for at least 100 m.

Handling and heating characteristics when lowering a 100 kg mass for a 100 metres plus descent.

This test attempted to investigate the degree of heating of the devices, as a result of friction, during long drops. A capstan was used to pull the rope upwards, while the device was controlled so as to maintain it within the reach of the operator who was standing on the floor. Using a probe, the temperatures of the device and the rope were then taken at frequent intervals. As the 'descent' progressed the speed and degree of heating could then be assessed. Due to the difficulties of temperature measurement and maintaining consistent descent rates, test control was unsatisfactory. The results are given for the three devices tested, they are indicative only.

D. Descender restraint force (see section 4.4.3 prEN 12841)

Although this test is specified in prEN 12841, in practice it was impossible to achieve consistent results that could be meaningfully compared.

The objective was to measure the force that must be applied on the free end of the rope to prevent descent of a 100 kg mass, when the device is in its minimum friction position. This force represents the restraining force which has to be applied by the operator to the rope. In practice it proved impossible to locate, and maintain, the minimum friction position on any of the devices. This test may be practical when applied to simple non-auto-lock descenders. It is not practical when the descenders in question are designed, in differing ways, to induce additional hands-on or hands-off friction.

In practice the variations between device designs, and the difficulty in making a straightforward test set-up, meant the attempt was abandoned. Most of the devices have some method of continuously varying friction making comparative results very difficult to achieve. Of far more use, although less quantifiable, were the impressions of users who tested the devices on the ropes.

The following table summarises the forces required to initiate sliding on the three ropes, as deduced from 8.2.A Minimum working strength tests:

Table 7
Force to initiate descent of descenders

Device	Force to initiate sliding under static load (kN)		
	Beal	Edelrid	Marlow
AML	>3	2.8	>3
Anthron AC30	>6	>6	>6
Petzl I'D	>3	5.5	>3
Petzl Stop	>3	3.5	>3
SRT Noworries	1.7	1.5	1.8
Troll Allp	1.9	1.9	1.9
Troll pro Allp tech	>3	5.7	>3

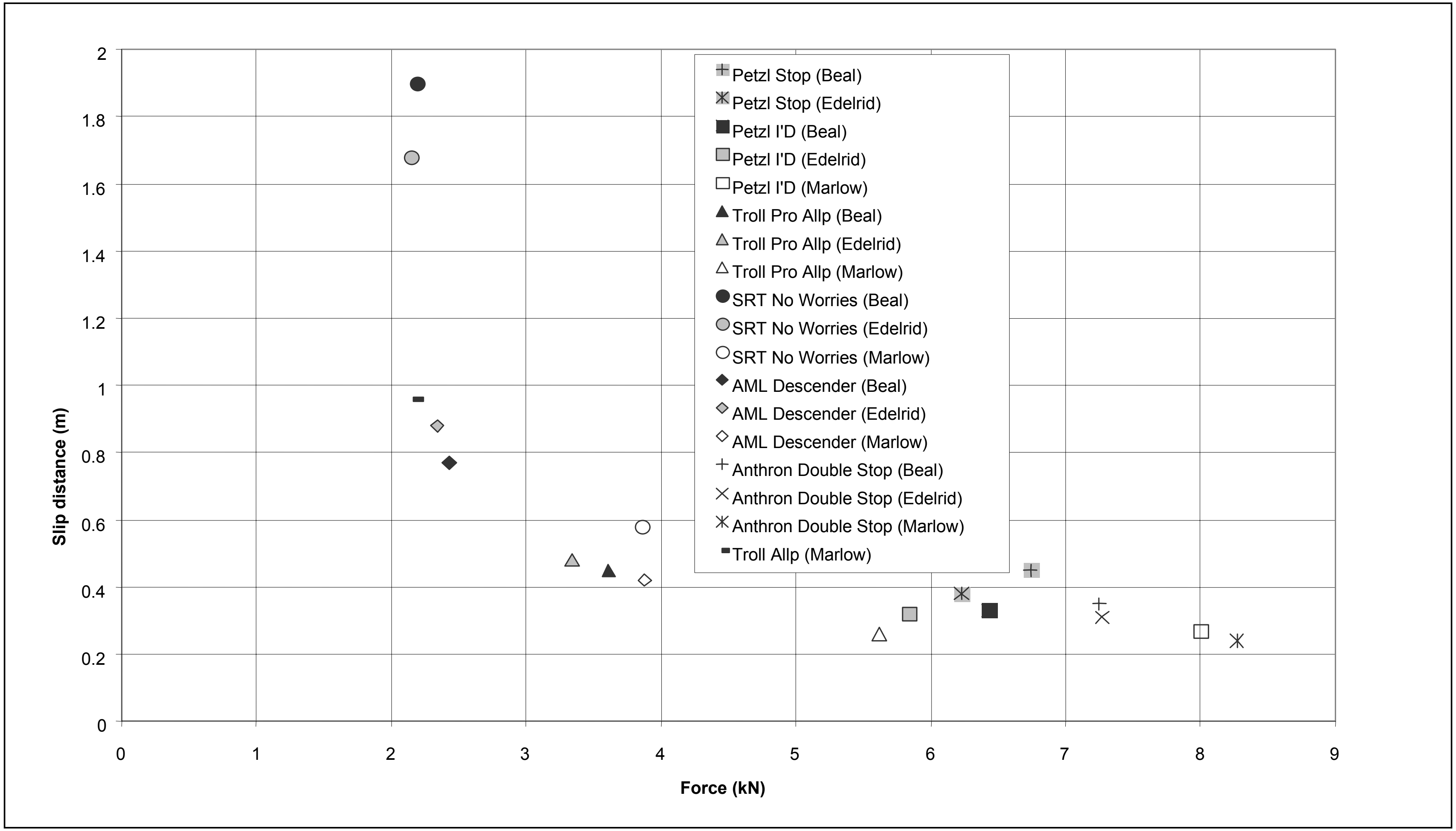

Figure 40
Type C Descending devices - dynamic performance

Note: The plotted data are averages for the performance with each of the ropes

6.4.3 AML

Material:	Aluminium
Weight:	546 gm
Design principle:	3-bobbin
Auto-lock type:	Double action

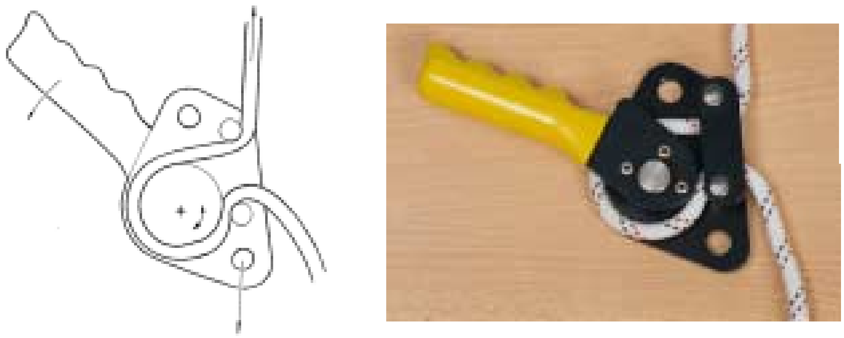

Figure 41
AML Type C descender

Description: A bight of rope is pushed between two steel posts and located around a capstan ~57 mm in diameter. The axle of the capstan is offset to create a cam action and a large handle (~15 cm long, 30 mm diameter) is attached to the top. This has two functions: to stop the rope falling off the capstan, and to progressively disable the cam action on the rope. The handle has a thick plastic cover with pronounced finger ridges.

Markings: Engraved on the back of the device are several batch numbers. These are mostly covered by a large sticker, provided with the device, which has the following markings: below the upper attachment hole, "TOP", below that, “TO STOP - LET GO OF HANDLE”, and below that, "AML 16682 BS EN 341".

Performance in use: Loading the rope is simple in principle but can be very awkward to do. This is due to the tight slot between the capstan and the guide pin, into which the rope must be forced.

Weighting the device automatically pulls the handle up into the stop position, ready for descent. Substantial effort is then required to pull the handle and initiate descent. However, the action is encouragingly progressive and quickly becomes familiar. Overcoming the cam action of the capstan requires constant effort, and releasing the handle quickly stops descent. Due to the nature of the handle, and its operation, the 'panic grab' scenario would be unlikely to apply to this device. Nevertheless, the device has a double-action auto-lock. In use it was found the second part of the auto-lock was quite difficult to achieve, requiring considerable physical effort and movement through a large arc. The progressive action and tricky installation mean the device would be best suited to use in escape kits, where it is pre-loaded on the rope for emergency use by novices. Rescue use is also a possibility, although the effort required to pull the handle when carrying a two-person load might mean it is not ideal.

Test performance: In the minimum working strength test the AML held the force of 3 kN when installed on Beal or Marlow ropes, but slipped on Edelrid rope. It also passed the minimum static strength test of 6 kN without damage.

In the dynamic tests the AML produced some impressive results, on the Beal and Marlow ropes, due to its large rounded capstan and mild cam action. On the softer Edelrid rope, however, slippage distances were high, on one occasion hitting the buffer after 2.5 m of descent.

In the descent performance test, it reached the highest temperature of any device: the rope leaving the device after 140 metres was measured at 115^0C.

6.4.4 Anthron Double Stop

Material: Aluminium with steel bobbins

Weight: 352 gm

Design principle: 2-bobbin

Auto-lock type: Double action

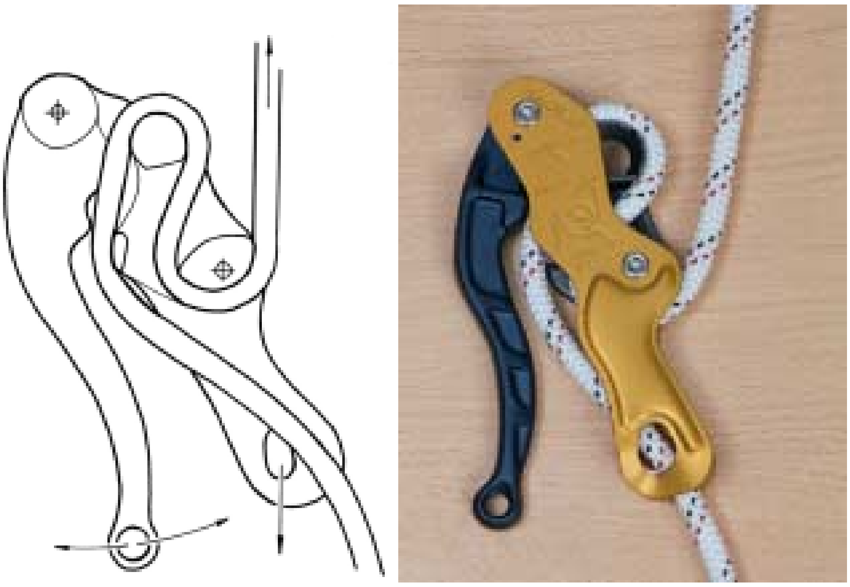

Figure 42
Anthron DSD-25 Type C descender

Description: The body of the device is constructed from two stamped aluminium plates connected at the top by a smooth aluminium bobbin. Halfway down the device there is a swivelling cast steel bollard arrangement around which the rope is threaded. A long cast aluminium handle extends down the full length of the device on one side. The side plates pinch together at the base where there is an attachment hole running through both plates. Weighting the device pulls the bollards back into the body of the device, trapping the rope against the top bobbin, and pushing the handle out. Squeezing the handle pushes the bollard arrangement out, reducing friction and allowing descent. Further squeezing then begins to trap the rope between the handle and bollard, increasing friction and halting descent.

Performance in use: In use the device is quite awkward to load and does not allow movement up the rope. However, the length and design of the handle allows extremely fine control of the friction applied. The action of reducing, and then increasing, friction occurs in a very smooth and progressive manner. Maintaining a constant descent rate requires the handle to be constantly squeezed to the central position. During descent, releasing the handle immediately halts descent. Likewise any over-squeezing of the handle immediately slows or stops the descent. The design is very user-friendly (except for loading) and very safe. Even a beginner would be unlikely to have trouble descending with this device. For these reasons it would be ideal for use in escape kits. The inability to move up the rope, however, limits its applicability to rope access. With large, e.g. rescue, forces the second part of the auto-lock works less well, requiring considerable force to trap the rope and slow descent. However the first part of the auto-lock is unaffected.

Markings: On the front of the device a fairly clear loading diagram with the top rope clearly shown ending at an anchorage with the word "UP ROPES/SEIL Ø 9 - 12 mm CE0123". On the rear of the device the loading diagram is repeated in the correctly (for the rear of the device) reversed orientation. A “!” instructions symbol is accompanied by the words "PROPER TRAINING IS ESSENTIAL BEFORE USE".

Test performance: In the static tests the unique cam design proved to be very efficient. It was the only descender to hold the minimum static strength force of 6 kN without any additional lock, relying purely on the cam action of the bollard arrangement.

This unwillingness to slip was reflected in the dynamic tests where the Anthron Doublestop produced the highest impact forces of any descender (8.5 kN).

In the descent performance test the Doublestop performed quite well, achieving a peak temperature of 85^0C, even after 140 metres of descent.

6.4.5 Petzl I'D

Material: Aluminium body, steel bobbin, plastic handle

Weight: 534 gm

Design principle: 1-bobbin

Auto-lock type: Double action

Figure 43

Petzl I'D Type C descender

Description: From the outside the I'D consists of two pressed aluminium plates with a large plastic handle attached. The plates are pinched together at the base where an attachment hole passes through them both. The rear plate acts as the main frame and has several components mounted on it. The front plate acts as a cover for the device and swivels aside to allow installation of the rope. Its attachment hole has a catch to allow access to place the rope without detaching the device from the main frame. Inside the device are four main components. At the top is a steel anvil against which the rope is trapped by a large cast steel bobbin below it. This bobbin is mounted on an axle and can rotate through about 30^0. The top section of the bobbin is cut away to create a slot between the bobbin and the anvil, and to create a cam action when the bobbin is rotated clockwise. When the device is weighted this cam motion occurs due to the friction of the rope running around the bobbin. The lower part of the cam is cut away to accommodate a fixed steel pin (~10 mm in diameter) around which the rope also runs. This pin extends out of the rear of the device and forms an axle for the large plastic handle. This is attached to the main bobbin by a clutch mechanism.

Clockwise rotation of the handle turns the bobbin clockwise, squeezing the rope against the anvil in a stepwise motion. This operation is used to lock off the device. Anti-clockwise rotation of the handle, when the device is weighted, progressively releases the cam action of the bobbin. However this only occurs up to about the 9 o'clock position. Beyond this the handle disengages and the force from rope friction rotates the bobbin, trapping the rope and stopping descent. This is to prevent the 'panic-grab and drop' scenario. Between the bobbin and the attachment hole is a small toothed cam. This is positioned purely to trap the rope should the device be installed upside down. This is the most complex device tested and the exact operation of the clutch mechanism cannot be seen without destroying the device.

Performance in use: In use the device is simple to install onto the rope, the handle must be in the unlocked position. Movement up the rope is easy, allowing slack rope to be easily taken in. A positive lock is then easily achieved by turning the handle clockwise. Alternatively, weighting the device, in a confident manner, immediately engages the stop action. A more tentative approach will not always have the same effect, although this can be avoided by engaging the lock. Turning the handle anti-clockwise meets resistance between the 10 o’clock and 11 o’clock positions. Movement beyond this steadily releases the cam, allowing the speed of descent to be controlled. Movement beyond about the 9 o'clock position disengages the clutch and the cam is free to lock. At first this action can be very frustrating, as the panic lock is very easy to trigger. However, practice allows any rate of descent to be maintained.

Markings: On the front of the device is a line diagram showing the device closed and the rope installed. The lower rope is held by a hand, the upper forms a loop. There is also an “!” instructions symbol. Inside the device the loop and hand symbols are repeated at the ends of the rope channel. On the top of the main bobbin are characters showing rope diameters from 10 to 11.5 inclusive. On the back of the device is “CE0197 EN 341 TYPE A MAX 150Kg/200m”.

Test performance: The I'D passed both of the static hold tests.

Although the I'D features a large cam, similar in dimensions to the AML descender, the cam action is quite severe and gave some high impact forces in the dynamic tests. These ranged from 5.3 kN to 7.8 kN, again dependent on the rope used.

The I'D produced very good results in the descent performance test. The I'D maintained a significantly lower temperature, 70^0C, than the other descenders even after a drop of 200 metres.

6.4.6 Petzl Stop

Material: Aluminium

Weight: 324 gm

Design principle: 2-bobbin

Auto-lock type: Single action

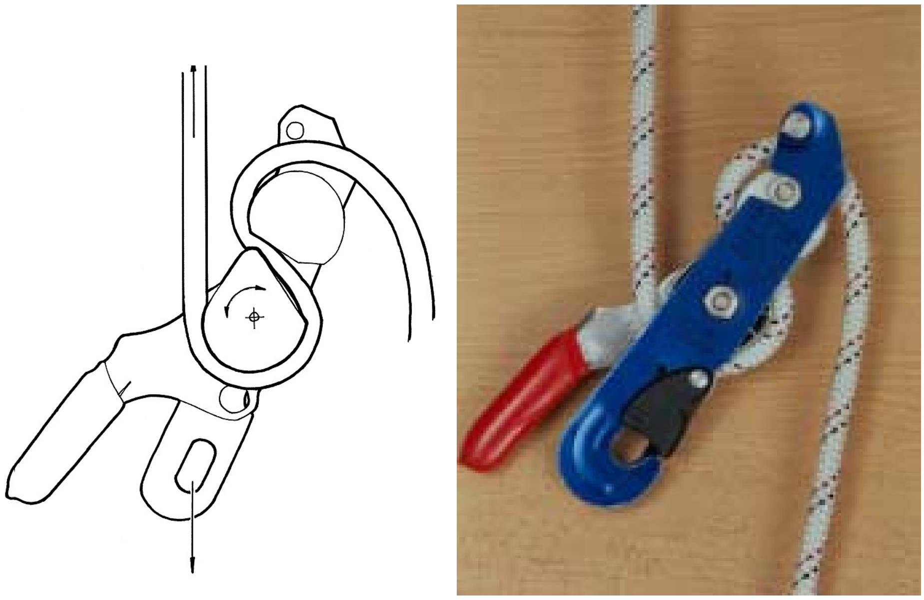

Figure 44
Petzl Stop Type C descender

Description: The Stop is of fairly simple design, consisting of two similarly sized bobbins around which the rope snakes in an 'S' fashion. The lower bobbin has a cam action driven by the friction of the rope on the cam. Two stamped aluminium plates form the sides of the device. The rear plate has a closed attachment hole and forms the main frame of the device. The front plate pivots around the axle of the lower bobbin to allow access to the interior. This plate has an open attachment hole, closed by a plastic catch, which allows the rope to be installed without unclipping the device from the harness. The lower bobbin is made from cast steel and has an attached aluminium handle, ~10 cm long, used to disable the cam action. The upper, fixed, bobbin is aluminium, but has a steel wear pin at the point where the rope is pinched by the cam action. At the top the device is closed by a steel post 7 mm in diameter. This can also be used to generate additional friction by looping the rope back over it.

Performance in use: Installing the device on the rope is relatively simple: the side plate is swung open and the rope is wound round the bobbins. The side plate then swings shut and the catch clicks shut over the attachment karabiner. Movement up the rope is possible, allowing slack rope to be taken in. The device should then be locked off before weighting. This is achieved by passing a bight through the attachment karabiner and then around the top of the device, forming a half hitch. When weighted this will prevent rope creeping through the stop mechanism, and guard against accidental release if the handle is knocked. To initiate descent the rope is unwound and held in the braking hand. The other hand then squeezes the handle to release the cam.

The correct technique is to release the cam fully and control descent with the braking hand rather than with the cam. This is a single auto-lock: no provision is made against the ‘panic grab and drop’ event. Ascending the rope is possible, though not easy, and it also functions well as a locking pulley when half-threaded.

Test performance: The static tests were passed without deformation to the device. A simple half-hitch rope lock was required to stop slippage.

Rather worryingly, for such a popular device, it was the only device to cause rope damage in the dynamic tests. Although impact forces were no higher than with other devices, the rope snagged between the side plate and bobbin, severing the sheath. Following this, the rope could not be removed and the device could not be reused.

6.4.7 SRT NoWorries

Material:	Aluminium with steel bobbins
Weight:	820 gm
Design principle:	3-bobbin
Auto-lock type:	Double action with disable screw

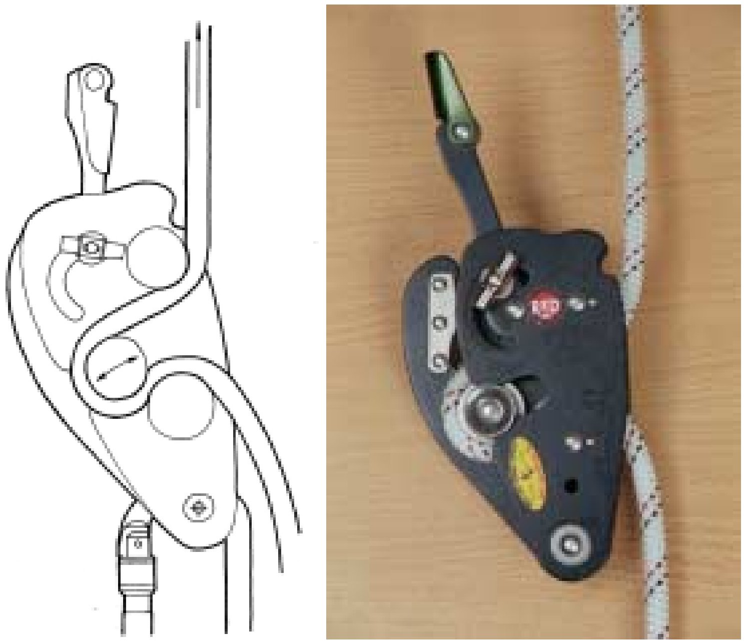

Figure 45
SRT Noworries Type C descender

Description: The SRT Noworries has three steel bollards around which the rope follows a sideways Ω shaped path. The middle bollard is slightly smaller and pivots out of the device to allow loading of the rope. The pivot is located at the base of the device and acts as the attachment post. The pivot also allows the middle bollard to pull into the device when loaded, when increased friction effects an auto-lock. To overcome this a handle is fitted which pushes it outwards, reducing friction and allowing descent.

The edge of the plate is shaped such that pulling the handle beyond a certain point no longer pushes it outwards, allowing the plate to move back in. Further downward movement of the handle actively pulls the plate back in.

This double-action auto-lock can be disabled at any point by tightening a wing-nut, which locks the handle in position. The idea of this is to allow hands-off descent at a constant rate.

Performance in use: Installation on the rope is fairly simple. A small catch releases the middle bollard and plate, which then swings open. It is not sprung so does not need to be held open. Movement up the rope is possible but not easy. On 10.5 mm rope the device is quite fast: only a small amount of handle movement is required to initiate descent. The handle position is basically vertical and can be a little awkward. Pulling the handle too far results in movement through an arc, where there is very little friction imparted to the rope, before the second part of the auto-lock is reached: this can result in a fast descent. To return to descent the handle must be pushed back up: again the handle is in a slightly awkward position. The handle is returned to the upper position by reversing the above procedure: again this must be done quickly to prevent a sudden drop as the friction decreases. Movement up the rope is difficult, although possible, and the instructions show the device being used for belaying and as a locking pulley.

Markings: on the front of the device a loading diagram with "UP" marked adjacent to the rope leading to the anchor, and a hand holding the free end of the rope. A safe working load of 300 kg is marked, and "MAX 2000KG" "STOP" and "GO" are marked in the appropriate positions around the locking key slot. There is no 'CE' mark. Since the sample was obtained for the tests it is understood that this device is now supplied with the CE mark.

Test performance: The static tests were passed without deformation, however an additional rope-lock (half-hitch around body) was required, as recommended in the instructions, to stop slippage.

The dynamic tests produced a somewhat inconsistent spread of results, again they were closely related to rope type. On the stiff Marlow rope results were excellent, but on the Beal and Edelrid ropes less friction was created and the device slipped long distances before arresting the fall.

6.4.8 Troll Allp

Material: Aluminium

Weight: 318 gm

Design principle: 3-bobbin

Auto-lock type: Screw type

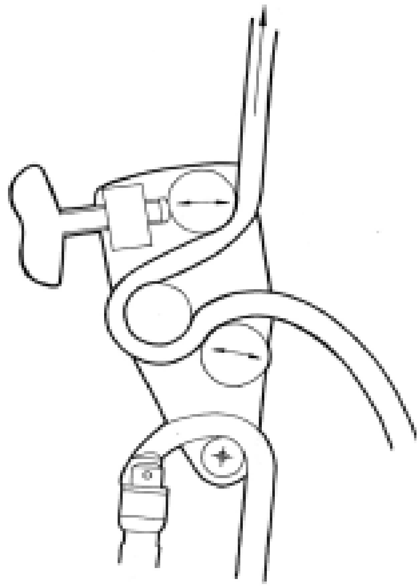

Figure 46
Troll Allp Type C descender

Description: The rope follows a sideways 'Ω' shaped path around three bollards. When loaded, rope friction pulls the middle bollard between the other two, generating friction and preventing movement. This action is overcome with a winged bolt arrangement that pushes them apart. A spring mounted on the attachment post pulls the bollards together when the device is not weighted. A sprung catch is mounted on the front plate and engages in a slot on the rear plate, this prevents accidental opening.

Performance in use: Installing the rope can be difficult, one hand is required to stop the side plates springing back together, while the other loads the rope, making sure it does not catch in the slots in the side plates. At this point the bolt should be screwed out as far as possible. When the device is weighted the bollards then pull together, preventing descent. Screwing the bolt in then slowly pushes the bollards apart and descent begins. Little effort is required to turn the bolt although the left-handed thread feels unfamiliar. However, it gives very fine control, and hands-off descent is possible, although speed will increase due to the progressive reduction of the weight of rope below the device. This can be overcome by keeping the rope in a bag, this is then slung from the operator's harness. Screwing the bolt out has the opposite effect, slowing descent. When the bolt is screwed out completely the device is in the stop position: there is no additional lock. Ascending the rope is difficult but possible, being easier if the device is kept tight on the rope rather than allowing slack above.

Markings: The front of the device shows a simple loading diagram. Stickers are mounted on either side of the key to indicate which direction to turn it: red "S" and green "G".

Test performance: The Troll Allp passed the minimum working strength test of 3 kN, but after 3 minutes holding a force of 6 kN the device was severely distorted and unusable. The cam action of the device was not sufficient to prevent slippage at the higher force and a knot had to be tied below the device.

The Allp did not perform well in the dynamic tests. Although the stiffer Marlow rope gave some reasonable results. On the Beal and Edelrid ropes the device failed to arrest the fall and the device hit the buffers at the base of the test rig.

6.4.9 Troll pro Allp tech

Material:	Aluminium with steel bobbins
Weight:	598 gm
Design principle:	3-bobbin
Auto-lock type:	Single action/ variable friction

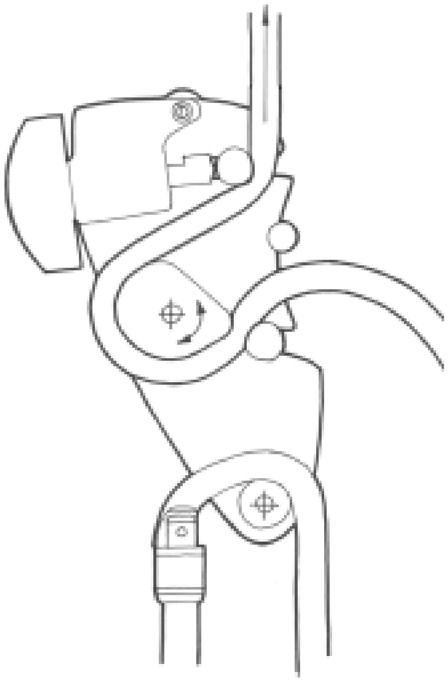

Figure 47
Troll pro Allp tech Type C descender

Description: This is Troll's second generation descender, and is a development of the Allp. As with the original, it has three bobbins around which the rope follows a sideways 'Ω' shaped path. The design is similar to the original Allp although the top and bottom bobbins are much reduced in size, being steel posts ~12 mm in diameter. The central bobbin is now steel and has a sprung cam action. A solid aluminium handle is attached to release this action. The friction-controlling bolt is now hidden within the device and a winged, closed nut is used to screw it in and out. The side plates remain aluminium but are larger, and the overall impression is of a larger, more solid and more refined device. The addition of cam properties to the central bobbin means there are now several ways to control descent.

Firstly, the cam and handle can be ignored and descent controlled solely with the bolt, as with the original Allp.

Secondly, the bolt can first be adjusted for the user's weight and rope type, and then the handle can be used as a single auto-lock: squeeze to go, release to stop.

Thirdly, both methods can be used together to allow varying friction over long drops or for various work purposes. The variable friction does not, however, completely remove the need for the user to maintain control on the rope below the device, with their braking hand. There is no double action auto-lock, but the variety of control methods, and the variable friction, markedly lessen the chances of one being required. Having said this, in inexperienced hands a 'panic grab and drop' is possible.

Performance in use: Once accustomed to the technique it is fairly simple to install on the rope and will allow ascent. The choice of control methods means the operator needs practice in order to establish the best method for him/her. This will come with experience of using the device. None of the control methods are difficult to learn.

The variety of control methods does, however, mean that mistakes can be made in a variety of ways: training, as with all devices, is essential.

Test performance: The pro Allp tech passed the static tests without damage.

Despite its similarities to the Allp and the Noworries, the pro Allp tech's cam bobbin means that it performs differently in a dynamic situation. Excellent, consistent results were obtained on Beal and Edelrid ropes, although with Marlow rope peak impact forces were a little higher. Slippages on all tests were consistently low.

6.4.10 Descenders: Summary

As with ascenders, the method of use for all of the descenders is fairly standard, so the tests give easily comparable results. Only two gave cause for concern: the Petzl Stop under dynamic loading, and the Troll Allp which failed the 6 kN hold test. It is worth noting that these are old designs: in both cases, the manufacturers have developed new generation devices, specifically for the industrial market, and these performed well. A move by industrial users to use the newer devices from these manufacturers is to be recommended. All the other devices performed well in the applied tests. For rope access selection must be based on good test performance, plus ease of use, versatility and resistance to wear.

It should be noted that all these devices required the operator to impart control, during descent, to a greater or lesser degree with the braking hand on the free rope.

For escape kits, the devices will be used, at most, occasionally and the resistance to wear is not so important. What is more important for these is a progressive action and double auto-lock to maximise safety for unfamiliar users.

For rescue kits the needs are different again, the primary concern being that control can be easily maintained even with large loads. This allows sudden shock loads to be avoided and thus increases safety.

7 ATTACHMENT LANYARDS (Cow’s tails)

7.1 INTRODUCTION

Cow’s tails are short lanyards used to connect the harness either to anchors, or to rope clamps. They are deployed to allow the user to maintain two points of connection to his/her harness at all times. Operatives usually carry several cow’s tails.

At one end they are linked directly to the harness belay loop, or screw-link connector, at the other they are linked into a karabiner that can then be used to clip into various anchors or rope adjustment devices.

For effectiveness, the lengths of cow’s tails need to be adjusted precisely to the user's height and arm length. For this reason, they are customarily constructed from lengths of rope with knotted terminations. Proprietary sewn cow’s tails are available, but only in fixed lengths, which may or may not suit the user’s size or technique.

Cow’s tails are subject to heavy use. It is imperative that they are withdrawn from use as soon as any damage, or significant wear, is apparent. In this respect, the operative will more readily retire cow’s tails made from knotted rope as they are cheaper than proprietary cow’s tails.

It is possible for cow’s tails to be clipped to anchors, or devices, below the harness attachment point. This makes fall factor 2 falls possible and, therefore, cow’s tails must have good shock-load absorbing qualities. If the user is aid climbing the cow’s tails will be the sole energy-absorbing component. If the cow’s tail is being used solely with a back-up device it need not be energy absorbing, as the device should absorb the energy by slipping.

The main variation in cow’s tails is the knots used to tie them. Ideally, these are of low bulk with some energy absorbing abilities.

7.2 METHODS

A dynamic test was used to examine how different cow’s tails perform in a fall situation.

The dynamic test applied was to drop a 100 kg mass through a distance equal to twice the length of the cow’s tails, i.e. a factor 2 fall.

Four different types were tested: Petzl sewn dynamic rope (Beal 11 mm ‘Apollo’), knotted dynamic rope (Beal 11 mm ‘Apollo’), knotted low-stretch rope (Beal 10.5 mm ‘Antipodes’) and knotted tape (Beal 26 mm flat). Before tensioning, all were approximately 60 cm in length, + or – 5 cm.

Three different knots were tested: overhand, figure-of-eight and barrel (double fisherman's). The tape was tied with a tape knot. Prior to the tests, all knots were pre-tightened with a 2 kN force, held for 20 seconds.

The maximum impact force was then recorded for each test. Each test was repeated three times.

The results are displayed below. The limit of the measuring equipment was 10 kN: ‘off scale’ indicates forces above this. On some tests, those which failed to record, the peak impact force existed for too short a time for the equipment to record.

Table 8
Impact forces from lanyards with 100 kg mass factor 2 fall

Material	Terminatio n	Impact force 1 (kN)	Impact force 2 (kN)	Impact force 3 (kN)	Average Impact force (kN)
Dynamic rope	Overhand	7.14	6.94	7.10	7.06
	Figure-of-8	6.65	6.62	7.48	6.90
	Barrel	6.33	6.33	6.30	6.32
Low stretch rope	Overhand	>10	>10	>10	>10
	Figure-of-8	8.73	9.15	9.40	9.09
	Barrel	8.73	8.89	No record	8.81
26 mm tape	Tape knot	8.69 (broke)	Broke, but no record	n/a	n/a
Petzl Jane (dynamic rope)	Sewn	>10	>10	>10	>10

7.3 KNOTTED ROPE COW'S TAILS

In all tests, unsurprisingly, the dynamic rope gave lower forces than the low stretch rope.

On the low stretch rope considerable variation was found between different knots:

- Overhand knots produced a reading beyond the range of the measuring equipment: this was estimated from the graph to be 12 kN
- Figure-of-eight knots performed considerably better, with impact forces of averaging 9 kN
- The Barrel knots performed slightly better again, giving impact forces just below 9 kN

With the dynamic rope the pattern was repeated, although the variations between the knots were less marked:

- The overhand knots gave consistent impacts of 7.0 kN to 7.2 kN, while the figure-of-eight results were slightly wider, at 6.7 kN to 7.6 kN
- The Barrel knots performed extremely well, delivering consistently low impact forces of 6.3 kN to 6.4 kN

The graphs produced, during the tests, show the steady tightening of the knots, particularly on the Barrel knot where the initial upward trace shows a steadily lessening gradient as energy is absorbed.

With all the knots tested, extreme tightening occurs during the impact: this would be obvious on inspection and in the workplace the cow's tail should be replaced immediately.

7.4 PETZL "JANE" SEWN TERMINATION COW'S TAILS

These ready-made cow's tails feature a short length of dynamic rope with loops sewn into each end. A variety of lengths is available, the 60 cm version was used for the test.

Although made from dynamic rope, the Janes created high impact forces. These forces could not be measured, they were outside the range of the recording equipment. They were estimated to be of the order of 10 kN to 11 kN.

Following the tests it was impossible to tell if they had been subject to a fall, despite the fact that after a fall of this severity the lanyard should be retired immediately.

7.5 KNOTTED TAPE COW'S TAILS

Beal 26 mm flat polyamide tape was used for the test. 60 cm lanyards were made up with a double overhand loop tied at each end. These cow's tails simply broke at the knot under the test conditions.

On the first test the recorded force was 8.7 kN. On the second test the machine did not record a peak, the force existed for too short a duration.

Under static loading, the knotted tape cow's tails breaking force was measured as 10 kN. (The ultimate breaking force of the tape is approximately 15 kN: thus, the knot reduces strength by about a third.)

Clearly tape slings of this type, i.e. tape with knots, is an unsuitable material for this purpose, as its static nature and weak knot strength will not absorb dynamic forces.

There is scope to conduct tests on cow's tails made from tape slings which have been sewn, down their length, to form lanyards with a small loop at each end for a connector.

7.6 COW'S TAILS - SUMMARY

The tests show that the best material for cow's tails is knotted dynamic rope. Of the knots tested, the Barrel knot produced the lowest impact forces, followed by the figure-of-eight.

As well as having the benefits of easy adaptation to the user it is currently the only way in which acceptable impact forces can be achieved.

All the knotted, dynamic rope, cow's tails produced impact forces between 6.3 kN and 7.6 kN: perhaps a little higher than ideal but much better than any alternative. In practice, forces are likely to be lower as the harness and body will also play a part in energy absorption.

Knotted tape cow's tails cannot be recommended for use where any dynamic loading is possible. There are sewn termination rope cow's tails on the market made from both dynamic and static rope: while these may be applicable to low fall factor situations, neither are suitable for use as cow's tails. Sewn dynamic rope cow's tails should be restricted to uses where the maximum possible fall is fall factor 1. Sewn cow's tails made of low stretch rope are not recommended for any dynamic loading situations.

Static rope tied with overhand knots gives a high force. However, with figure-of-eight or barrel knot (double fisherman's) the impact forces are lower, 9 kN. This figure is too high to recommend for use, but it is interesting to note that it might prove useful in an emergency.

8 LANYARDS (FALL ARREST)

8.1 INTRODUCTION

Lanyards are commonly used in fall arrest situations and have mostly been developed purely for industrial use. However, the Charlet Moser energy absorber block has been designed for ice climbing.

All the types tested consisted of an energy-absorbing unit with a progressive tearing and extending action to lessen the impact force of a fall. Most utilise tear webbing which is designed to commence tearing above a certain load. This tearing action absorbs energy. An alternative design utilises the tearing of stitching to absorb energy.

The short energy absorbing blocks are extended to the working length required with a lanyard of rope or tape. Others are complete units supplied in a finished state. One end is then attached to either a dorsal or sternal attachment point on the harness, while the other is supplied with a connector to attach the user to the anchor point. The industrial standard BS EN 355[13] states that the maximum length of the lanyard, including connectors, is 2 metres.

The lanyards were primarily tested for their dynamic performance, under fall factor 2 conditions, with a 100 kg mass. The tests were carried out using the 'catch plate' rig at Petzl. See section 14.4.5, in the Appendix, for details. The latter requires the use of a As fall arrest lanyards are permitted to be up to two metres long this involved a total drop of 4 metres - a realistic but exacting test. This test is in accordance with the BS EN 355. The standard also states two additional points: the energy absorbing block should withstand a static force of 2 kN without deployment, and the maximum braking force should not exceed 6 kN when tested with a rigid mass. On one test this maximum was exceeded by 1 kN, but only for less than 1/100 second. It can be argued that such a force acting for this short time would not be damaging to the operative, especially as their harness will absorb some of the energy thereby reducing the force on the body.

The maximum lanyard extension allowed in a fall is 1.75 m. Assuming that, after a fall, the distance from the harness connection point to the underside of the operative's feet is 2 m, then adding this distance, the lanyard length and the lanyard extension gives 5.75 m. This last dimension is the minimum safe height for the anchor point to be above the ground.

The graphs produced by the chart recorder give a critical insight into the manner in which the different blocks absorb energy. Seven different lanyards from six manufacturers were tested dynamically.

Six different lanyards from six manufacturers were also tested on the Lyon long pull rig. The force to initiate tearing, the peak force achieved during tearing, and the final breaking force were recorded. Each test was repeated twice. This test allowed visual appraisal of the energy absorption at a speed low enough for the human eye to appreciate. The conditions, however, are not as realistic as in the dynamic test, and the results must be considered less credible than those from the dynamic tests. The limited length of the long pull rig prevented full deployment of all of the lanyards. Comparison of the two sets of test results shows the value of the dynamic test. See Appendix 7 for the results.

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[13] BRITISH STANDARDS INSTITUTION
BS EN 355: 1993 Personal protection equipment against falls from a height - Energy absorbers

8.2 BEAL "BEP" ENERGY ABSORBER

Length 0.2 m

Principle Tear webbing

Type Component

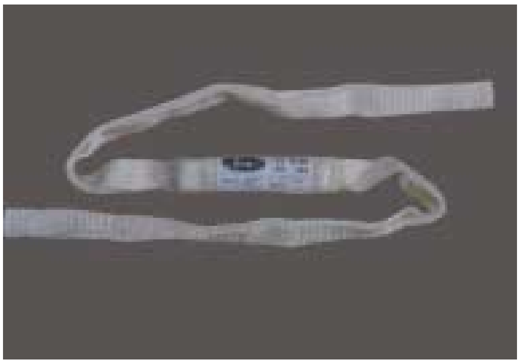

Figure 48
Beal energy absorber block (shown removed from protective sleeve)

Description: The BEP consists of a small (160 x 30 x 40 mm) block of white tear webbing. Clear shrink sleeve allows easy visual inspection of the block. It appears to be identical to both the Petzl Absorbica and the Miller/Dalloz block, differing only in the labelling.

Test performance: It was tested under the dynamic test conditions. Results differed slightly from the Miller energy absorbing block: the graph trace had sharper peaks.. This can be attributed to two factors: firstly the BEP, being a component energy absorber, rather than a complete lanyard with energy absorber, was subjected to the maximum drop of 4 metres by the test weight onto the catch plate. Secondly, the Miller block's attached lanyard will have stretched to some extent, absorbing energy and thus reducing the peak force.

On the tests performed on the BEP, individual peaks just exceeded 6 kN (by less than 1 kN) and only for a single peak (approximately 1/100th second). It is suggested that this is not significant enough to warrant a failure.

8.3 BH SALA

Length 2 m

Principle Tear webbing

Type Complete lanyard with energy absorber

Figure 49
BH Sala 'zorba' with rope lanyard

Description: Two different lanyards were obtained from BH Sala, both confusingly called 'Zorba'. They both included similar energy absorbing blocks of 45 mm wide white tear webbing. However, one had a rope lanyard attached, while the other had both a tape lanyard and an additional tape loop. This loop takes the load should the energy absorber section be fully deployed. They both have similar tear webbing and performed in a very similar manner.

Test performance: In the drop test they performed well with graph traces showing smooth deployment without exceeding 6 kN. However, on one test the lanyard deployed fully, indicating there is little margin for safety beyond the standard.

8.4 CHARLET MOSER

Length 0.12 m

Principle Tear stitching

Type Component

Figure 50
Charlet Moser shock absorber
(shown complete at the top, extended at the bottom)

Description: This small energy-absorbing block was originally designed for ice climbing to limit the forces imposed on screw-in ice protection during a fall. As such, it is only certified to the mountaineering standard for use as a sling. However, it does have applications in industry where its small size is attractive.

To justify the use of this unit, which is only certified as a none energy absorbing sling, the user must carry out a hazard identification and risk assessment in order to show that use of this unit is appropriate in the workplace.

Test performance: Unlike most of the other devices it operates by progressive breaking of a stitch pattern, rather than tear webbing. It has a smooth arrest pattern. However, its overall energy absorbing abilities are much less than the larger industrial devices. With a 100 kg mass, the maximum fall arrested safely was 0.5 metre with a force of 3.3 kN. Falls of 1 metre, or more, resulted in complete deployment with a large final peak force. With a 1 metre fall the peak force was 7.5 kN. The fall distances quoted were the height that the mass dropped before it engaged the catch plate on the test rig.

8.5 PAMMENTER & PETRIE (P & P)

Length 2 m

Principle Tear stitching

Type Complete lanyard with energy absorber

Figure 51
Pammenter & Petrie 'NRG' lanyard
(shown after test)

Description: Three identical '*NRG*' lanyards were obtained from P & P, complete with captive steel karabiners. The lanyards consisted of a single 3.4 m length of tape, part of which is folded and sewn as an energy absorber. The stitching pattern, in contrast with the Charlet Moser device, appeared fairly coarse. Before deployment the total length, including connectors, was two metres.

Test performance: In the dynamic test the graphs showed some cause for concern. The traces showed wide ranging peaks and troughs indicating jerky deployment. On the first test a peak value of 8.4 kN was seen. However, this only represented a single peak value of short duration. A final rounded peak was seen as the stitching stopped tearing, when the energy absorbing element reached full deployment, and the load was restrained by the lanyard. This was far more marked on the P&P lanyard than any other.

8.6 PETZL “ABSORBICA”

Length 0.2 m

Principle Tear webbing

Type Component

Description: Outwardly identical to the Beal “BEP” and Miller/Dalloz block, except for the labelling, the Absorbica performs in a similar fashion.

Test performance: To avoid duplication, the Petzl block was tested in the static pull test rig, while the BEP block was tested in the dynamic drop test rig at Petzl.

In the static pull the deployment appeared to be very jerky, with high peak forces of up to 8.5 kN. Peak forces were lower in the dynamic test.

8.7 PETZL “ABSORBICA I”

Length 0.8 m

Principle Tear webbing

Type Complete lanyard with energy absorber

Figure 52
Petzl ‘Absorbica I’
(shown with energy absorbing section removed from its sleeve)

Description: This lanyard comes as a complete unit and is available in several versions: as a simple lanyard, as a ‘Y’ lanyard, and with or without connectors. The simplest version was tested: at 80 cm it was the shortest complete lanyard tested. The “Absorbica I” consists of a tape sling sewn into a closed loop of tear webbing. The tear webbing is protected by an elastic sock, which can easily be removed to allow inspection of the energy absorber section.

Test performance: In the drop test it performed well with a steadily increasing force. There were no large peaks or troughs, indicating consistent tearing, and the three tests produced results ranging from 4.72 kN to 5.23 kN.

8.8 MILLER/ DALLOZ

Length 1.2 m

Principle Tear webbing

Type Complete lanyard with energy absorber

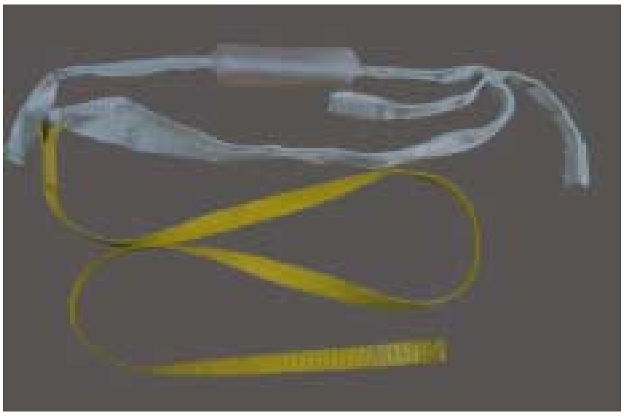

Figure 53
Miller/Dalloz lanyard
(shown with the energy absorbing section removed from its sleeve)

Description: The energy absorbing part of this lanyard appears to be identical to the BEP/Absorbica, this time with a sewn tape lanyard attached.

Test performance: This gave good results in the dynamic test. The drop was arrested without any large peak forces and showed consistent results between tests. The block did not fully deploy indicating a considerable safety margin. Maximum force was 5.27 kN.

8.9 SPANSET

Length 2 m

Principle Tear webbing

Type Complete lanyard with energy absorber

Figure 54
Spanset energy absorbing lanyard

Description: The Spanset lanyard consists of a lanyard and block arrangement, similar to the other lanyards. However, the entire assembly is protected by a tough covering layer. This consists of heavy-duty heat-shrink on the block and a plasticized tape tube over the remainder. This adds to the weight and bulk of the lanyard but will give resistance to damage.

Test performance: Results from the drop test were excellent. The block deployed at a very consistent force of 4 kN. The graph trace shows fewer force variations during the energy absorption than on any other test. The energy-absorbing element did not deploy fully, leaving a substantial safety margin.

8.10 LANYARDS - CONCLUSIONS

Fall arrest lanyards are subject to the standard BS EN 355 and the research did not produce any surprising results. The lanyards all arrested the drops safely, the prime concern being over margins of safety.

The major concern with lanyards is not performance when new, but longevity. All the lanyards tested were constructed all, or partly, from polyamide tape, a material that is particularly susceptible to weakening as a result of abrasion. The likelihood of contaminants, such as paint, reaching the load bearing material is also high. Only one of the lanyards tested, from Spanset, had any form of abrasion protection. Ideally, all lanyards would include this kind of protection.

Lanyards are routinely subject to high levels of wear and tear. In rope access, operatives are constantly in suspension and, therefore, very attentive of the state of their equipment. In fall arrest situations the lanyard is often seen as a hindrance rather than a help and is very rarely called into use. As a result, operatives are unlikely to pay special care to their lanyard. Any protective covering is therefore extremely useful. However, even the Spanset lanyard, which was otherwise well protected, neglected to protect the tape where it rounds the connecter. This is the point where, potentially, wear will be greatest.

9 PRUSIK KNOTS

9.1 INTRODUCTION

Prusik knots are tied around the working rope using a supple rope, or cord, whose diameter is, preferably, smaller than that of the working rope. They are designed to grip the working rope when loaded, but slide when unloaded.

They are widely used by both rescue teams and arboriculturalists, particularly in the United States of America. Within rope access they are not widely used and as a result there is little consensus on which knot should be used for what purpose. This is partly due to the variety of suitable knots and partly due to the variations in performance due to rope types. Just as there is no standard working rope, there is no standard rope for tying prusik knots. The resulting permutations possible from these variables mean that it is very difficult to predict how a knot will perform. Most users have to gain this knowledge from experience. The following tests simply serve to illustrate how, under static loads, different knots behave on different ropes.

The different types of knots have slightly different properties, and hence different knots are preferred in different situations. Similarly different ropes tend to be preferred for different knots. The five knots tested were those used by respondents to the questionnaire.

9.2 TESTS

Five different knots were tested, using three diameters of working rope and two types of prusik rope. In addition, one of the working ropes was obtained and tested in both a new and a worn state. Most prusik knots are tied with a closed sling of rope (prusik loop) rather than a rope end. The Blake knot is the only exception to this.

Kernmantel and hawser laid suspension ropes were tested. Polyamide from Edelrid and polyester from Beal for the kernmantel ropes. The hawser laid rope was made from polyamide. The material used for the knots was 10 mm diameter “Prusik Regate”, made from polyester and 6 mm accessory cord, both made by Beal.

The knots were subjected to a static test to determine the force that they would hold without slipping. The test was limited to 4 kN: knots which reached this force without slippage then had to hold it for 2 minutes to detect creeping.

The results can only be taken as a guide, however, as many factors can affect their performance.

The age and state of both the working rope and the prusik rope are very important: brand new rope may not grip as well as older rope that has been worn in and lost some of its sheen.

Slight differences in tying and 'setting' the knot will affect how readily the knot grips the rope when first and subsequently loaded. Similarly varying the diameters of both working rope and prusik rope will affect performance.

9.3 BACHMANN KNOT

Figure 55
Bachman knot tied with 6 mm accessory cord

This knot is different from the others in that it is tied around the back bar of a karabiner as well as the rope. In the tests an offset 'D' 12 mm steel industrial karabiner was used. The karabiner is not used as a handle and will cause the knot to slip if it is weighted. The knot's advantage is that it does not jam and extra friction can be easily added.

It held the 4 kN force on all the ropes when tied with 6 mm accessory cord.

When tied with 10 mm Prusik Regate rope on kernmantel ropes it slipped on 10.5 mm, between 0.6 kN and 1.0 kN, and on 13.5 mm, between 1.6 kN and 1.9 kN, but held the 4 kN force on the hawser-laid 12 mm rope.

9.4 BLAKE KNOT

Figure 56
Blake knot tied with "Prusik Regate" 10.0 mm rope

The Blake knot is the preferred knot amongst arboriculturists. In contrast with the other knots it is tied with a rope end rather than a loop.

It was the only knot tested to hold the 4 kN force for all test combinations. With the thicker 10 mm Prusik Regate rope it released easily. When tied in the thinner 6 mm accessory cord it was a little more difficult to release.

9.5 FRENCH PRUSIK

Figure 57
French prusik knot tied with 6 mm accessory cord

The French prusik is one of the simplest prusik knots, its main advantage being that it will release under load.

In all the tests it was very easy to release after the load was removed. It was able to hold higher forces when used on the thicker 12 mm and 13 mm ropes. On the 10.5 mm rope it slipped at 0.5 kN when using 10 mm Prusik Regate rope and at 1.3 kN on the thinner 6 mm accessory cord.

9.6 KLEIMHEIST KNOT

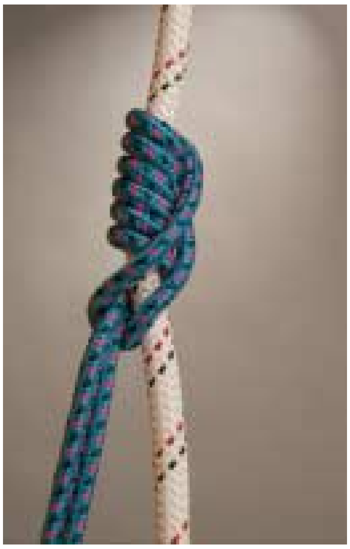

Figure 58
Kleimheist knot tied with 6 mm accessory cord

Popular in climbing circles, the Kleimheist is another fairly simple knot. The knot was tied using a sling made of 6 mm accessory cord. This was wrapped around the rope two or three times and then back through itself, to create a type of helical knot.

When tied in the thicker 10 mm Prusik Regate rope it slipped on all the ropes at forces below 0.5 kN. In contrast, when tied with 6 mm accessory cord it held the 4 kN force on all the ropes.

9.7 PRUSIK KNOT

Figure 59
Prusik knot tied with 6 mm accessory cord

The prusik knot is the original, and best known, 'ascender' knot. It is based on a Lark's foot but with extra turns.

It held the force on all but one test. Tied with the 10 mm Prusik Regate rope the knot slipped at 0.5 kN when tested on the 10.5 mm rope.

9.8 SUMMARY

Prusik knots clearly work. Some are better suited to holding large loads while others are more suitable when an easy release is required.

The combination of main rope and prusik rope is critical to how the knot will behave. Even with the limited variety tested, significant differences are seen between the combinations. Great experience would be required to predict the behaviour of any combination. It would be more realistic to adopt one knot and rope combination, and experience its behaviour until its performance in different situations can be assured.

For most situations, in rope access, a device would be available which would perform in a predictable fashion. Prusik knots are probably best suited to non-PPE applications such as hauling and suspending equipment.

There is much scope for further work on prusik knots. A study into their behaviour under dynamic loads would be particularly interesting, as concerns are often raised about melting, due to friction, when the knot slides under heavy loading.

10 CONCLUSIONS

10.1 GENERAL CONCLUSIONS AND COMMENT

The summaries and conclusions given in each section of the report will not be repeated here. What follows is a final overview.

This project has been conducted during a period of rapid development in both techniques and equipment for work at height. Many of the rope adjustment devices, which were tested, may already have been superseded by subsequent models.

Exceptions to this are ropes, which currently, and for the last decade, have been the least changing element in rope access systems. The elasticity that polyamide ropes provide (dynamic ropes where falls from above anchor point are possible, low stretch ropes where only falls from below the anchor point are possible) is a major key to limiting loads, experienced by the operative, to safe levels. While they remain the core element in rope access, all other system components will be designed around them. The standard BS EN 1891 was specifically drafted to include low-stretch ropes suitable for rope access, and provides a secure and appropriate basis for buying and deploying ropes appropriate for rope access and arboriculture. The Standard BS EN 892 is designated for dynamic mountaineering ropes. It is also appropriate for work applications involving potential fall factor 2 drops.

The ability to tie knots to form terminations anywhere along a rope is of key importance to the practicality and versatility of rope access and work positioning systems. The tests performed on knot strength demonstrate that there are a number of knots which give appropriate security and which can be used with confidence.

Existing standards for rope adjustment devices come from different backgrounds, and are unsatisfactory. It is to be hoped that prEN 12841 will now be processed and completed as speedily as possible, and that devices used in rope access for ascent, descent and back-up security will subsequently be tested and certified to this Standard.

Protection of rope against the effects of abrasion over harder surfaces is essential. Ideally, this should be achieved by rigging to avoid any such abrasion. Failing that, rollers remove all risk provided that the rope remains in place on the rollers. However, they are not applicable to all situations and, where a textile protector has to be deployed, of the types tested canvas achieved clear superiority over others.

Future development could involve the deployment of static ropes with the introduction of dynamic load absorbers at every anchor point. This could radically alter the ropes which might be used, and that, in turn, could radically alter the adjustment devices used in conjunction with the ropes. This is not likely to occur for at least a decade, if ever, but it is important that the path to radical change is not closed by an over rigid adherence to existing ways of working.

The advantages of rope access and similar work systems do not derive from the equipment employed alone. The motive force for the system is provided by the operative. The worker and his/her equipment combine to form a machine. This machine only functions as well as the sum of its parts. The ropes and devices are essentially passive, the dynamic element is provided by the worker’s strength and skills. The worker is required to have the intelligence, as well as the strength, to work in this way. It follows that this method of working requires rigorous training, practice and assessment before the equipment investigated can be used effectively and safely. The words ‘for use by trained operatives only’ could well be added to the comment on every item of equipment featured in this report.

11 FUTURE WORK

This study has highlighted a number of areas which merit further investigation:

A. A study of the effects of increase in the sheath mass of ropes on the performance of rope adjustment devices.

B. A study of the effects of rope wear on the performance of rope adjustment devices.

C. A study into the load-distributing abilities of more complex knots, such as the double figure-of-eight on a bight and the alpine butterfly.

D. Further investigation into the effect of contaminants (particularly rust and bird droppings) on rope strength.

E. A study into the effects of tightening, due to use, on the energy-absorbing abilities of knots used in cow's tails.

F. An investigation into the effects of both knotting and wear on the strength of the webbing components used in rope access.

G. A study into the abilities of prusik knots to absorb dynamic forces.

H. Measurement of the forces generated when carrying out a 'snatch rescue'.

I. A study into the protection of the rope from abrasion by different types of carpet.

J. A study into the abrasion of ropes when running over different types of edge, e.g. scaffold tubes.

K. A study into the effect on ropes from side to side movement across an edge.

12 APPENDICES

12.1 APPENDIX 1 PERSONNEL INVOLVED IN THE PROJECT

The testing was carried out by Lyon Equipment staff, supported by staff from Beal, rope manufacturer, Petzl, equipment manufacturer and the Leeds University School of Textile Industries, when the facilities of these establishments were used. This report was made possible by their co-operation.

The report was written by Lyon Equipment staff:

Adam Long	BSc (Hons) IRATA level 1
Malcolm Lyon	BSc Chairman IRATA Health Safety and Equipment Committee
Graham Lyon	BA(Open) CEng MICE MIQA

Support to the test programme, and the writing of the report, was provided by:

Dave Brook	BSc MSc Research Fellow, Leeds University School of Textile Industries
Fred HusØy	Managing Director of Aak A/S (Norway) and Convenor of CEN/TC160/WG3/PG6[€]
Paul Seddon	Consultant for interpretation of European Standards
Phil Tate	Metallurgist and consultant for Personal Protective Equipment type approval testing
Peter Ward	IRATA level 3T (trainer) & A (Assessor) Training Manager, Spanset Ltd

Line diagrams:

Chris Blakeley	BA (Hons) IRATA level 3T (trainer) Technical consultant and trainer, Lyon Equipment Ltd

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[€] CEN = European Committee for Standardisation
TC160 = Technical Committee 'Protection from falls from a height including working belts'
WG3 = Working Group 'Personal equipment for work positioning and the prevention of falls from a height'
PG6 = Project Group 'Rope adjustment devices'

12.2 APPENDIX 2 QUESTIONNAIRE - SUMMARY OF REPLIES

Total number of replies received was 41. Not all respondents answered all of the questions.

12.2.1 ROPES

Table 9

Question- "Which three ropes do you most regularly use?"

Make	Type	Diameter (mm)	Main Support	Safety Back-up	Hauling rope
			Number of replies		
Beal	Low stretch	10.5	22	18	10
	Low stretch	11.0	1	1	1
	Low stretch	11.5	1	2	1
	Low stretch	13.0	1	-	-
	Dynamic	11.0	1	9	-
Lyon[14]	Dynamic	10.5	-	12	-
Blue water	Dynamic	11.0	1	1	-
Cousin	Dynamic	11.0	1	1	-
	Low stretch	11.0	-	2	1
Edelrid	Low stretch	10.5	8	8	5
	Low stretch	11.0	1	1	-
	Dynamic	11.0	-	1	-
Edelweiss	Dynamic	11.0	1	2	-
Marlow	Low stretch	10.5	7	5	4
	Low stretch	11.0	2	1	1
	Double-braid	16.0	-	-	1
	Polypropylene	16.0	-	-	1
	Dynamic	11.0	1	4	-
ROCCA	Low stretch	10.5	1	1	1
	Dynamic	11.0	1	1	-
Polyester braided	Low stretch	16.0	-	-	2
	Low stretch	12.0	1	-	-
Mammut	Low stretch	10.0	3	3	1
	Dynamic	11.0	-	1	-

[14] Lyon branded rope is made by Beal, Vienne, France

12.2.2 TYPE A, B & C DEVICES

Table 10
Question- "Which devices do you use?"

Back-Up Device	"Which back-up device do you use?"	
Make	Device name	N° of replies
Petzl	Shunt	27
Komet	Stick Run (As a work positioning lanyard)	1
Wild Country	Ropeman	11

Chest Ascender	"Which chest ascender do you use?"	
Make	Device name	N° of replies
Petzl	Croll	36
Anthron	AC30	1

Hand Ascender	"Which hand ascender do you use?"	
Make	Device name	N° of replies
Petzl	Basic	4
	Ascension	37
ISC	Handled ascender	1

Descender	"Which descender do you use?"	
Make	Device name	N° of replies
Petzl	Stop	37
	I'D	2
	Grigri	2
	Figure-of-8	2
	Autostop	1

12.2.3 Hardware ratings

Respondents were asked to rate the performance, and ease of training, of the devices which they used.

Table 11
Rating of the performance, and ease of training, of the different devices used

Device	Rating			Training	
	Poor	Satisfactory	Good	Easy	Difficult
Petzl Shunt	-	13	14	20	4
Komet Stick Run	-	-	1	1	-
Wild Country Ropeman	8	2	-	-	-
Petzl Croll	1	13	27	22	2
Anthron AC30	-	1	-	1	-
Petzl Ascension/ Basic	-	11	27	27	-
ISC handled	-	-	1	-	-
Petzl Stop	-	13	23	22	2
Petzl I'D	-	-	2	1	-
Figure-8	-	1	1	1	-
Autostop	-	-	1	1	-

12.2.4 Connections to harness

Table 12
Question- "What do you use to connect devices to your harness?

"What do you use to connect the back-up device to your harness?"		
Connector	Length range (m)	N° of replies
Lanyard	single 0.6 or 1.0 twin 1.5	13
Cow's tail	0.5 to 2.0	25
Strop	-	-

"What do you use to connect the hand ascender to your harness?"		
Connector	Length range (m)	N° of replies
Lanyard	0.6 to 1.0	12
Cow's tail	0.5 to 1.3	25
Strop	0.6 to 2.0 (flat tape)	3

Table 13
Question- "What do you use for the operative to clip into anchors?

Connector	Length range (m)	N° of replies
Lanyard	0.6 to 1.0 and 1.5	14
Cow's tail	0.2 to 1.0	25
Strop	-	3

12.2.5 Rope Protectors

Table 14
Question- "Which rope protectors would you use?"

Location	Type	N^{o} of replies
Parapet wall, close to anchor point	Canvas/ PVC Velcro sleeve	24
	Carpet square	19
	Wire strop	1
	Parapet edge rollers	5
	Padding, e.g. kit bag, gloves etc.	8
	Rubber compressor/ hose pipe	3
Projection midway down rope	Canvas/ PVC Velcro sleeve	32
	Re- belay	7
	Wire strop	2
Arboriculture	Cambium saver	1

12.2.6 Knots

Table 15
Question- "Which knots do you regularly use?

Knot	Number of replies
Overhand	3
Figure-8	28
Figure-9	32
Clove hitch	5
Figure-8 on-the-bight	11
Bowline	4
Double fisherman’s	9
Alpine butterfly	27
½ double fisherman’s	1

12.2.7 Knots versus sewn terminations

Table 16

Question- "Do you prefer to use knots or sewn terminations?"

	Knots	No preference/ either where applicable	Sewn connections
N^o of replies	27	6	3

Table 17

Question- "Which prusik knots do you regularly use?"

Knot	N^o replies
Bachman knot	8
Kleimheist knot	2
Prusik knot	15
French prusik	1
Blake knot	2
Distel knot	1

12.3 APPENDIX 3 ROPE ABRASION

Table 18

Summary of abrasion resistance of rope over different edges using different protection

Type of edge	Protection used	Peak load (kN)	Approx. min load (kN)	Total test time (minutes)	Approx number of cycles	Damage incurred
Steel 90°	None	1.80	0.36	3	15	Rope sheath severed
	Lyon PVC	1.55	0.47	20	100	Rope sheath severed, core damage
	PVC scraps	1.55	0.50	60	300	PVC melted/ removed, fabric intact
	Air line pipe	1.78	0.38	15	75	Rope sheath severed core damage
	Lyon canvas	1.55	0.47	54	270	Rope sheath severed
	Petzl rollers	1.34	0.59	120	600	Aluminium stains on rope, otherwise OK
	Carpet (foam backed)	1.61	0.40	5	25	Rope sheath severed
Concrete coping	None	1.48	0.50	120	600	Slight sheath damage, concrete polished
	Lyon PVC	1.49	0.46	60	300	PVC melted/ removed, rope glazed
	PVC scraps	1.60	0.46	30	150	PVC melted/ removed, creeps off edge
	Air line pipe	1.71	0.49	10	50	Pipe worn through, providing no protection
	Lyon canvas	1.43	0.47	60	300	Both canvas and rope slightly glazed
	Petzl rollers	1.34	0.58	100	500	Aluminium stains on rope, otherwise OK
	Carpet (foam backed)	1.43	0.49	15	75	Large hole in carpet, slight sheath damage
Concrete 90°	None	1.75	0.39	<2	8	Rope sheath severed
	Lyon PVC	1.67	0.48	20	100	Rope sheath severed
	PVC scraps	1.64	0.48	60	300	PVC melted/ removed, fabric intact
	Air line pipe	1.84	0.37	15	75	Rope sheath severed
	Lyon canvas	1.47	0.45	90	450	Rope undamaged, slight wear on canvas
	Petzl rollers	1.38	0.58	60	300	Aluminium stains on rope, otherwise OK
	Carpet (foam backed)	1.44	0.56	12	60	Rope sheath severed, core damage

12.4 APPENDIX 4 TEST MACHINES, LOCATIONS AND METHODS

The test methods are described in the same order in which the results are presented.

12.4.1 Ropes

Ultimate static strength.

Test machine Instron 100 kN vertical straining frame

Location Beal, Vienne, France

A static test machine was used to pull rope samples to destruction. The difficulty of terminating the rope, without weakening it, was overcome by the use of a capstan arrangement.

Figure 60
Photograph: Capstan arrangement used to break rope samples

The crossheads were moved apart at a constant speed of 1 mm/sec, over a distance of 1.5 m. The first full length travel of the upper crosshead serves to stretch the rope. The upper crosshead is returned to the start position and the ropes tightened around the capstans. A second travel of the upper crosshead may then break the rope, if not the sequence has to be repeated. The forces were recorded on a chart recorder.

12.4.2 Knots

Static strength.

Test machine Hydraulic long pull rig

Location Lyon Equipment Ltd., Dent

Testing the strength of a single knot presents the difficulty of terminating the other end of the rope. To overcome this knots were tested in pairs, by making a short lanyard with a knot at each end. This arrangement permitted comparative strength tests to be carried out. To find average strengths identical knots were used at each end of the lanyard and the test repeated. These lanyards were tested, in all cases on a simple static pulling rig. A hydraulic ram was used to pull the lanyard over a length of travel of 1 m. A chain dog arrangement was used to change the position of the fixed anchor, allowing the full length of the ram to be used when necessary.

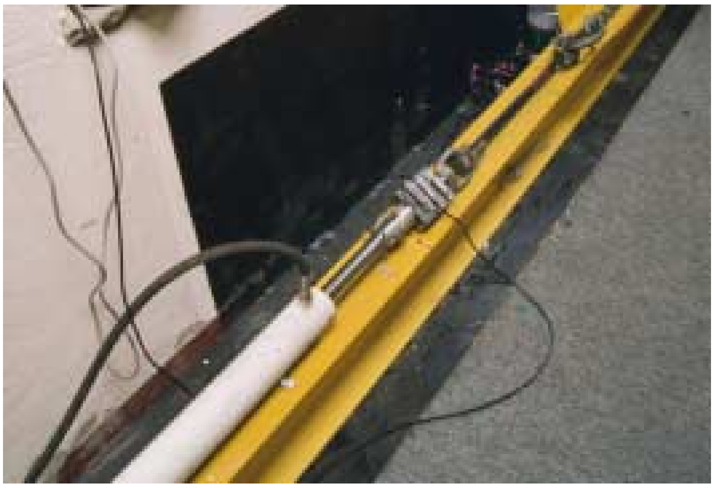

Figure 61
Photograph: Long pull test rig, Dent

Method: Two knots, of the same type, were tied in the sample rope at least 250 mm apart, to create a short lanyard. This assembly was then pre-tensioned to 2 kN, for a minimum of 10 seconds, and then allowed to relax for a minimum of 30 minutes. The sample was then attached to the anchors/crossheads of the test machine, using connectors with a cross-sectional diameter of 12 (+/- 0.1) mm. Force was then applied at a rate of 500 mm/min until the sample broke. The maximum force held was recorded.

12.4.3 Anchor forces.

Test machine 'Mecmesin' 25 kN portable load cell

Location Firbank Viaduct, Cumbria

These tests were the only ones performed on site rather than in a test laboratory. A pair of ropes (Beal 'Antipodes' 10.5 mm low-stretch) were rigged, free-hanging, from the viaduct as required by IRATA Guidelines (i.e. no knots were pre-tensioned). The forces generated by an IRATA level 3 technician moving on them were then studied. The forces were measured by continuous readings from an in-line load cell. Two double figure-of-eight knots were tied, about 1 m apart, below the anchor of the working (suspension) rope. A 25 kN capacity load cell was then connected between the knots, so that the load was directed through it. The load cell was positioned as near to the anchors as possible whilst ensuring it was below any obstructions. The output from the load cell was then continuously logged on a portable laptop computer, at a sampling rate of 10 Hz. Loads on the back-up rope were not measured

12.4.4 Rope protectors cycling a load over an edge

Test machine 1	Instron 25 kN vertical straining frame
Location	Leeds University, Department of Textile Industries
Test machine 2	Lloyd Instruments 50 kN vertical straining frame
Location	Lyon Equipment Ltd., Dent

Rope protectors were tested by cycling a weighted rope over an edge. Tests were carried out on two test machines, an "Instron" machine at Leeds University and a "Lloyd Instruments" machine at Dent. Both operated on the same design principle; a vertical frame which allows an upper crosshead to be moved relative to a fixed lower crosshead. A pulley was fixed to the lower crosshead, the upper crosshead was cycled up and down. This action cycled the rope over the edge of the test bench. A steel mass of 85 kg was suspended by the rope, below the edge, to represent the weight of an operative. The rope was then cycled through a distance of 50 mm to represent the operative moving around on his/her rope. This cycling distance was chosen as it was slightly greater than the distance in which the sheath weave pattern of the rope was repeated.

Method: Beal 'Antipodes' 10.5 mm rope (low–stretch) was used for all the tests. The rope was terminated with a double overhand knot. The knot was pre-tensioned to 2 kN, for a minimum of 10 seconds, before use. The rope was connected to the upper crosshead, and then directed through a pulley, connected to the lower crosshead, and over the edge of the test bench. A rope clamp was then used to attach a rigid steel 85 kg mass. Various edges were then clamped to the edge of the test bench. Similarly, the various rope protectors were positioned between the rope and edge. To run a test, the crosshead was first raised until the weight was suspended 150 mm above the floor. The upper crosshead was then cycled through a vertical distance of 50 mm, at a speed of 500 mm/min. Damage to both the rope and protector was inspected at intervals. relative to the severity of the edge, and the maximum and minimum forces, as recorded by the machine, were noted.

Figure 62
Photograph: Lloyd Instruments LR50K test machine (at Lyon Equipment)

12.4.5 Devices/ Rope clamps

- **Static tests**

Test machine Lloyd Instruments 50 kN vertical straining frame

Location Lyon Equipment Ltd., Dent

These tests were performed on Lyon Equipment's computer controlled vertical pull test machine. This was programmed to pull the sample until the required load was reached, whereupon it held the load for the required time period. As the test progressed a graph was produced on the computer screen. If the device slipped before the required load was reached this can clearly be seen on the graph.

Method for minimum working strength tests: The sample rope was terminated with an overhand knot. This was pre-tensioned to 2 kN, for a minimum of 10 seconds, and then allowed to relax for at least 30 minutes before use. The rope was then connected to the upper crosshead of the test machine. The device was located onto the rope, at a minimum distance of 300 mm below the anchor point, and connected to the lower crosshead of the machine. Force was then applied at a speed of 500 mm/min. When a force of 1 kN was reached, the distance between the device and the anchor was measured, and the position of the device on the rope marked. The force was then increased as the upper crosshead moved, at a rate of 500 mm/min, up to the specified load. This was maintained (+/- 0.1 kN) for 3 minutes.

Specified loads: Type A = 4 kN, with <100 mm slippage

Type B = 4 kN, with <100 mm slippage

Type C = 3 kN, with <300 mm slippage

At the end of the test, the position of the device on the rope was again marked, and the distance from the start position (i.e. the distance slipped) measured. The maximum slippages allowed by prEN 12841 are given above. Following the test the device was examined for distortion or damage.

Method for minimum static strength tests: The test was carried out as in the minimum working strength test, except that a single overhand knot was tied below the device to prevent slippage. The upper crosshead was then moved at a rate of 500 mm/min up to the specified load, and again held for 3 minutes.

Specified loads: Type A = 12 kN

Type C = 6 kN

The main concern was that the device did not release the rope, whether by distortion of the device or by cutting of the rope. Following the test the device was examined for distortion or damage.

The test is not applicable to Type B devices

- **Dynamic tests**

Test machine	Both catch-plate and lanyard rigs at Petzl's dynamic test facility
Location	Petzl, Crolles, France

Two test rigs were used. The first was a simple arrangement: the device which was to be tested was installed on a rope hanging from a load cell. A steel mass was attached to the device by a wire lanyard. The weight was raised to the required height and then dropped. This test arrangement is specified in the relevant standard. Unfortunately it is difficult to accurately replicate tests with this method. Exact replication of the orientation of the connecters and the lie of the wire lanyard cannot be guaranteed from test to test, this tends to produce inconsistent results. The pendulum action of the weight on the lanyard is also a factor.

The method is also time consuming. Each test takes 20 minutes.

The second rig was more sophisticated in that no lanyard was required. The device is installed on a rope hanging from a load cell. It is then connected to a steel catch-plate weighing approximately 10 kg. The catch-plate sits between two vertical rails down which the test mass falls. The latter is lifted to the required height and then dropped, hitting the catch-plate and transferring the force to the device on the rope. This set-up allowed tests to be performed quickly, allowing more replications to be carried out, as well as producing more consistent results.

Figure 63
Guided weight of Petzl catch-plate test rig

Figure 64
Guided weight in contact with 'catch plate' and lower buffer

Methods (catch-plate rig): The sample rope was terminated with an overhand knot which was pre-tensioned to 2 kN, for a minimum of 10 seconds and allowed to relax for at least 30 minutes, before use. This knot was then attached to the load cell of the dynamic test rig, and the device located on the rope, a minimum of 1 m below the anchor. This position on the rope was marked with a marker pen. The catch-plate was then suspended from the device, and located carefully in position. The 100 kg rigid steel mass was then raised to a height of either 1 m or 2 m above the catch-plate, (i.e. either fall factor 1 or 2) and released.

As required by prEN 12841, Type A devices were subjected to a fall factor 2 drop, Type B and C devices to a fall factor 1 drop. The peak impact force reached was then deduced from the output of the chart recorder. The distance from the start position of the device, on the rope, to the end position (i.e. the slippage distance) was also recorded. These results were then compared to assess performance.

- **Descent tests**

Test machine Ceiling mounted capstan, digital temperature probe

Location Petzl, Crolles, France

All descender devices were subjected to a descent test which examined temperature rise. A 100 kg mass was suspended from the device whilst the rope was pulled upwards by a capstan. Heating was measured over a distance of 100 metres. Speed was a little difficult to control but was reasonably consistent at around 0.35 m/sec. Two temperature probes were used to monitor the temperature of the device. This was recorded by video camera.

12.4.6 Cow’s tails

- **Dynamic tests**

Test machine Catch-plate drop test rig

Location Petzl, Crolles, France

The cow’s tails were made by tying two knots, of the same type, in a short length of rope. This was adjusted so that its total length was about 500 mm. The knots were then individually pre-tensioned to 2 kN, for a minimum of 10 seconds, and allowed to relax for a minimum of 15 minutes. Following this pretensioning the length of the lanyard was 600 mm (+/- 5 mm). (Note: the sewn cow’s tails on test were not pre-tensioned.) One end of the cow’s tail was then attached to the load cell of the dynamic test rig, and the catch-plate attached to the lower end. The 100 kg rigid steel mass was then raised 1.2 m (i.e. a fall factor 2) above the catch-plate and released. The peak impact force was then recorded on the chart recorder.

12.4.7 Lanyards

- **Static tests**

  Test machine Hydraulic long pull rig

  Location Lyon Equipment Ltd., Dent

  Due to the length of these lanyards it was not possible to use the computer-controlled vertical-pull Lloyd test machine. Instead, the simple hydraulic ram rig was used, and results had to be read from the digital display as the forces changed. Forces recorded were: the initial force required to deploy, the peak force reached during deployment, and the final force required to break the lanyard. Even this rig, with 4 metres between the anchor points, was not long enough for some of the lanyards. These were deployed as far as was possible but the final breaking strength could not be established. In all the tests the lanyards were tested in the form in which they were supplied (i.e. no conditioning or pre-tensioning actions were carried out).

- **Dynamic tests**

  Test machine Catch-plate drop rig

  Location Petzl, Crolles, France

  These were performed in the same manner as the cow's tail tests, but with longer drops corresponding to twice the length of the lanyard (i.e. fall factor 2). The short component energy absorbing blocks were tested with a drop of 4 metres, representing a fall factor 2 with the greatest extension permitted by EN 567.

- **Prusik knots**

  Static tests

  Test machine Lloyd Instruments 50 kN vertical straining frame

  Location Lyon Equipment Ltd., Dent

  These were performed in the same manner as the static device tests (see above), on Lyon Equipment's computer-controlled Lloyd Instruments test machine. Test parameters were: hold 4 kN for 3 minutes, maximum allowed slippages 300 mm.

12.5 APPENDIX 5 ABRASION TESTS: RECORDED RESULTS

12.5.1 Preliminary tests

A. Concrete edge: unprotected

Test duration = approx 2 hours/ 600 cycles

Peak load = 1.48 kN, min load = ~0.50

Flattening of rope, some sheath damage, polishing of concrete edge

Flaw in concrete may have caused rope damage.

B. Steel edge: unprotected

Test duration = approx 5 minutes/ 25 cycles

Peak load = 1.80 kN, min load ~0.36 kN

Sheath severed

C. Steel edge: roll module protection

Test duration = 2 hours/ approx 600 cycles

Peak load = 1.34 kN, min load ~0.59 kN

Flattening of rope, black aluminium marks, *sheath undamaged*

D. Steel edge: compressor pipe protection

Test duration = 32mins / approx 160 cycles

Peak load = 1.78 kN, min load ~0.38 kN

Pipe holed, *sheath severed,* several core strands cut.

E. Steel edge: Lyon PVC protector

Test duration = approx 20mins / ~100 cycles

Peak load = 1.67 kN, min load ~0.49 kN

PVC bunched, then wore through. Edge then unprotected- *sheath damaged.*

F. Steel edge, Lyon canvas protector

Protector laid flat over edge, secured top and bottom to prevent bunching.

Start time 9:57

Peak load = 1.55 kN min load = 0.47 kN

After 20 mins, approx 100 cycles, little damage. Flattening of rope, slight wear marks on canvas.

Restarted 10:20

After a further 20 mins, total cycles now approx. 200, top layer of canvas worn through, slight wear on sheath.

Restarted 10:43

Test stopped at 10:57- sheath almost severed. Rope protector worn through at contact point.

Total of 54 minutes/ approx 270 cycles.

G. Steel edge, Lyon PVC protector

Protector laid flat over edge, secured top and bottom to prevent bunching.

Start time 11.10

Peak load = 1.55 kN min load = 0.47 kN

After 5 mins, approx 25 cycles, top layer of PVC removed, rope flattened and stained yellow.

Restarted 11:17:20

After further 5 minutes, total of approx 50 cycles, PVC appears to be wearing through quickly. Little damage to rope other than staining.

Restarted 11:24:30 – sheath damage observed to begin around 11:27

Further 5 minutes, total 15 mins/ approx 75 cycles, steel can just be seen through protector, causing sheath damage.

After a further 5 minutes the sheath is totally destroyed and core damage has begun.

Total of 20 minutes/ approx 100 cycles

H. Steel edge, Rubber compressor pipe protection

Start time 11:45

Peak load = 1.78 kN min load = 0.38 kN

After 5 minutes, approx 25 cycles, pipe cut down top to inspect inside. Hole already worn through pipe, beginnings of sheath damage. Rope well blackened with rubber.

Restarted 11:54

After further 5 minutes, total cycles approx 50, pipe now has large hole. However sheath damaged not that advanced- yet.

Restarted 12:02:10

After further 5 minutes, sheath totally destroyed, beginnings of core damage. Large hole in pipe.

Total of 15 minutes/ approx 75 cycles

I. Concrete edge, Lyon canvas protector

Protector laid flat over edge, secured top and bottom to prevent bunching.

Start time 12:18

Peak load = 1.43 kN, min load = 0.47 kN

After 20 mins, approx 100 cycles, fabric slightly polished, rope flattened.

Restarted 12:42

After further 20 mins, total cycles approx 200, no change.

Further 70 minutes, rope flattened and slightly glazed. Canvas glazed on both sides but shows no signs of rupture.

Total of 110 minutes/ approx 550 cycles

J. Concrete edge, Lyon PVC protector

Start time 14:28

Peak load = 1.49 kN, min load = 0.46 kN

From start, PVC grips rope and slides and stretches back and forth over the edge.

After 5 mins, approx 25 cycles, the protector shows signs of damage. The PVC melts and flakes off, staining the rope red.

Restart 14:36

After a further 5 mins, total 50 cycles, the PVC has gone from the wear point on the edge, leaving only fibres showing. As a result the protector no longer grips the rope but remains steady.

Restart 14:45

After a further 10 mins, total cycles now approx 100, there is little change except for the fibres becoming more glazed.

Restart 14:58

After a further 20 mins, both PVC and rope surfaces are very glazed, resulting in heat build-up and friction which prevents the rope running smoothly.

Restart 15:21

After a further 20 mins, situation little different. Rope slides in a jerky fashion, causing heat build-up. Layers of PVC fused together.

Total of 60 minutes/ 300 cycles

K. Concrete edge, Compressor pipe

Start 15:53

Peak load = 1.71 kN, min load = 0.49 kN

After 5 minutes/ approx 25 cycles, pipe well worn, rope well blackened with rubber.

Restarted 16:00:30

After a further 5 minutes the pipe has worn right through, creating a hole around 20m by 4mm. The pipe no longer offers any protection.

Total of 10 minutes/ 50 cycles

L. Concrete edge, Petzl roll module

Start 16:12

Peak load = 1.34 kN, min load = 0.58 kN

After 40 minutes/ approx 200 cycles, rope flattened and stained grey with aluminium.

Restarted 9:35

After a further 60 minutes, little change

Total of 100 minutes/ approx 500 cycles

M. Concrete edge, PVC "rope bag" (scraps folded twice to give 4 layers)

Start 10:45

Peak load = 1.60 kN, min load = 0.46 kN

During initial 6-7 minutes of the test, the PVC grabs and slides with the rope. Once the coating has rubbed off this ceases, however when one stops the test for inspection it is difficult to reposition the protector in exactly the same place.

After 10 minutes most of the PVC has rubbed off at the wear point, staining the rope blue.

Restarted 10:53

As peak loads are greater on the up part of the cycle than the down the material tends to be pulled up over the edge – moving the wear point.

After a further 10 minutes the PVC has been removed over a long strip above and below the wear point. On unfolding the material it is apparent that wear is occurring on all the surfaces at the wear point.

Restarted 11:06

Further 10 minutes – PVC gradually slides up over edge, until the top layer is no longer protecting the edge. The other layers then follow suit. Test abandoned at this point.

Total of 30 minutes/ approx 150 cycles

N. Steel edge, PVC "rope bag" (scraps folded twice to give 4 layers)

Start time 11:25

Peak load = 1.55 kN, min load = 0.50 kN

As before, PVC grips and slides with rope until PVC coating has been rubbed off.

After 10 minutes/ approx 50 cycles localised wear across edge. Again, difficult to reposition material accurately as rope drags it when returning to the start point.

Restart 11:38

Further 10 minutes results in the material remaining stationary with the fibres providing a smooth running surface. The 3 layers of material underneath provide a slight increase in radius over the edge, so wear does not occur as fast as with the PVC protector.

Restart 11:51

During the next 10 minute stretch the 4 layers of PVC appear to be providing good protection. Peak loads are low, indicating smooth running over the edge.

On inspection the top layer of material is still intact, with 3 more layers underneath.

Restart 12:05

Further 30 minutes – situation similar to test 2.5. Rope runs jerkily over material, creating heat. Wear slow; although top layer is almost worn through, wear on the three layers restricted to PVC removal. Heat has lightly fused layers together.

Total of 60 minutes/ approx 300 cycles

O. Concrete edge, carpet

Start 10:50

Peak load = 1.43 kN, min load = 0.49 kN

After 5 minutes/ approx 25 cycles, rope flattened, pile flattened and polished.

Restart 11:03

After further 5 minutes/ total 50 cycles, rope marked, small hole in carpet- little protection.

Restart 11:11

After a total of 15 minutes/ 75 cycles, large hole in carpet, slight sheath damage.

P. Steel edge, carpet

Start 11:23

Peak load = 1.61 kN, min load = 0.40 kN

After 2 minutes/ 10 cycles, small hole worn in carpet, sheath damage just beginning.

Restart 11:28

After further 3 minutes, total 25 cycles, sheath destroyed, carpet offering no protection.

Q. Paving slab, Lyon canvas

Start 11:50

Peak load = 1.47 kN, min load = 0.35 kN

After 5 minutes, rope flattened but undamaged. Rope protector polished but intact.

Restart 11:57

After further 10 minutes, total approx 75 cycles, little change. Rope protector becoming very polished and heat beginning to build up in the rope, but no significant damage to either.

Restart 12 :09.

Further 10 minutes- little change, further polishing and heat build up.

Restart 12:22

After another 15 minutes, total now 40 minutes, approx 200 cycles, little changed, rope now quite hot.

Restart 12:43

After a total of 50 minutes, 250 cycles still no change.

Restart 14:08

After another 20 minutes, (total 70/ 350 cycles) very slight damage to the rope protector. Rope itself still shows no damage.

Restart 14:32

Final 20 minute stretch brings total to approx 450 cycles.

R. Paving slab, unprotected

Start 15:01

Peak load = 1.75 kN, min load = 0.39 kN

After 8 cycles sheath is destroyed

S. Paving slab, Lyon PVC

Start 15:10

Peak load = 1.67 kN, min load = 0.48 kN

During first 5 minutes, PVC covering grips rope until it begins to flake off. At end of initial 25 cycles, PVC coating removed and material is beginning to wear through. Rope stained yellow, but otherwise O.K.

Restart 15:17

After further 5 minutes, total 50 cycles, rope heating up and showing slight sheath damage. Protector is wearing through slowly.

Restart 15:25

After a total of 15 minutes, the hole in the protector is growing, and sheath damage is advancing

Restart: 15:33

Final 5 minute period leads to a still larger hole in the protector and sheath failure after 100 cycles.

T. Paving slab, roll module

Start 15:47

Peak load = 1.38 kN, min load = 0.58 kN

After 20 minutes/ 100 cycles rope is flattened and shows slight aluminium stains.

Restart 16:10

After total 40 minutes/ 200 cycles, flattening and staining more pronounced.

Restart 16:34

After 60 mins 300 cycles, no major changes. Sheath stained grey but structurally sound.

U. Paving slab, carpet

Start 10:17

Peak load = 1.44 kN, min load = 0.56 kN

After 5 minutes/ 25 cycles small hole in carpet, very beginnings of sheath damage.

Restart 10:25

After another 5 minutes/ total of approx 50 cycles, large hole worn in protector/ no longer appears to be offering any protection, however sheath damage still only minor.

Restart 10:33

After only 2 minutes more it is obvious sheath damage has progressed rapidly, and the test is stopped, by which time core damage is beginning.

V. Paving slab, Compressor pipe

Start 10:48

Peak load = 1.84 kN, min load = 0.37 kN

After 5 minutes, approx 25 cycles, the first thing that is apparent is the high loads being generated. On inspection the compressor pipe has already worn right through, with the rope covered in black rubber, and sheath damage beginning.

Restart 10:55

After another 5 minute period the situation has worsened, although the sheath damage is still relatively minor. The blackening of the rope does however make detailed inspection difficult.

Restart 11:03

After a total of 15 minutes/ approx 75 cycles the sheath has been destroyed, and the rope is coated in rubber for ~200mm. Without removing the pipe for inspection, however, little damage is seen.

W. Paving slab, PVC scraps

Start 11:17

Peak load = 1.64 kN, min load = 0.48 kN

From the start the fabric grips the rope and moves with it. Unless restrained it will soon creep up or down and remove itself from the edge. By restraining the material and preventing it from moving the rope begins to wear a groove in the PVC coating. Once the coating has been removed it will slide over. This generates a lot of friction and the rope heats up considerably.

After 10 minutes/50 cycles, much PVC has been removed, yet the fabric continues to creep around and must be repositioned periodically.

Restart 11:32

After approx 100 cycles/20 minutes the top layer of PVC remains intact. The rope is now stained blue with a coating of PVC where it crosses the edge. The fabric no longer grips the rope and it slides more easily.

Restart 11:48

After a further 20 minutes, the top layer of fabric remains intact. The fibres however appear irregular and the rope runs jerkily over them.

Restart 11:11

After a full 60 minutes/ approx 300 cycles the situation remains the same, heat has steadily built up due to the jerky running of the rope. The fabric however remains intact. All four layers are fused together and the back layer shows some damage from the rope.

X. Steel edge, Carpet (canvas back)

After 9 cycles both carpet and sheath have worn through, exposing core.

Y. Coping stone, Carpet (canvas back)

20 cycles: canvas showing through, nylon pile melted together.

40 cycles: As above, progressing further.

60 cycles: Thin melted layer seems to be holding up. Probably due to it simply lying over the rounded edge.

100 cycles: v. thin layer of fused material remains.

130 cycles: rope running directly over edge.

Z. Paving slab, Carpet (canvas back)

10 cycles: fibres fusing together

20 cycles: edge appears to be showing through

30 cycles: little change. Rope now flattened and stained with melted nylon.

70 cycles: fused layer now very thin. Slight sheath damage beginning. Friction has unfortunately pulled the edge back from the edge of the bench, lessening the severity of the abrasion.

100 cycles: Sheath badly damaged.

12.6 APPENDIX 6 KNOTS - STRENGTH TESTS

Table 19
Beal 10.5mm Antipodes (low stretch) knot tests

Knot	Test 1	Test 2	Test 3
	Breaking force (kN)	Breaking force (kN)	Breaking force (kN)
Overhand	17.82	18.57	18.46
Figure-8	18.42	18.86	20.58
Figure-9	22.34	19.71	18.88
Figure-10	21.41	22.07	23.22
Figure-8 on the bight	17.91	17.98	20.80
Bowline	19.71	18.97	18.52
Alpine Butterfly	18.58	19.23	17.62
Double Fisherman's	*36.98	*37.80	*41.87
½ Double Fisherman's	19.06	20.32	19.83
Clove Hitch	Slipped at 10.5	15.69	Slipped at 10

Note: * denotes the measured force when tested on a loop of rope. It is not the strength of the knot. See discussion on this knot in section 3.3.9

Note: Test 1, 2 & 3 refer to different ways of tying the knots.
- Test 1 Both knots tied the same way, live rope on top as it entered the knot.
- Test 2 One knot tied as in Test 1, other knot tied with live rope on the bottom as it entered the knot.
- Test 3 Both knots tied the same way, live rope on the bottom as it entered the knot.

Table 20
Edelrid 10.5mm rope (low stretch) knot tests

Knot	Test 1 Breaking force (kN)	Test 2 Breaking force (kN)	Test 3 Breaking force (kN)
Overhand	19.34	18.14	19.68
Figure-8	20.22	20.07	19.90
Figure-9	25.01	21.52	21.62
Figure-10	21.89	22.32	23.14
Figure-8 on the bight	18.58	20.47	21.45
Bowline	16.50	18.79	18.30
Alpine Butterfly	19.08	19.42	19.02
Double Fisherman's	*43.8	*42.5	*44.5
½ Double Fisherman's	22.92	22.02	22.65
Clove Hitch	Slipped at 15	Slipped at 11	15.9

Note: * denotes the measured force when tested on a loop of rope. It is not the strength of the knot. See discussion on this knot in section 3.3.9.

Note: Test 1, 2 & 3 refer to different ways of tying the knots.

Test 1 Both knots tied the same way, live rope on top as it entered the knot.
Test 2 One knot tied as in Test 1, other knot tied with live rope on the bottom as it entered the knot.
Test 3 Both knots tied the same way, live rope on the bottom as it entered the knot.

Table 21
Marlow 10.5mm rope (low stretch) knot tests

Knot	Test 1	Test 2	Test 3
	Breaking force (kN)	Breaking force (kN)	Breaking force (kN)
Overhand	19.48	19.47	20.40
Figure-8	22.14	21.81	22.08
Figure-9	24.51	25.08	22.64
Figure-10	24.68	24.68	25.71
Figure-8 on the bight	20.14	20.79	22.45
Bowline	21.17	20.10	21.29
Alpine Butterfly	20.22	20.81	20.89
Double Fisherman's	45.41*	45.70*	46.85*
½ Double Fisherman's	21.96	22.58	23.31
Clove Hitch	Slipped at 12.5	Slipped at 5	Slipped at 4.5

Note: * denotes the measured force when tested on a loop of rope. It is not the strength of the knot. See discussion on this knot in section 3.3.9.

Note: Test 1, 2 & 3 refer to different ways of tying the knots.

Test 1 Both knots tied the same way, live rope on top as it entered the knot.

Test 2 One knot tied as in Test 1, other knot tied with live rope on the bottom as it entered the knot.

Test 3 Both knots tied the same way, live rope on the bottom as it entered the knot.

Table 22
Beal 11mm rope (dynamic) knot tests

Knot	Test 1	Test 2	Test 3
	Breaking force (kN)	Breaking force (kN)	Breaking force (kN)
Overhand	14.58	14.57	15.62
Figure-8	16.76	16.51	16.56
Figure-9	16.92	17.47	16.14
Figure-10	17.44	17.33	17.61
Figure-8 on the bight	15.48	14.75	15.56
Bowline	13.97	14.65	13.92
Alpine Butterfly	14.84	14.97	15.01
Double Fisherman's	*29.90	*28.23	*29.08
½ Double Fisherman's	16.72	16.63	15.99
Clove Hitch	13.54	14.39	13.48

Note: * denotes the measured force when tested on a loop of rope. It is not the strength of the knot. See discussion on this knot in section 3.3.9.

Note: Test 1, 2 & 3 refer to different ways of tying the knots.

Test 1 Both knots tied the same way, live rope on top as it entered the knot.
Test 2 One knot tied as in Test 1, other knot tied with live rope on the bottom as it entered the knot.
Test 3 Both knots tied the same way, live rope on the bottom as it entered the knot.

12.7 APPENDIX 7 LANYARDS - STATIC TESTS

Table 23
Lanyard static tests

Brand	Test 1			Test 2			Comments
	Initial tear force (kN)	Peak tear force (kN)	Final break force (kN)	Initial tear force (kN)	Peak tear force (kN)	Final break force (kN)	
BH Sala	~2.00	10.23	Too long to test	Not tested			Jerky deployment: reflected in peak force
Charlet Moser	1.90	3.10	26.64	1.96	3.36	25.19	Very smooth deployment
P & P	Too long to test			Too long to test			
Petzl Absorbica	4.06	7.31	16.10	4.64	8.48	20.49	Jerky deployment
Petzl Absorbica I	2.35	6.32	18.49	3.46	6.33	18.33	Fairly jerky deployment
Spanset	2.50	6.30	19.54	-	-	-	-

12.8 APPENDIX 8 TYPE A BACK-UP DEVICES - MINIMUM STATIC STRENGTH TEST

Table 24
Type A Back-up devices – minimum static strength

Device	Rope			Force to fail (kN)	Comments
	brand	Diameter (mm)	Pass/ Fail		
Ushba, Stop Lock	Edelrid	10.5	-	-	Not tested
Komet Stick Run	Edelrid	10.5	Pass	Progressive distortion above 11 rope not released.	At 12kN device severely distorted. Rope jammed in device.
Petzl Microcender	Edelrid	10.5	Pass	-.	No distortion visible
Petzl Rescucender	Edelrid	10.5	Pass	-	No distortion visible
Petzl Shunt	Edelrid	10.5	Fail	5.5	Body opens up and releases rope
SSE Stop & Go	Edelrid	10.5	Pass	Side plate distorts at 11 but does not release rope.	Device unusable after test. Rope jammed in device.
Tractel Stopfor d	Edelrid	10.5	Pass	-	No distortion visible
Troll Rocker	Edelrid	10.5	Fail	Side plates distort, allowing rope to get jammed. sheath fails at 10.8, core then fails at lower loads.	Device unusable after test. Rope jammed in device.
Wild Country Ropeman	Beal	10.5	Fail	Rope sheath fails at 7. Core then cut at 9.5	Toothed cam cuts rope steadily- no slippage is seen.

All rope was low stretch

Note: 'Pass/Fail' in the above table only applies in relation to the test and criteria employed, and may not be relevant to the safety and practicality of the item in question when it is used in any specific application

12.9 APPENDIX 9 TYPE A BACK-UP DEVICES - DYNAMIC TESTS

Table 25
Type A Back-up devices – dynamic tests

Device & rope type	Rope brand	Rope diameter (mm)	Force (kN)	Slip (m)	Comments
Ushba Stop Lock (low stretch rope)	Edelrid	10.5	5.26	-	Rope broke, device distorted & rope jammed in device
	Marlow	10.5	5.80	-	
Komet Stick Run (Low stretch rope)	Beal	10.5	2.74	1.70	-
			2.35	1.69	-
			2.58	1.73	-
	Edelrid	10.5	2.87	2.40	hit buffer
			2.23	2.50	hit buffer
			2.05	2.50	hit buffer
	Marlow	10.5	3.19	1.70	-
			2.74	1.75	-
			2.68	1.68	-
Komet Stick Run (dynamic rope)	Beal	11	2.87	2.17	severe sheath damage
			2.90	2.00	sheath stripped
			3.61	2.00	sheath stripped
Petzl Microcender (low stretch)	Beal	10.5	5.75	0.55	Device No. 1
			4.54	0.84	Device No. 1
			3.01	1.17	Device No. 1
			2.78	1.43	Device No. 1
			4.41	0.87	Device No. 2
			3.49	1.09	Device No. 2
	Edelrid	10.5	4.47	1.28	-
			4.18	1.11	-
			4.98	1.00	-
	Marlow	10.5	4.02	0.96	-
			3.51	1.12	-
			3.58	0.95	-

Table continued on next page

Device & rope type	Rope brand	Rope diameter (mm)	Force (kN)	Slip (m)	Comments
Petzl Rescucender (dynamic rope)	Beal	11	6.00	0.52	-
			6.38	0.50	-
			5.97	0.51	-
Petzl Rescucender (low stretch rope)	Beal	10.5	6.02	0.67	-
			6.12	0.67	-
			6.28	0.67	-
	Edelrid	10.5	3.43	1.60	-
			5.12	1.00	-
			6.05	0.90	-
			5.38	0.99	-
	Marlow	10.5	5.98	0.77	-
			5.63	0.73	-
			5.53	0.74	-
Petzl Rescucender (dynamic rope)	Beal	11	6.40	0.48	-
			5.92	0.65	-
			5.25	0.66	-
Petzl Shunt (low stretch rope)	Beal	10.5	1.99	1.69	
			2.36	1.77	
			2.49	2.50	Hit buffer
	Edelrid	10.5	2.01	2.50	Hit buffer
			1.87	2.50	
			1.76	2.50	Ran off end of rope
	Marlow	10.5	2.80	1.50	
			2.96	1.46	
			2.52	2.00	
Petzl Shunt (dynamic rope)	Beal	11	2.56	1.72	
			4.23	1.80	Sheath stripped
			4.42	1.77	Sheath stripped
			2.31	1.80	
SSE Stop & go (low stretch rope)	Beal	10.5	4.01	1.45	
			3.66	1.60	
			3.69	1.60	
	Edelrid	10.5	6.04	1.60	
			4.85	1.71	
			4.15	1.89	
	Marlow	10.5	6.55	0.91	
			6.33	1.11	
			5.18	1.07	

Table continued on next page

Device & rope type	Rope brand	Rope diameter (mm)	Force (kN)	Slip (m)	Comments
SSE Stop & Go (dynamic rope)	Beal	11	4.23	0.81	
			4.33	0.75	
			3.88	0.88	
Tractel Stopfor D (low stretch rope)	Beal	10.5	2.90	2.50	Hit buffer
			2.86	2.50	Hit buffer
	Edelrid	10.5	2.90	2.50	Hit buffer
			2.86	2.50	Hit buffer
	Marlow	10.5	4.53	1.06	
			4.34	1.30	
			4.24	1.40	
Tractel Stopfor D (dynamic rope)	Beal	11	3.10	1.74	
			3.13	1.32	
			3.07	1.45	
Tractel Stopfor D (low stretch rope)	Beal	10.5	3.97	0.87	
			3.23	0.92	
			3.20	0.99	
	Edelrid	10.5	4.01	0.81	
			3.75	0.98	
			3.50	1.05	
	Marlow	10.5	4.17	0.71	
			4.23	0.67	
			4.71	0.63	
Tractel Stopfor D (dynamic rope)	Beal		4.27	0.69	
			4.30	0.69	
		11	4.08	0.70	

Table continued on next page

Device & rope type	Rope brand	Rope diameter (mm)	Force (kN)	Slip (m)	Comments
Wild Country Ropeman (low stretch rope)	Beal	10.5	no record	Hit buffer	Sheath stripped
			6.30	Hit buffer	Sheath stripped
			5.18	-	Core & sheath broke
	Edelrid	10.5	3.93	-	Sheath stripped
			4.09	-	Peak 1 at sheath break
			4.95	-	Peak 2 when sheath bunched
			4.83	-	Sheath stripped
	Marlow	10.5	4.03	-	Peak 1 at sheath break
			4.25	-	Peak 2 when sheath bunched
			3.52	-	Sheath stripped
			3.87	-	Peak 1 at sheath break
			4.00	-	Peak 2 when sheath bunched
	Beal	11	4.67	1.99	
			4.03	-	Hit buffer
			4.32	2.20	
Troll Rocker (low stretch rope)	Beal	10.5	3.97	0.87	
			3.23	0.92	
			3.2	0.99	
	Edelerid	10.5	4.01	0.81	
			3.75	0.98	
			3.5	1.05	
	Marlow	10.5	4.17	0.71	
			4.23	0.67	
			4.71	0.63	
Troll Rocker (dynamic rope)	Beal	11	4.27	0.69	
			4.3	0.69	
			4.08	0.70	

12.10 APPENDIX 10 TYPE A BACK-UP DEVICES - MINIMUM WORKING STRENGTH

Table 26
Devices Type A – back-up – minimum working strength test

Device	Rope			Pass/ Fail	Slip (mm)	Comments
	Brand	Ø (mm)	Type			
Ushba, Stop Lock	Beal	10.5	Low stretch	-	-	Not tested
	Edelrid	10.5		-	-	
	Marlow	10.5		-	-	
	Beal	11.0	Dynamic	-	-	
Komet Stick Run	Beal	10.5	Low stretch	Fail	+300	Slipped at ~2.3 kN
	Edelrid	10.5		Fail	+300	Slipped at ~2.5 kN
	Marlow	10.5		Fail	+300	Slipped at ~2.7 kN
	Beal	11.0	Dynamic	Fail	+300	Slipped at ~3.1 kN
Petzl Microcender	Beal	10.5	Low stretch	Fail	+400	Slipped at ~3.4 kN
	Edelrid	10.5		Fail	+400	Slipped at ~2.2 kN
	Marlow	10.5		Fail	+400	Slipped at ~3.2 kN
	Beal	11.0	Dynamic	Fail	+400	Slipped at ~3.5 kN
Petzl Rescucender	Beal	10.5	Low stretch	Pass	10	-
	Edelrid	10.5		Pass	15	-
	Marlow	10.5		Pass	10	-
	Beal	11.0	Dynamic	Pass	~20	-
Petzl Shunt	Beal	10.5	Low stretch	Fail	+300	Slipped at ~2.3 kN
	Edelrid	10.5		Fail	+300	Slipped at ~2.5 kN
	Marlow	10.5		Fail	+300	Slipped at ~2.5 kN
	Beal	11.0	Dynamic	Fail	+300	Slipped at ~2.7 kN
SSE Stop & go	Beal	10.5	Low stretch	Fail	+400	Slipped at ~1.9 kN
	Edelrid	10.5		Fail	+400	Slipped at ~2.8 kN
	Marlow	10.5		Fail	+400	Slipped at ~2.4 kN
	Beal	10.5		Fail	+400	Slipped at ~2.1 kN
	Beal	11.0	Dynamic	Fail	+400	Slipped at ~3.4 kN
Tractel Stopfor d	Beal	10.5	Low stretch	Fail	+300	Slipped at 2.5(peak 3.5) kN
	Edelrid	10.5		Fail	+300	Slipped at 2.2(peak 2.6) kN
	Marlow	10.5		Fail	+300	Slipped at ~2.7 kN
	Beal	11.0	Dynamic	Fail	+300	Slipped at ~2.5 kN

Table continued on next page

Note: 'Pass/Fail' in the above table only applies in relation to the test and criteria employed, and may not be relevant to the safety and practicality of the item in question when it is used in any specific application

Device	Rope			Pass/ Fail	Slip (mm)	Comments
	brand	Ø (mm)	Type			
Troll Rocker	Beal	10.5	Low stretch	Pass	15	
	Edelrid	10.5		Fail	+400	Slipped at ~3.4 kN
	Marlow	10.5		Pass	25	
	Beal	11.0	Dynamic	Pass	15	
Wild Country Ropeman	Beal	10.5	Low stretch	Pass	10	Sheath damaged
	Edelrid	10.5		Pass	15	Very difficult to release
	Marlow	10.5		Pass	70	Took time to bite
	Beal	11.0	Dynamic	Pass	17	Sheath damaged

Note: 'Pass/Fail' in the above table only applies in relation to the test and criteria employed, and may not be relevant to the safety and practicality of the item in question when it is used in any specific application

12.11 APPENDIX 11 TYPE B DEVICES - ASCENDERS - BODY TEST

Table 27
Type B - Ascenders - Body test

Make/ Model	Pass/ Fail	Comments
Camp Pilot	Pass	Slight distortion to top hole on rear of device
ISC Handled	Pass	No deformation
Petzl Ascension	Pass	Distortion to top hole on rear of device
Anthron AC30	Pass	Some distortion to body- may be due to problems with grips. Repeated test with 12 mm maillons- slight deformation to top hole
Kong Chest	Fail	Top hole failed at 8.5 kN Repeated with maillons- failed at 8.6 kN
Petzl Croll	Fail	Top hole failed at 12.2 kN Repeated test with maillons- top hole failed at 10.9 kN

Note: 'Pass/Fail' in the above table only applies in relation to the test and criteria employed, and may not be relevant to the safety and practicality of the item in question when it is used in any specific application

12.12 APPENDIX 12 TYPE B DEVICES - ASCENDERS -DYNAMIC TESTS

Table 28
Type B devices – ascenders – dynamic tests

Device	Rope			Test		
	Brand	Diameter (mm)	Type	Force (kN)	Pass/ Fail	Comments
Anthron AC30	Beal	10.5	Low stretch	5.11	Pass	
				5.46	Pass	
				5.14	Pass	
	Edelrid	10.5	Low stretch	5.94	Pass	
				6.55	Pass	
				6.42	Pass	
	Marlow	10.5	Low stretch	6.89	Pass	
				6.26	Pass	
				6.77	Pass	
Camp Pilot	Beal	10.5	Low stretch	4.35	Pass	
				4.15	Pass	
				4.15	Pass	
	Edelrid	10.5	Low stretch	4.72	Pass	
				5.20	Pass	
				4.85	Pass	
	Marlow	10.5	Low stretch	4.46	Pass	
				4.74	Pass	
				4.55	Pass	
ISC	Beal	10.5	Low stretch	5.66	Pass	Only one device used for all tests
				5.35	Pass	
				4.83	Pass	
	Edelrid	10.5	Low stretch	6.20	Pass	
				6.04	Pass	
				6.55	Pass	
	Marlow	10.5	Low stretch	6.52	Pass	
				6.36	Pass	
				6.29	Pass	

Note: 'Pass/Fail' in the above table only applies in relation to the test and criteria employed, and may not be relevant to the safety and practicality of the item in question when it is used in any specific application

Table continued on next page

Device	Rope			Test		
	Brand	Diameter (mm)	Type	Force (kN)	Pass/ Fail	Comments
Kong Camclean	Beal	10.5	Low stretch	4.59	Pass	
				4.56	Pass	
				5.04	Pass	
	Edelrid	10.5	Low stretch	5.62	Pass	
				5.02	Pass	
				5.94	Pass	
	Marlow	10.5	Low stretch	6.41	Pass	
				6.05	Pass	
				5.54	Pass	
Petzl Ascension	Beal	10.5	Low stretch	4.84	Pass	
				5.00	Pass	
				4.74	Pass	
	Edelrid	10.5	Low stretch	5.27	Pass	
				4.92	Pass	
				6.29	Pass	
	Marlow	10.5	Low stretch	5.69	Pass	
				5.59	Pass	
				5.14	Pass	
Petzl Croll	Beal	10.5	Low stretch	4.69	Pass	
				4.82	Pass	
				4.79	Pass	
	Edelrid	10.5	Low stretch	5.23	Pass	
				5.42	Pass	
				5.58	Pass	
	Marlow	10.5	Low stretch	5.36	Pass	
				5.62	Pass	
				5.90	Pass	

Note: ‘Pass/Fail’ in the above table only applies in relation to the test and criteria employed, and may not be relevant to the safety and practicality of the item in question when it is used in any specific application

12.13 APPENDIX 13 TYPE B DEVICES – ASCENDERS - MINIMUM WORK

Table 29
Devices type B - Handled ascenders – minimum work strength test

Device	Rope			Test		
	Brand	Diameter (mm)	Type	Pass/ Fail	Slip (mm)	Comments
Camp Pilot	Beal	10.5	Low stretch	Pass	15	Slight sheath damage
	Edelrid			Pass	10	-
	Marlow			Pass	15	Releases easily
ISC	Beal	10.5	Low stretch	Pass	8	Very easy release
	Edelrid			Pass	10	on all ropes
	Marlow			Pass	8	-
Petzl Ascension	Beal	10.5	Low stretch	Pass	10	-
	Edelrid			Pass	10	-
	Marlow			Pass	10	-

Note: 'Pass/Fail' in the above table only applies in relation to the test and criteria employed, and may not be relevant to the safety and practicality of the item in question when it is used in any specific application

Table 30
Devices type B - Chest ascenders – minimum work strength test

Device	Rope			Test		
	Type	Diameter (mm)	Brand	Pass/ Fail	Slip (mm)	Comments
Anthron AC30	Low stretch	10.5	Beal	Pass	0	
			Edelrid	Pass	5	
			Marlow	Pass	5	
Kong/Dalloz	Low stretch	10.5	Beal	Pass	5	
			Edelrid	Pass	5	
			Marlow	Pass	5	
Petzl Croll	Low stretch	10.5	Beal	Pass	5	Slight sheath damage
			Edelrid	Pass	<5	
			Marlow	Pass	<5	

Note: 'Pass/Fail' in the above table only applies in relation to the test and criteria employed, and may not be relevant to the safety and practicality of the item in question when it is used in any specific application

12.14 APPENDIX 14 TYPE C DEVICES– DESCENDERS – STATIC TESTS

Table 31
Devices type C – descenders – static tests

Device	Rope			Test		
	Brand	Diameter (mm)	Type	Pass/ Fail	Slip (mm)	Comments
AML	Edelrid	10.5	Low stretch	Pass	Not applic -able	Slip not measured
Anthron Double Stop	Edelrid	10.5	Low stretch	Pass	~30	Knot not required- self locking sufficient
Petzl I’D	Edelrid	10.5	Low stretch	Fail	+300	Locked with handle
				Pass	Not applic -able	Locked with knot
Petzl Stop	Edelrid	10.5	Low stretch	Pass	~50	Locked as per instructions, not with knot.
SRT Noworries	Edelrid	10.5	Low stretch	Pass	~50	Locked off as per instructions- rope bent sharply over top edge of device
Troll Allp	Edelrid	10.5	Low stretch	Fail	Not applic -able	Locked with knot. Survives 3 minutes but device distorted and unusable
Troll pro Allp Tech	Edelrid	10.5	Low stretch	Pass	~50	Locked with knot. No damage visible

Note: ‘Pass/Fail’ in the above table only applies in relation to the test and criteria employed, and may not be relevant to the safety and practicality of the item in question when it is used in any specific application

12.15 APPENDIX 15 TYPE C DEVICES - DESCENDERS – DYNAMIC TEST

Table 32
Devices type C – Descenders – dynamic test data

Device	Rope Brand	Rope Ø (mm)	Rope Type	Force (kN)	Slip (m)	Comments
AML	Beal	10.5	Low stretch	2.42	0.68	
				2.36	0.77	
				2.52	0.86	
	Edelrid	10.5	Low stretch	2.42	0.83	
				2.42	0.83	
				2.17	0.97	
	Marlow	10.5	Low stretch	3.58	0.42	
				3.71	0.43	
				4.35	0.41	
Anthron Double Stop	Beal	10.5	Low stretch	4.34	*0.35	Rigged incorrectly
				6.89	0.37	
				7.34	0.38	
				7.53	0.31	
	Edelrid	10.5	Low stretch	7.18	0.34	
				7.18	0.28	
				7.47	0.32	
	Marlow	10.5	Low stretch	8.24	0.24	
				8.43	0.26	
				8.15	0.21	
Petz l I'D	Beal	10.5	Low stretch	6.39	0.36	
				6.61	0.31	
				6.29	0.32	
	Edelrid	10.5	Low stretch	6.39	0.36	
				6.61	0.31	
				6.29	0.32	
	Marlow	10.5	Low stretch	7.72	0.28	
				7.47	0.28	
				7.82	0.24	

Note – table continued on next page

Device	Rope			Force (kN)	Slip (m)	Comments
	Brand	Ø (mm)	Type			
Petzl Stop	Beal	10.5	Low stretch	6.74	0.45	Sheath stripped and device jammed onto the rope
				6.23	0.38	Sheath stripped and device jammed onto the rope
SRT Noworries	Beal	10.5	Low stretch	2.35	*	Short rope, 3.5m, hit buffer.
				2.19	1.77	
				2.19	2.00	
	Edelrid	10.5	Low stretch	2.07	1.75	
				2.23	1.60	
	Marlow	10.5	Low stretch	3.74	0.40	
				4.00	0.62	
				3.84	0.72	
Troll Allp	Beal	10.5	Low stretch	1.40	>2.5m	Did not stop
				1.45	>2.5m	Did not stop
				1.41	>2.5m	Did not stop
	Edelrid	10.5	Low stretch	1.41	>2.5m	Did not stop
				1.55	>2.5m	Did not stop
	Marlow	10.5	Low stretch	2.04	1.00	
				2.18	0.96	
				2.26	0.91	
Troll pro Allp tech	Beal	10.5	Low stretch	3.91	0.42	
				3.56	0.47	
				3.37	0.51	
	Edelrid	10.5	Low stretch	3.33	0.47	
				3.27	0.47	
				3.43	0.49	
	Marlow	10.5	Low stretch	5.15	0.28	
				5.53	0.27	
				6.17	0.23	

12.16 APPENDIX 16 TYPE C DEVICES – DESCENDERS WORKING STRENGTH

Table 33
Device type C- Descender working strength test

Device	Rope			Test		
	Type	Diameter (mm)	Brand	Pass/ Fail	Slip (mm)	Comments
AML	Low stretch	10.5	Beal	Pass	20	
			Edelrid	Fail	+300	Slipped at 2.8 kN
			Marlow	Pass	15	
Anthron double stop	Low stretch	10.5	Beal	Pass	15	
			Edelrid	Pass	15	
			Marlow	Pass	15	
Petzl I'D	Low stretch	10.5	Beal	Pass	10	
			Edelrid	Pass	7	
			Marlow	Pass	5	
Petzl Stop	Low stretch	10.5	Beal	Pass	20	
			Edelrid	Pass	25	
			Marlow	Pass	20	
SRT Noworries	Low stretch	10.5	Beal	Fail	+300	Slipped at 1.7 kN
			Edelrid	Fail	+300	Slipped at 1.5 kN
			Marlow	Fail	+300	Slipped at 1.8 kN
Troll Allp	Low stretch	10.5	Beal	Fail	+300	Slipped at 1.9 kN
			Edelrid	Fail	+300	Slipped at 1.9 kN
			Marlow	Fail	+300	Slipped at 1.9 kN
Troll pro Allp tech	Low stretch	10.5	Beal	Pass	20	
			Edelrid	Pass	25	
			Marlow	Pass	25	

Note: 'Pass/Fail' in the above table only applies in relation to the test and criteria employed, and may not be relevant to the safety and practicality of the item in question when it is used in any specific application

12.17 APPENDIX 17 LANYARD - DYNAMIC TESTS

Table 34
Lanyard dynamic tests

Device	Fall factor	Peak impact force (kN)	Comments
Beal BEP	2	n/a	Failed to record
		5.99	
		6.79	
BH Sala	2	4.50	
		4.92	
		4.66	
Charlet Moser	1	3.17	First peak
	4	>10	Second peak
	2	8.93	Third peak
	0.5	2.05	First peak
	0.5	3.30	Second peak
Pammenter & Petrie	2	8.40	
		5.17	Max force of very short duration
		6.32	
Petzl Absorbica I	2	4.72	
		5.14	
		5.23	
Miller/Dalloz	2	5.27	
		4.72	
Spanset	2	4.84	

12.18 APPENDIX 18 PRUSIK KNOTS

Table 35
Prusik knot tests

Bachman knot

Main rope			Prusik cord (mm)	Pass/ fail	Sliding force (kN)	Comments/ ease of release
Brand	type	Ø (mm)				
Edelrid	Low stretch	10.5	Prusik Regate 10	Fail	0.6-1	Steady slip
Beal Baobab	Low stretch	13.5	Prusik Regate 10	Fail	1.6-1.9	Steady slip. Easy to release
Hawser new		12	Prusik Regate 10	Pass	N/A.	Little slippage. Easy release
Hawser used		12	Prusik Regate 10	-	-	-
Edelrid	Low stretch	10.5	Accessory cord 6	Pass	N/A.	Slight slippage whilst loading. Very easy to release.
Beal Baobab	Low stretch	13.5	Accessory cord 6	Pass	N/A.	
Hawser new		12	Accessory cord 6	Pass	N/A.	
Hawser used		12	Accessory cord 6	Pass	N/A.	

Kleimheist knot

Brand	type	Ø (mm)	Prusik cord (mm)	Pass/ fail	Sliding force (kN)	Comments/ ease of release
Edelrid	Low stretch	10.5	Prusik Regate 10.	Fail	0.3-0.4	Slipped steadily at low loads
Beal Baobab	Low stretch	13.5	Prusik Regate 10.	Fail	-	At 4 kN, knot inverts, twisting rope and reducing function.
Hawser new		12	Prusik Regate 10.	Fail	0.4	At 4 kN, knot inverts as above. Very difficult to release.
Hawser used		12	Prusik Regate 10.	Fail	-	Knot inverts at 2.8 kN. Very difficult to release.
Edelrid	Low stretch	10.5	Accessory cord 6	Pass	Jerky slippage 2-4	Release OK
Beal Baobab	Low stretch	13.5	Accessory cord 6	Pass	No slippage	Release OK
Hawser new		12	Accessory cord 6	Pass		
Hawser used		12	Accessory cord 6	Pass		

Note: 'Pass/Fail' in the above table only applies in relation to the test and criteria employed, and may not be relevant to the safety and practicality of the item in question when it is used in any specific application

Table continued on next page

Prusik knot

Main rope			Prusik cord (mm)	Pass/ fail	Sliding force (kN)	Comments/ ease of release
Brand	type	Ø (mm)				
Edelrid	Low stretch	10.5	Prusik Regate 10.5	Fail	0.45	Releases easily. Slipped at relatively low loads
Beal Baobab		13.5		Pass	3.8 slight slippage	Stretches Baobab sheath releases easily
Hawser new		12		Pass	2.8	Slipped during increasing force, holds static load. Release difficult
Hawser used				Pass	3.5	Slipped slightly. Difficult to release.
Edelrid	Low stretch	10.5	Accessory cord 6	Pass	Little slippage	OK release
Beal Baobab		13.5		Pass	Little slippage	OK release
Hawser new		12		Pass	No slippage	Easy release
Hawser used				Pass	No slippage	Easy release

Note: 'Pass/Fail' in the above table only applies in relation to the test and criteria employed, and may not be relevant to the safety and practicality of the item in question when it is used in any specific application

Table continued on next page

French prusik						
Main rope			Prusik cord (mm)	Pass/ fail	Sliding force (kN)	Comments/ ease of release
Brand	type	Ø (mm)				
Edelrid	Low stretch	10.5	Prusik Regate 10.5	Fail	0.4-0.55	Slides steadily at low loads. Releases very easily
Beal Baobab		13.5		Pass	3-3.4 starts to slip jerkily	Releases very easily
Hawser new		12		Fail	2.5 jerky slippage	Reaches 3.5 kN during jerk. Very easy to release
Hawser used				Pass	Slight slippage as it beds in	Releases easily
Edelrid	Low stretch	10.5	Accessory cord 6	Fail	1.3	Slipped steadily at first, then jerkily Very easy to release
Beal Baobab		13.5		Fail	3	Slipped steadily at 3 kN. Very easy to release
Hawser new		12		Pass	~40 mm slippage	Very easy to release
Hawser used				Pass	~30 mm slippage	Very easy to release
Blake knot						
Edelrid	Low stretch	10.5	Prusik Regate 10.5	Pass	Slight jerks at 3.6	Easy release
Beal Baobab		13.5		Pass	Little slippage	Releases easily
Hawser new		12		Pass	Little slippage	Releases easily
Hawser used		12		Pass	Little slippage	Releases OK, requires a little unwrapping
Edelrid	Low stretch	10.5	Accessory cord 6	Pass	Slight jerks between 3-4	
Beal Baobab		13.5		Pass		Sheath stretches, releases OK
Hawser new		12		Pass	Some slippage between 3-4	Release OK
Hawser used				Pass		Some stretch. Release fairly easy

Note: 'Pass/Fail' in the above table only applies in relation to the test and criteria employed, and may not be relevant to the safety and practicality of the item in question when it is used in any specific application

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