Ropes and Friction Hitches
used in
Tree Climbing Operations

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CONTENTS

1. INTRODUCTION

This report presents the results of a research project carried out into ropes and friction hitches commonly in use in tree climbing operations in the United Kingdom. The ropes and friction hitches in question are used by arborists as part of roped systems for ascending into trees, positioning themselves within trees, and descending from trees.

The background to the research project is described in some detail, followed by a discussion of the results and conclusions based on the findings. The data arising from the various tests are presented in full in tables at the end of the report and in summary within the body of the report.

It is hoped that the results of the research will be of subsequent value in the process of setting standards for tree climbing operations within the arboricultural industry.

2. BACKGROUND

Tree climbing techniques used by arborists in the UK have traditionally (for at least half a century) depended on the humble prusik[1] hitch, used as a friction hitch in a doubled rope system, for the purposes of ascending, positioning and descending (see photographs 1 & 2). The advantages of such a system are enormous in as much as they allow a tree climber both freedom of movement and adequate safety, factors which directly affect every day productivity. Alternative roped access techniques can be impractical, slow to implement and even at times dangerous.

Photograph 1 Ascending

Photograph 2 Decending

Perhaps the biggest drawbacks of the tree climber's friction hitch techniques are the need to ensure correct application of the friction hitches and the problems associated with controlling the friction heat that can be generated in their operation. If friction hitches are tied correctly, they typically out-perform mechanical devices used for similar purposes in general tree work. An additional advantage of friction hitches is that when the cord becomes worn it can be discarded at a low cost of replacement.

[1] The word 'prusik' is used throughout this report in two distinct ways, specific and generic. Where it is capitalised it refers specifically to the traditional Prusik hitch as illustrated in photograph 3 on page 10. Without capitalisation it refers generically to all hitches tied by winding cord around a rope.

The main reasons why friction hitches are chosen over mechanical devices are: -

- Low weight
- Sensitivity
- Familiarity
- Low cost
- Easy replacement

However, up until the present time no research has been carried out to determine the actual strength of friction hitches when used in the doubled rope system adopted by arborists. There are specific concerns about the strength of friction hitches following wear associated with descents. Of particular interest is the amount of wear and subsequent loss of strength that a friction hitch can receive in fast descents or extended use.

The variety of friction hitches and cords currently in use in the tree climbing arena further complicates the situation, fuelled in the large part by the international tree climbing competition circuit. The competitions reward the safest, most efficient and most productive competitors and have led to a great deal of innovation over a relatively short period of time. This innovation has naturally been transferred through to industrial practices. Although innovation in itself is never a bad thing, there is a need for more objective criteria to be applied before some techniques and equipment can be safely endorsed for general use in the industry.

The traditional technique of securing the doubled rope system with the tail end of the climbing line has been largely replaced by the ‘split tail’ technique. This was originally popularised in the UK by Merrist Wood College. It originally included a Prusik loop of 12 mm 3-ply nylon attached to both ends of the climbing line, but it can now utilise a variety of different diameter cords and other high performance prusik-type friction hitches.

Current industry recommendations in the UK only specify the use of a climbing line consisting of rope with a minimum diameter of 10mm, with no specific mention of friction hitch cord diameters (FASTCo[1] Safety Guide SG401). In the USA, the ANSI[2] Z133 standard recommends ½” diameter *synthetic* rope and a split tail of equal strength (although this standard is currently being reviewed and is in need of clarification). However, both of these recommendations preclude the use of certain cords that may well be suitable for use, and allow the use of some cords that may be entirely unsuitable. Heat resistance, flexibility and knotted strength are criteria that need to be considered in addition to rope diameter and strength.

It is traditionally thought that the friction hitch is the weak link in the tree climbing system, but this has never been determined objectively. The only published research so far carried out on friction hitches has been based on single rope techniques for sports and industrial use.

Of further interest is the *type* of rope used for tree climbing as these ropes are often used to tie friction hitches on themselves. FASTCo Safety Guide SG401 does not specify which rope types are the most suitable. Rope types could include either natural fibre rope (written out of ANSI Z133) or synthetic rope. Similarly, types of rope *construction* are also not specified (e.g. single-braid, double-braid or kernmantel construction), but under LOLER[3] regulations ropes used should be ‘fit for purpose’ (as tree work lifelines).

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[1] Forestry and Arboriculture Safety and Training Council
[2] American National Standards Institute
[3] Lifting Operations and Lifting Equipment Regulations (LOLER) 1998

The standard that European manufacturers of ropes for use in tree work must meet is that for low stretch industrial ropes (EN1891 - Type A). This standard was designed for kernmantel ropes, but other constructions can be awarded the CE mark if they meet the minimum strength requirements. If a rope has passed the 'Type A' test criteria (of EN1891), it will have been shown that it can withstand a static force of 22kN without terminations (e.g. knots), and 15kN with terminations. It will also have met the requirement to produce a peak force of less than 6kN in a fall of factor 0.3 with a 100Kg mass. 'Type B' ropes (as specified in EN1891) are of a lower performance than 'Type A' ropes and require greater care in use. Guidance is needed on the suitability of such ropes for tree work, and their relative advantages and disadvantages where they are sold as fit for the purpose of tree work. A typical example is that of some ropes manufactured in the USA which are designed for tree work but do not carry a CE mark. They may, however, be more suitable for tree work (especially with respect to knotability and abrasion resistance) than kernmantel ropes which do carry the EN1891 standard.

Furthermore, there is no European standard specifically for cord used for friction hitches. In sport climbing and general mountaineering friction hitches are tied with accessory cord. This has a standard (EN594) applying to cords of from 4mm to 8mm diameter. They are not required to absorb energy but are designed to hold a load. However, these cords are typically of a kernmantel construction and are generally considered to be too elastic for tying many of the tree climbing friction hitches. They also tend to abrade very rapidly when used in descent. To add to this complexity, some cords that have been designed and marketed as friction hitch cords do not carry a CE mark for use as either lifeline or accessory cord. These latter cords are generally more supple and of larger diameter than 8mm accessory cord, but not strong enough to conform to EN1891-Type B requirements. Cords of between 8mm and 12mm in diameter are chosen for tree work because of their increased abrasion tolerance and strength. Larger diameter cords also perform better in descent, because they tend not to bite onto the rope too tightly and can therefore be released more readily when tending slack.

Rope which is used for *lifting* persons is also covered by other legislation, namely PUWER[4], LOLER, personal protective equipment regulations, and the European Union Machinery Directive (98/37/EC). These variously give guidance on: -

- rope usage and provision
- planning of safe systems of work
- adequate strength and suitable safety factors
- suitability of equipment
- thorough examination of, and record keeping relating to, lifting equipment.

More accurate information on friction hitch cord and rope strength would help the industry in achieving compliance with the approved codes of practice issued by the HSE[5].

Accordingly, research was required to provide objective comparable results about cords, rope and friction hitches used in tree work rope systems. To enable the required research to be carried out a contract was awarded to *Treevolution* during March 2002.

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4 Provision and Use of Work Equipment Regulations 1998 (PUWER 98)

5 Health and Safety Executive

3. AIMS AND OBJECTIVES

The aim of the research was to provide comparable and reproducible information about the strengths of various ropes, cords and friction hitches utilised by arborists as part of rope systems used in tree climbing operations.

The objectives of the research were to determine: -

- Which cords are suitable for use in typical tree climbing operations, considering: -
  - abrasion and heat resistance
  - knotability
  - strength
  - fitness for purpose (including compliance with CE marking and manufacturers' recommendations)
- Which hitch configurations are the most effective, considering: -
  - slippage or failure
  - strength
  - distribution of friction heat
  - ease of release after loading
- Which cord is the most effective for the commonest hitches used in tree work and in competitions, considering: -
  - knotability
  - cord diameter
  - cord length
- How friction hitches fare when subjected to fall arrest, considering: -
  - slippage
  - friction heat damage
- How friction hitches fare when loaded with two people during aerial rescue, considering: -
  - slippage
  - friction heat damage
- At what loading various hitches slip or fail.
- How friction hitches fare when subjected to rapid descents.

To meet these objectives it was decided to carry out investigations on test rigs at the National Access & Rescue Centre (NARC) in order to determine: -

- Which hitch and cord combinations perform adequately in a doubled rope pull test.
- Which hitch and cord combinations perform adequately in a single rope pull test.
- Which hitch and cord combinations perform adequately in a doubled rope drop test for drops of minimal fall factor up to fall factor 2.
- Which hitch and cord combinations perform adequately in a single rope drop test for drops of fall factors 1 and 2.
- Where possible, the force at which the friction hitches slip.
- The peak force, average force and minimum force of failures, for general comparison.
- The most common points of failure.
- Where possible, the peak force at the point at which the system under investigation stalls the test rig.
- The peak force in a drop test if a system does not fail.

4. METHODS USED

A test rig was chosen to enable the setting up of rope systems that simulate as closely as possible those used in the arboricultural industry.

Using the test rig, a control configuration was established using a popular rope used for tree climbing (New England Safety Blue ‘Hi-Vee’) and a popular cord sold as fit for the purpose of tying friction hitches (Beal ‘Regate’ prusik cord). Using this control configuration, tests were carried out to produce a set of data that could be used to make comparisons with other configurations of rope, cord and hitches.

Following the establishment of control data, a series of the most popular hitch configurations were then rigged up using new samples taken from the reels of control rope and cord, and these configurations were tested on the rig. This was done for both doubled line and single line pull tests. The ropes were terminated in knots which reflect common industry practice. The use of knots for this purpose also enabled an assessment of whether these methods of termination, being potentially the weakest parts of the configurations (as compared to using stitched or spliced eye terminations) showed sufficient strength. Various other modern and traditional hitch and cord configurations were also tested on other popular tree climbing ropes, and the results of all the tests were then compared with the control data.

The best performing hitches were then drop tested on both a doubled rope system and a single rope system in order to reflect both good and bad industry practice respectively. These tests also showed how the hitches performed in shock loaded situations. In both configurations, the hitches were moved up the rope by pulling the rope through a slack tending pulley before applying the shock loading. This method highlighted any inconsistencies in hitch performance between slacking off on a rope and suddenly having to regain a grip on the rope.

Some of the testing employed old, wet and dirty ropes as lifelines in order to reflect the effects of time and usage in harsh conditions against the control data. Three of the drop tests were undertaken with a used cord with a slight memory from previous wrapping. Further explanations can be found in the tables of results at the end of the report.

In some of the tests the friction hitches themselves were tied with used cord. Typically, the cords used showed some stiffened areas as a memory from previous tying. Also, some wear was obvious enough to show up in some fraying of fibres, but not in excessive burns. If worn rope or cord was used, this is specifically stated in the results tables (but not necessarily in the results summaries).

The types of hitches tested (which typically represent those most likely to be encountered in the arboricultural industry) are as follows: -

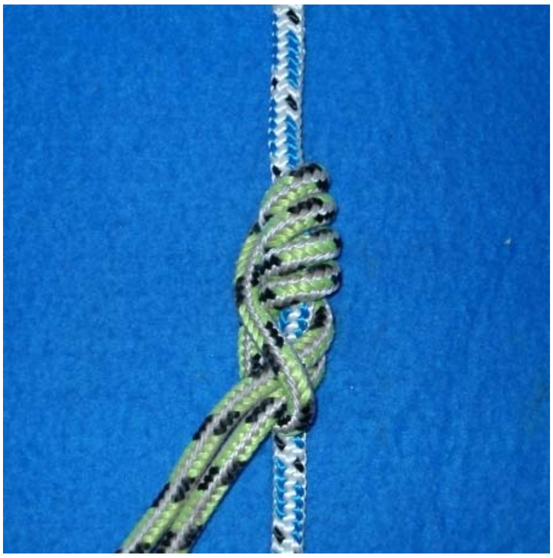
- 4- & 6-wrap Prusik
- 5-wrap Swabisch
- 5-wrap Distel
- 4-wrap Klemheist
- 4-wrap Blake’s
- 4-wrap Tautline
- 6-wrap Helical
- 6- & 7-wrap Valdotain Tresse (French prusik tied with an eye-to-eye sling).

Photographs of all the above hitches (except the 7-wrap Valdotain) are presented on the next two pages.

Photograph 3 **4- & 6-wrap Prusik**

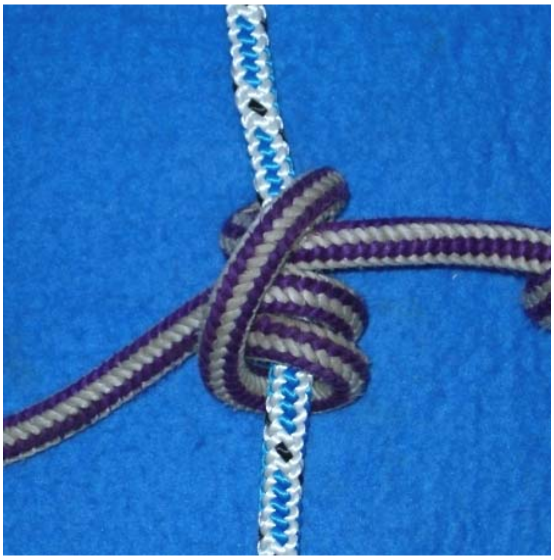
Photograph 4 **5-wrap Swabisch**

Photograph 5 **5-wrap Distel**



Photograph 6 **Klemheist**

Photograph 7 **Blake's**



Photograph 8 Tautline

Photograph 9 Helical

Photograph 10 6-wrap Valdotain

5. TESTING LIMITATIONS

5.1 PULL TEST RIG

The pull test rig could typically provide approximately one metre of pull. Therefore, some systems that held, but then repeatedly jumped, were able to dissipate energy and run for the entire length of the test bed without a failure. In these latter cases, a test bed with two metres of pull would probably have resulted in a failure, as the heat generated by slippage causes fusing and reduced strength in the friction hitches. However, it took some of the hitches as long as 30 seconds to reach the end of the test bed, which was an extremely high performance (although the benefits of this increased resistance to the eventual burning out of the friction hitch is probably of little value).

Some of the pull test configurations overwhelmed the hydraulics of the ram and stalled the test rig at about 3500Kg!

It was difficult to determine the force at which some of the hitches began to slip or jump, as these events tended to happen suddenly as indicated on a fast moving digital display. However, approximations were made where two observers were able to agree on the point at which the slippage began. Also, some of the friction hitches responded differently to tensioning. Some hitches required a little extra time to seat properly on the rope (or failed to grip during the test due to poor seating). In work conditions it is normal to spend some time in seating the hitch (especially when the hitch cord is new), by placing body weight onto the hitch two or three times before venturing off the ground. This is the nature of friction hitches - they are dependent on the skill of the user to apply them properly, and disastrous results may occur if they are not dressed and set appropriately.

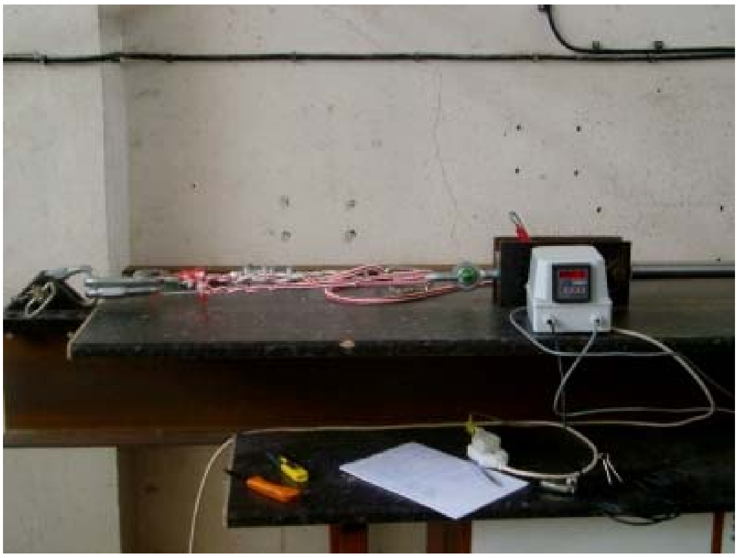
5.2 DROP TEST RIG

The drop test rig had a maximum height of nine metres. Most trees would allow for much more rope to be paid out, which would allow for more energy absorption and for lower forces to develop. Also, the final anchor point in a tree is likely to have some flexibility and therefore to be able to absorb energy from the system, although this will be dependent on the actual position of the climber in the tree relative to the anchor point.

6. TESTING SETUP AND PROCEDURES

6.1 THE DOUBLED ROPE PULL TEST

This consisted of two oval 16mm Maillon Rapides to simulate a friction saver. This gave a slightly better bending radius than the two rings of a typical friction saver. The climber's harness was simulated by clipping karabiners to a 16mm shackle. At an early stage in the testing it was established that a single karabiner was the weakest link in a typical doubled rope system. Once this had been established, the climbing line termination (typically a bowline) and friction hitch loop were placed directly into the 16mm shackle on the ram and load cell. Friction hitches that required a separate karabiner were set up as in the field, the friction hitch being attached to one karabiner and the climbing line to another. Alternatively, the climbing line was terminated in a bowline and anchored directly to the shackle. The results tables at the end of the report explain exactly how each test was set up. The doubled rope pull test rig is illustrated in photograph 11 below.



Photograph 11 The doubled rope pull test rig

6.2 THE SINGLE ROPE PULL TEST

This consisted of two 16mm oval Maillon Rapides as the anchor. The rope was tied into these with a bowline. The friction hitch was then attached to a karabiner which in turn was attached to a 16mm shackle on the ram and load cell.

6.3 THE DOUBLED ROPE DROP TEST

This consisted of two 16mm oval Maillon Rapides as the anchor, suspended from a gantry nine metres above the ground. The friction hitch and lifeline termination were tied into separate karabiners and clipped into a 100Kg mass. The weight was then winched to the required height and the slack in the system adjusted by pulling on the climbing line with the aid of a micro-pulley tending the hitch. The load cell was placed in the top anchor.

6.4 THE SINGLE ROPE DROP TEST

This consisted of one 16mm shackle as the anchor suspended from a gantry nine metres above the ground. The lifeline was terminated in the top anchor with a bowline. The friction hitch was tied into a karabiner and clipped into a 100Kg mass. The weight was then winched to the required height and the slack in the system adjusted by pulling on the climbing line with the aid of a micro-pulley tending the hitch. The load cell was placed in the top anchor. The single rope drop test is illustrated in photograph 12 below.

Photograph 12 The single rope drop test rig

7. GENERAL DISCUSSION

7.1 GENERAL

The results of this research are objectively measured and comparable results. They are both justified and reproducible, but only inform on the tensile strength of typical systems. To determine the residual strengths of the friction hitches would require further research.

The results are presented in detail in the tables of results at the end of the report (starting on page 45). Summaries of the results are included in the next section (section 8, pages 23 to 35). In the following discussion reference is made mainly to the summaries but occasionally directly to the tables.

7.2 SAFETY FACTORS

The concept of 'safety factor' was used in evaluating the results. This is defined as the ratio of the load that would cause failure to an item of lifting equipment to the load that is imposed upon it in service. In use, a particular safety factor is selected in order to allow for detrimental criteria such as wear and tear, dynamic loading etc. A safety factor selected for personal protective equipment is normally greater than that selected for rigging equipment.

In calculating safety factors in tree climbing it is generally assumed that the weight of a climber is 100Kg including the equipment being carried. Thus, in order to calculate the safety factor implied by a particular test result, the peak force recorded is divided by 100 (i.e. by the assumed weight in kilograms of the climber).

At the present time there is no agreed safety factor for rope and cord configurations in use in arboriculture. By comparison, IRATA* guidelines for industrial roped access recommend a safety factor of 10:1 for a life-line, whilst the EU Machinery Directive recommends a safety factor of 14:1 for ropes used in life support systems. The 10:1 recommendation for life-lines used in roped access applies to low-stretch kermantel ropes which have good resistance to wear over a long period of time. Also, in roped access a safety line is used in addition to a work-line, thereby effectively doubling the safety factor to 20:1. On the other hand, the Machinery Directive recommendation of 14:1 is intended to accommodate any loss of strength associated with knots and to provide an *indefinite* service life.

Arborists generally use single-braid ropes that are known to lose strength with the passage of time due to the conditions in which they are employed. This is because they have little protection against the entry of grit into the body of the rope, and because the external load-bearing fibres are subject to abrasion from the surfaces of trees.

Also, arborists generally use just one rope employed in a doubled rope system which provides both work-line and safety line. The minimum safety factor recorded in the tests on such a doubled rope system was in the region of 22:1, which is in line with the effective implied safety factor of 20:1 deriving from the IRATA recommendation. By comparison, the lowest safety factor recorded in the tests on a single rope system was in the region of 19:1, which is in excess of the Machinery Directive recommendation and very close to the 20:1 minimum safety factor implied by the IRATA recommendation.

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* Industrial Rope Access Trade Association

The only system tested which produced a safety factor less than 20:1 was that using 6mm Dyneema, which failed at a peak loading that implied a safety factor of around 14:1. In this latter case, the failure was due to heat damage, which indicates that such cords may not be suitable for use as friction hitches due to their lower critical melting point (150º Fahrenheit) as compared to polyester or nylon (350º Fahrenheit).

7.3 DOUBLED ROPE PULL TEST

Based on the results achieved with the control configuration (Tables 1 & 2 and Summary A) it was possible to make the assumption that a minimum strength of 2223Kg (being the lowest peak force recorded) would be perfectly adequate for a doubled rope system used for personal protection.

In the control configuration, both the lifeline factory eye splice and the friction hitch were initially placed in one karabiner. It can be seen from Summary A that the weak point of this configuration is the karabiner, but overall the system gave a safety factor of approximately 22:1. This result incorporates the strength reduction associated with the knots and gives a safety margin which is well above both the 10:1 and the 14:1 safety factors referred to in the third paragraph of section 7.2 (previous page). This performance can therefore be judged to be adequate to compensate for strength reductions due to heavy wear.

With the lifeline and friction hitches terminated in separate karabiners the peak forces recorded gave safety factors ranging from 26:1 to 36:1 (Tables 1 & 2 excluding the first entry, and Summary A excluding the minimum peak force recorded). The actual peak force recorded depended on the particular hitch being used. When compared with the 2223Kg peak force recorded for the configuration which gave the lowest safety factor, these results represent substantial safety factors which are adequate to compensate for strength reductions arising from heavy wear. Such high safety factors are desirable for a system in which the rope is used as both work line and safety line.

From Summary A it can also be seen that the lifeline termination is the weakest link in the doubled rope system when the rope is passed through two friction saver rings (simulated by the two 16mm Maillon Rapides). The weakest exception to this was the Helical which broke in the half double fishermans but still gave a safety factor of approximately 26:1. Spliced products (e.g. the factory eye splice) stalled the test bed without failing. Such products might be expected to produce higher peak forces under longer pulls, but such strength is not considered to be necessary considering the high safety factors otherwise recorded.

In comparison to the control configuration, all other hitch and cord variations tested on the doubled rope pull test achieved a peak force of at least 2789Kg (see Summary B). These included 13mm polyester/polyamide split tails, 6mm polyester double-braid and 6mm Dyneema cord (with polyester sheath).

The minimum peak force of 2789Kg in Summary B was recorded for the 13mm split tail tied into a 4-wrap Tautline hitch. This was a surprising result as, although the cord used (Yale 'XTC Plus') has a higher breaking strength (see Table 20) than that used for the control configuration (Beal 'Regate'), in this particular setup it proved to be weaker.

The thin Dyneema cord produced very high results, although this is not a cord recommended for use in the field as it has a low melting point of 150° Fahrenheit. The thin polyester braid of the Dyneema cord would soon burn through, leaving a very vulnerable core.

Over all the doubled rope pull test results, the highest recorded result was for a 7-wrap Valdotain tied with Beal 'Regate' (Table 2), whilst a 7-wrap Valdotain tied with 5/16" Ultra Tech came a close second (Table 9).

The Ultra Tech cord had spliced eyes and a Technora (aramid-type) core which has high heat resistance and strength for its diameter (the outer jacket is of polyester braid). Although this cord performed well, Technora is not rated highly for its knotted strength and its use in the field is therefore questionable. The spliced eyes were only protected by a resin cover, and aramid fibres are highly susceptible to both internal and external abrasion and are sensitive to UV light and some chemicals. Repeated flexing, as in a friction hitch, can cause significant internal abrasion and premature failure (ref: *On Rope* - Smith & Padgett). It is therefore difficult to know when to replace such cord. However, it may be that its high tensile strength can compensate adequately for these factors. This cord is sold in the USA by some retailers as being suitable for friction hitches.

7.4 SINGLE ROPE PULL TEST

As with the doubled rope pull test, the control configuration for the single rope pull test utilised Yale 'XTC Plus' and Beal 'Regate' cord. The results for the control configuration are summarised in Summary D. Of those setups which tested satisfactorily when using these cords (see Summary D), the lowest failure rating was for the 6-wrap Prusik which still gave a high safety factor of just under 19:1 after strength reduction due to knots. The point of failure in this setup was the lifeline bowline.

The results of testing various other hitch and cord combinations on the single rope pull test are shown in Summary E. These results show that 6mm Dyneema produced the lowest failure strength at 1376Kg. Again, this gives a high safety factor, but Dyneema should be considered unsuitable for use as a prusik cord for general use because of its low critical melting point. The 8mm polyester double braid also gave good results with most of the hitches.

7.5 DOUBLED ROPE DROP TEST

The doubled rope drop test results (see Summary F) show that, in a Type* 1 fall, a climber working in a position approximately 8 metres beneath an anchor point is likely to incur a fall force in the region of 683Kg. A Type 1 fall assumes that the climbing is undertaken with 25cm of slack in each leg of the doubled rope, which is generally regarded as acceptable practice. This result is likely to be an overstatement of the force that would occur when working on taller trees, because of the potential for paying out a greater amount of rope with which to absorb the energy, and the potential for some flexing of a high anchor branch.

The forces recorded were slightly lower when the slack was only allowed on one leg of the rope. These (Type 2) falls (see Summary G) averaged a peak force of 565Kg. In this configuration the shorter hitches performed better, probably because virtually all the slack could be removed from the system.

In all the Type 1 and Type 2 fall tests (Summaries F & G) no damage occurred to any of the hitches and they could all be easily released after absorbing the drops.

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* Definitions of fall types are given in Table 18 at the end of the report.

The ‘fall factor 1’ (Type 3) drops on the doubled rope system produced an average force of 770Kg (see Summary H). Only one hitch welded to the rope. The higher forces recorded are likely to be due to there being less rope available to absorb the fall, and to the reduced stretch incurred by the doubled configuration.

The ‘fall factor 2’ (Type 4) drops on doubled rope averaged 1115Kg (see Summary I) .These were dangerously high results, and a climber would be likely to suffer serious injuries from such forces resulting from a ‘factor 2’ fall in a doubled rope system. However, only two of the hitches welded to the lifeline. That the hitches stood up so well to such high anchor forces is probably due to the fact that (theoretically) in a doubled rope system only half of the force is transmitted to the hitch.

The friction hitches used in the Type 4 falls acted as energy absorbers by slipping about 15cm as compared to the 3cm slippage in the Type 3 falls. This was because all of the fall energy acted upon the friction hitches.

It is remarkable that none of the friction hitches failed in the drop tests, and that such low forces could be achieved in ‘factor 2’ falls without the use of specifically constructed energy absorbers.

7.6 SINGLE ROPE DROP TEST

The ‘fall factor 1’ (Type 5) and ‘fall factor 2’ (Type 6) drops on single rope (see Summaries J & K) produced results which were surprisingly similar to each other, averaging 662Kg (Type 5) and 679Kg (Type 6) respectively. In fact, the Type 5 fall with Ultra Tech produced a higher peak force (700Kg) than the average of all the ‘fall factor 2’ falls using polyester hitches! This result with the Ultra Tech is probably due to the poor energy absorption properties of aramid-type fibres.

7.7 ROPE STRENGTHS

A comparison between the control configuration and used single-braid ropes (Summaries A & C respectively) show approximately a 40% strength loss in the knotted lifeline for a heavily used 18-month old rope. The minimum strength recorded for the 18-month old doubled rope system was 1770Kg. This still gives a safety factor of 17:1 after strength reduction associated with the knots. From Table 19 it can be seen that a 4-year old single-braid rope in a doubled rope system failed at a force of 1485Kg in a pull test to determine the knotted breaking strength.

An indication of the residual strength of single-braid ropes (approximately 80% sheath mass) shows that they perform less well over time than ropes of kernmantel construction, but still provide at least a 10:1 safety factor, including allowance for strength reduction due to knots, over a 4-year period of heavy wear (see Table 19).

The reduction in strength that occurs over time is probably due to load-bearing fibres of a single-braid rope being exposed to external abrasive wear and grit infiltration (causing internal abrasion). In contrast, low stretch kernmantel ropes have load-bearing fibres protected by a tightly braided jacket, and correspondingly increased strength retention over time. However, typical low stretch kernmantel ropes do not accept knots as easily as single braid ropes and certainly cannot be tied satisfactorily into friction hitches (as used in the traditional 3-knot arborist system).

This situation is further confused by ropes being introduced into the market that are neither a true single braid (typically 80% sheath mass) or kernmantel, and which resemble more of a double braid with almost 50% sheath mass (e.g. Cousin ‘Forester II’). These ropes have good knotability, are very strong and appear to handle abrasion well, although they are not as popular as single braid ropes. However, they may yet prove to perform better than the more traditional types of rope. Their residual strength and field performance has not been determined during this research.

8. SUMMARIES OF RESULTS

The results of the various tests are presented in detail at the end of the report, from page 45 on.

In this section, summaries of the results are presented in tabular form on pages 25 to 35. Each of these summaries has been developed from selected results tables in order to illustrate specific aspects of the tests carried out, and to draw out conclusions of interest. Not all the results presented in the results tables have been summarised, and those requiring a detailed breakdown of the results should refer to the tables at the end of the report.

The points of discussion presented at the foot of each summary table, some of which have already been referred to in the general discussion in the previous section, are intended to inform the general conclusions in section 9. Taken together, these form the basis for the recommendations made in section 10 of this report.

Summary A

DOUBLED ROPE PULL TEST

CONTROL CONFIGURATION

Beal 'Regate' prusik cord and New England 'Safety Blue Hi-Vee' climbing line (new unused cord and rope)

Summary of results presented in Tables 1 & 2

Maximum peak force recorded*	Minimum peak force recorded*	Average peak force recorded*
3567Kg Recorded for 7-wrap Valdotain Tresse. Caused failure of the lifeline bowline.	2223Kg Recorded for 4-wrap Prusik with lifeline terminated in a factory eye splice. Both Prusik and lifeline clipped into one HMS-type alloy karabiner. Karabiner failed after the Prusik gripped a depression behind the internal splice termination, thereby preventing normal slippage.	3086Kg Average of results for: - 4-wrap Prusik, 6-wrap Prusik, 6-wrap Valdotain, 7-wrap Valdotain, 6-wrap Helical, 5-wrap Distel and 5-wrap Swabisch. Additional 4-wrap Prusik slipped to end of test bed without a failure – peak force recorded 3269Kg.

Discussion

- If both the lifeline and friction hitch are connected to one karabiner, the karabiner (minimum 22kN BS) is the weak link, but a substantial 22:1 safety factor was recorded.
- If two karabiners are used to terminate the doubled system, the climbing line termination is the weakest link (when a recognised knot is used). This gives a minimum safety factor of 26:1 after strength reduction due to knots. The exception was the Helical where a half double fishermans was used to terminate the lifeline), although this still gave a 26:1 safety factor. The half double fishermans tested out stronger than the bowline, with the Alpine Butterfly being the weakest of the different methods of terminating the climbing line.

*** Failed systems only**

Summary B

DOUBLED ROPE PULL TEST

Various hitch and cord configurations on braided climbing lines

Summary of results presented in Tables 4, 5, 6, 7, 8 & 9

Maximum peak force recorded*	**Minimum peak force recorded***	**Average peak force recorded***
3500Kg Recorded for 7-wrap Valdotain with 5/16” Ultra Tech. Caused climbing line to fail in the bend over the anchor. (Spliced eyes used in hitch and lifeline. Only one 16mm shackle as anchor).	2789Kg Recorded for 4-wrap Tautline with 13mm Yale XTC Plus. Caused climbing line to fail in the bowline termination.	3211Kg Average of results for: - 4-wrap Prusik, 6-wrap Prusik, 4-wrap Klemheist, 4-wrap Blake’s, Tautline & Suislide, 6 & 7-wrap Valdotain, 6-wrap Helical and 5-wrap Distel. The following hitches slipped to the end of the test bed without failing: - 4-wrap Klemheist with 10mm ‘Regate’ (800Kg) 6-wrap Valdotain with 10mm double braid (2416Kg) 4-wrap Prusik with 12mm 3-ply (3247Kg) 4-wrap Prusik with 10mm 3-ply (3044Kg)

Discussion
• 6mm Dyneema showed excellent strength characteristics when knotted. Since the friction hitch did not slip, this prevented heat building up to a point that might cause failure during descent in working conditions. However, Dyneema has a melting point similar to that of poylpropylene, and is therefore considered to be unsuitable for arborist friction hitches. • The minimum failure force recorded (2789Kg) still gives a substantial safety factor. It is a point of interest that the thicker traditional cords and friction hitches were out-performed by many of the thinner cords and new-style friction hitches. However, this does not take account of wear in working conditions (see results for worn cord in Summary C).

*** Failed systems only**

Summary C

DOUBLED ROPE PULL TEST

New Beal ‘Regate’ and used Edelrid ‘Xperience’
(18 months old, stiff, wet & dirty)

Summary of results presented in Tables 10 & 11

Maximum peak force recorded*	Minimum peak force recorded*	Average peak force recorded*
2022Kg Recorded for 6-wrap Prusik. Caused climbing line failure over the anchor.	1770Kg Recorded for 5-wrap Distel. Caused climbing line to fail in the Alpine Butterfly termination.	1960Kg Average of results for: -: 6-wrap Prusik, 7-wrap Valdotain, 6-wrap Helical, 5-wrap Distel and 5-wrap Swabisch. The following friction hitches slipped to the end of the test bed without failing: - 4-wrap Prusik (1297Kg) 6-wrap Valdotain (1906Kg)

Discussion

- The climbing line was stiff, wet and dirty. This probably helped in reducing heat build up in the friction hitches, but resulted in failure of the climbing line. Most of the climbing line failures were in the Alpine Butterfly, which appears to be consistently weaker than the bowline or half double fishermans.
- The used rope showed a strength reduction of approximately 40% over its 18-month period of usage. This is in stark contrast to kernmantel ropes which have been shown to have little strength reduction after 15 years of regular use. However, the single braid of the used rope has no protection from grit and wear, and a reduction in strength is therefore to be expected.
- The minimum strength recorded was 1770Kg, which still gives a large 17:1 safety factor after strength reduction due to knots.

*** Failed systems only**

Summary D

SINGLE ROPE PULL TEST

<u>CONTROL CONFIGURATION</u>

Beal 'Regate' and Yale 'XTC Plus'
(new unused cord and rope)

Summary of results presented in Table 12

Maximum peak force recorded*	Minimum peak force recorded*	Average peak force recorded*
1900Kg Recorded for 7-wrap Valdotain Tresse. Caused failure of the lifeline bowline.	1873Kg Recorded for 6-wrap Prusik. Caused failure of the lifeline bowline.	1886Kg Average of results for: - 7-wrap Valdotain and 6-wrap Prusik. The following friction hitches slipped to the end of the test bed without failing: - 6-wrap Valdotain (1536Kg) 6-wrap Helical (1243Kg) 4-wrap Prusik (1582Kg)

Discussion

- The minimum peak force at failure still gives a substantial 18:1 safety factor after strength reduction due to knots.
- The friction hitches that slipped/jumped helped in dissipating energy gradually. This is a desirable characteristic for loadings of over 300Kg (approximately), as it means that they would easily hold a climber's weight without slipping but would slip when overloaded (e.g. if a heavy branch pulled the climber).
- Even in a single line pull test, the friction hitch is still stronger than the knotted lifeline.
- Most of the hitches showed the desirable characteristic of slippage without failure.

*** Failed systems only**

Summary E

SINGLE ROPE PULL TEST

Various hitch and cord configurations on braided climbing lines

Summary of results presented in Table 13

Maximum peak force recorded*	Minimum peak force recorded*	Average peak force recorded*
1805Kg Recorded for 6-wrap Valdotain with 8mm polyester double braid. Failure within the friction hitch.	1376Kg Recorded for 4-wrap Prusik with 6mm Dyneema. Failure within the friction hitch.	1629Kg Average of results for: - 4-wrap Prusik, 6-wrap Valdotain and 4-wrap Blake’s.

Discussion

- On a single line, 6mm Dyneema gave a 13:1 safety factor after strength reduction due to knots. This is below the requirement of the Machinery Directive, but above the standard 10:1 used in industrial roped access. However, the low melting point of Dyneema may exclude its use as an arborist friction hitch.
- Again, using the thicker cord with a Blake’s hitch resulted in failure at a lower point than with some thinner cords.
- Although these friction hitches failed before the knotted lifeline, they are still closely matched.
- Even in a single line pull test, the friction hitch is still stronger than the knotted lifeline.
- Most of the hitches showed the desirable characteristic of slippage without failure.

*** Failed systems only**

Summary F

DOUBLED ROPE DROP TEST (Type 1 fall)

Various hitch and cord configurations on various braided lifelines

Summary of results presented in Tables 14, 15 &16

Maximum peak force recorded*	Minimum peak force recorded*	Average peak force recorded*
784Kg Recorded for 4-wrap Prusik with 10mm Beal ‘Regate’. No failure.	615Kg Recorded for 6wrap Valdotain with 8mm polyester double-braid on Yale ‘XTC Plus’ climbing line. No Failure.	683Kg Average of results for: - 4-wrap Prusik, 6-wrap Valdotain and 4-wrap Blake’s.

Discussion

- In one test run a 6-wrap Valdotain failed to grip the lifeline and arrest the fall. This was tied with 10mm Beal ‘Regate’ cord which had a slight memory from previous wraps. 7 wraps may be more reliable.
- With this type of fall the forces appear to be around the 6kN mark.
- No damage or slippage was noticeable on the friction hitch cords.

*** No failed systems**

Summary G

DOUBLED ROPE DROP TEST (Type 2 fall)

Various hitch and cord configurations on various braided lifelines

Summary of results presented in Tables 14, 15 &16

Maximum peak force recorded*	Minimum peak force recorded*	Average peak force recorded*
649Kg Recorded for 6-wrap Valdotain with 10mm Beal 'Regate'. No failure.	424Kg Recorded for 4-wrap Blake's hitch with Cousin 'Forester II' 13mm split tail. No failure.	565Kg Average of results for: - 6-wrap Valdotain, 4-wrap Prusik and 4-wrap Blake's.
Discussion		
• The type 2 fall appears to provide a lower peak force than a type 1 fall. In practice this would require one leg of the doubled system to be kept taught with 50cm slack in the other, rather than 50cm slack in both legs. • The test rig only allows for short distances of rope and a rigid anchor. In reality, more rope may be paid out to absorb the fall. • In reality, the final anchor point is likely to have much more 'give' as the tree/branch will flex to absorb some of the fall energy. • Climbers should avoid slack in the climbing system. • No damage to friction hitches.		

*** No failed systems**

Summary H

DOUBLED ROPE DROP TEST (Type 3 fall : Fall factor 1)

Various hitch and cord configurations on various braided lifelines

Summary of results presented in Tables 14, 15 &16

Maximum peak force recorded*	Minimum peak force recorded*	Average peak force recorded*
892Kg Recorded for 4-wrap Prusik tied with 10mm Beal 'Regate'. No failure, but the Prusik welded to the rope.	641Kg Recorded to 6-wrap Valdotain tied with 10mm Beal 'Regate'. No failure. No damage to hitch.	770Kg Average of results for: - 6-wrap Valdotain, 4-wrap Prusik and 4-wrap Blake's.
Discussion		
• Slightly higher forces than types 1 & 2 falls. This is probably because of the limited amount of rope that was available to absorb the fall (i.e. just one metre, which was doubled in order to produce less stretch). • Only one friction hitch was damaged, at less than a peak force of 1000Kg.		

*** No failed systems**

Summary I

DOUBLED ROPE DROP TEST (Type 4 fall : Fall factor 2)

Various hitch and cord configurations on various braided lifelines

Summary of results presented in Tables 14, 15 &16

Maximum peak force recorded*	**Minimum peak force recorded***	**Average peak force recorded***
1282Kg Recorded for 4-wrap Blake’s with 13mm Cousin ‘Forester II’ split tail. No failure. Split tail welded to climbing line.	942Kg Recorded for 4-wrap Prusik with 10mm Beal ‘Regate’. No failure. No damage to the Prusik.	1115Kg Average of results for: - 6-wrap Valdotain, 4-wrap Prusik and 4-wrap Blake’s.

Discussion
• Only the 8mm double braid and 12mm split tail welded to the lifeline. The 10mm ‘Regate’ friction hitches fared better. However, all friction hitches held the loads with minimal damage. This is probably because the lifeline was doubled, and in theory this suggests that only half of the force is shared by the friction hitch. • The forces arising in a ‘fall factor 2’ fall with doubled rope are very high and appear to be likely to cause damage to the climber. This is probably because the rope exhibits less stretch than if it was used as a single line. In addition, the low stretch construction is not a feature of a rope designed to dissipate energy from a fall arrest.

*** No failed systems**

Summary J

SINGLE ROPE DROP TEST (Type 5 fall : Fall factor 1)

Various hitch and cord configurations on various braided lifelines

Summary of results presented in Table 17

Maximum peak force recorded*	Minimum peak force recorded*	Average peak force recorded*
700Kg Recorded for 6-wrap Helical with 5/16" 'Ultra Tech' split tail. No failure. Split tail welded to climbing line.	624Kg Recorded for 6-wrap Helical with Beal 10mm 'Regate'. No failure. Split tail welded to climbing line.	662Kg Average of results for: - 6-wrap Valdotain.
Discussion		
• Both cord types held the fall with similar results to the doubled rope drop test for falls of 'fall factor 1'. • The Ultra Tech cord produced a much higher force, probably due to its poor energy absorption characteristics. • This type of fall was aimed at simulating a fall on a pole whilst 'topping down', using a single line chokered around the stem.		

*** No failed systems**

Summary K

SINGLE DROP TEST (Type 6 fall : Fall factor 2)

Various hitch and cord configurations on various braided lifelines

Summary of results presented in Table 17

Maximum peak force recorded*	**Minimum peak force recorded***	**Average peak force recorded***
694Kg Recorded for 6-wrap Helical with 10mm Beal ‘Regate’ split tail. No failure. Split tail welded to climbing line.	665Kg Recorded for 6-wrap Prusik with 12mm ‘Dacron’ polyester. Tied on 3-ply nylon climbing line. No failure. Split tail welded to climbing line.	679Kg Average of results for: - 6-wrap Prusik and 6-wrap Helical.

Discussion
• The 6-wrap Prusik probably gave a lower peak force due to the increased energy absorption of the 3-ply nylon lifeline. • The forces were not much higher than those for the ‘fall factor 1’ falls. This is probably due to the slippage and resultant energy absorption of the friction hitch. • The recorded forces were almost 50% (on average) lower than the doubled rope ‘fall factor 2’ falls. This may be due to more force being put on the friction hitches, enabling them to act as energy absorbers by slipping. The single rope set-up also allows for more stretch from the rope for the same mass, thus allowing more energy absorption.

*** No failed systems**

9. GENERAL CONCLUSIONS

Prusik-type friction hitches generally produced high tensile and dynamic strengths when subjected to the tests carried out during this research. Even though these tests quite accurately simulated real field systems, the results are limited to new cords being tested once. Further testing would be required using worn friction hitch cords in order to draw comparisons with various worn or aged cords and rope. Having said that, friction hitches rarely last long enough to worry about long term residual strength. However, this relies on operators acting responsibly in deciding when to discard cord – spare cord should always be available in the field.

Furthermore, there is much scope for specific cords to be designed with suitable strength (1700Kg would be ample), but with high external heat resistance and good knotted strength. For example, a cord with a braided core of polyester and a jacket of aramid fibre would, theoretically, solve the problems associated with residual knotted strength and heat resistance.

Single braid ropes typically offer the best performance in day-to-day tree work. However, such ropes are known to lose strength with wear. The tests carried out in this project indicated that single-braid ropes with heavy wear still have a *knotted* breaking strength of just under 1000Kg after 4 years of use. Further research/discussion is required to determine whether 4/5 years or 2/3 years is a more suitable disposal period for single-braid ropes, bearing in mind that any particular rope being used may be employed as both work line and safety line.

In the doubled rope pull tests even the weakest friction hitch cords demonstrated suitable strength. The weakest minimum strength cords with good all-round results (1700Kg) were 8mm double-braid polyester and 10mm Beal 'Regate'. The 6mm cords tested showed good results on the doubled rope pull test but, due to likely rapid wear, do not appear to be suitable for use. Such cords would seem to be especially unsuitable to use in a single rope system. The 8mm to 13mm diameter cords produced the best strengths, and are more suitable for use with specific hitch configurations e.g. 8mm double braid worked well with a 6-wrap Valdotain. The 10mm cords had some reliability problems when tying the Valdotain with only 6 wraps. In the latter case, 7 wraps were found to be more reliable. A 12mm or 13mm cord is preferable with a Blake's hitch in order to prevent it tightening too much in normal use.

Cords of 10mm diameter (with a minimum breaking strength of 1700Kg and a minimum critical melting point of approximately 350º F) produced acceptable results in all tests conducted with 4- and 6-wrap Prusiks and with the 5-wrap Distel and Swabisch hitches.

Cords of 13mm diameter (with a minimum breaking strength of 2818Kg and a minimum critical melting point of approximately 350º F) produced acceptable results with 4- and 6-wrap Prusiks and with the Tautline and Blake's hitches.

Cords of 8mm diameter (with a minimum breaking strength of 1700Kg and a minimum critical melting point of approximately 350º F) produced acceptable results in tests conducted with the Valdotain (French prusik). However, these cords are more vulnerable to abrasion and heat damage and provide little for the hand to grip.

Cords of 6mm diameter (with a minimum breaking strength of 625Kg and a minimum critical melting point of approximately 350º F) produced acceptable results with the Valdotain (French prusik) in the doubled rope pull tests. However, its performance was not determined in the single rope pull test or in the drop tests. These cords are vulnerable to heat and abrasion damage and provide very little for the hand to grip.

Probably the best all-rounder was the 6-wrap Helical used with 10mm Beal 'Regate' cord. Because it could be adjusted easily for both reliability and performance, in the doubled rope test the Helical helped to dissipate energy by jumping to the end of the pull test bed, and in the single rope drop test it acted as a shock absorber.

In a working environment, the climber should not rely on the friction hitch as an energy absorber, especially in a doubled rope system, and should keep slack to a minimum at all times. If the friction hitch is fallen onto in either a single or double line system, in a fall of factor 1 or 2 it will probably seize onto the line and thereby arrest the fall. The disadvantage of this is that self rescue would not be possible unless the line can be secured through a descender (or second friction hitch) before cutting the welded friction hitch. Such a scenario is only likely when topping down on a pole, which is an extreme operation where arresting a fall is itself the main priority. In such a situation, the lifeline should be chokered (either doubled or single) around the stem at waist height in order to avoid a factor 2 fall.

Some of the friction hitches, notably the 4-wrap versions, slipped at relatively low loadings. This would not be a concern during routine operations, but a rescue scenario could cause the friction hitch to slip if two persons are being supported on one line. In this situation, a 5- or 6-wrap variation is preferable, possibly backed up with a descender. Alternatively, a different rescue technique could be utilised e.g. Method C as described in the FASTCo/AA *Aerial Rescue Guidance Notes.* A rescue knife should also be carried by the rescuer in order to cut a welded friction hitch free from the lifeline (see FASTCo Safety Guide 402).

10. RECOMMENDATIONS

10.1 SAFETY FACTORS

A minimum safety factor of 14:1 (as per the EU Machinery Directive recommendation) should be adopted for rope and cord configurations used by arborists. In order to achieve this in practice, a safety factor of 20:1 should ideally be aimed for in order to accommodate the abrasion and accelerated wear that occurs to single-braid ropes used in arboricultural work. This should also ensure that ropes used in both doubled and single rope systems reach the required safety specifications.

10.2 CHOICE OF ROPE FOR WORK/LIFE-LINES

Ropes for use by arborists in the traditional doubled or single rope systems should meet the EN1891 - Type B standard which ensures that they are capable of withstanding falls of ‘fall factor 1’. However, not all ropes conforming to the EN1891 - Type B standard have the same knotability. As it is important that the rope should be capable of tying an effective friction hitch back on itself, the knotability of the rope should be checked before purchase or use.

10.3 CHOICE OF CORD FOR FRICTION HITCHES

For general use (and for initial tree climbing experience) the minimum specification for cords used for friction hitches should be 10mm diameter, of polyester or nylon construction, and with a minimum strength of 1700Kg. In some applications cord diameters of up to 13mm might be preferred due to the fact that these larger diameters are more likely to accommodate excessive wear and can provide a better profile for the hand to grip.

The use of 8mm diameter cords (of minimum breaking strength 1700Kg) should not be prohibited as these generally provide acceptable safety factors. However, cords of this diameter are generally less forgiving and more prone to abrasion and heat damage. They also provide a less satisfactory profile for the hand to grip. Nevertheless, cord of this diameter did appear to be more reliable when used in the Valdotain (French prusik). In using these smaller diameter cords it should be emphasised that their satisfactory use can depend on the increased knowledge and responsibility that comes with extended practice. They should, therefore, not be considered to be suitable for use by operatives who have not demonstrated the necessary experience and understanding by attending, and achieving the objectives of, an advanced techniques course that includes instruction in the use of friction hitches such as the Valdotain (French prusik) and Helical.

Although cords of 6mm diameter performed satisfactorily with the Valdotain (French prusik) in the doubled rope system, their performance was not determined in single rope systems or in the drop tests. Cords of this diameter are also vulnerable to heat and abrasion damage, and provide little for the hand to grip. For these reasons cords of 6mm diameter cannot be recommended for use as friction hitches in arboriculture.

No cord should be used that is not synthetic and/or does not have a minimum critical melting point of 350º Fahrenheit. For this reason, cords such as Spectra/Dyneema and cords incorporating polypropylene should not be used.

In selecting a particular cord consideration should always be made of its bending characteristics, its UV resistance and the abrasion resistance of both its cover (sheath) and core fibres. With regards to the bending characteristics of cords, those that are more supple will be more effective at gripping the host rope than cords that have more spring or are more stiff.

10.4 FRICTION HITCH AND CORD COMBINATIONS

Assuming the use of 13mm diameter rope for work/life-line, the following combinations of cord and friction hitches should be adopted as industry best practice at entry level for tree climbers attending a *Basic Tree Climbing* course, for those being assessed for NPTC* CS38 certification, and for general use in tree climbing within the arboriculture industry: -

- cord of 10mm diameter with the 4- and 6-wrap Prusiks and the 5-wrap Distel and Swabisch hitches.
- cord of 13mm diameter with the 4- and 6-wrap Prusiks and the Tautline and Blake's hitches.

In general, friction hitch cords of 2-3mm diameter less than that of the lifeline performed most reliably. The 4- and 6-wrap Prusiks and the Blake's hitch were exceptions to this.

10.5 REPLACEMENT OF ROPES AND CORDS

The results of this research project suggest that ropes used for work/life-lines by arborists in the traditional doubled or single rope systems should be retired after 2 to 3 years of normal usage unless and until further research can show that a longer replacement period is acceptable.

Cords used for tying friction hitches should be replaced after three months of normal usage in order to mitigate against reductions in safety factors arising from deterioration due to surface wear, internal abrasion, UV degradation (in those fibres which are susceptible) and frequent flexing. Within this three month period, cords should be immediately replaced if 25% of the outer fibres are visibly abraded, if the surface of the cord has become glazed in appearance (cf. Samson Ropes guidance notes) or if any of the internal fibres are exposed. For this purpose it is recommended that supplies of replacement cord should always be available at the work site.

10.6 FURTHER RESEARCH

It is recommended that further research be carried out to determine: -

- the residual strengths of the cords tested in this research.
- whether a 4 to 5 year period is more suitable than 2 to 3 years for the normal usage of single braid ropes before replacement.
- the suitability for use in arborist rope systems of more exotic fibres such as Technora, Vectran and Kevlar.
- the optimum design features for ropes and cords used in the arborist rope systems (e.g. a heat and abrasion resistant sheath combined with a core with suitable bending and strength characteristics).

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Results tables

DOUBLED ROPE PULL TEST (CONTROL DATA): Beal 'Regate' prusik cord & New England 'Safety Blue Hi-Vee' climbing line

Prusik cord	Beal 'Regate' prusik cord		10mm diameter		Age: New		Previous use: None
Climbing line	**New England 'Safety Blue Hi-Vee'**		**12.7mm diameter**		**Age:** New		**Previous use:** None
Test type & setup	**Pull test on a doubled rope system** (as adopted as industry best practice by arborists). Setup incorporating two 16mm Maillon Rapides, back to back, as the anchor.						
Hitch type	**Hitch configuration/ termination**	**Climbing line termination**	**Simulated harness anchor**	**Slippage with 1 metre of pull**	**Point of failure**	**Peak force recorded**	**Notes**
4-wrap Prusik (sample 2a)	Loop tied with a double fishermans knot.	Factory eye splice	Both splice and Prusik clipped into one alloy HMS-type karabiner.	Little. Prusik gripped swelling approx. 60cm from eye splice (internal splice termination).	Karabiner	2223 Kg	The karabiner is the weak link in the system when both the friction hitch and the end of the climbing line are clipped into one HMS-type karabiner. Test to be re-run without splice to check for slippage.
4-wrap Prusik (sample 2aa)	Loop tied with a double fishermans knot.	Bowline	16mm shackle to avoid further karabiner failure.	100cm – load at point of slippage not determined.	None – ran to full extent of test rig.	3269 Kg	Slipped every 7cm for 100cm before Prusik seized on the rope. Prusik remained intact without losing the load.
6-wrap Prusik (sample 2b)	Loop tied with a double fishermans knot.	Alpine Butterfly	16mm shackle	5cm at approx. 2200 Kg	Alpine Butterfly in climbing line.	2600 Kg	Extra turn increases friction and appears to hold rather than slip. Alpine Butterfly appears to be significantly weaker than the bowline termination.
6-wrap Prusik (sample 2bb)	Loop tied with a double fishermans knot.	Bowline	16mm shackle	5cm at approx. 2500 Kg	Bowline in climbing line.	3552 Kg	Appears to confirm that the Alpine Butterfly is significantly weaker than the bowline, and the 6-wrap Prusik will hold at high loads rather than slip.

DOUBLED ROPE PULL TEST (CONTROL DATA): Beal 'Regate' prusik cord & New England 'Safety Blue Hi-Vee' climbing line

Prusik cord	Beal 'Regate' prusik cord	10mm diameter	Age: New	Previous use: None
Climbing line	New England 'Safety Blue Hi-Vee'	12.7mm diameter	Age: New	Previous use: None
Test type & setup	**Pull test on a doubled rope system** (as adopted as industry best practice by arborists). Setup incorporating two 16mm Maillon Rapides, back to back, as the anchor.			

Hitch type	Hitch configuration/ termination	Climbing line termination	Simulated harness anchor	Slippage with maximum of 1 metre of pull	Point of failure	Peak force recorded	Notes
7-wrap Valdotain (French prusik) (sample 2d)	Eye-to-eye sling terminated each end with half a double fishermans knot.	Bowline	Valdotain to alloy HMS-type karabiner. Bowline to 16mm shackle.	55cm of slippage. First jump at 1600Kg.	Bowline in climbing line.	3567Kg	Prusik welded to climbing line. Karabiner still intact and functioning normally.
6-wrap Helical (sample 2e)	Dead-eye sling terminated at one end with half a double fishermans knot.	Half double fishermans knot	Two HMS-type alloy karabiners, one for the hitch and one for the climbing line.	Jumped every 7cm for 100cm of slippage. First slip at 1500 Kg.	Half double fishermans used in the Helical.	2676 Kg	Failed in the single-leg hitch of the Helical at a higher rating than the Alpine Butterfly climbing line termination (6-wrap Prusik sample 2b).
5-wrap Distel (sample 2f)	Eye-to-eye sling terminated each end with half a double fishermans knot.	Bowline	Distel to alloy HMS-type karabiner. Bowline to 16mm shackle.	First slip at 2000 Kg. Jumped every 7cm for 90cm.	Bowline in climbing line.	3446 Kg	Prusik seized to climbing line with little damage. Karabiner still functional.
5-wrap Swabisch (sample 2g)	Eye-to-eye sling terminated each end with half a double fishermans knot.	Bowline	Swabisch to alloy HMS-type karabiner. Bowline to 16mm shackle.	Slipped once for 7cm at 3200Kg.	Bowline in climbing line.	3504 Kg	Little damage to Swabisch which eventually seized to the climbing line. Karabiner still functioning normally.

PULL TEST: Beal 'Regate' prusik cord & New England 'Safety Blue Hi-Vee' climbing line

Prusik cord	**Beal 'Regate' prusik cord**	**10mm diameter**	**Age:** New	**Previous use:** None
Climbing line	**New England 'Safety Blue Hi-Vee'**	**12.7mm diameter**	**Age:** New	**Previous use:** None
Test type & setup	**Pull test** to determine the knotted breaking strengths of various configurations. Setup incorporating two 16mm Maillon Rapides, back to back in pairs, as the anchors.			

Rope type	Configuration	Terminations	Point of failure	Peak force recorded	Notes
New England Safety Blue Hi-Vee.	Single line pull test with knots at both ends. Pulled over one metre.	Figure-of-8 at one end with half a double fishermans knot at the other end.	Figure-of-8	1943Kg	The half double fishermans knot appears to be a stronger termination than a figure-of-8 as an end termination in a straight pull. The anchors gave approximately a 2.5:1 bend ratio.
New England Safety Blue Hi-Vee.	Single line pull test with knots at both ends. Pulled over one metre.	Figure-of-8 at one end with a bowline at the other end.	Bowline	2014Kg	Figure-of-8 appears to be stronger than the bowline, but the bowline broke at a higher rating against the figure-of-8, as compared to the rating at which the figure-of-8 broke against the half double fishermans knot.
Beal Regate	Tied into a loop (endless sling) and pulled over one metre.	Joined together with a double fishermans knot.	Bend over the anchor	2718Kg	Appears to support the claim that endless slings are 70% stronger than eye-to-eye slings (type for type). Appears to suggest that a double fishermans knot does not weaken the loop significantly as compared to a stitched loop (which is normally expected to have the 70% increase in strength claimed for endless slings). The anchor gave approximately a 3:1 bend ratio. It is possible that the cord is stronger than its rating.
Beal Regate	Bent over the anchors to create a Basket hitch.	Each leg tied onto a separate alloy karabiner with half a double fishermans knot.	Bend over the anchor	2714Kg	Appears to be of similar strength to the endless sling, with the half double fishermans knot holding up well. Maybe a higher rating would be achieved with a larger bend ratio at the anchor.

DOUBLED ROPE PULL TEST: 3-ply nylon & New England 'Safety Blue Hi-Vee' climbing line

Prusik cord	**3-ply nylon general purpose rope**	**12mm diameter**	**Age:** New	**Previous use:** None			
Climbing line	**New England 'Safety Blue Hi-Vee'**	**12.7mm diameter**	**Age:** New	**Previous use:** None			
Test type & setup	**Pull test on a doubled rope system** (as adopted as industry best practice by arborists). Setup incorporating two 16mm Maillon Rapides, back to back, as the anchor.						
Hitch type	**Hitch configuration/ termination**	**Climbing line termination**	**Simulated harness anchor**	**Slippage with maximum of 1 metre of pull**	**Point of failure**	**Peak force recorded**	**Notes**
4-wrap Prusik	Endless loop terminated with double fishermans knot.	Bowline	16mm shackle	Slipped at 300Kg for 123cm.	None	3247Kg	Slipped for the entire length of the test bed, initially at low forces, until heat build-up created fusion and higher ratings.
6-wrap Prusik	Endless loop terminated with double fishermans.	Bowline	16mm shackle	Slipped for 12cm before seizing. Force not recorded.	Bowline in climbing line.	3340Kg	Gripped similarly to the 'Regate' 10mm 6-wrap Prusik, causing failure in the bowline of the climbing line, at a similar load.

DOUBLED ROPE PULL TEST: 3-ply nylon & New England 'Safety Blue Hi-Vee' climbing line

Prusik cord	**3-ply nylon general purpose rope** **10mm diameter** **Age:** New **Previous use:** None						
Climbing line	**New England 'Safety Blue Hi-Vee'** **12.7mm diameter** **Age:** New **Previous use:** None						
Test type & setup	**Pull test on a doubled rope system** (as adopted as industry best practice by arborists). Setup incorporating two 16mm Maillon Rapides, back to back, as the anchor.						
Hitch type	**Hitch configuration/ termination**	**Climbing line termination**	**Simulated harness anchor**	**Slippage with maximum of 1 metre of pull**	**Point of failure**	**Peak force recorded**	**Notes**
4-wrap Prusik	Endless loop terminated with double fishermans knot.	Bowline	16mm shackle	Slipped at 400Kg for 112cm.	None	3044Kg	Slipped for the entire length of the test bed, initially at low forces, until heat build-up created fusion and higher ratings.
6-wrap Prusik	Endless loop terminated with double fishermans.	Bowline	16mm shackle	Slipped for 15cm. Load not determined.	Bowline of climbing line.	3294Kg	Similar performance to previous 6-wrap Prusiks, i.e. little slippage then seizure, causing failure in the climbing line bowline.

DOUBLED ROPE PULL TEST: Various hitch, cord & lifeline configurations

Test type & setup	**Pull test on a doubled rope system** (as adopted as industry best practice by arborists). Setup incorporating two 16mm Maillon Rapides, back to back, as the anchor.						
Hitch type & cord	**Hitch configuration/ termination**	**Climbing line & termination**	**Simulated harness anchor**	**Slippage with maximum of 1 metre of pull**	**Point of failure**	**Peak force recorded**	**Notes**
4-wrap Prusik with 6mm Dyneema (sample 6c)	Endless sling terminated with a triple fishermans knot.	Yale 'XTC Plus' terminated with a bowline.	Hitch to HMS alloy karabiner. Climbing line to 16mm shackle.	70cm of slippage. Load not recorded.	Within the Prusik hitch.	3145Kg	Slippage caused eventual melting of the polyester sheath, followed by a rapid heat fusion and failure of the core.
4-wrap Klemheist with 6mm Dyneema (sample 6h)	Endless sling terminated with a double fishermans knot.	Yale 'XTC Plus' terminated with a bowline.	Hitch to HMS alloy karabiner. Climbing line to 16mm shackle.	1cm of slippage before biting.	Bowline of the lifeline.	3398Kg	The 4-wrap Klemheist does not appear to be as prone to slippage as the 4-wrap Prusik.
7-wrap Valdotain with 6mm polyester braid on braid. (sample 6a)	Eye-to-eye sling terminated each end with half a double fishermans knot.	Yale 'XTC Plus' terminated with a bowline.	Hitch to HMS alloy karabiner. Climbing line to 16mm shackle.	None	Within the hitch.	3151Kg	Continued to hold after the initial failure because of the crossed over braids. Little slippage probably caused by the thinner (as compared to the 10mm Valdotain) cord biting into the lifeline
6-wrap Valdotain with 6mm polyester braid on braid. (sample 6aa)	Eye-to-eye sling terminated each end with half a double fishermans knot.	New England 'Safety Blue Hi-Vee' terminated with a half double fishermans.	Hitch to HMS alloy karabiner. Climbing line to 16mm shackle.	Slipped for 15cm. No load recorded.	Within the half double fishermans knot of the hitch.	3251Kg	Less friction (i.e. one less wrap) may have caused slippage as compared to the above.

DOUBLED ROPE PULL TEST: Various hitch, cord & lifeline configurations

Test type & setup	**Pull test on a doubled rope system** (as adopted as industry best practice by arborists). Setup incorporating two 16mm Maillon Rapides, back to back, as the anchor.						
Hitch type & cord	**Hitch configuration/ termination**	**Climbing line & termination**	**Simulated harness anchor**	**Slippage with maximum of 1 metre of pull**	**Point of failure**	**Peak force recorded**	**Notes**
6-wrap Valdotain with 8mm polyester double braid (sample 4a)	Eye-to-eye sling terminated with half a *triple* fishermans knot.	Yale 'XTC Plus' terminated with a bowline.	Hitch to HMS alloy karabiner. Climbing line to 16mm shackle.	2cm before biting onto lifeline.	Bowline in the lifeline.	3163Kg	Only the top three wraps seized onto the lifeline.
6-wrap Valdotain with 8mm polyester double braid (sample 4b)	Eye-to-eye sling terminated with half a *double* fishermans knot.	Yale 'XTC Plus' terminated with a bowline.	Hitch to HMS alloy karabiner. Climbing line to 16mm shackle.	2cm before biting onto lifeline.	Bowline in the lifeline.	2965Kg	Only the top three wraps seized onto the lifeline.
4-wrap Klemheist with 10mm Beal 'Regate' (sample 6g)	Eye-to-eye sling terminated with half a double fishermans knot.	Yale 'XTC Plus' terminated with a bowline.	Hitch to HMS alloy karabiner. Climbing line to 16mm shackle.	Slipped at 800Kg to the end of the test bed.	None	800Kg	Little damage to the hitch as it failed to bite adequately.
6-wrap Valdotain with 10mm polyester double braid (sample 8a)	Eye-to-eye sling terminated with half a double fishermans knot.	New England 'Safety Blue Hi-Vee' terminated with a half double fishermans.	Hitch to HMS alloy karabiner. Climbing line to 16mm shackle.	Slipped for 140cm to end of test bed, jumping every 10cm.	None	2416Kg	Outer braid destroyed.

DOUBLED ROPE PULL TEST: Various hitch, cord & lifeline configurations

Test type & setup	**Pull test on a doubled rope system** (as adopted as industry best practice by arborists). Setup incorporating two 16mm Maillon Rapides, back to back, as the anchor.						
Hitch type & cord	**Hitch configuration/ termination**	**Climbing line & termination**	**Simulated harness anchor**	**Slippage with maximum of 1 metre of pull**	**Point of failure**	**Peak force recorded**	**Notes**
4-wrap Tautline with Yale 'XTC Plus' split tail. (sample 6d)	Yale 'XTC Plus' 13mm split tail with eye splice.	Yale 'XTC Plus' terminated by bowline.	Both hitch and bowline to 16mm shackle.	Little. Hitch rolled out up to the stopper knot.	Lifeline at bowline.	2789Kg	
4-wrap Blakes with 13mm Cousin split tail. (sample 5a)	Cousin Forester 2-split 13mm tail with stitched eye splice.	Yale 'XTC Plus' terminated by bowline.	Both hitch and bowline to 16mm shackle.	Little.	Lifeline bowline.	3283Kg	Blakes seized onto line.
4-wrap Blakes tied with tail of the 13mm Yale lifeline. (sample 6f)	Three knot system tied with Yale 'XTC Plus'.	Yale 'XTC Plus' terminated by bowline.	Bowline to 16mm shackle.	None.	Lifeline bowline.	3238Kg	Blakes seized onto line.
4-wrap 'Sui-slide' hitch tied with tail of 13mm Yale lifeline. (sample 6e)	Three knot system tied with Yale 'XTC Plus'.	Yale 'XTC Plus' terminated by bowline.	Bowline to 16mm shackle.	25cm at 200Kg before seizing onto lifeline.	Lifeline bowline.	3234Kg	

DOUBLED ROPE PULL TEST: Various hitch, cord & lifeline configurations

Test type & setup	**Pull test on a doubled rope system** (as adopted as industry best practice by arborists). Set up incorporated two 16mm maillon rapides, back to back, as the anchor.						
Hitch type & cord	**Hitch configuration/ termination**	**Climbing line & termination**	**Simulated harness anchor**	**Slippage with maximum of 1 metre of pull**	**Point of failure**	**Peak force recorded**	**Notes**
Samson 'Treemaster' 12mm split tail and 4-wrap Blakes hitch.	12mm split tail with spliced eye (including thimble) into steel karabiner.	Samson 'Treemaster' 12mm 3-ply with spliced eye.	Hitch to karabiner and lifeline to 16mm shackle.	15cm at approximately 1000Kg.	None	3500Kg	Some slippage as the hitch tightened. The system held to the end of the test bed.
3-ply 12mm 'Dacron' polyester spliced prusik loop with 4- wrap Prusik.	Prusik loop spliced. Terminated in 16mm shackle.	12mm 'Multiplait' nylon with bowline.	Hitch and lifeline to 16mm shackle.	100cm at approximately 600Kg.	None	1040Kg	As the hitch seized onto the lifeline, higher forces were recorded, up to a maximum of 1040Kg. The amount of slippage is probably due to the stiffer prusik cord (of equal diameter) not biting as well on the softer rope.
Used 5/16" Ultra Tech with 6-wrap Valdotain	Eye-toeye sling terminated with half double fishermans.	Yale 'XTC Plus' with bowline	Hitch to karabiner and lifeline to 16mm shackle.	30cm at approximately 1500Kg.	None	3143Kg	The cord used to tie the hitch was very stiff after testing.
5/16" Ultra Tech with 7-wrap Valdotain.	Eye-to-eye sling terminated with spliced eyes.	Yale 'XTC Plus' with spliced eye.	Hitch to karabiner and lifeline to 16mm shackle.	None	Lifeline over the bend at the anchor.	3500Kg	Only one 16mm Maillon was used, giving a smaller bending radius. This probably caused the failure.
3/8" Samson Tenex with 5- wrap Distel.	Eye-to-eye sling with spliced eyes.	Yale 'XTC Plus' with bowline.	Hitch to karabiner and lifeline to 16mm shackle.	100cm at approximately 900Kg.	None	2964Kg	

Table 10 of 20

DOUBLED ROPE PULL TEST: Beal ‘Regate’ prusik cord & Edelrid ‘Xperience’ climbing line

Prusik cord	**Beal ‘Regate’ prusik cord**	**10mm diameter**	**Age:** New	**Previous use:** None			
Climbing line	**Edelrid ‘Xperience’**	**13mm diameter**	**Age:** 18 months	**Previous use:** Heavy	**Condition:** Stiff, wet & dirty		
Test type & setup	**Pull test on a doubled rope system** (as adopted as industry best practice by arborists). Setup incorporating two 16mm Maillon Rapides, back to back, as the anchor.						
Hitch type	**Hitch configuration/ termination**	**Climbing line termination**	**Simulated harness anchor**	**Slippage with maximum of 1 metre of pull**	**Point of failure**	**Peak force recorded**	**Notes**
4-wrap Prusik (sample 1a)	Endless loop terminated with double fishermans knot.	Bowline	16mm shackle	Slipped at 1100Kg for 50cm.	None	1297Kg	No heat damage to Prusik or rope. This appears to be due to the high water content of the rope. Prusik easily loosened.
6-wrap Prusik (sample 1b)	Endless loop terminated with double fishermans knot.	Alpine Butterfly	16mm shackle	Slipped for 4cm. Load not recorded.	Climbing line over the anchor.	2022Kg	No heat damage to rope or Prusik. This appears to be due to the high water content of the rope. Prusik easily loosened. It is possible that the climbing rope broke before the Prusik had the chance to seize
6-wrap Valdotain (French prusik) (sample 1c)	Eye-to-eye sling terminated each end with half a double fishermans knot.	Alpine Butterfly	Valdotain to alloy HMS-type karabiner. Bowline to 16mm shackle.	Slipped for 100cm at 1300Kg. Not a continuous slip but a series of jumps.	None	1906Kg	Some melting of the climbing line to the Valdotain prusik, but the prusik was still intact and moveable.
7-wrap Valdotain (French prusik) (sample 1d)	Eye-to-eye sling terminated each end with half a double fishermans knot.	Alpine Butterfly	Valdotain to alloy HMS-type karabiner. Bowline to 16mm shackle.	None	Alpine Butterfly in climbing line.	1994Kg	No melting or damage to Valdotain prusik or climbing line.

Table 11 of 20

DOUBLED ROPE PULL TEST: Beal 'Regate' prusik cord & Edelrid 'Xperience' climbing line

Prusik cord	**Beal 'Regate' prusik cord**	**10mm diameter**	**Age:** New	**Previous use:** None
Climbing line	**Edelrid 'Xperience'**	**13mm diameter**	**Age:** 18 months	**Previous use:** Heavy **Condition:** Stiff, wet & dirty
Test type & setup	**Pull test on a doubled rope system** (as adopted as industry best practice by arborists). Setup incorporating two 16mm Maillon Rapides, back to back, as the anchor.			

Hitch type	Hitch configuration/ termination	Climbing line termination	Simulated harness anchor	Slippage with maximum of 1 metre of pull	Point of failure	Peak force recorded	Notes
6-wrap Helical (sample 1e)	Dead-eye sling terminated in one end with half a double fishermans knot.	Bowline	Hitch to HMS alloy karabiner. Climbing line to 16mm shackle.	4cm of slippage. Load not recorded.	Climbing line over the anchor.	2020Kg	The bowline certainly appears to be stronger than the Alpine Butterfly. The Helical appears to have similar performance to the Valdotain.
5-wrap Distel (sample 1f)	Eye-to-eye sling terminated each end with half a double fishermans knot.	Alpine Butterfly	Hitch to HMS alloy karabiner. Climbing line to 16mm shackle.	Jumped 5cm twice (total of 10cm). Load not recorded.	Alpine Butterfly in climbing line.	1770Kg	
5-wrap Swabisch (sample 1g)	Eye-to-eye sling terminated each end with half a double fishermans knot.	Alpine Butterfly	Hitch to HMS alloy karabiner. Climbing line to 16mm shackle.	Jumped twice over 7cm. Load not recorded.	Alpine Butterfly in climbing line.	1995Kg	

SINGLE ROPE PULL TEST (CONTROL DATA): Beal 'Regate' & Yale 'XTC Plus' configurations

Prusik cord	**Beal 'Regate' prusik cord**		**10mm diameter**		**Age:** New	**Use:** None	
Climbing line	**Yale 'XTC Plus' lifeline**		**13mm diameter**		**Age:** New	**Use:** None	
Test type & setup	**Pull test on a single rope system** (as occasionally adopted by arborists). Setup with lifeline terminated in two 16mm Maillon Rapides.						
Hitch type	**Hitch configuration/ termination**	**Climbing line termination**	**Simulated harness anchor**	**Slippage with maximum of 1 metre of pull**	**Point of failure**	**Peak force recorded**	**Notes**
6-wrap Valdotain (sample 7b)	Eye-to-eye sling with half double fishermans.	Bowline	Alloy karabiner attached to hitch and 16mm shackle.	Slipped 50cm to end of test bed.	None	1536Kg	All wraps seized onto the lifeline.
7-wrap Valdotain (sample 7c)	Eye-to-eye sling with half double fishermans.	Bowline	Alloy karabiner attached to hitch and 16mm shackle.	Slipped 5cm.	Lifeline bowline.	1900Kg	Extra wrap appears to give increased friction and slippage resistance, thereby overloading the lifeline termination.
6-wrap Helical (sample 7e)	Dead-eye sling terminated in one end with half a triple fishermans.	Bowline	Alloy karabiner attached to hitch and 16mm shackle.	Slipped at approximately 500Kg for 40cm to end of test bed.	None	1243Kg	Slippage resists failure and reduced peak force.
6-wrap Prusik (sample 7f)	Endless sling terminated with a double fisherman.	Bowline	16mm shackle	1cm of slippage.	Lifeline bowline	1873Kg	The 6-wrap Prusik grips equally well on the single rope system as on the doubled rope system.
4-wrap Prusik (sample 7g)	Endless sling terminated with a double fisherman.	Bowline	16mm shackle	Slipped at approximately 350Kg for 40cm to end of test bed.	None	1582Kg	The 4-wrap Prusik slips as easily as on the doubled rope system.

Table 13 of 20

SINGLE ROPE PULL TEST: Various hitch, cord & lifeline configurations

Test type & setup	**Pull test on a single rope system** (as occasionally adopted by arborists). Setup with lifeline terminated in two 16mm Maillon Rapides.						
Hitch type & cord	**Hitch configuration/ termination**	**Climbing line & termination**	**Simulated harness anchor**	**Slippage with maximum of 1 metre of pull**	**Point of failure**	**Peak force recorded**	**Notes**
10mm Beal Regate with Distel (sample 7h)	Eye-to-eye sling terminated with half double fishermans.	Yale 'XTC Plus' with bowline	Alloy karabiner into hitch and 16mm shackle	Slipped at 650Kg for 45cm to end of test bed.	None	1566Kg	Similar performance to the 6-wrap Valdotain and Helical.
8mm double-braid polyester with 6-wrap Valdotain (sample7a)	Eye-to-eye sling terminated with half double fishermans.	Yale 'XTC Plus' with bowline	Alloy karabiner into hitch and 16mm shackle	Slipped for 15cm. Force not recorded.	Half double fisherman in hitch	1805Kg	Outer braid severely damaged from slippage, weakening the cord enough to cause failure before overloading the bowline.
6mm Dyneema 4-wrap Prusik (sample7i)	Endless sling terminated with a double fisherman.	Yale 'XTC Plus' with bowline	Alloy karabiner into hitch and 16mm shackle	Slipped at approximately 900Kg and slipped for 10cm.	Within the hitch.	1376Kg	Rapid destruction of the cord after the polyester braid had burnt through.
13mm Yale XTC split tail with Blakes hitch (sample 7d)	Yale XTC split tail (dead-eye sling with spliced eye)	Yale 'XTC Plus' with bowline	Spliced eye to 16mm shackle	No slippage	Blakes hitch	1707Kg	Instant hitch disintegration. Splice pulled 1cm and tightened into a 90 degree bend.

DOUBLED ROPE DROP TEST: Beal 'Regate' prusik cord & Edelrid 'Xperience' climbing line

Prusik cord	**Beal 'Regate' prusik cord**	**10mm diameter**	**Age:** New	**Use:** None	
Climbing line	**Edelrid 'Xperience'**	**13mm diameter**	**Age:** 18 months	**Use:** Heavy	**Condition:** Stiff, wet & dirty

Fall type *	Hitch type	Hitch configuration/ termination	Climbing line termination	Simulated harness anchor	Slippage	Point of failure	Peak force recorded	Notes
1	6-wrap Valdotain	Eye-to-eye sling terminated with half double fisherman	Half double fisherman	Two alloy karabiners, one attached to hitch and one to lifeline. Both clipped into 100Kg weight.	None	None	675Kg	No damage to hitch; could be released after load removed. †
2	As above	As above	As above	As above	None	None	649Kg	No damage to hitch; could be released after load removed. †
3	As above	As above	As above	As above	None	None	641Kg	No damage to hitch; could be released after load removed. †
4	As above	As above	As above	As above	None	None	1123Kg	No damage to hitch; could be released after load removed. †
1	4-wrap Prusik	Endless sling terminated in a double fishermans	Half double fisherman	Two alloy karabiners, one attached to hitch and one to lifeline. Both clipped into 100Kg weight.	None	None	784Kg	No damage to Prusik.
2	As above	As above	As above	As above	None	None	622Kg	No damage to Prusik.
3	As above	As above	As above	As above	None	None	892Kg	Prusik welded to rope (sample 2b)
4	As above	As above	As above	As above	None	None	942 Kg	No damage to Prusik (sample 2c)

*** See Table 17 for definitions of 'fall types'.**

† The same piece of rope was used for these four drops, without any noticeable damage (see sample 2a).

DOUBLED ROPE DROP TEST: Various hitch, cord & lifeline configurations

Fall type *	Hitch type & cord	Hitch configuration/ termination	Climbing line & termination	Simulated harness anchor	Slippage	Point of failure	Peak force recorded	Notes
1	Blakes hitch with Cousin 'Forester II' split tail	Stitched eye split tail 13mm	Used Edelrid 'Xperience' 13mm with bowline	Single alloy karabiner attached to weight	None	None	636Kg	No damage to split tail; could be released from lifeline after load was removed.
2	As above	As above	As above	As above	None	None	424Kg	As above
3	As above	As above	As above	As above	None	None	790Kg	As above
4	As above	As above	As above	As above	None	None	1282Kg	Split tail welded to lifeline.
1	6-wrap Valdotain – used Beal 'Regate' 10mm with *slight* memory from previous wraps but undamaged	Eye-to-eye sling with half double fishermans	As above	Two alloy karabiners, one attached to hitch and one to lifeline, both clipped into 100Kg weight.	Hitch failed to bite lifeline	None	None	Load caught by catch rope. Hitch failed to catch lifeline after slacking off.
1	As above	As above	As above	As above	None	None	761Kg	The right hand leg of hitch was tucked under left hand leg on bottom braid, before attaching to karabiner.
1	As above	As above	As above	As above	Hitch bit lifeline, then released, then bit lifeline.	None	632Kg	Tied as above. Inconsistent performance with severe consequences (sample 3a).

*** See Table 17 for definitions of 'fall types'.**

DOUBLED ROPE DROP TEST: Various hitch, cord & lifeline configurations (continued)

Fall type *	Hitch type & cord	Hitch configuration/ termination	Climbing line & termination	Simulated harness anchor	Slippage	Point of failure	Peak force recorded	Notes
1	6-wrap Valdotain with polyester 8mm double braid	Eye-to-eye sling with half double fishermans	13mm Yale 'XTC Plus' with spliced eye	Two alloy karabiners, one attached to hitch and one to lifeline, both clipped into 100Kg weight.	None	None	615Kg	Good bite performance on lifeline from thinner prusik cord. No damage to Valdotain prusik.
3	As above	As above	As above	As above	None	None	758Kg	Difficult to leave enough slack because the weight of the rope falls through the hitch.

*** See Table 17 for definitions of 'fall types'.**

SINGLE ROPE DROP TEST: Various hitch, cord & lifeline configurations

Fall type *	Hitch type & cord	Hitch configuration/ termination	Climbing line & termination	Simulated harness anchor	Slippage	Point of failure	Peak force recorded	Notes
Type 5	6-wrap Helical with Beal 'Regate'.	Split tail to karabiner with half a double fishermans.	13mm Yale 'XTC Plus' with bowline.	Hitch to steel karabiner	3cm	None	624Kg	Welded to lifeline with slight surface melting of hitch to rope.
Type 6	6-wrap Helical with Beal 'Regate'.	Split tail to karabiner with half a double fishermans.	13mm Yale 'XTC Plus' with bowline.	As above	15cm	None	694Kg	Welded to lifeline with slight surface melting of hitch to rope.
Type 5	6-wrap Helical with used Ultra Tech.	Split tail to karabiner with spliced eye.	13mm Yale 'XTC Plus' with spliced eye.	As above	3cm	None	700Kg	Welded to lifeline with slight surface melting of hitch to rope. Higher force may be due to the extremely poor energy absorption properties of aramid fibres.
Type 6	6 wrap Prusik with 12mm polyester 3-ply.	As above	12mm nylon 3-ply with bowline.	As above	15cm	None	665Kg	Welded to lifeline with slight surface melting of hitch to rope. Slightly lower force than the braided rope may be due to the higher stretch characteristics of 3-ply nylon.

See Table 17 for definitions of 'fall types'.

FALL TYPES

Type	Description
1	Anchored with approximately 14 metres of rope doubled over the anchor (two 16mm Maillon Rapides). The load (100Kg mass) is lifted to create 50cm of slack. The slack is distributed evenly between both legs of the rope.
2	Anchored with approximately 14 metres of rope doubled over the anchor (two 16mm Maillon Rapides). The load (100Kg mass) is lifted to create 50 cm of slack. The slack is distributed unevenly on the friction hitch leg of the rope. The other leg is drawn taut.
3	**Fall factor 1** with a 100Kg mass held opposite, and 50cm away from, the anchor on the doubled rope system (100cm divided by the two legs of the rope). The paid out rope is distributed evenly between both legs of the rope.
4	**Fall factor 2** with a 100Kg mass suspended 100cm above the anchor (200cm of rope paid out, divided by the two legs of the rope). The paid out rope is distributed evenly between both legs of the rope.
5	**Fall factor 1** with a 100Kg mass held opposite, and 50cm away from, the anchor on a single rope (anchored in a bowline over one 16mm shackle).
6	**Fall factor 2** with a 100Kg mass and 100cm of rope paid out above the anchor on a single rope (anchored in a bowline over one 16mm shackle).

<u>*Table 19 of 20*</u>

PULL TEST: 4-year old used rope – Samson 'True Blue'

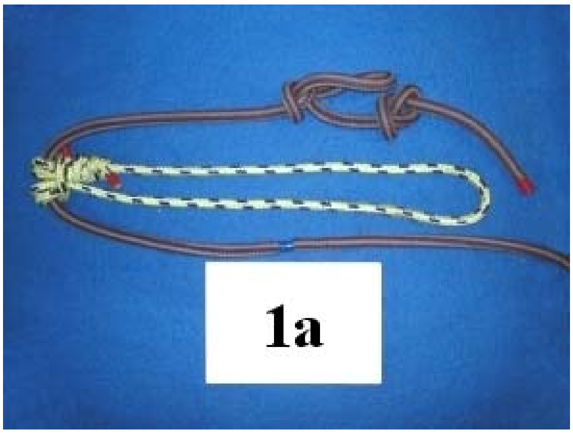
Test type & setup	**Pull test to determine knotted breaking strengths** (of various configurations). Setup incorporating two 16mm Maillon Rapides, back to back, as the anchors.				
Rope type	**Configuration**	**Terminations**	**Point of failure**	**Peak force recorded**	**Notes**
Samson 'True Blue'	Single line pull test with knots at both ends. Pulled over one metre.	Half a double fishermans knot on both ends.	Knot	983Kg	The rope failed with very little recoil energy.
Samson 'True Blue'	Single line pull test with knots at both ends. Pulled over one metre.	Half a triple fishermans knot on both ends.	Knot	1004Kg	As above.
Samson 'True Blue'	Tied into a loop (endless sling). Pulled over one metre.	Bowline on both ends	Knot	986Kg	Very little difference between the peak forces. This still gives a safety factor of around a 10:1 for single line work, even after the strength loss associated with the knots.
Samson 'True Blue'	Doubled rope system with bowline termination and 4-wrap Blakes hitch with used 13mm split tail (Samson 'Blue Streak').	Bowline in lifeline, chokered splice in split tail.	Bowline	1485Kg	An old tired rope with heavy wear still gives a 14:1 safety factor, even after the strength loss associated with the knots (when used doubled).

ROPE AND CORD SPECIFICATIONS

Rope manufacturer	Rope trade name	Construction type	European standard	Diameter	Material	Breaking strength	Sheath mass	Core mass	Knotability
Yale	XTC Plus	16-strand single braid	EN 1891 Type A	½”	100% Polyester	Average 6,200lbs (2,812Kg)	NS	NS	NS
Edelrid	Xperience	16-strand single braid	EN 1891 Type A	13mm	Polyamide	35kN	80%	NS	.68
Cousin	Forester II	NS	EN 1891 Type A	13mm	Polyamide	3748daN	55.5%	44.5%	.83
New England	Safety Blue Hi-Vee	16-strand single braid	EN 1891 Type A	13mm	NS	7,000lbs (3,175Kg)	83.6%	NS	.58
Liros	Rainbow	Braid on braid	NA	6mm	Polyester	625Kg	NS	NS	NS
Liros	Hercules	Double-braid	NA	8mm	Polyester	1700Kg	NS	NS	NS
Liros	Rainbow	Double-braid	NA	10mm	Polyester	2200Kg	NS	NS	NS
Beal	Regate	Double-weave	NA	10mm	Polyester	1700Kg	NS	NS	NS
Liros	Dyneema	NS	NA	6mm	Spectra with polyester jacket	2000Kg	NS	NS	NS
Samson	True Blue	12-strand single braid	NA	½”	100% polyester	7,300lbs (3311Kg)	NS	NS	NS
Samson	Blue Streak	16-strand single braid	NA	½”	Polyester with nylon core	8,100lbs (3674Kg)	NS	NS	NS
Samson	Ultra Tech	NS	NA	5/16”	Polyester jacket with Technora core	7,800lbs (3538Kg)	NS	NS	NS
Samson	Tenex	12-strand hollow braid	NA	3/8”	Polyester	5,400lbs (2449Kg)	NS	NS	NS
Samson	Treemaster	3-ply	NA	½”	Polyester	7,000lbs (3,175Kg)	NS	NS	NS

Notes: NS= Not specified NA=Not applicable (although, as these ropes are American, ANZI Z133.1 may apply)

Photographs of tested samples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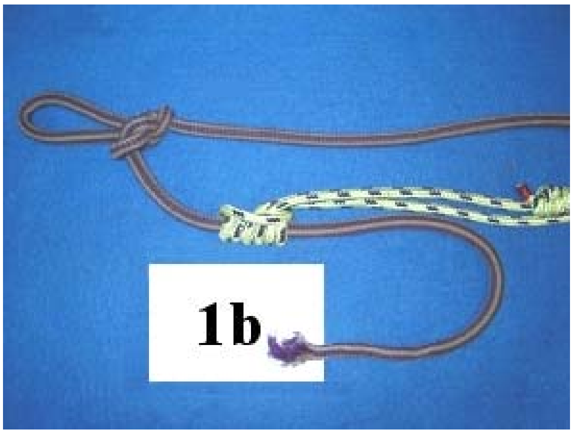
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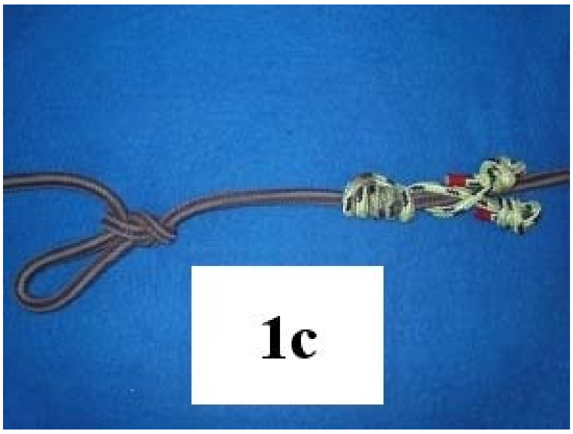
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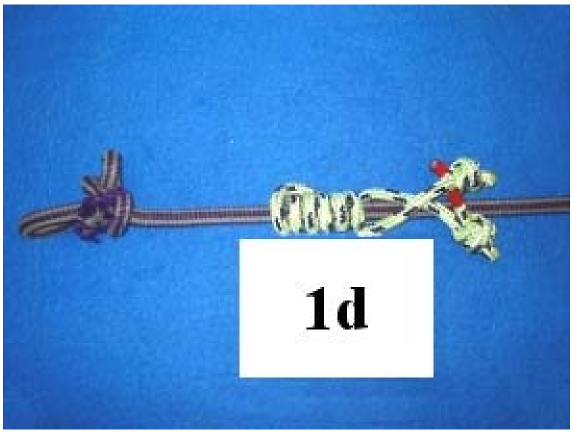
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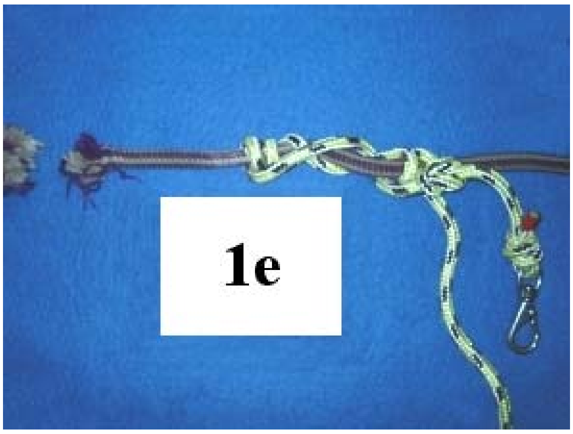
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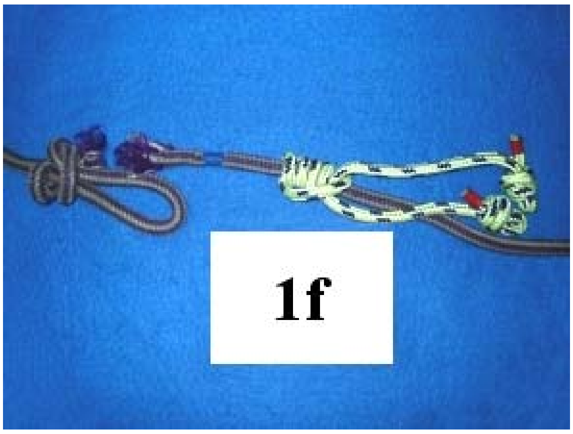
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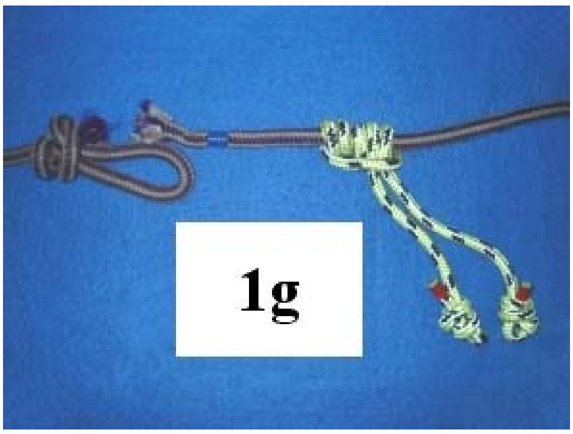
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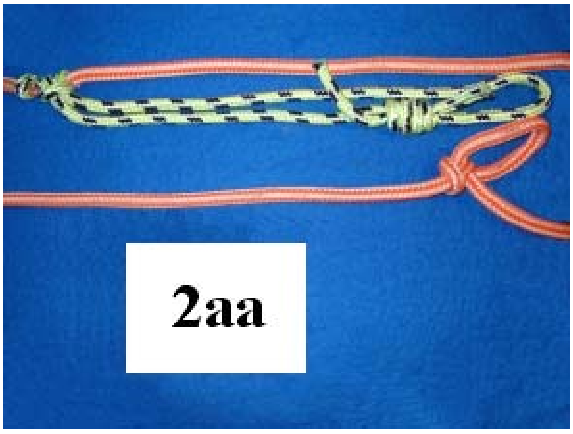
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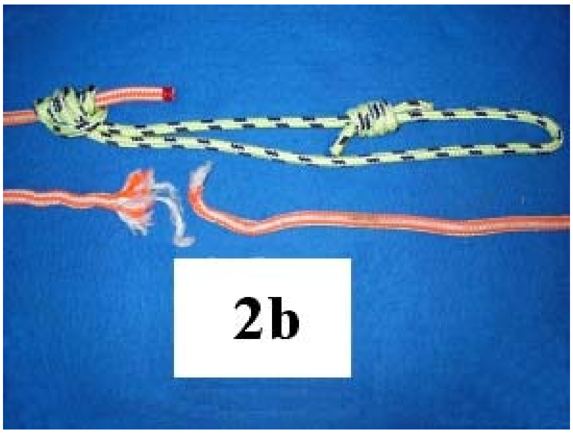
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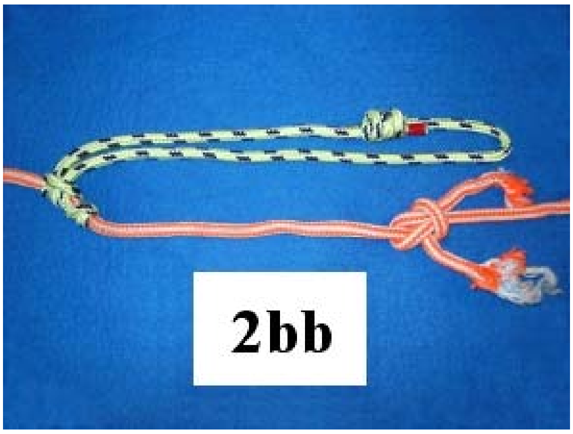
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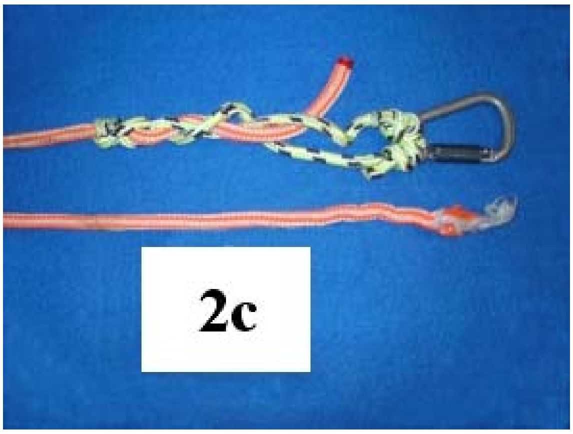
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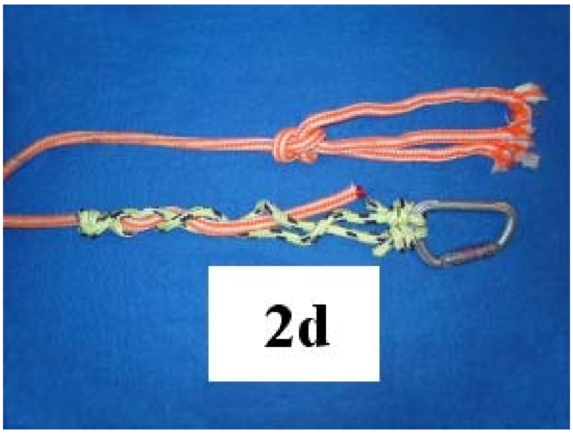
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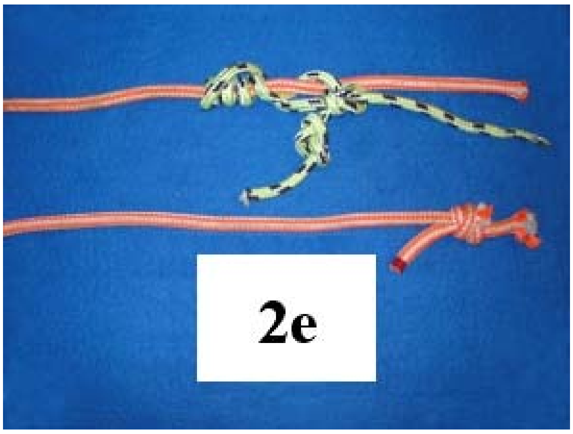
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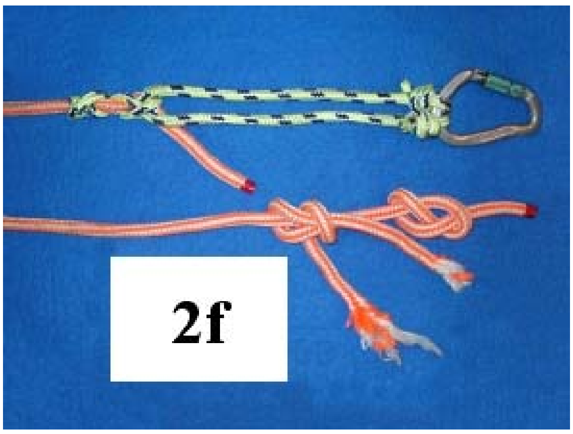
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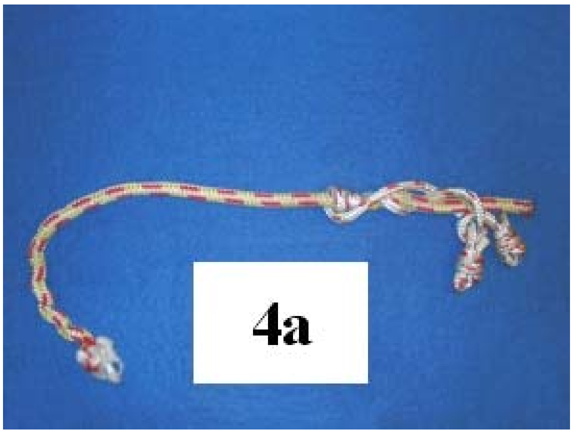
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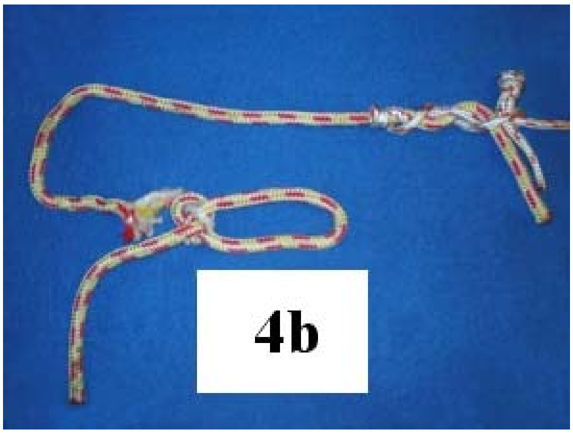
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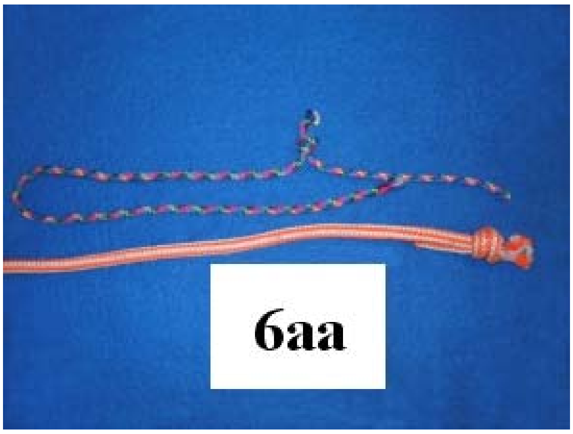
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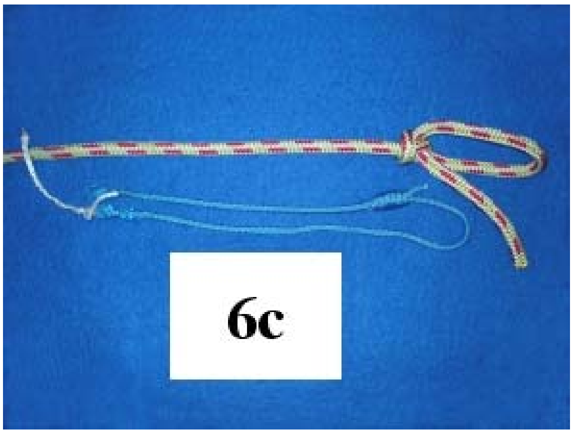
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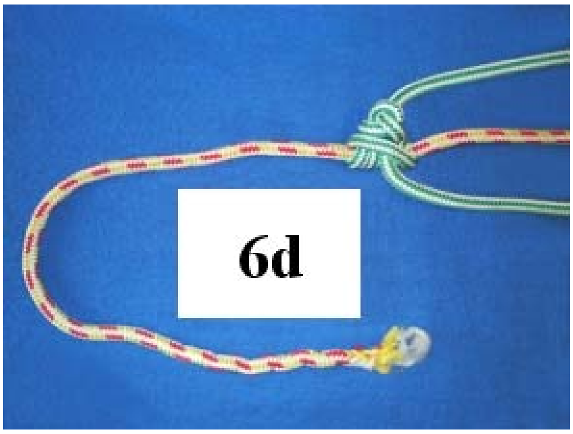
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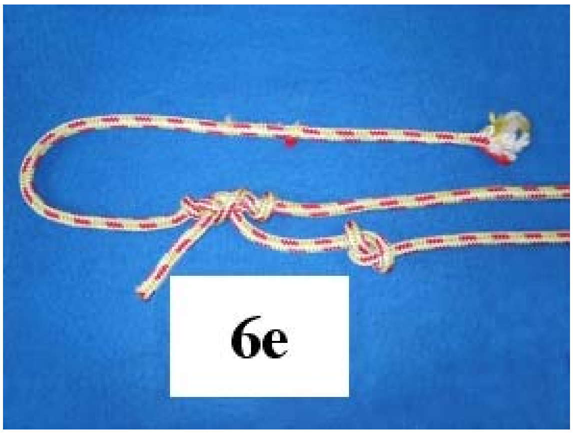
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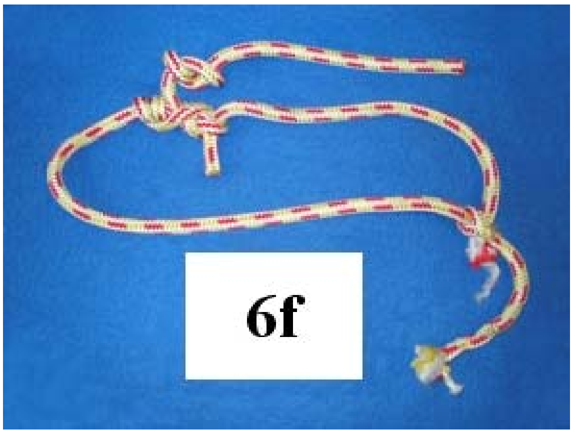
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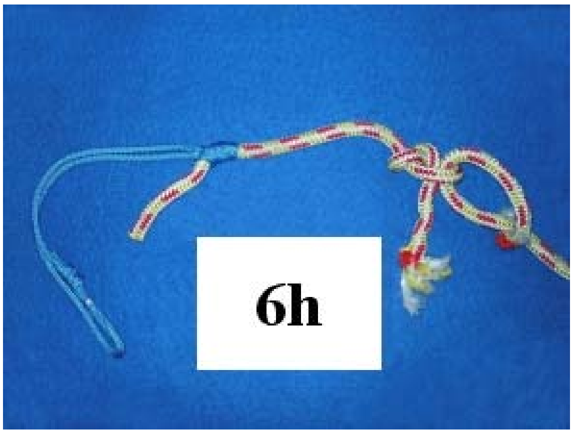
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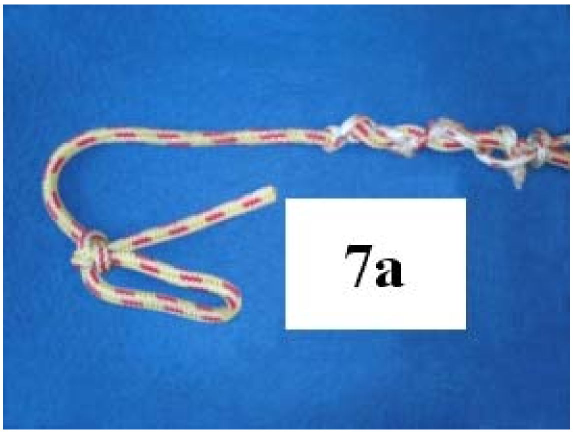
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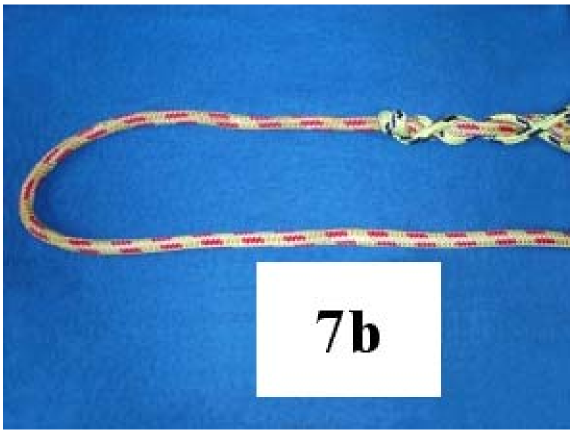
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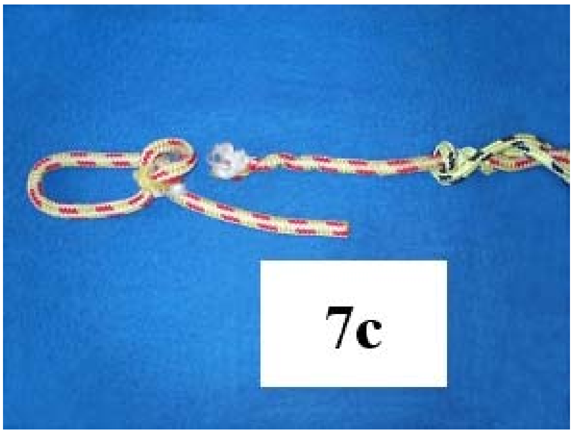
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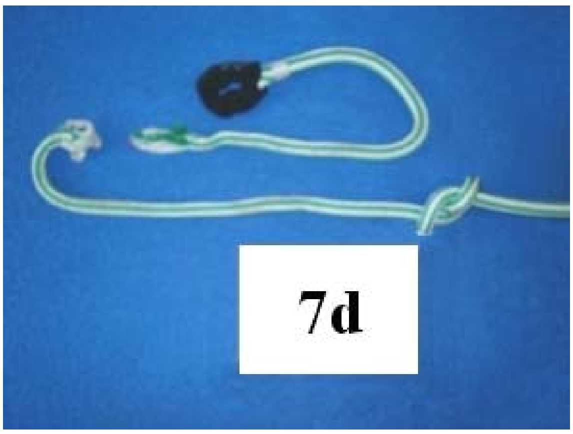
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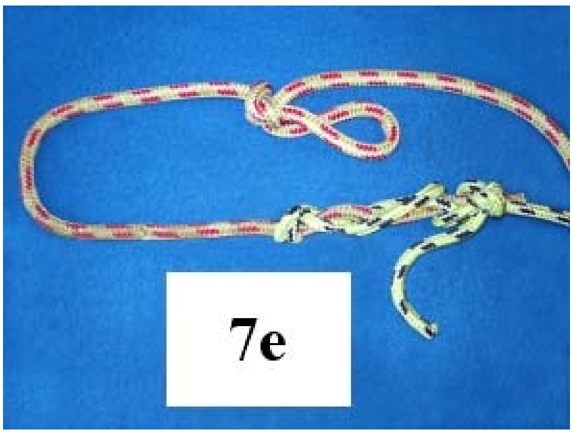
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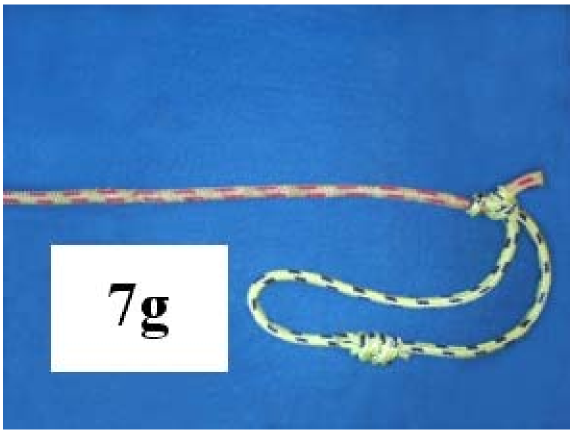
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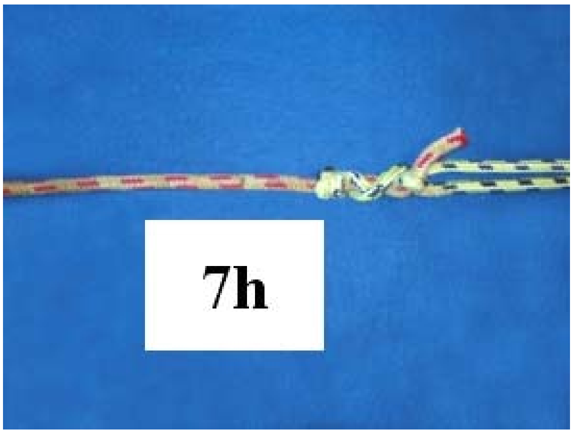
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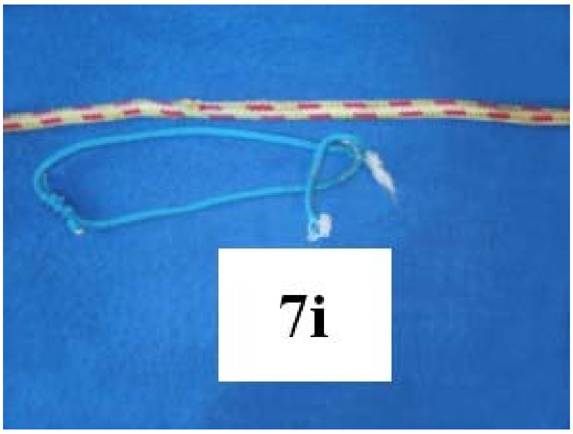
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