3 KNOTS

3.1 INTRODUCTION

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

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

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

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

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

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

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

3.2 METHODS

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

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

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

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

3.3 RESULTS

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

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

3.3.1 Double overhand knot

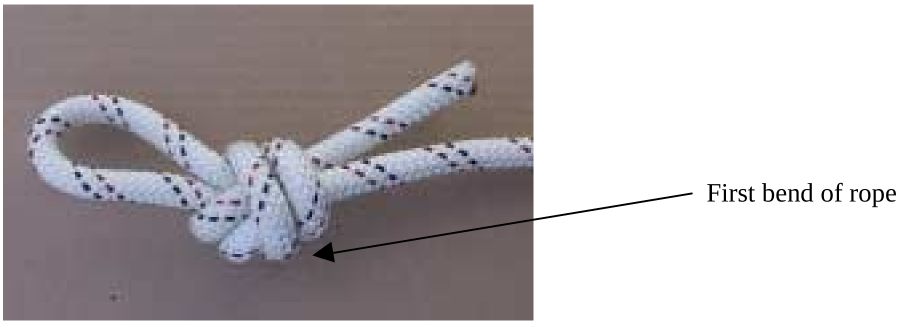

Figure 2
Double overhand knot

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

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

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

3.3.2 Double figure-of-eight knot

Figure 3
Double figure-of-eight knot

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

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

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

3.3.3 Double figure-of-nine knot

Figure 4
Double figure-of-nine knot

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

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

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

3.3.4 Double figure-of-ten knot

Figure 5
Double figure-of-ten knot

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

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

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

3.3.5 Double figure-of-eight on the bight

Figure 6
Double figure-of-eight on a bight

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

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

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

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

3.3.6 Bowline

Figure 7
Bowline knot

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

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

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

3.3.7 Alpine butterfly

Figure 8
Alpine butterfly knot

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

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

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

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

3.3.8 Barrel knot

Figure 9
Barrel knot

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

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

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

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

3.3.9 Double fisherman's

Figure 10
Double fisherman's knot

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

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

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

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

3.3.10 Clove hitch

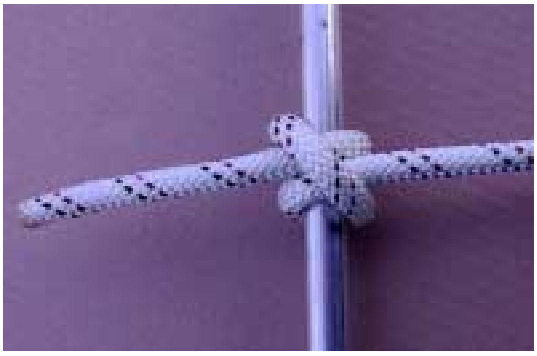

Figure 11
Clove hitch knot

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

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

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

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