Mountaineering ropes

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A piece of rope placed in an Egyptian tomb about 5300 years ago is the oldest known and is now in Cairo Museum.

The origins of the rope-making craft go back to the days when jungle dwellers rubbed a few fibrous strands between the palm and the thigh and so created a device which, because of the frictional grip of one fibre on the other, required a relatively large tensile force to pull it apart. A development of that was the use of plaited thongs, and there are backward areas of the world where even now such a technique is used.

As recently as the nineteenth century, manufacture was a hand process in which the operator walked backwards down the long rope walk, laying rope as he went. The man has been replaced by machines but for hawser-laid ropes the system is otherwise little different. Since the nineteenth century new materials and designs have been developed. In parallel, attitudes have changed since the day 90 years ago when Haskett-Smith dismissed the rope, with other aids, as one of a group of illegitimate devices for use by bad climbers.

The importance of continuous fibres, made possible by the creation of man-made materials, cannot be exaggerated. A filament is as weak as the join to the next filament. Continuous filaments obviate such joints and materially enhance strength. Instead of reliance being placed on the resistance to being pulled apart of fibres a few inches long, a long filament is created by forcing a nylon pellet through a fine die. Obviously, the size and even the cross-sectional shape of the fibre may be controlled by appropriate changes in die design.

The benefit climbers have derived from the availability of nylon is illustrated by the fact that climbing ropes approaching some 22 kN (5000 lbf) breaking load are readily obtainable anywhere. The same tensile strength in a Grade I manilla (the best natural fibre rope presently available) would call for a rope of over 51-mm (2-in) circumference and weighing over two and a half times as much.

Several types of nylon are in current commercial use, of which the two used for climbing ropes are Nylon 6·6 (used for hawser-laid ropes made to BS 3104) and Nylon 6 (the continental Perlon). They are in effect identical, and marginal differences in properties are easily lost among more important parameters such as rope construction effects. Obviously, the strength of a rope should be a direct reflection of the strength of its constituent fibres, but this value is approached only when the fibres are parallel to each other and axially loaded. In practice, unless a sheath is incorporated, as in kernmantel, a twisting to-

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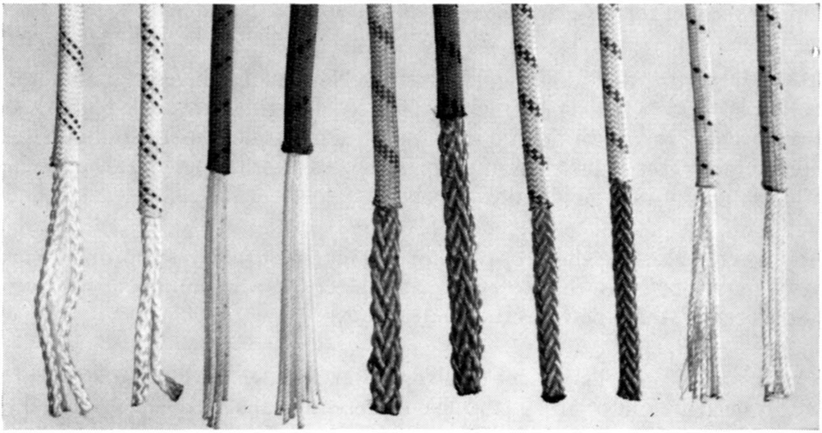
gether or a laying of the strands is necessary. The strength of the fibres is thus lost to an extent varying with the angle and twist, the actual material from which the fibres are made and the type of construction. For a No 4 rope about two-thirds of the possible strength is realised in practice. All kernmantel ropes have twisting of substrands to an amount varying with the actual construction.

Another disadvantage of parallel fibres is the relatively low energy absorption consequent in the small stretch. To this intrinsic stretch must be added a value from another source to bring the total up to an amount of practical usefulness. This added amount is produced by the rope structure and will vary considerably with different structure designs, particularly with the degree of compactness in the rope before loading. A loosely bound rope will extend a good deal on first loading as the constituent fibres and strands are forced together. This capacity is of course irreversible, and energy absorption cannot be as high on a second loading; for that reason a rope should be rejected after heavy loading. The contribution to extension by construction will be about twice that available from nylon stretch in the fibre itself.

Another parameter influencing stretch and therefore energy absorption is the angle of twist. If the angle between a strand centre-line and the circumference of the rope is low there will be a good deal of extension due to opening out, as in a spiral wire, following from the extra length of fibre required to complete a close coil spiral.

Although a very high proportion of the number of climbing ropes in use is hawser-laid nylon, the influx of kernmantel ropes over recent years has been startling. Makers of such ropes are scattered over Europe and there is a considerable variety of construction, as shown in Pl 28. The designer of a rope will be seeking the optimum performance from requirements which may be to some extent incompatible. For example abrasion resistance, flexibility, energy absorption, tensile strength, gripping quality, knottability and knot retention, resistance to frictional heat, low-temperature performance, edge strength and



28 *Variety of Kernmantel Rope constructions* This and next four illustrations: National Engineering Laboratory (Crown Copyright Reserved)

knot strength, water resistance, repeated loading effects, lightness and cheapness are hardly likely to be obtainable all at the 100% level in the same rope.

Given the extensibility of nylon (relative to that of manilla or wire) and the enormous importance of energy absorption in a climbing rope, the fact that the energy-absorption capacity of nylon is eight times greater than the same weight of manilla and twenty-seven times greater than wire, means that there is no choice in materials.

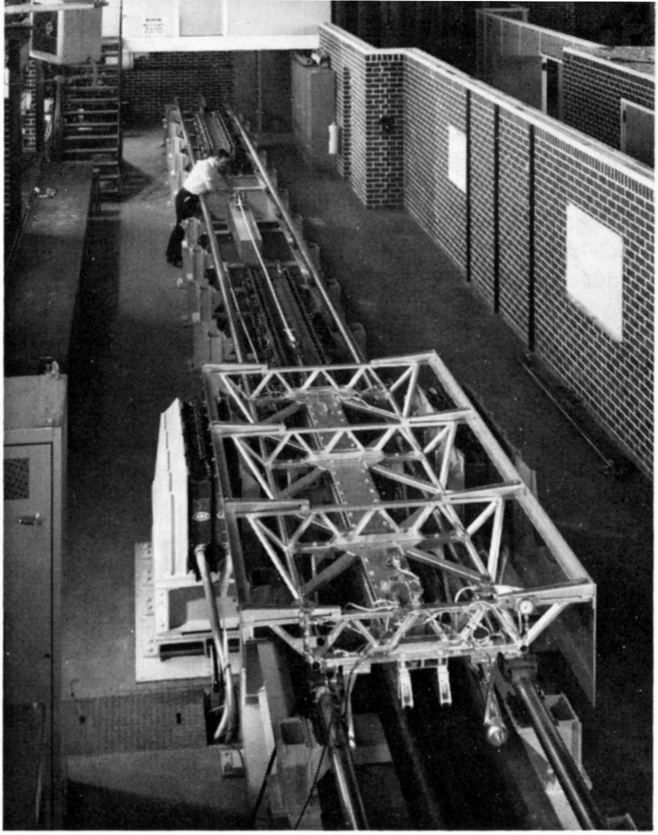
The growing use of polypropylene as a climbing rope, in an attempt to keep down costs, appears to be confined so far mainly to outdoor pursuits centres run by various educational authorities. The energy-absorption capacity of polypropylene, although only about three-fifths that of nylon, is adequate for use in instructional work so long as catching falling seconds is all that is required. The energy of even a heavy second falling a couple of feet is little enough. The danger lies in the probability that young people trained on polypropylene will continue to use it, attracted by lower cost. A 14-stone climber falling from a 50-ft run out will have a factor of safety of under 2 if using a 1½-inch diameter polypropylene rope.

But if the material must be nylon the form in which the fibres are used is much less obvious. For example, it may be readily accepted that the abrasion resistance of a hawser-laid rope will be inferior to that of a kernmantel, because in the former a smaller amount of fibre will be load-bearing against an abrasive effect; a plaited rope will be better, a braided one best. But a braided rope costs more and, although one would not allow price to affect the selection of safety equipment, it is reasonable for a purchaser to ask for evidence of enhanced rope properties for his extra money.

At the Department of Trade and Industry's National Engineering Laboratory at East Kilbride a project entitled 'Evaluation of Highly Stressed Sports Gear' s a searching investigation into the properties of new and used climbing gear. Some nine-tenths of the current programme deals with ropes and is supplying information for both new and used ropes.

Any work evaluating the properties of a component requires appropriate test machinery. For ropes the most important piece of such equipment has been, until recently, that known as the Dodero test.

The test simulates the impact of a rope over an edge during the arrest of a fall. A dead-weight of 80 kg (176 lb), representing the climber, is allowed to fall freely and must be held by the rope. The peak force in the rope must not exceed 1200 kgf (2660 lbf) for the first drop, and the same test specimen must survive at least two drops in order to qualify for the UIAA certificate. In fact, all ropes sold by the important European makers survive several drops. The limitation of this test is that it is basically a pass/fail test which, while an admirable type test for proving the reliability of a new rope, provides only a part of the information about rope behaviour and properties required for assessment.



29 *Dynamic Rope Testing Machine*

Much more information can be supplied by tests using equipment at the Laboratory, particularly the new and unique NEL Dynamic Rope Testing Machine shown in Pl 29. A falling climber is simulated by a carriage propelled by a linear induction motor and floating on frictionless air bearings. The motion of the carriage before and after it subjects the rope to impact is followed by photographic and electronic equipment which enables the extension of the rope and the energies involved to be measured. The machine can re-create the force involved when a climber falls up to 14·3 m (47 ft) and can provide loads sufficient to break any climbing rope.

For comparative static work energy absorption is measured by assessing the area under the appropriate load-extension curve, and thus for the first time dynamic and static figures are available from the same apparatus. Results so far indicate that climbing ropes, like other man-made fibre ropes, have a much lower breaking load under dynamic loading than under quasi-static rates. For hawser-laid ropes the reduction is about 7% at 50 ft/sec and for kernmantels about 9% at the same speed. The situation regarding energy absorption is much more complex, there being indications that the effect of dynamic loading is different in different constructions and perhaps with different knots and the point is being pursued.

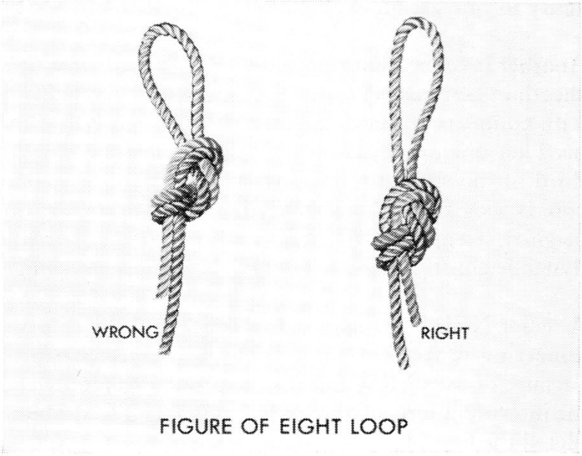
It is also apparent that, at the static test speed, the breaking load is markedly below that expected because of the well-known weakening effect of a knot. If a rope, or indeed any other component, is deliberately bent out of its natural position various stresses are induced. When a rope is knotted an important tensile stress exists in the outermost fibres of these parts of the knot which are passing over others, while compression exists at the insides of two surfaces which meet. The combined effect of these tensile and compressive forces produces a shear component which provides a centre of weakness which invariably results in failure at or near the knot.

Tests to establish the relative strength of the main mountaineering knots place them in the order shown in Table 1, the figures being the relative strength of the knot to the unknotted rope. The results shown in the table are based on manufacturers guaranteed minimum figures. In practice the strength of a climbing rope is significantly above the minimum and the effect will be to make some of the figures given unrealistically high. That is particularly so in the case of the hawser-laid ropes. The relative values of one rope and one knot to another will not be affected. It has been suggested that the effect of a knot would be different in different ropes, and indeed different constructions and sizes would have the effect of producing different shear and other stress patterns at the knot. To establish data on the point a programme of static tests was carried out on figure-of-eight, bowline and overhead knots, on each of the four main 11-mm ropes (Edelrid, Edelweiss, Viking and No. 4 hawser) available in the UK, and the corresponding 9-mm ropes. This programme shows that a knotted hawser-laid rope is stronger than a kernmantel rope of the same size with the same knot. These results again do not show a clearly definable relationship between strength and energy absorption. In some cases strong ropes have lower energy absorption than weaker ones and in other cases the reverse. Tests and analysis to establish conclusions about optimum properties continue.

Table 1 Percentage of unknotted strength (manufacturers specification) for ropes with different knots

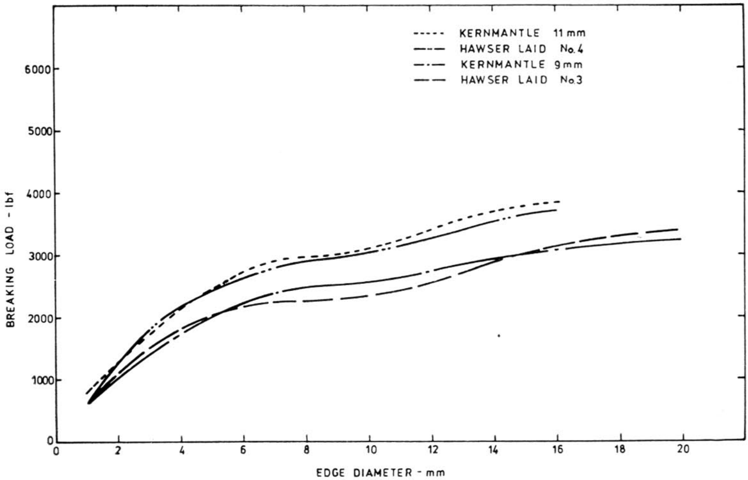
	Knot		
Rope	Figure of-eight	Bowline	Double overhand
Hawser-laid Nylon No. 4	92	82	77
Hawser-laid Nylon No. 3	99	85	79
Viking 11 mm	79	75	65
Viking 9 mm	82	74	69
Edelrid 11 mm	85	69	69
Edelrid 9 mm	86	71	79
Edelweiss 11 mm	79	73	66
Edelweiss 9 mm	80	78	67

The strength and ease in tying the figure of eight have brought it to the top in popularity but note should be made of the two ways of tying it, illustrated in Pl 30 The load-bearing rope may form the outside of the knot or the inside and in tests using a kernmantel rope there was a loss of strength of 8% in both 9- and 11-mm sizes when the knot was tied the wrong way. On the hawser-laid ropes to BS 3104 Nos. 3 and 4 the corresponding loss is 12% with the No. 3 and 11% with the No. 4.



30 *Figure of Eight Loop Knot*

Loading over an edge also seriously weakens a rope and the effect is illustrated in Pl 31 The values illustrated are for a rope in good condition, and cuts would have their own additive effect.



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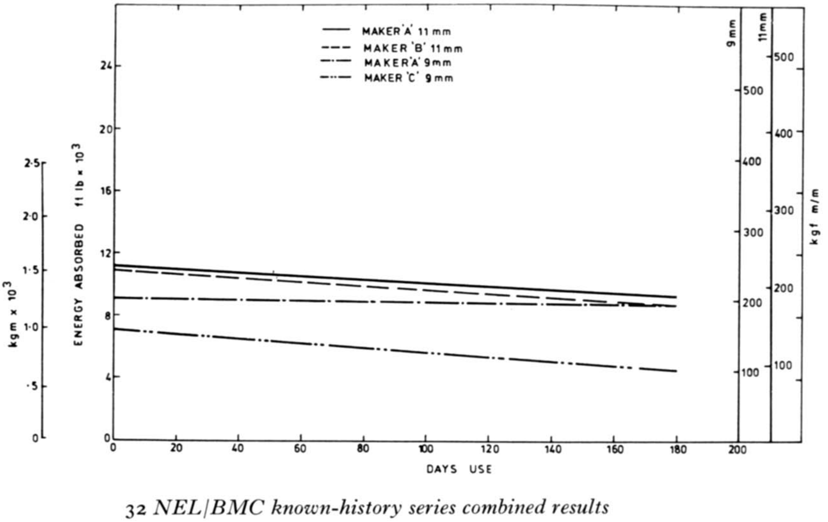
31 *Static Tests to show the effect of Edge Diameter on Breaking Load*

The edge load values vary in form according to construction, and for hawser-laid ropes a plateau exists in that region around 6 to 12 mm, the zone which includes the average karabiner diameter. A preliminary study of the dynamic results again shows the presence of the plateau in the same zone and further study to provide an explanation of the phenomenon is in progress.

Another investigation is into the relative load-bearing capacity of the core and sheath in kernmantel rope. Sheaths were separated from cores and both tested with complete ropes as controls. Results show that for the three most widely used kernmantel ropes on the UK market, the sheath contributes about one-third of the strength under static conditions—or, put another way, once the core is seen through a damaged sheath the rope is down to two-thirds of its original strength. This effect under dynamic conditions and the static and dynamic contributions to energy absorption are being investigated.

A major NEL investigation has concerned the rate of deterioration of mountaineering ropes. For some time this subject has aroused controversy, both because of conflicting qualitative pronouncements and of interpretations and misinterpretations of the early evidence. The Laboratory has recently completed the first phase of a study of used ropes in collaboration with the Equipment Sub-Committee of the British Mountaineering Council. Contrary to findings elsewhere, NEL results show that the average mountaineering rope deteriorates in use by 0·2 kg/m/day, if energy absorption is the criterion. Plate 32 shows the general pattern for the energy-loss rate for these ropes for which representative figures are available, although the interpretation is complicated by the scatter about the mean shown in Pl 32 being greater in some



32 *NEL/BMC known-history series combined results*

ropes than in others. The number of days use after which a rope should be discarded obviously varies with the criterion adopted. If a climber is prepared to accept, say, 25% loss of energy-absorption capacity as the rejection point, the figure shows that some 100 to 150 days of use would not lead into the rejection zone. This deterioration follows, of course, from actual use and no real evidence exists that a properly looked after rope will deteriorate in storage.

Current activity in rope testing at NEL is continuing, and the foregoing summarises what has been done so far. Obviously, much of it represents partial answers to existing questions and there are other aspects of the work in which the questions themselves are as yet incompletely defined.

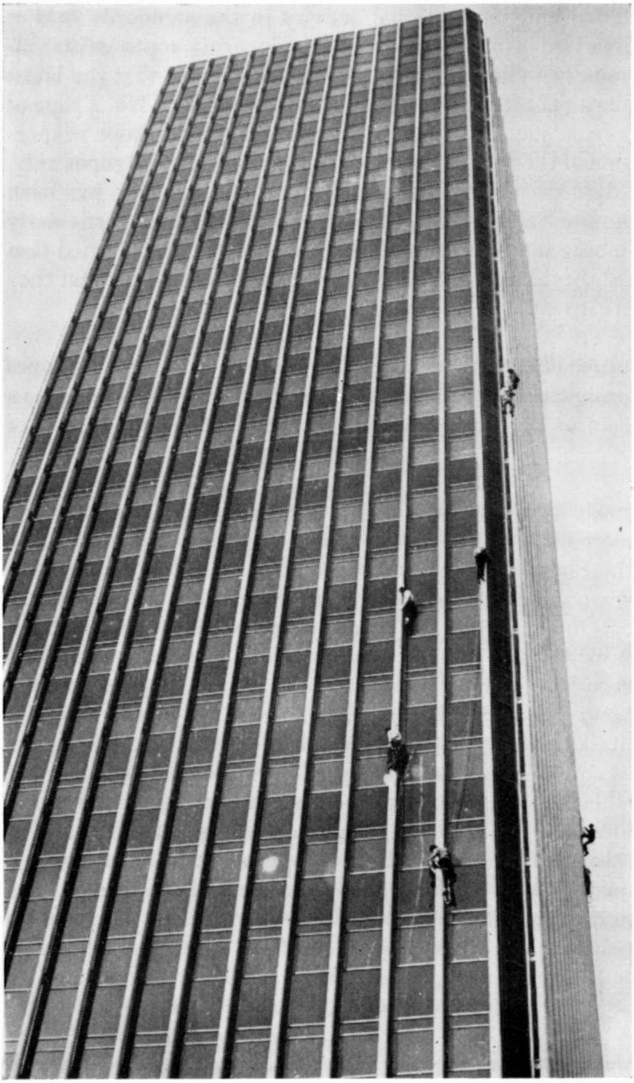
A good deal of national and international activity in the standards field is going on. British Standard 3104 on nylon mountaineering ropes exists, although recent catalogues of climbing gear have failed to note that the latest revision of the Standard calls for a minimum breaking load for a No. 4 rope of 4500 lb, the increase from 4200 lb reflecting the upward trend in rope properties. The real limitation of the Standard is that it covers hawser-laid ropes only, and no British Standard exists for kernmantel rope. The question has been raised and an appropriate Standard should emerge in the future, particularly if pressure from climbing interests is applied. It should not be assumed that absence of a Standard is evidence of lack of interest in these ropes or that they are in any way less trustworthy than others.

One technical committee of the BSI deals entirely with mountaineering ropes and the ISO Sub-Committee which considers rope and cordage now includes a working group to examine the whole question of specifications and testing of climbing ropes.

Progress has been made since the turn of the century, when a writer in the *Alpine Journal* wondered if a climbing rope would hold a 10-stone man in a 30-ft fall, through the First War comment in the *Fell & Rock Climbing Club Journal* that no rope would stand the shock of a falling leader in a climb involving a long run-out, to the present day when evidence of fatalities following rope failure through inadequacy in rope manufacture and construction is, to say the least, difficult to find. There is a lot to be done, but competition among makers, interest among users and the considered use of the wide range of evaluation facilities backed by the thoughts and views of experienced climbers will ensure that stagnation is avoided. Frequent exchange of constructive comment among all those responsible for a rope from the raw material through manufacture, evaluation and use in climbing is absolutely essential. Naturally, different teams working in the same field often produce early results widely at variance and it is perfectly normal for an odd result, an isolated incident or a contradictory fact to conflict with something in earlier findings. The process of reconciling contradictory views and facts is one from which a good deal of understanding of the field may result, and it is thus particularly important for controversial views and earlier results to be made known.

While those who are accustomed to the research environment accept and understand this aspect, unfortunately such evidence as non-constructive criticism in some sections of the climbing press suggest that the point may not be universally taken.

The NEL work described in this paper has been carried out by a team of people. Several points made arise from discussion both within the Laboratory, and in the fibre- and rope-making and rope-using fields. To all those whose words and whose work have contributed to the text the author expresses his gratitude. The work forms part of the programme of the NEL and is published by permission of the Director. It is Crown Copyright reserved.



33 *Science University—Paris* (*The Economist* printed this with the caption 'Skyscrapers make kidnapping tougher') Photo: Central Press