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## WHAT KIND OF ROPE ?

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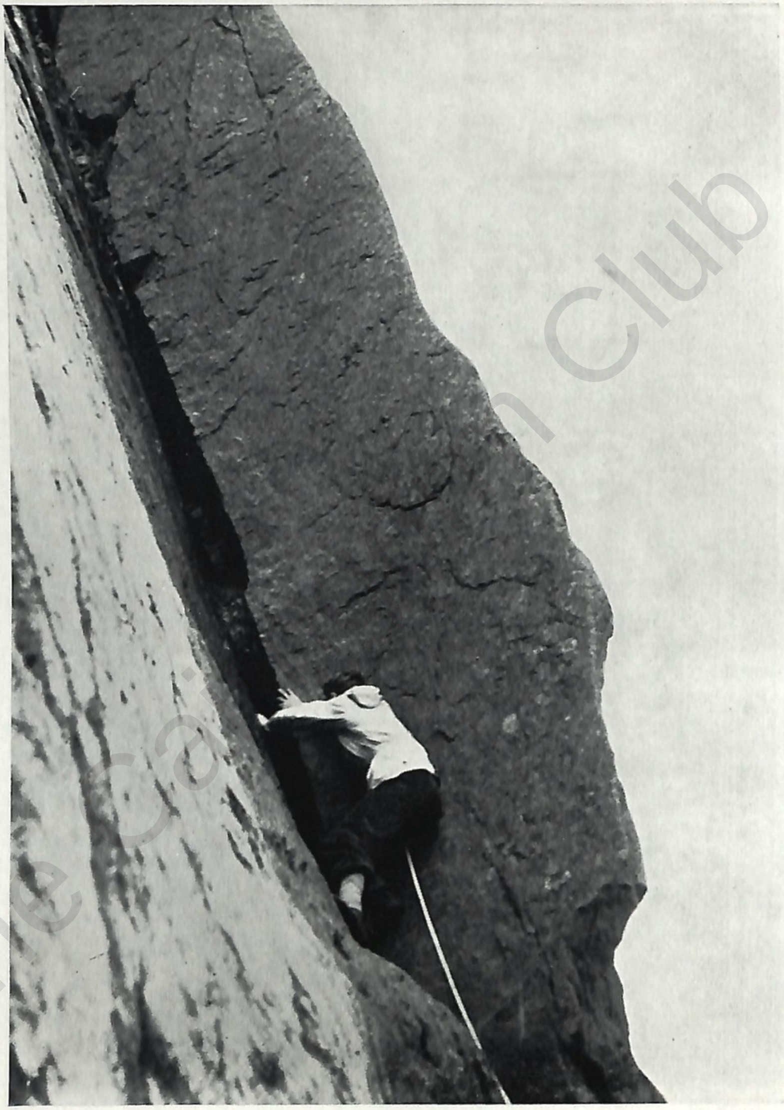
If someone were to take the trouble to run a poll to find out why we choose the equipment we do, we should probably read something as diverting and as unprofitable as the typical pre-election poll. At a guess, the " don't knows " are likely to be as numerous as any other group, yet a life may depend on one's choice of rope, and it is well to have some more rational basis for buying a climbing rope than the fashion of the moment, the sales talk of a dealer, the feel of a brand-new and tightly coiled rope fresh from its package, or even the feel of one's wallet. The present practice is to use a full-weight nylon rope of about 1¼ inch circumference weighing about 4 lb. per 100 feet for rock climbing and rather thinner nylon for the Alps, but are these the best choices we can make ?

There are, of course, many varieties of mountaineering, and it would be unreasonable to expect one rope to be ideal for them all. To narrow the field (and to keep this article within bounds) let us consider only the British climber whose interest is mainly in the major crags under both summer and winter conditions. For him it is obvious enough that the rope must be flexible under all conditions—dry, wet, and freezing—and it must have great strength and flexibility, how great we shall see. It is also very desirable that the rope should be light in weight and resistant to wear and deterioration when not in use. These properties are possessed in varying degrees by ropes of various materials, constructions, and sizes, while some may be obtained only at the expense of others, and a rational choice of rope must involve an assessment of their absolute and relative importance.

The most exacting duty ever likely to be demanded of a rock climber's rope is that of holding a falling leader—and even the most competent leaders have been known to fall. Much has been written



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Crimson Slabs

on the problems of holding a falling leader, notably by Tarbuck who has drawn attention to the intolerably great loads which a second may have to withstand if he tries to hold the rope without letting it slip under control, but let us do a little elementary dynamics to help us to find what a rope has to do in stopping a falling leader in order to determine how much strength and elasticity it must have. I say strength and elasticity because these are the properties commonly measured in testing ropes, but we cannot consider them separately, and it will simplify our approach if we consider how much energy a rope must be capable of absorbing.

When a rope is stretched, whether in a testing machine or in an accident, we may say that work is being done on the rope or that the rope is absorbing energy—these being merely two ways of saying the same thing. (The concepts of work and energy are alike as sell and buy are alike.) The unit used for measuring work and energy is distance × force (usually foot-lb.), and by continuously measuring the amount by which a rope stretches and the load on it we can compute the energy absorbed by the rope. The energy absorbed increases as the rope stretches and reaches its maximum immediately it breaks. For any given load and type of rope the extension is proportional to the original length of rope, and so the energy absorbed by a rope is proportional to its length, and we may express the capacity of a particular type of rope to absorb energy in foot-lb. per foot of rope. The convenience of this measure of a rope's performance arises from the fact that a climber who falls acquires kinetic energy (Greek *kineo*, move) which is also measured in foot-lb., and when the rope becomes taut and begins to arrest his fall we may imagine that his kinetic energy is transferred to the rope. It is thus simple arithmetic to see whether the falling climber's kinetic energy is less than the maximum which his rope can absorb, in which case his rope holds, or greater, in which case it fails.

Suppose a leader, weighing 200 lb. in his clothes, falls when he is 50 feet above his well-belayed second, and that he falls 100 feet freely before the rope becomes taut and begins to arrest his fall. He will continue to fall while the rope stretches—say, a further 20 feet—making a total fall of 120 feet, and in falling he acquires energy equal to his weight multiplied by the height of his fall, that is, 24,000 foot-lb. Now if the second is intelligent and alert, he may allow the rope to slip under control so that most of the leader's energy is absorbed in friction. But the second may not have heard of Tarbuck, or he may have read and ignored his teaching, or the rope may become jammed behind a flake beyond the second's control, so that the leader's survival depends on whether his 50 feet of rope will absorb 24,000 foot-lb. of energy before it breaks.

Suppose the rope is the currently popular full-weight nylon rope weighing about 4 lb. per 100 feet. Such a rope will withstand, when new, over 3,200 lb. and stretch by more than 40 per cent. before it breaks. Recent tests on a large number of nylon ropes have shown that on average each foot of such rope will absorb about 500 foot-lb. of energy before breaking when extended in a tensile testing machine —rather more when extended rapidly as would be the case in an accident. Thus the 50 feet of rope between the leader and the second will, if new, absorb not much more than 25,000 foot-lb. before it breaks, which is uncomfortably close to the 24,000 foot-lb. of the falling leader. An extreme case, you may think, so let us see what happens if the same leader is only 5 feet above the second when he peels off, the rope jamming again at the level of the second. He falls freely for 10 feet before the slack is taken up and another 2 feet while the rope stretches, making a total of 12 feet, so that he acquires $12 \times 200 = 2,400$ foot-lb. of energy. The 5 feet of rope will absorb a little more than $5 \times 500 = 2,500$ foot-lb.—leaving a still more uncomfortably small margin. In fact, the shorter the run-out the smaller the margin, so please don't get the idea that it is any less lethal to fall off on a run-out of 5 feet than on a run-out of 50 feet.

You may still protest that I have staged artificial and rather improbable accidents in that there are few situations in British rock climbing where a leader may fall freely for more than twice the length of rope paid out. A study of a number of accidents has, however, shown that something much worse may happen. A leader falls and in so doing drags the rope over the face of the crag, and when he has fallen perhaps 50 feet the rope becomes snagged over a flake or in a notch at a distance of 15 feet or less from his waist knot. The second can do nothing to free the rope and the leader's survival clearly depends on the ability of the 15 feet or less of rope to absorb his kinetic energy without breaking. The most the rope can absorb is 7,500 foot-lb., but the leader's energy is 10,000 foot-lb., so that the rope must break. Note that this conclusion holds even if the rope is undamaged by its contact with the rock at the point where it became jammed. Examples of this kind of accident have been investigated and reported on in *Mountaineering*, March 1952 and September 1954. At the time they were investigated it was thought that the ropes concerned failed largely because of laceration suffered during contact with the rock, but it is clear that the ropes concerned would have failed even if they had not been damaged—indeed, that the present full-weight nylon rope of 4 lb. per 100 feet is only capable of holding a falling leader in favourable circumstances.

This may seem a discouraging conclusion, and you may ask whether it is worth paying the extra price for nylon. So consider very briefly your chances with manila or Italian hemp rope of $5\frac{1}{2}$ lb. per 100 feet—the size hallowed by tradition as full weight for ropes of natural fibres. With a breaking load of 2,500 lb. and extension of 15 per cent. compared with the 3,200 lb. and 40 per cent. of a 4 lb. nylon rope, this rope can absorb at most only one-third as much energy as the nylon, so that there will be many possible accidents in which a 4 lb. nylon rope would hold a leader but a $5\frac{1}{2}$ lb. manila or hemp rope would certainly fail.

You may wonder by now where all this is leading—I say that the present full-weight nylon rope is inadequate for rock climbing and that full-weight manila or hemp is still more inadequate. But can I offer anything better ? Can my dynamics compute what minimum sort and size of rope we must use in order that a leader may be spared the hazard of a breaking rope if he falls ? The answer is yes—if only you can tell me in advance exactly what is going to happen in any particular accident. But just as it is impossible to predict the events of a climbing accident so it is impossible to predict the maximum energy per foot which a rope will be called on to absorb in emergency. Consequently, it is impossible by any rational process to determine the minimum type and size of rope which can be relied on never to fail in an accident, and unless we choose to use ropes very much heavier than our present full-weight nylon we must recognise that there will always be some risk of rope failure in rock climbing. But we can and should choose our rope so that the risk of failure is reasonably small.

We should, of course, see if we can give the leader a better chance by using a rope of some other material than nylon or the natural fibres. Terylene is a very promising synthetic fibre with many attractive properties (including even less water absorption than nylon), but so far no rope manufacturer has succeeded in making Terylene rope with more than about one half of the energy absorption of nylon, weight for weight. In fact, no other material yet used for rope manufacture exceeds or even approaches nylon's capacity to absorb energy, weight for weight, so that our only available means for increasing a falling leader's chance of survival is to use a nylon rope heavier than 4 lb. per 100 feet. We cannot calculate just how much heavier our rope should be, so we have to guess, or, in parliamentary language, use our judgment. If we use the heaviest nylon rope we can handle and afford we shall have an easy conscience. A nylon rope of about 5½ lb. per 100 feet need not be unmanageably heavy or inflexible; it has substantially greater energy absorption and is much less weakened by local damage and wear than a 4 lb. rope. Maybe we should go still heavier, but the 5½ lb. rope seems to be a tolerable compromise between security and weight (yes, and cost), and perhaps I am not unduly prejudiced by the fact that rope of this weight is available from at least one reputable manufacturer.

There are, of course, snags even with nylon. All textile materials are weakened by heat, but nylon can be melted at temperatures not much above 200° C. This is well above any temperature likely to be reached in use with this exception—when a running belay is threaded directly through a standing loop of nylon rope. In the event of a fall the friction heat generated may melt the standing loop. Note that the running rope does not melt, since the heat is distributed along the length of the rope and no point of it gets hot enough to weaken it seriously. The moral is always to use a snap-link between a running rope and a standing loop. Then, again, nylon is damaged severely by organic and inorganic acids, and although hemp and manila also suffer attack by acids it is particularly necessary to keep nylon away from acid. Nylon is degraded by exposure to sunlight, but the bright filament used in rope manufacture is less vulnerable than the delustred nylon used in some other textiles. In any case, the total exposure to sunlight in the life of a climbing rope is relatively small, and I should expect that wear is more likely to limit the useful life of a nylon rope. Resistance to wear is very difficult to assess—nylon stands up to fine abrasion better than natural fibres, but I know of no tests to measure the resistance of any rope to the severe abrasion or laceration which may occur in an accident. Until we know more about this property, perhaps we should include a substantial factor of ignorance in choosing the size of rope to use.

And what of the other properties I mentioned in my second paragraph? We must be prepared to carry more weight but not, I suggest, unreasonably. For the rest, nylon will give us a high degree of flexibility, low water absorption, and consequent freedom from freezing, and total immunity to mildew.

And when you have your heavier-than-full-weight nylon rope, please remember that in an accident it may need all the help you can give it by allowing it to slip under control—and that if it should become jammed then the " give " of a Tarbuck knot may make all the difference between failure and survival.

One final word of caution. Not all rope manufacturers seem to know how to make good nylon yarn into good rope, and some nylon rope is very inferior to the best in energy absorption, flexibility, and stability. In no other activity is rope called on to withstand such severe treatment, and only the best possible ropes which the industry can produce may be considered good enough for mountaineering. When better ropes can be made we must have them, and I cannot imagine a time when we shall not need better ropes than the industry can produce. For the immediate future, let us hope that advances in materials and methods of manufacture will give us ropes with greater energy absorption weight for weight, greater flexibility, and greater resistance to damage such as occurs when a rope becomes snagged in an accident.

Many of the tests referred to in this article were performed in the course of the work of the Committee of the British Standards Institution which is preparing a British Standard for nylon mountaineering ropes. For the rest, I have drawn freely on the work of the Equipment Sub-Committee of the British Mountaineering Council, whose assistance I gratefully acknowledge.