CAVING EQUIPMENT: THEORY, DESIGN, TESTING AND THE NEED FOR STANDARDS

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Abstract

Most testing reported in the literature is poorly designed and executed. The need for standards to evaluate equipment against, and for standardised methods of testing is outlined. Methods of development for standards are suggested. A review of desirable characteristics for S.R.T. ropes and reliable test data leads to presentation of a draft standard for public discussion.

INTRODUCTION

In a fairly extensive review of the speleological literature worldwide I have found that random snippets of essentially useless pieces of data, commonly called "test results", appear frequently. Amongst all the verbiage written on equipment design and testing there is very little which meets acceptable standards of testing design and reporting. The vast proportion of "testing" done by cavers and reported in club newsletters and journals is functionally meaningless. Almost every single report examined used a different test method, different equipment under different conditions, and most frequently was unrepeated. As responsible speleologists concerned about our own and others' safety, we need to be more critical of the equipment we use and particularly how we justify that feeling that "I'm all right, Jack. It won't break while I'm on it!"

It is relevant at the beginning of this paper to quote comments made by John Bosler (1977) at the last Australian Speleological Federation (A.S.F.) conference:

> The development of proper testing procedures should be the province of a skilled technician. Too often I hear of testing procedures which consist of taking one or two specimens from a large batch and testing them to destruction under one type of load, in conditions which barely duplicate the field conditions. Using this scanty data, sweeping claims are then made about the performance of the entire batch. This sort of procedure is far from adequate.
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> A good procedure includes proper sampling techniques and multiple testing across a wide range of loading conditions, duplicating the field conditions as nearly as possible. Where relevant, mean values and standard deviations should be determined.

WHY TEST?

There are three basic reasons for testing caving equipment.

1. Development. Almost all equipment progresses from an initial idea to prototype construction, then field and laboratory testing to iron out the bugs, followed occasionally by production if the idea was good and the tests gave

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satisfactory results. Depending on the nature of the particular equipment, this development testing is usually to answer questions of the nature of "how" or "why" it works. There may be several prototypes developed by trial and error and modified in accordance with test results before an item is considered to be acceptable.

2. Quality control. Once the equipment is in production and is circulated widely the question arises as to whether the items are all the same. Quality control testing requires the establishment of a norm or ideal which all items tested should meet or exceed. Wide divergence from the norm indicates poor quality control and reflects largely on the manufacturer. Large numbers of items must be tested over a period of time to ensure quality standards are met and are continuing to be met.

3. Consumer testing. Consumer testing is usually "one-off" testing, usually quite independent of the manufacturer, which seeks to determine whether a given consumer purchasing a given item, can expect that item to meet relevant standards of performance and, in particular, how it compares with similar items from different manufacturers. Assuming the testing methods are consistent, reliable, unbiassed and relevant (and that is not always the case), then consumer testing becomes for the manufacturer, and the consumer, a "luck-of-the-draw" situation. Manufacturer A may have one in 1000 items which fail to meet the test standard, while for manufacturer B the ratio might be one in 100. Providing distribution is even, a random sample of one of each item gives manufacturer A a much better chance of having a "good" item tested than manufacturer B - but this does not exclude the possibility of getting one of the few "good" items from B and the rare "poor" one from A. In order for their products to perform well under this system, then manufacturers must maintain high quality control or be lucky. From the consumer's point of view, of course, he wants the lowest chance of getting a "dud" - not only from a value for money point of view but also, far more importantly, from the point of view of safety. Consumer test methods are outlined in the International Standards Organisation (I.S.O.) guide number 12 (I.S.O., 1977).

RELEVANT STANDARDS ARE NEEDED

In order to evaluate caving equipment, we require mutually agreed upon standards of performance before we start any testing program. Standards need to be very carefully framed. It is of no use to specify performance criteria which cannot be reliably and reproducibly repeated and it is of little use to specify tests which are not relevant to the use of the item. There are currently very few acceptable standards by which caving equipment can be evaluated. Those that do exist were initially set up for other uses of the equipment and may not on closer examination be particularly relevant to caving use. A good standard for caving equipment must take into account conditions encountered in caves, be it high humidity, intermittent immersion in water or abrasion from mud as well as the manner in which the equipment is used. By now, most cavers should be aware of the clear difference between ropes designed for climbing which meet the Union Internationale des Associations d'Alpinisme (U.I.A.A.) standard and superficially similar ropes for caving which do not require high energy absorption and consequent elasticity. Similarly caving helmets worn by the vast proportion of cavers are designed for industrial use where a broad rim is useful and where constant abrasion is rare. Your helmet if tested now would be unlikely to meet the standard it was designed to meet!

INTERNATIONAL STANDARDS AND AUSTRALIAN STANDARDS

As cavers, we need to sit down and prepare our own standards for our own equipment. There are already some moves in this direction in Britain. The most logical move would be for the International Union of Speleology (I.U.S.) to set up a committee and sponsor drafting of relevant standards. This will probably take years, so A.S.F. should consider looking at its own situation and get on with the job, before more time and money is wasted in irrelevant, non-repeatable and scientifically worthless testing programs.

WHAT STANDARDS ARE REQUIRED?

Standards are required for equipment where life is directly endangered. I would propose as an initial list the following: rope for S.R.T.; descenders; ascenders; helmets and ladders.

The standards would specify what are the required minimum safety requirements for strength, durability, age or use-related deterioration, dynamic and static testing, standard practice in use and methods of testing and reporting of results.

HOW SHOULD STANDARDS BE DEVELOPED?

Anyone who has had experience with the Standards Association of Australia (S.A.A.) will tell you that standards are neither easy to write, nor easy to get agreement upon.

The S.A.A. procedure is to form a committee comprised of all interested parties - manufacturers, consumers, academics and, if necessary, government. This committee wrangles its way to a draft standard which is published for public comment and after all comment has been considered, publishes the standard in its final form. It should be noted that Australian Standards thus established by consensus have no weight in law. No-one is compelled to manufacture to such a standard until required to do so by specific direction of government or parliament.

DRAFT STANDARDS

In order to stimulate discussion, included here is a review of a number of aspects which must be considered in the drafting of standards for caving equipment.

All standards should include a preamble setting out what the standard is, how it arose and basic definitions of terms used in it. Then follows specification of the performance required, the methods to be used to assess the performance and the manner in which the results should be reported.

If special testing equipment is required, it is usually described in appendixes. Standards need not be long and involved documents, nor do they necessarily require extensive and costly testing equipment or procedures. To illustrate the procedure I will give an example.

ROPE FOR S.R.T. - REVIEW OF CHARACTERISTICS

Many properties of ropes are important for S.R.T. The most important characteristics of an S.R.T. rope are that it be sufficiently strong and have a low stretch. Other characteristics to consider are type of construction and abrasion resistance, thermal conductivity, melting and softening temperatures, shock strength or energy absorption, diameter in relation to handling characteristics, stiffness and effect of environmental factors such as sunlight, water and common chemical substances which may affect the physical characteristics of the rope.

The ultimate tensile strength of a rope is important since the stronger the rope the greater the safety factor. It is generally considered that a rope must be able to sustain a force of at least 10 kN (equivalent to the weight of 1000 kg) although such a rope would have little in reserve as a safety factor to account for degradation of physical properties with time. Knots and abrasions rapidly reduce the strength of a rope - remember it is the weakest link in the chain that will fail first (Bosler, 1977). Selection of a rope should be made keeping this is mind. Clearly, then a rope with a tensile strength of 3000 kg or greater, would give a good safety factor when knotted and no longer new,as the combination of a knot and ageing can reduce the rope's strength by over half what it was when new.

Abrasion of a rope can occur when the rope moves and rubs against a rock surface. Generally the rougher the rock or sharper the edge, the quicker the rope is damaged. However, it should be noted that abrasion can occur on quite smooth surfaces (see, for example, Eavis, 1974; Weiner & Sheehan, 1966, for detailed discussion). The more elastic the rope the more it will stretch and the more likely rope bounce set up during abseiling or prusiking will cause severe rope damage due to abrasion. A rope should be retired when the number of cut strands in the sheath reaches 50% (Penberthy, 1972). A rope for abseiling and prusiking should be judged on how little it will stretch under a typical bodyweight plus, say, a pack. It is common to quote percentage rope stretch under a load of about 80 kg.

Although an S.R.T. rope is not expected to absorb the energy of a fall, some small shock loading may occur. Cowlishaw (1978) has suggested that a figure around 800-1200 J m^{-1} is appropriate, allowing for reduction in energy absorption with age and use. It should be noted that energy absorption capacity (E.A.C.) decreases very approximately as the square of the ultimate tensile strength (U.T.S.). If the U.T.S. is halved then the E.A.C. is only about one quarter - don't fall on an old rope! In caving, a maximum likely fall factor is 0.3 and Cowlishaw (1978) suggests that a peak force should not exceed 6 kN. Limited testing to date suggests that most current S.R.T. ropes will meet this criterion (see also Hawkins, 1977).

There are two main types of rope construction - laid and "kernmantle".

Laid ropes comprise of strands twisted together, each strand being composed of many monofilaments or staples twisted together. The most common laid ropes used for abseiling are nylon climbing ropes made to BS 3104. These ropes are generally much more elastic than is desirable for abseiling and have a tendency to cause spin on freefall drops.

"Kernmantle" is a German word describing a rope constructed with a core of twisted or straight strands surrounded by one or more plaited sheaths. Depending on the details of construction, a kernmantle rope can be very elastic or very inelastic. Climbing ropes must take a "leader-fall" under dynamic conditions and are designed to absorb a lot of energy by stretching. Kernmantle ropes specifically designed for abseiling and prusiking are quite different from climbing rope and should not be confused.

Although polyamide (Nylon/Perlon/Grilon)* has a greater elasticity than polyester (Terylene/Dacron)* as a monofilament it is possible to construct very low stretch kernmantle ropes for abseiling and prusiking. Such ropes should not be used as a lead-rope for climbing.

The sheath can act solely as protection for the core or it can contribute a significant proportion of the strength of the rope. From the point of view of abrasion affecting strength it is obviously better if the core provides the strength and the sheath provides protection. All ropes should be frequently inspected for abrasion damage.

Abseiling generates a good deal of heat, the heavier the person the longer the drop and the faster the abseil the more heat is developed. A rope with a high thermal capacity and conductivity will absorb heat better than one with lower capacity and conductivity, but this factor is less important if the rope is wet. Nylon does absorb a small amount of water, but does not swell and water does not markedly affect its tensile strength. It will withstand temperatures up to 150°C for hours without undue loss of strength.

The diameter of the rope will affect not only its strength (a linear increase with diameter) but also its handling and whether it suits commonly used descenders or ascenders. Too thick a rope is stiff and must be fed through the descender, while too thin a rope does not generate sufficient friction, giving rise to overly fast abseils - it is also much harder to grab effectively to control the descent - suitable rope diameters are in the range 10 to 12 mm with an optimum of 11 mm.

While chemically very stable, nylon is attacked by phenol, cresol and acids. No foods or drinks and very few household products contain these chemicals in concentrations high enough to cause damage. The only product of great concern is battery acid. Polyester (Terylene/Dacron) resistance is good with weak alkalais and all but hot strong acids. Battery acid has no effect under atmospheric temperatures. The only chemicals of real concern are strong alkalies such as caustic soda in the concentration found in NiFe cell caving lamps.

From the above discussion it seems desirable to require tests of ultimate tensile strength, wet and dry elongation under load of 80 kg, energy absorption, diameter of rope, abrasion resistance, and knottability.

TEST PROCEDURE - PRELIMINARY DRAFT

1.1. All tests unless specified otherwise should take place at 20°C, deviation to be noted.
1.2 A minimum length of 10 m (?) shall be presented for testing.
1.3 After conditioning at 20°C for at least one hour.

2.1 The diameter of the rope shall be measured with vernier calipers (or a micrometer?) in at least 10 places along the length of the sample.
2.2 The average of these measurements shall be reported as the diameter and the maximum deviation noted.

* Alternative brand names for basically the same product.

3.1 The test length shall be cut in half. One half will be immersed in clean water (at 20°C) for 20 minutes (?), removed and allowed to drip for 5 minutes (?).
3.2 Both test lengths to be weighed and mass per unit length (kg/m) and proportion of water absorbed (mass of water / mass of unit length rope) reported.
3.3 The "wet" rope shall be dried until it is within 1% (?) of the mass of the dry rope.

4.1 Both the ropes shall be tested in the following manner:-
4.2 Load the rope without impact with 80 kg - maintain the load for 10 minutes.
4.3 Unload - maintain the rope unloaded for 10 minutes.
4.4 Load the rope with 5 kg and mark two reference points one metre apart in order to measure the elongation.
4.5 Load the rope without impact up to 80 kg total. After 60±5 seconds, measure the distance between the reference points and calculate the elongation as a percent (U.I.A.A., 1977).
4.6 The average percentage elongation to be reported.

5.1 In each rope an overhand knot will be formed. The rope to be subjected to a tension of 10 kg for one minute after which the tension will be reduced and maintained at 1 kg.
5.2 As long as the tension lasts, it must be impossible to introduce a rod of a diameter equal to that of the rope into any part whatever of the knot without forcing it.
5.3 The test with the knot should be made in both directions (U.I.A.A.,1977).
5.4 Penetration of rod to be reported and rope noted to be "stiff".

6.1 The dry rope shall then be cut into three lengths each length to be mounted in a tensile test jig (Instron or similar machine?). The rope ends to be wound three times round a 5 cm diameter rod (clamped in the jaws) - see Eavis, 1974 - and tied off in a suitable manner.
6.2 The jaws to be expanded slowly until failure occurs and a plot of force versus extension to be kept.
6.3 The average of the three results for ultimate tensile strength and percent--age extension at failure to be reported and total energy absorption per unit length (kJ/m) and shock strength (J/m) to be calculated and reported (for example, see Cowlishaw, 1978).

7.1 The "wet" rope (now dry) to be similarly cut into three lengths and each length to be cyclically loaded with a mass of 30 kg over a steel right angle, making contact with both faces of the bar (90° angle of contact). A 5 cm stroke to be used and a suitable cycle rate in the range 1200 - 3000 Hz be maintained until failure of the sheath for kernmantle ropes or 30% of strands cut for laid ropes (see Isenhart, 1977).
7.2 Nature of failure and average number of cycles to failure to be reported.

CONCLUSION

A far higher quality of testing of caving equipment than has hitherto been the case is required. A.S.F. should move to establish carefully considered and well documented standards against which caving equipment can be evaluated, by rigorous, repeatable and statistically relevant test methods. Until such time as mutually agreed upon standards are established we should be very wary of inadequately carried out "tests" of equipment upon which lives depend.

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