On the retirement age of caving ropes

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This document aims to provide a clean-slate assessment of the issues surrounding the retirement age of caving ropes in the context of CUCC's usage. It considers the factors influencing rope degradation, how a retirement age might be set, checking and testing, storage conditions, manufacturers' recommendations and economics.

The following summary of conclusions is designed to be accessible without reading the rest of the document.

Summary of conclusions

1. For ease of management and avoidance of misunderstandings, a single maximum lifetime figure for CUCC ropes would be preferable, irrespective of diameter or manufacturer.
2. The lifetime should apply to all CUCC trips, including Expo, with any ropes brought by others onto such trips being subject to the same. Any rope not within the lifetime, including rope stored in Austria, should be taken out of service immediately.
3. Since the policy is for a University club and it is difficult to estimate rope lifetimes (c.f. the next point), the figure should be conservative.
4. Some sources of invisible rope damage (as stated by manufacturers) are particularly prevalent on Expo: substantial ingrained dirt, strong sunlight and prolonged humidity. The combination of dirt, humidity and repeated rope stretching during use is apparently particularly deliterious.
5. Care should be taken not to read too much into the results of drop testing, especially when using it to claim ropes are safe, rather than unsafe. However drop testing is a good simulation of Expo, since anchor and/or rock failure is a real risk there, unlike typical UK sport caving trips.
6. Drop testing results conducted on CUCC ropes in autumn 2016 were poor, including two ropes no older than five years surviving **only one** "standard" fall.
7. More investigation is required to build a better picture of CUCC rope behaviour under drop testing, including new, old, wet and dry ropes. The taking of samples for testing before and after Expo should become standard procedure.
8. There are few manufacturers' recommendations available as to rope lifetime. There are "potential lifetime" claims of ten years, although it seems very likely this is only for light use, as shown by Mammut confirming that 10 years is only acceptable if the rope was used for at most one week each year (much less than typical CUCC use).
9. It should be a priority to improve storage conditions for rope left in Austria at Base Camp between expeditions. Manufacturers assume consistently good storage conditions when making claims about potential lifetimes. Leaving tangled, wet and dirty ropes in piles or bags on the floor of the Tackle Store for extended periods should also be avoided.
10. Rope should be derigged when possible so that it can be washed and checked at the end of the expedition. However if rope must be left in the cave, it seems plausible that keeping it sufficiently deep below the surface so the temperature remains above zero, and in a dry, ventilated place, would not cause undue degradation.

11. The amount of wear and tear imposed on ropes by the expedition, the poor storage conditions in Austria, the 2016 drop test results and the manufacturer's claims as described imply that the maximum lifetime figure should be set very much below ten years.

12. The existing CUCC figure of five years has served the club well for many years. As far as I know there has not been any incident involving the breaking of a rope during this time.

13. The results for 9mm rope in the 2016 drop testing results imply that a University club is caving on ropes with a safety factor of one. This seems an unjustifiable position.

    - The question must be addressed as to whether 9mm and/or 9.5mm rope should be retired *earlier* than five years of age, at least until more testing has been done.
    - A policy could be set whereby 10mm rope is the minimum diameter purchased. Actual 10mm (not 10.5mm) makes little difference to tacklesack size and weight over 9mm but gives a much higher safety margin.
    - Buying 10mm on a 5-year replacement cycle appears cheaper than buying 9mm on a 4-year replacement cycle.
    - If a 10mm minimum is thought too extreme, a 9.5mm minimum could be set, which looking at the Cordes Courant figures still gives a notable increase in safety margin (9 drops compared with 6 when new).

14. Notwithstanding the above points about 9mm, pending further drop test investigations and improvement of storage conditions, five years seems acceptable as the maximum lifetime figure for the present time. The economics of this figure are shown in this document to be acceptable.

15. The Club should also consider whether storage conditions and lifetimes are appropriate for other items of safety-critical gear, for example tape slings and metalwork, in a similar manner to this document. There has been at least one recent incident of poor storage conditions for such items (an entire Daren drum of rusty metalwork discovered in 2016 whose contents had not been dried).

Causes of reduced rope lifetime

It seems likely that rope lifetime is mostly reduced by use but with some component attributable to simply the passing of time. Expedition use is likely to impose the most wear and tear on CUCC ropes, by some margin, with the following being particular hazards:

- Large numbers of people abseiling and prussiking on ropes, especially for entrance pitch ropes of major caves, with corresponding tight knots in place for several weeks.
- Grit being worked into ropes over a period of several weeks without cleaning, sometimes in conjunction with ice. There are frequent reports of very muddy ropes.
- Physical damage due to contact with the generally sharp rock or falling choss.
- Anchor failure due to poor rock, or similar, causing falls onto ropes (some of which may not be reported).
- Exposure to strong UV radiation when being carried around or left rigged on an entrance pitch partially in the sun.
- Long periods left wet or damp due to poor weather; or ice or natural watercourses underground.
- Careless behaviour by individuals leading to ropes being walked on when lying around at Top Camp, etc.

Setting a maximum lifetime for ropes

Some of the hazards to rope, if they cause damage, yield visible or palpable signs (for example, a cut sheath, or a lump). These should be found during a normal rope checking session. CUCC has a good record of checking ropes after each trip, although for the expedition, examination is left until the end.

However some other causes of damage may leave no noticeable signs. As far as CUCC's use of rope goes, the most significant risks here would seem to be grit being ground into the rope, UV radiation and invisible damage due to falls.

It is mainly because of this second class of damage, in conjunction with natural degradation of rope fibres over time, that limits must be set on the lifetime of rope. These limits need to be adequately conservative to reflect the fact that there seems no good way of identifying that invisible damage has not occurred.

In the context of CUCC

It seems appropriate for a university club such as CUCC to adopt a more conservative attitude towards such limits than individuals who cave on rope that they themselves own. CUCC's committee surely has a duty of care towards undergraduate and graduate students, who entrust their lives to the safety-critical gear of the Club.

For many years (I think at least the last two decades) CUCC has retired rope and other safety-critical items after "five years", which typically translates as six expeditions. This figure applies no matter what the diameter of the rope or the manufacturer.

Setting a single lifetime number like this seems sensible for the following reasons:

- It doesn't require any management in order to achieve safety. CUCC is stretched as it is and any system that requires this is doomed to failure. That failure could be someone getting hurt.
- Furthermore, safety-critical systems should in general be kept as simple as possible. It seems wrong to design such systems based on a potentially over-optimistic "gut feeling" view of future failure; instead, a more appropriate methodology would be based on the use of evidence and careful risk assessment.
- A very simple policy is easy to communicate to others and should help avoid misunderstandings. This is particularly important given that the retirement of rope happens at the end of Expo.

If any compromise has to be made on a single lifetime number, the most manageable would seem to be based on rope diameter (for example 9-and-9.5mm versus everything else).

If the lifetime were not to apply to all CUCC trips, including Expo, then the Club would potentially be in the position of not having a coherent story to present to the University as and when required. (Indeed, upon expedition accidents in the past the Senior Treasurer has been hauled before the University authorities to explain himself. Expo may not be an "offical University expedition" but it most certainly is vested in the name of CUCC.) The University authorities have the power to withhold grant money, impose burdensome conditions on, and even deregister CUCC if they are so inclined. As such, to ensure that the Club continues to provide enjoyment for future generations of students—as well as the continuance of the expedition in good standing—all CUCC trips should be subject to the lifetime figure. It's only fair to those who will succeed us.

On the same theme, any decisions made officially by CUCC—for example at a general meeting—should be *implemented* without delay, by ensuring that the stock of rope (whether kept in the UK or Austria) remains in compliance.

CUCC cannot control how ropes brought onto the expedition by others have been treated. Short of an outright ban on such, the only practical policy would seem to be to deem that such ropes can only be used if they are within the CUCC lifetime limit.

Drop testing

Drop testing has been suggested as a means of establishing confidence in ropes. However care must be taken—as explained succinctly by the following email of Mark Dougherty:

> "This scheme relies on a basic assumption, that the test gives a fully representative idea of the condition of the whole rope. I don't believe that assumption is necessarily valid.
>
> A simple counter-example is isolated damage to a particlar part of the rope. The damage might be visible and picked up by inspection or it might not. This whole discussion revolves around the basic premise that a rope can look OK but in fact not be OK. You can't simply reverse that argument and say "if one bit of the rope is OK, so must all the rest be".
>
> Apart from isolated damage (possibly cause by abrasion, falling etc.), ropes are not used or worn equally throughout their length. The bits near the end don't tend to get abseiled/prussiked on much, but on the other hand they get knots tied and loaded on them much more. Or they can get coiled and hung up in the sun, with the outside coils getting toasted while the inside ones are in the shade (or any one of a hundred other things which might lead to uneven deterioration over the length of the rope). Obviously we want to try and test the weakest part of the rope (a chain is only as strong as its weakest link), but what empirical evidence is available which suggests that the middle of the rope is necessarily going to be the weakest part?
>
> Busting one piece of rope also gives you only one piece of data. Obviously you try to control the experiment and make it as "standard" as possible, but there will still be experimental variation.
>
> So I'm sceptical about drop testing as a very useful tool for improving safety. A more pragmatic approach is to have a large safety margin and use ropes for caving which are much stronger than the loads likely to be applied to them, so that unexpected damage or wear is not disastrous. That's a practical approach which has served the caving community excellently over the years."

Drop testing can reasonably, however, be used to build up a picture as to how ropes degrade over time. It can also be used to determine that particular ropes are not fit for use any longer. In autumn 2016 Martin Green had samples of CUCC rope tested using BCA's portable drop testing rig during EuroSpeleo / Hidden Earth. The results were as follows:

Rope	**Diameter (mm)**	**Age (years)**	**Falls survived**
2012 CUCC crossed out	9	4	1
CUCC 2011 11m	9	5	1
CUCC 2010 10m	9	6	2
CUCC 2011 24m	10	5	10
CUCC faint 2009 19m	10	7	3
CUCC 2008 7m	10	8	8
CUCC 2008 32m	10	8	2
CUCC 2010 39m	10.5	6	4
CUCC 2011 66m	11	5	17
CUCC 2009 19m	unknown	unknown	1

(*Methodology, quoted directly from BCA email:* The tests was conducted using a wet 0.8m overall length sample and used a Fall Factor 1.0 drop each time with a 100kg test mass. EN 1891:1998 requires that a SRT rope can survive at least 5 drops using a 2m long sample. Whilst Type A ropes must achieve this with a 100kg mass, Type B uses a 80kg test mass. I always use a 100kg test mass as most cavers dressed for caving weigh more than 80kg. In addition, the standard requires the test to be done on a specially conditioned dry rope. As wetting the rope will reduce the number of drops survived by around a factor of two, I conduct tests using a rope which has been immersed in water for at least two hours. But the reduced length of the samples I use to test do not impart the same impact on the rope. Some work

suggests this over estimates the drop survivability of the rope. EN 892: 2012 requires a dynamic rope to survive 5 drops though in a slightly different configuration to that required by EN 1891:1998.)

The fact that some of the ropes tested only survived one fall is obviously concerning – this indicates a safety factor of one. Furthermore, how do we know that these were the worst ropes in CUCC's arsenal at the time? We don't.

The quoted methodology suggests that drop test results may be influenced by a factor of two by wetting the rope. For this reason and owing to the results obtained it seems that a larger-scale programme of testing CUCC ropes would be valuable to instigate. New, mid-life and old ropes should be included. It is important to include new ropes to see how the experimental testing correlates with manufacturers' number-of-falls figures (which at least some manufacturers do provide).

Such work should help calibrate drop testing against manufacturers' claimed numbers and provide useful insights—although, as above, care would be needed not to over-interpret the results. Conclusions might be able to be drawn of the form, for example, that some particular manufacturer's rope tends to fare poorly.

It seems unlikely that a sufficiently large corpus of ropes can be obtained from CUCC to obtain statistically-significant estimations as to reasonable retirement ages (for some requested factor of safety). This would be very interesting work to undertake, if it were found feasible, but it seems most unlikely to happen in the near term.

Storage conditions in the UK

The conditions in the tackle store, when ropes are chained and hung up, seem to be in line with manufacturers' recommendations. Temperatures for the most part will be moderate, there is good ventilation, ropes are not tangled or knotted, and nothing is stacked on top of the ropes. The only notable exception seems to be that Mammut recommend ropes are stored between 15C and 25C.

Rope, however, gets left in piles and sometimes in bags after trips for extended periods of time. In some cases there are probably tight knots left in the ropes. These storage conditions are not in line with manufacturers' recommendations.

Storage conditions in Austria

A fairly large amount of rope is left in Austria each year. The majority is kept in the roof of the Potato Hut in lidded plastic drums. The drums have some small holes in the sides with a view to emitting air.

Ropes should be washed, checked, cut and dried at the end of the expedition before being packed in the drums—although it should be noted that it is perfectly possible for it to be infeasible to dry rope at the end of the expedition due to the weather.

On arrival in Austria in either 2017 or 2018 (I don't recall which for certain), the drums were opened to reveal a large quantity of musty-smelling damp rope. It seems clear that such storage conditions run counter to manufacturers' recommendations with respect to storing ropes in ventilated conditions without excess humidity. Furthermore, since the temperature almost certainly fluctuated around zero for some duration, it seems probable that forces were exerted on the ropes internally due to the formation and subsequent melting of frost.

Storing rope tightly packed in drums may also run contrary to recommendations about avoiding tangles and pressure on ropes from above during storage. It probably depends how tightly they are packed in.

Storage conditions at Base Camp should be changed to conform to manufacturers' guidelines. We could ask the Gasthof if they could provide a better place for rope storage, preferably somewhere in a shed, where it could be hung up as in the tackle store.

Some rope probably ends up being left in caves in Austria across the winter; although this should be avoided as much as possible so rope can be washed and checked. Areas that are deep enough to be away from the freezing conditions induced by the low surface temperatures seem like potentially acceptable storage locations so long as the rope can be kept dry and well-ventilated. Leaving rope on pitches that may flood during the winter, or in mostly-sealed bags, should be avoided.

It should be noted that it is unclear why humidity is cited by manufacturers as something that degrades rope over time during storage. It sounds as if, during use, humidity exacerbates the ingress and action of grit inside a rope, particularly when being stretched repeatedly as it might be during prussiking. However this doesn't explain humidity during periods when the rope is being stored. This point could be worthy of future investigation, although as far as CUCC policy goes, the manufacturers' guidelines should probably be taken at face value.

Manufacturers' recommendations

Current recommendations

These were collected from data sheets on manufacturers' web sites in June 2019.

Beal "Antipodes": "The potential lifetime of this product in use is 10 years. Attention: This is only a potential lifetime, a rope could be destroyed during its first use. It is the inspections which determine if the product must be scrapped more quickly. Proper storage between uses is essential. The lifetime of the rope in use must never exceed 10 years. Abrasion, UV exposure and humidity gradually degrade the properties of the rope."

Cordes Courant "Equirial": The following specifications were given. Some of the numbers differ between the HTML and PDF versions.

- Certification : CE EN 1891 type A
- Diameter : 9, 9.5, 10, 10.5, 11 mm
- Mean breaking strength : 22.3 (23.3?), 27.9, 31.8, 32.4, 33.5 kN
- Resistance with figure-eight knot : 15, 17.9, 20.4, 22, 23.2 kN
- Elongation 50/150 Kg : 3.9, 4, 3.8, 3.6, 3.9
- Weight per metre : 53, 61, 66, 73, 75 gr
- Knotting quality : 0.9, 0.8, 0.9, 0.85, 0.7
- Sheath percentage : 47, 41, 43, 40, 39.5
- Fall number : 6, 9 (or 6?), 11, 14, 18

(9mm and 9.5mm are "type B", fall number corresponds to 80kg; 10mm and above are "type A", fall number corresponds to 100kg.)

Lifetime stated as 10 years: "Ropes have a potential life of 10 years from the date they are manufactured. The actual life of a product has ended when it qualifies for rejection (see diagrams). The following are factors that can influence the actual life of a product: intensity, frequency of use, usage environment, the user's competence, maintenance, storage, etc..."

"The range of temperature that the product is designed to be used in is between approx. –35C and +55C."

Storage and transport: "After usage, store the rope in a bag that protects against ultraviolet rays, humidity, chemicals, etc... Whenever possible, use ventilated bags to evacuate excess humidity."

Storage pictograms:

- Do not flatten (no weight on top)

- Keep away from heat (presumably this means severe heat given that the storage temperature seems to be given as -35 to +55C)
- Ventilated

Gleistein: On internal rope wear: "It is most often caused when grit becomes trapped in a rope which is repeatedly flexed in wet conditions."

I didn't find any documentation as to manufacturer's approved rope lifetime, which is surprising, as there is an EU directive requiring the provision of such information.

Mammut "Performance Static": 10 year service life so long as frequency of use doesn't exceed one week per year. "Frequency of use is only ONE factor that influences the approximate durability. The actual service life depends solely on the condition of the product which is influenced by various factors. Invisible internal wear can be caused by flexing or repetitive loading phenomena that are aggravated by moisture or accumulation of solid particles."

They have "wet ropes" on a list of hazards to the rope (the others include chemical damage, shock loading, etc). Also "tangles".

Mammut notably states 15-25C for storage, which seems a reduced range compared to other manufacturers.

Recommendations from 2012

The following is from Abaris, a rope access equipment supplier; it appears the information was collected in 2012.

Beal Lifetime = Time of storage before first use + time in use (Beal ropes / cords can be kept for 5 years before first use without affecting its future lifetime duration in use). Beal Semi-static rope lifetime: Intensive and daily use 6 months, Daily use of average intensity 1 year, Weekly and intensive use 1 year, Weekly use of average intensity 2 years, Periodic daily use of use average intensity 3 years, Several uses during the year of average intensity 5 years, very occasional light use 10 years.

Edelrid Total shelf-life assuming ideal storage conditions and no use is 12 years from date of manufacture (Storage life before first use without depreciation of maximum useable life is 2 years from date of manufacture). Occasional and appropriate use without obvious wear and tear and with optimal storage is 10 years.

Mammut rope lifespan unused and optimally stored 10 years. Rarely used (Twice a year) 7 years. Occasional (Once a month) 5 years. Regularly used (Several times a month) 3 years. Frequently used (each week) 1 year. Constantly used (almost daily) less than 1 year.

Observations on manufacturers' guidelines

- Manufacturers' guidelines as to how much rope can be used without compromising its lifetime vary. However the impression I get is that a 10-year lifetime is only expected to be attained if (a) storage conditions are consistently good and (b) the rope has had relatively light (albeit extended) use. For example, typical usage of a CUCC rope over one year far exceeds the current Mammut manufacturer's statement of maximum one week per year usage, to attain 10 years' life. This is approximately consistent (maybe slightly less conservative, but ropemaking techniques may have advanced) with the more detailed manufacturers' statements from 2012.
- The 2012 guidelines from Beal and Mammut tend to indicate that an appropriate lifetime for CUCC rope would have been five years at that time. Even increasing that to seven years would drop Mammut's permitted uses down to only two trips a year. (And this is presumably assuming good storage conditions.)
- At least for Mammut, which is the only data point available, there appears to have been an increase in permissible usage for a given lifetime since 2012. Their current guideline

for 10 years, of one week's usage per year, appears to correspond to around 6 years back in 2012. However a single data point must be treated with low confidence (especially given that there could have been subjective variation within the firm of Mammut itself, too, as regards the statement of the guidelines).

Economics

The cost of replacing rope (and indeed other safety-critical equipment) should be taken into account when deciding which trips are within the Club's reach. This of course includes objectives for forthcoming expeditions.

Costs should not be used as a way of arguing for extended rope lifetime. Instead, an acceptable safety standard should be decided upon (based on other factors), and then funds raised accordingly and/or objectives restricted. Remember the old adage from the airline industry: "if you think safety is expensive, try having an accident".

In CUCC's case it is unlikely that objectives would have to be restricted given the relatively low costs involved and, in particular, the way some portion of them are split between expedition members. Suppose for example that Expo needs 2500m of rope on a 5-year replacement cycle, so 500m a year. Even without bulk discounts, that works out at around 700 GBP per year, of which at least half (possibly more) could presumably be covered by CUCC's Societies Syndicate grant—which is awarded specifically for safety-critical gear.

So this leaves 350 GBP to be split between expedition participants per year. Let's suppose there are only 20 people, which is on the low side. This would mean the average cost per participant for rope is around 18 GBP. If the replacement cycle were say 10 years instead, it would fall to 9 GBP. So the difference is centred around 10 quid per participant per year (some might pay a bit more and some might pay a bit less depending on how long they come to Expo for). This is an order of magnitude less than expedition costs per week. Even for people coming for several weeks, it seems unlikely the cost is going to go beyond four or five pints of beer, *per year*.

No material reduction in safety can be justified for such a small cost.
