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TECHNICAL COMMITTEE

NOTE 04/03

HOW STRONG DOES YOUR CLIMBING GEAR NEED TO BE?

SUMMARY:

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HOW STRONG DOES YOUR CLIMBING GEAR NEED TO BE?

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Introduction

By "gear" I am meaning ropes, karabiners, slings, chocks, etc, all items which come under the heading "equipment to protect against falls from a height" in the jargon of the European Directive on Personal Protective Equipment. One answer to the question could justifiably be: strong enough to satisfy the requirements of the standard for the item concerned, because to support the Directive there are European standards that specify the safety requirements and test methods for each item of equipment. But examination of the standards does not get to the fundamentals of the question. The standard for slings specifies a minimum strength requirement of 22 kN, for connectors (karabiners) the requirement is 20 kN for most types when tested with the gate closed, whereas for chocks the requirement is 2 kN, and the rope standard does not specify *any* strength requirement at all. Far from clarifying the matter, studying individual standards is only likely to confuse. Standards are utilitarian documents; in general they do not explain *why* they are the way they are.

The Safety System and Individual Components

It might be nice to think that somewhere there is a standard laying down the requirements for the complete safety system. But in reality this is not possible; the requirements would differ depending on the route being attempted. Although climbers do not design the safety system, they construct the safety system every time they climb a route. And the level of protection they provide on one pitch may be very different from the level of protection on another, especially on traditional routes with leader-placed protection. Every time a running belay is placed, the safety system is changed, and the level of protection provided increases (one hopes). The further you climb beyond that runner, the more the level of protection decreases, even though the strength of the runner has not changed. At some stage, on a single pitch climb, falling off may mean hitting the ground. In this case, how strong your gear is becomes of no relevance.

In a situation where climbers create their own safety system as they climb, it might seem impossible to say how strong the gear needs to be, since it all depends on how and for what purpose it is used. But this is not really any different from other activities where standard components are available. In industry where heavy loads have to be lifted, every crane will have its maximum working load clearly marked, and the limitations to its use defined. The nearest we have to that in climbing gear is the chock. Chocks are produced with breaking strengths of 2 kN, 5kN, 7kN, 10 kN, 15 kN, or more. What is missing in the instructions is *any indication of the situation in which any particular strength of chock should or should not be used.*

Comparison of Chocks and Slings

Whereas chocks come in a range of strengths, all slings, irrespective of shape, size, or purpose, have a minimum strength of 22 kN as demanded by the standard. But where is the logic in this? If a chock strength of 7 kN is acceptable, why shouldn't the sling attached to it (and karabiners also) be acceptable at this strength? So why shouldn't slings be manufactured with strengths of 2 kN, 5kN, 7kN, 10 kN, 15 kN, etc?

Different approaches to standards

The above comparison highlights two fundamentally different approaches to standards for safety-related equipment, viz.:

A. investigate the worst conceivable loading that can be applied to an item, in the worse case accident scenario, demand that value (with some margin) as the minimum strength requirement for all components of that type.
B. Investigate the range of loadings that can arise in different definable accident scenarios, allow a corresponding range of strengths in the standard, and provide information to enable the user to choose the component strength appropriate to the anticipated accident scenario.

There is also a third approach, which is often the way the first standards are produced, when there is limited information available:

C. The pragmatic approach: survey what equipment is available on the market, find out what works well, and what frequently fails, and define a standard which separates the good from the bad.

Several of the standards developed in this way, and then as more experimental data became available there was a change to approach A.

This orderly progression did not always occur. Prior to the European Directive on PPE there was no legal requirement for mountaineering equipment to meet the requirements of the UIAA standards, the only standards available at that time. Manufacturers were free to produce whatever climbers demanded, and in the late 70s and 80s that was lighter and lighter karabiners. With the method of manufacture at that time, this meant weaker and weaker karabiners, especially in gate-open strength. Karabiners started breaking more frequently than before, until this design trend was reversed. This led to a minimum gate-open strength requirement of 7 kN in the current standards. Although this has not stopped karabiners from breaking, breakage is now more infrequent and for different reasons. Fortuitously, the experimental work done at that time has added to our understanding of the loads applied to running belays in typical climbing falls.

Most (but not all) of the standards for mountaineering equipment are based on approach A, a single minimum strength requirement that covers all eventualities. This works very well in many cases. The best example is the sling standard. Modern slings of 22 kN strength are so light and relatively cheap that there is no incentive to produce slings of different strengths. And this is to the benefit of the climber, since he knows that all his slings will be strong enough for whatever purpose. Although logic might suggest that 7 kN slings should be linked to 7 kN chocks, and 10 kN slings to 10 kN chocks, as mentioned earlier, in practice this would be a nightmare, and the climber is much better off with a sling standard where one strength covers all. The approach is simple, avoids mistakes, and does not require education of the climber. There are strong advocates of approach A to the standards; the argument has been put bluntly that, “Climbers are stupid. If the standard allows for a lower strength component in some circumstances (which usually will have a lower weight), then they will use this component all the time, and there will be accidents. So we must only allow one minimum strength which will cover the worst conceivable loading.”

Unfortunately this simple straightforward approach cannot be applied to chocks or camming devices. Because they have to fit into a range of sizes of crack, obvious physical constraints apply. Unless small devices are made from very special (expensive) materials, inevitably they will be less strong. To cover the worst conceivable case the strength requirement would have to be set at about 20 kN, and this is clearly impracticable, if not impossible. But experience tells us that such a strength is generally not necessary. At some time, most of us will have survived on a chock of 7 – 10 kN strength, so 20 kN is clearly not *essential.* Some may have survived on chocks of 3 or 4 kN strength, but that cannot be depended upon! What is clear is that this range of sizes and strengths all have their uses, but some can be relied upon more than others.

This created a problem for the advocates of Approach A when the EN standard for chocks was being written. They would have banned chocks below a certain strength, and this created panic in the UK climbing press at the time, with stories of RPs being banned, etc. Due to the collective efforts of the UK delegates at the time, this was avoided, and a wide range of strengths was allowed (2 kN minimum for chocks, 5 kN minimum for camming devices). Several of us were aware of the inconsistency between these standards and some of the others, but owing to the pressure to get all the standards finished, the problem was put on the back-burner at that time. But the problem has not gone away, and this paper attempts, amongst other things, to address the problem.

Do "Levels of Protection" apply?

In writing a standard, the rules allow different levels of protection to be provided within one standard. For example, industrial heat-resistant clothing covers different categories depending on the temperature and time of exposure to be protected against. So perhaps this concept could be applied to chocks and camming devices. But it soon becomes apparent that this concept does not really apply in climbing. One does not choose the chock strength depending on the level of protection needed. Whether one places a chock at all is dependent on a mental assessment of the hazard involved, and one's ability to overcome the hazard. Once it has been decided to place a chock, the choice is dependent on the features of the rock. The strength of the chock is whatever it happens to be, and may be a source of mental comfort or concern, as the case may be! The point is that a chock is chosen primarily for its size, not primarily for its strength.

In addition, in climbing the "level of protection" is not easy to define, let alone relate to chock strength. Protection against what? If a climber climbs 10m and places a 15 kN chock, that might *seem* to provide a high level of protection. But if the climber continues for 5m, falls off, breaks his leg on a projecting rock before the rope comes tight, the chock has provided no protection against him breaking his leg, though it may have protected him from dying by stopping him falling another 20m.

Categorisation by Failure Strength Bands

The alternative approach proposed here is to categorise chocks by putting them into a small number of failure strength bands. The boundaries between the failure strength bands will be chosen such that the performance of a chock in any particular situation can be defined by the strength band it is in. By performance here I mean whether the chock will survive all possible loads without breaking, or whether the user can confidently expect it to survive, or whether the probability is that it will fail, etc. Although these definitions cannot be precise, the information should give the climber the information he needs so that he can feel confident, or not, about the strength of the chock he is using, in any particular situation.

This categorisation applies equally to camming devices as to chocks. It can also be applied to all pieces of climbing gear in the safety system, and in the process of defining the strength bands it answers the question: "How strong does your climbing gear need to be?" It will become apparent that how strong an item needs to be depends on where it is placed, and hence some items of climbing gear do not need to be as strong as others.

The Determination of Failure Strength Bands

To decide on suitable strength bands it is necessary to analyse the full range of possible climbing falls. To start, we can ask, "What is the worst conceivable fall that the safety system is designed to protect against, and what are the forces that are generated?" But it is a presumption that the system ever was *"designed".* More realistically, like Topsy, it just grew. In the beginning there was only the climbing rope, and it is still the case that without the rope there is no safety system, everything else is just an add-on. So it is sensible to start with the rope and enquire what the rope is designed to do, and how strong it needs to be.

EN-892	DYNAMIC MOUNTAINEERING ROPES	UIAA-101

This representation of EN 892 and UIAA 101 does not contain the full details of the test methods and requirements in these standards; it gives only a simplified pictorial presentation.
For full details, EN 892 and UIAA 101 should be consulted.

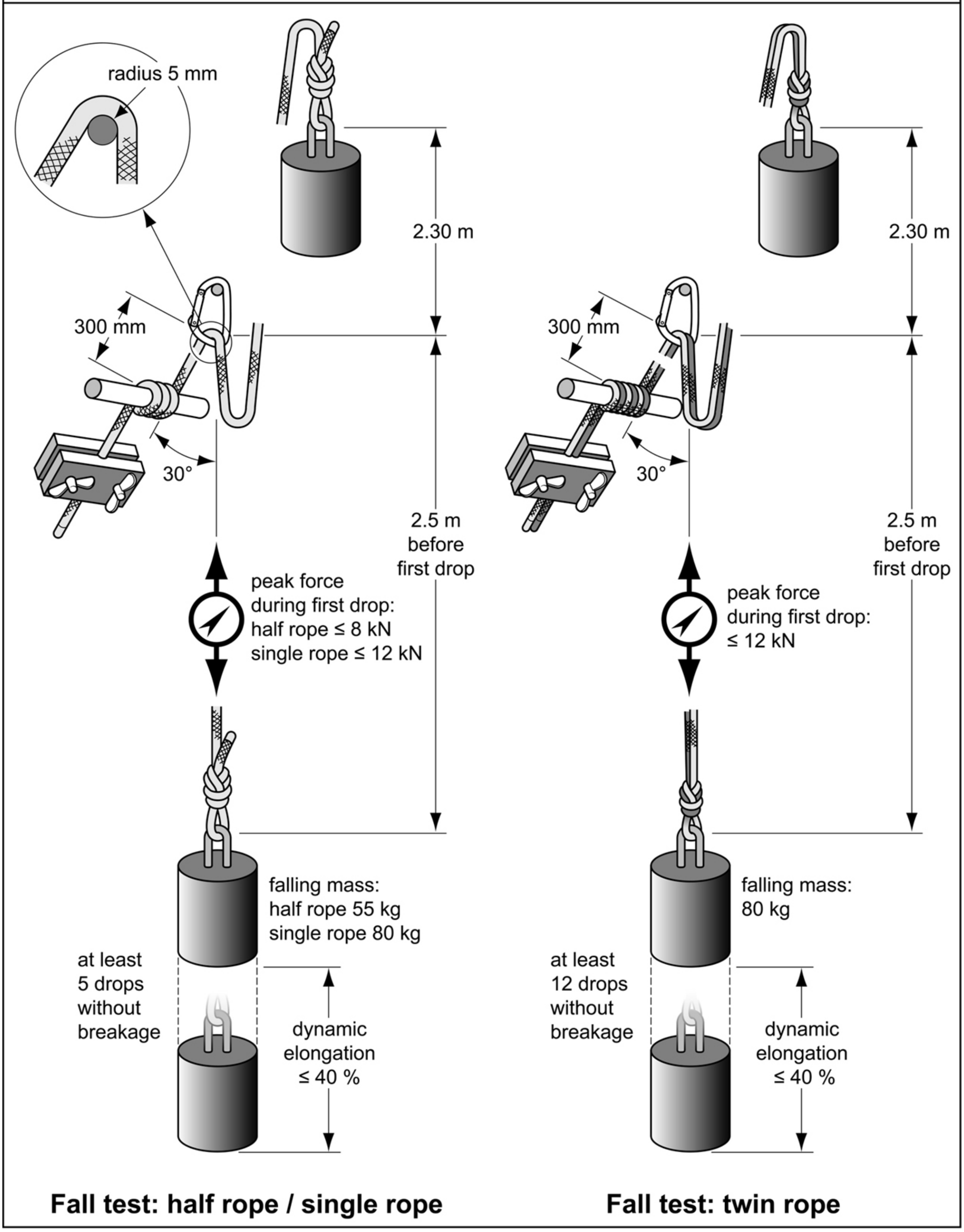


Fig 1 Essentials of the Standard Drop Test for Mountaineering Ropes

Maximum force in the worst conceivable accident

The rope is designed to meet the requirements of the rope standard EN 892. In the context of forces in worst conceivable accidents, it has to survive five consecutive drop tests simulating a near fall-factor 2 fall with the rope running over a karabiner next to the stance, and a static belay. The peak force the rope applies to the falling mass shall not exceed 12 kN on the first drop. The essentials of the standard drop test are shown in figure 1. This test and the requirement on the force in the rope define the highest force that can arise in the worst case design basis accident. I say “design basis” because it is possible for more severe accidents to occur, but these are outside the design basis for the safety system (in so far as there is a design basis). For example, the rope to the climber could jam in a crack during the fall, reducing the effective rope length, and producing a fall-factor greater than 2. In this case a higher force will be generated, but also the rope could be cut through by the rock. In either case this is outside the design basis. Some other points should be noted about the drop test:

- The test uses an 80 kg falling mass. Some time ago, tests were done which showed that the peak forces were approximately the same as would arise with a 100 kg (15½ stone) falling human body. Any climber whose mass, complete with rucksack, climbing gear, etc, exceeds 100 kg will produce higher forces in the worst conceivable accident.
- The test is done on a brand new rope. Well used ropes may stiffen up and produce higher forces, or may become floppy and generate lower forces. There is no firm evidence on which to base a change from 12 kN. In any case, modern ropes are tending to produce peak forces significantly lower than 12 kN, so there is no reason to increase this figure for used ropes.

From the above, the highest conceivable force in the rope to the climber is 12 kN, and the worst loads on other items of the protection system can be derived from this value.

Maximum force on the climber and at the stance

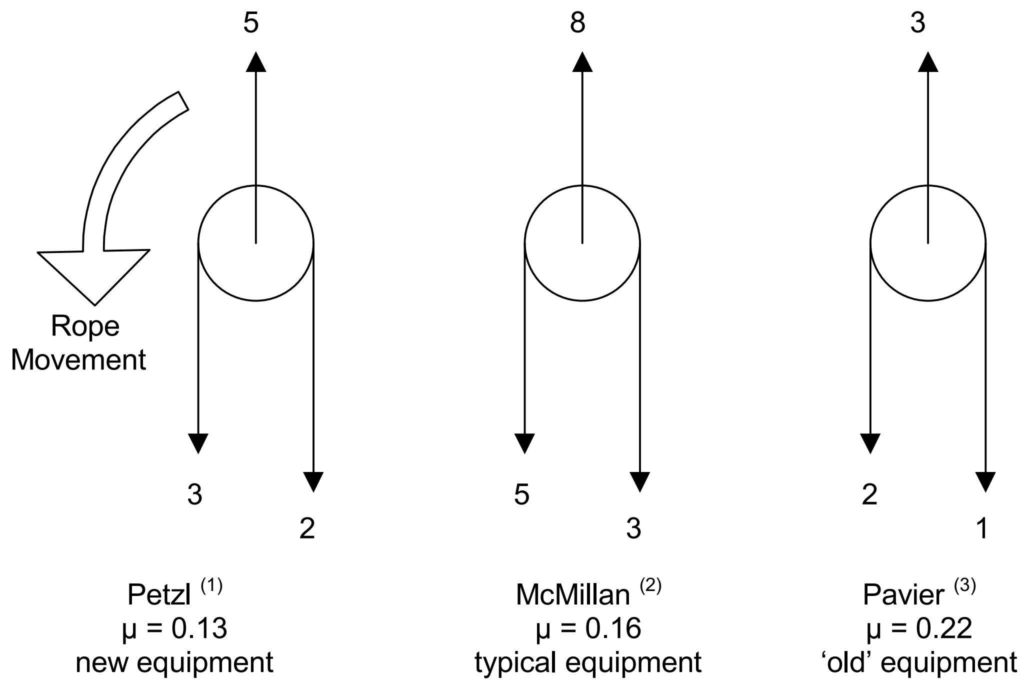
The force in the rope is obviously applied to the falling climber and his harness, and also to the belay device and its anchorage at the stance. Since failure at any of these points would be potentially catastrophic, all equipment which could be used at these points should have a minimum failure strength of at least 12 kN. This includes harnesses, connectors, belay devices, slings, safety pitons, rock anchors, chocks, frictional anchors, and ice anchors. Although dynamic belaying devices should reduce the load significantly, the peak load of 12 kN could arise in theory, if the device blocks due to the rope jamming or a knot forming at the entry to the device.

If there were a running belay, as in the drop test, the force the rope applies to the stance would be reduced. But there may not be a running belay, or it may fail, and because security at the stance is essential it would be unwise to consider a highest force less than 12 kN.

Maximum force on a running belay

The maximum force on a running belay would be generated where a climber clips the rope through a karabiner directly above the stance, climbs upwards and falls before placing any further protection. If the karabiner acted as a frictionless pulley, the maximum force on the runner would be 24 kN, due to the pull of the rope on both side of the karabiner. But the force will be reduced due to the effect of friction as the rope is pulled through the karabiner. This effect is illustrated in figure 2, where the ratios of the forces in the two parts of the rope and the total load on the karabiner are given The highest load on the karabiner (and hence the runner) would arise with the lowest friction, which would be given by a new rope and a shiny karabiner. Petzl data for this case gives a force on the runner of 20 kN for a force of 12 kN in the rope to the falling climber (see table 1). Using this value, all the equipment associated with the running belay needs to be able to withstand a force of 20 kN.

Although slings, and connectors can achieve this failure load, and rock anchors might (depending on direction of pull), chocks, frictional anchors, and ice anchors are not designed to withstand such a high load. This does not mean that such devices do not provide adequate protection; it is simply an indication that with dynamic belaying, the load on a running belay is generally much less than 20 kN. To decide what strengths are required in running belays, it is necessary to investigate the range of forces generated with dynamic belaying.



[1] Petzl catalogue 1999
[2] McMillan – measurements on own equipment
[3] Pavier – private communication regarding research at Bristol University

Fig 2   Force ratios for a rope being pulled through a karabiner

Table 1 Runner force with a *static belay*

Peak force in rope to falling climber	**New equipment Low friction (Petzl)**	**Typical equipment Typical friction (McMillan)**	**Well-used equipment High friction (Pavier)**
12 kN	20 kN	19.2 kN	18 kN

Forces on running belays when using dynamic belaying

For a complex geometry, with many running belays, the calculation of forces is very complicated. A full analysis must await the outcome of the research work on belaying methods currently being conducted by the Italian Alpine Club, CAI-CMT. In the meantime a simple approach will be adopted. What is needed is estimates of:

- The highest force likely to be generated on a running belay
- A typical force generated on a running belay in a simple geometry
- The lowest force generated on a running belay

The peak force generated in the rope at the belay device depends on the type of belay device in use, and the amount of hand force being applied by the belayer. Experimental measurements have indicated that the peak force generated in the rope is very unlikely to exceed 4.0 kN at the belay device. Research in the UK, using popular belay devices, has shown that the peak force in the rope, using popular dynamic belay devices (not the GriGri), does not exceed 2.5 kN, and is generally no more than 2.0 kN.

For a simple geometry of a single running belay, with the ropes running vertically, the forces can be calculated as before, but again depend on assumptions about the friction between rope and karabiner.

Taking the values 4 kN and 2.0 – 2.5 kN as high and typical forces generated in dynamic belaying, and using the force ratios above, the loads on the running belay are given in Table 2.

Table 2: Runner force with *dynamic belaying*

	New equipment Low friction (Petzl)	**Typical equipment Typical friction (McMillan)**	**Well-used equipment High friction (Pavier)**
Highest belay force 4 kN	10 kN	10.7 kN	12 kN
Typical belay force 2 - 2.5 kN	5.0 – 6.25 kN	5.3 – 6.7 kN	6.0 – 7.5 kN

From the table, the "highest" force on the running belay is 12 kN, with dynamic belaying. Current information from the CAI research is that the maximum force they have measured on a running belay is less than 12 kN, which supports this figure as an upper bound. This is very fortuitous for setting strength bands, since it happens to be the same as the worst conceivable load on the stance with a static belay.

Also from the table, the highest "typical" load on the runner is 7.5 kN. However, test work done in the UK in the 1980s to determine the necessary gate-open strength of karabiners attached to running belays, showed that karabiners with a 6 kN gate-open strength could fairly easily be broken, using dynamic belaying in simple geometry, whereas 7 kN karabiners could not. That work suggests that, in practice, 7.0 kN can be taken as the minimum strength requirement to survive the typical force generated in dynamic belaying.

Minimum loading

The lowest force on a running belay has been investigated by Schubert (4). If the karabiner of the running belay is close to the rope attachment to the climber's harness, and the climbing rope is not tight but there is minimum slack, if the climber falls, the minimum load on the runner is 3.0 kN. This is the minimum fall that a climber can make, and suggests that the minimum acceptable strength for chocks should be raised from 2 kN to 3 kN. However, there is an argument that these very small chocks, that fit in cracks where nothing else will fit, can be used in twos and threes, connected together in such a way as to share the load. This does not change the experimental evidence that the absolute minimum load on a running belay is 3.0 kN using dynamic belaying.

Strength Requirements

Based on all the above analysis the strength requirements for climbing gear associated with a stance, and with running belays, can be put into bands as shown in table 3. These bands apply particularly to chocks and camming devices, but could also be applied to ice screws, pitons, bolts, etc.

(4) Private communication from Pit Schubert concerning research by the German Alpine Club

Table 3 Failure Strength Bands for Climbing Gear, particularly Chocks and Camming Devices

Failure Strength S	At a Stance	As a Running Belay
S ≥ 20 kN	If used correctly, sufficiently strong to withstand the highest conceivable forces generated in a fall.	If used correctly, sufficiently strong to withstand the highest conceivable forces generated in a fall.
20 > S ≥ 12 kN	If used correctly, sufficiently strong to withstand the highest conceivable forces generated in a fall. **Rock 2 or bigger** **Friend 0 or bigger**	If used correctly, sufficiently strong to withstand the highest conceivable forces generated in a fall, provided a dynamic belay is in use and effective. **Rock 2 or bigger** **Friend 0 or bigger**
12 > S ≥ 7 kN	Not recommended. In an emergency it can be used provided it is backed up with a device of similar strength in such a way as to share the load. **Rock 1** **Friend 00**	If used correctly, sufficiently strong to withstand typical forces generated in a fall, provided a dynamic belay is in use and effective. It cannot be relied upon to withstand the highest forces that could be generated in a fall. **Rock 1** **Friend 00**
7 > S ≥ 3 kN	Not suitable for use at a stance. **Micro-chocks**	Even if used correctly, and with a dynamic belay in use, it cannot be relied upon to withstand typical forces generated in a fall. Wherever possible, it should be backed up with a device of similar strength, in such a way as to share the load. **Micro-chocks**

Currently, most items of climbing gear, except chocks and camming devices, are not affected by the concept of failure strength bands. For example, slings and most types of karabiner are in the highest strength category, 20 kN or greater. However, the EN standard for ice screws specifies one strength only – 10 kN minimum (15 kN minimum in the UIAA standard). But there is no logical reason why ice screws of different strengths could not be produced and categorised by the failure strength band.

The harness standard requires a minimum strength of 15 kN (though currently the test only specifies an upward pull direction). This is consistent with the foregoing analysis, since the worst conceivable load is 12 kN.

Conclusion

- The reasoning and analysis in this paper, and the strength bands proposed, form a rational way of deciding what strength is needed for your climbing gear in any particular situation, that is, how strong your climbing gear needs to be.
- The strength bands are of greatest relevance to chocks and frictional anchors, but could also be applied to ice screws, pitons, etc.
- It would be very advantageous if agreement could be reached with manufacturers on a means of indicating the strength band, by colour coding perhaps, so that the strength band is readily apparent to the climber. This information should also be included in the instructions for use.
- If the use of strength bands is going to gain popularity, some catchy names need to be formulated to indicate the strength bands or categories.

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