Sharp edge testing of mountaineering ropes

1 Introduction

1.1 Correlation Sharp edge testing – UIAA Working Group

This report and the investigation is a contribution to the work of the UIAA Working Group (WG) Sharp Edge. For many years the WG Sharp Edge has been working on this subject. There have been done quite a lot of investigations to collect enough basic know how. For many different reasons it was not possible to define a test method which could be accepted by the UIAA Safety Commission (SAFCOM).
The results of this will now be presented to the members of the WG. The report gives an overview to this subject and shall be a platform for discussions and future activities of the WG.
The target is to prepare a proposal for a new UIAA-standard of sharp edge testing based on all the reports of this subject.

1.2 Why do we need a sharp edge standard?

The investigations of Pit Schubert (President of the UIAA SAFCOM) and others about mountaineering accidents with ropes tell us that the influence of sharp edges (rocks) is the most common reason for rope breakage

Other reasons are:

- Contact of ropes with battery acids
- Melting of yarns under load and friction of rope on rope (or rope on tape)

The principle target of the UIAA SAFCOM is to improve safety standards of climbing equipment. The introduction of a sharp edge test in a new standard could become an additional requirement for ropes with a higher safety potential. The end user will get a better classification of ropes to select the right rope for the right application.

1.3 Distinction: cutting proof – sharp edge proof

The terms 'cutting proof' and 'sharp edge proof' are often mixed up or misinterpreted.
When talking about rope breakage with influence of sharp edges, we may consider, that there is always a combination of cutting action and sharp edge load. Especially on falls with a swinging action (lateral movement) over sharp edges we find rope breakage.

The standard for protective gloves against mechanical risks (EN 388) defines cutting proof as follows:

- Number of cycles with constant speed until the test-sample is cut through

Analogously we may define sharp edge proof as follows:

- Withstanding one drop under sharp edge load
  (r = 0.75mm, H = 4.80m, m = 80kg)

<u>or</u>

- Reaching a limit breaking energy of minimum 5.5kJ under sharp edge load
  (r = 0.75mm, H = 4.80m, m = 80kg)

But, just defining of the term 'sharp edge proof' does not bring us to a new standard. More important is to work out an accepted test method which fulfils the following basic demands:

- reproducible (on repetition under same circumstances)
- selective (distinction between good and bad)
- simple (test method is comprehensible)
- quantify

1.4 Results of former investigations

The following are the most recent investigations:
- Carlo Zanantoni – Sharp edges tests on DODERO with variation of radius and fall factor
- Mammut / Beal – Proposal for a standard and sharp edge tests on DODERO with / without catch plate
- Radek Faborsky - Sharp edges tests on DODERO with variation of fall factor and falling weight

The above mentioned investigations were done in accordance to the drop test apparatus DODERO of EN 892. The following parameters were changed:
- fall factor (falling height)
- geometry an radius of the sharp edge tool
- weight of the falling mass
- with / without catch plate

The main experience of all these investigations is, that the distinction between a 'good' rope (high dynamic performance and sharp edge proof) and a 'bad' rope (inferior dynamic performance) is not explicitly possible with the applied test methods. They are not selective enough. The investigation by Zanantoni shows the lack of this correlation.

1.5 New targets

This investigation follows some new approaches:
- measuring and calculating the energy absorption until rope breakage
- static tests with different arrangements
- sharp edge tests without friction over the edge (symmetric arrangement)

All test series were done with Mammut ropes with a diameter from 9.0 to 11.0mm. An additional sharp edge test was done with several 'sharp edge proof' ropes from other manufacturers

2 Test basics

2.1 Standard for dynamic mountaineering ropes prEN 892:2001

The drop test apparatus (DODERO) and test method is defined in the standard prEN 892:2001 §5.6. The following figure shows the geometric construction:

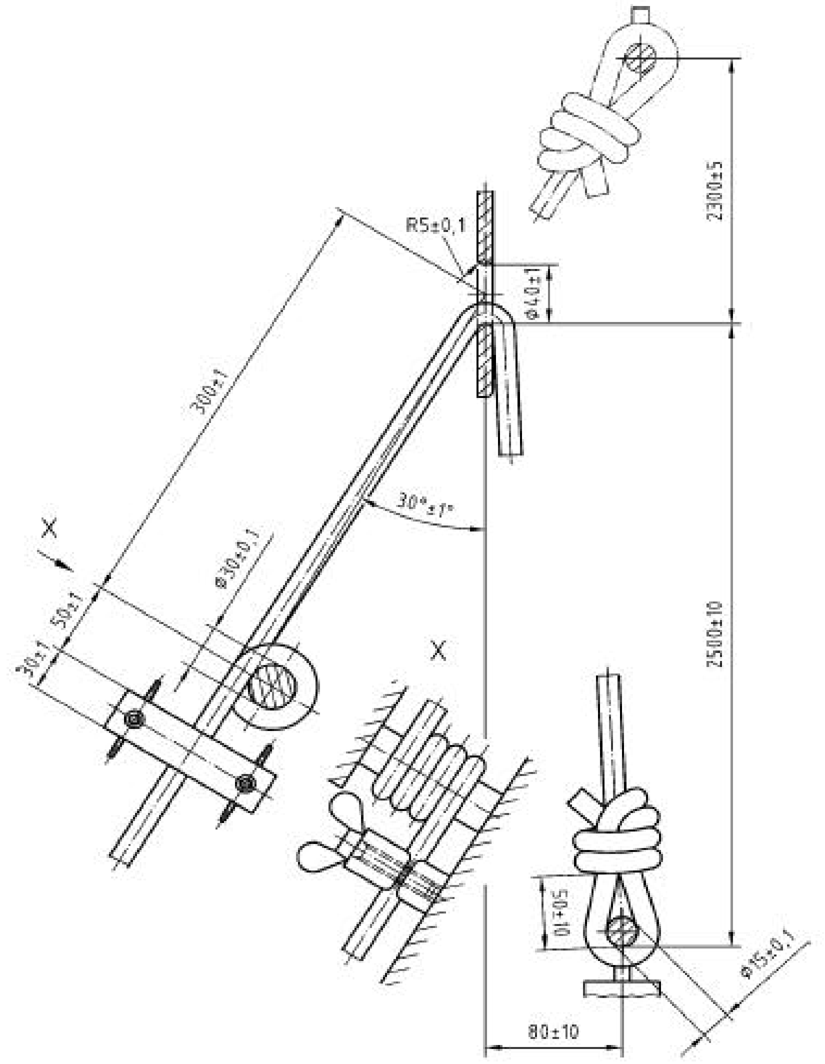

Figure 9 — Layout of apparatus for single strand test (half ropes, single ropes)

Fig. 1 DODERO (prEN 892:2001, § 5.6)

The main parameters are:

- fall height h = 4.8m
- weight of falling mass m = 80kg
- radius of orifice plate R = 5mm
- fall factor SF= 1.78 (quotient fall height vs. loaded rope length)

To fulfil the test the following limits must be reached:

- number of drops ≥ 5
- peak force ≤ 12 kN
- dynamic elongation (1. drop) ≤ 40%

2.2 Sharp edge standard of the German military

The German military standard (BWB, TL 4020-0015) is applied for half ropes in a double strand. In comparison to EN 892 the following changes are defined:

- sharp edge radius R = 0.75mm
- catch plate (weight 5kg)
- minimum number of drops = 1
- less than 10% sheath breakage (yarns cut) after 1. drop

Note:
Several tests are showing that the additional requirement - *less than 10% sheath breakage after 1. drop* – is hard to fulfil for most ropes!

The rope is attached to a catch plate. On the drop the rope is not in motion before the falling mass loads the catch plate.

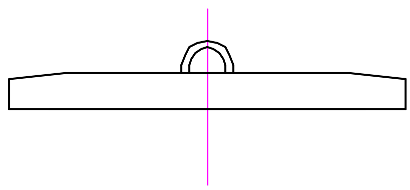

Fig. 2 catch plate

2.3 Sharp edge standard proposal – Mammut / Beal (Mai 2000)

The proposal was made to have a more simple test method and to reduce unrepeatable influences (friction, width of the edge)
The following changes are defined:

- new layout for sharp edge tool with radius R = 0.75mm (s. Fig. 3)
- width of edge limit = 25mm
- no catch plate

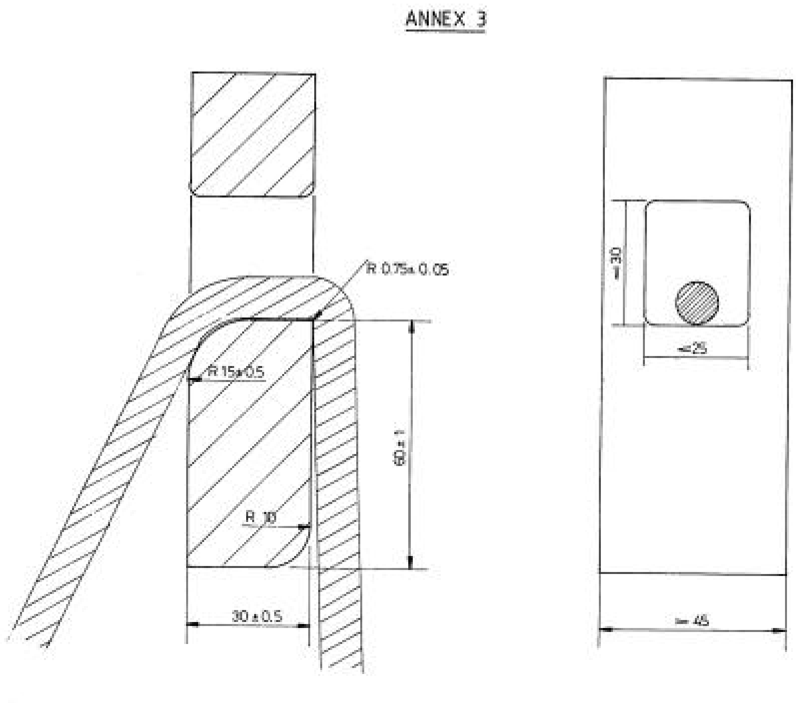

Fig. 3 Layout of sharp edge tool - Mammut / Beal

3 Test conditions

3.1 Test samples

The following table shows the rope data (EN 892) of the test samples.

test sample	diameter	weight per meter	number of drops (80kg)	peak force (80kg)	dynamic elongation (80kg)
	[mm]	[g/m]	[-]	[kN]	[%]
A	9.0	51	3	8.5	33
B	10.0	65	9	9.4	30
C	10.5	69	12	9.3	30
D	11.0	76	15	9.5	29

Table 1 rope data (EN 892)

3.2 Conditioning

The test samples were dried for at least 24h (50°C, <10%rLF) and then conditioned in an atmosphere of 20°C and 65% relative humidity.

3.3 Test apparatus

The following test apparatus was used:

- Tension machine, Zwick – 100kN with optical measuring of elongation
- drop test apparatus, Mammut – 20kN force transducer, speed measuring
- RET microscope

3.4 Drop test apparatus Mammut

The drop test apparatus has a digital data storage and analysis. By data import into MS Excel the data are analysed and graphed.
The following parameters are measured (or calculated):

- time, position and speed of falling mass
- number of drops
- peak force and force characteristic (curve)
- dynamic elongation
- energy absorption

3.5 Statistics

Because of time constraints it was only possible to have three tests with each sample and test method. The test was repeated, when there was a big spread between single values. This gives acceptable reproducibility.

4 Test series

4.1 Static

4.1.1 Simple tension test

The simple tension test is done to measure the maximum energy absorption without influence of a sharp edge. The position of rope breakage must be in the free length of the rope. Therefore the rope is applied over a 'mussel head' (without knots) to the machine. The rope elongation is measured with optical sensors and reflective tape. (s. Fig. 4)

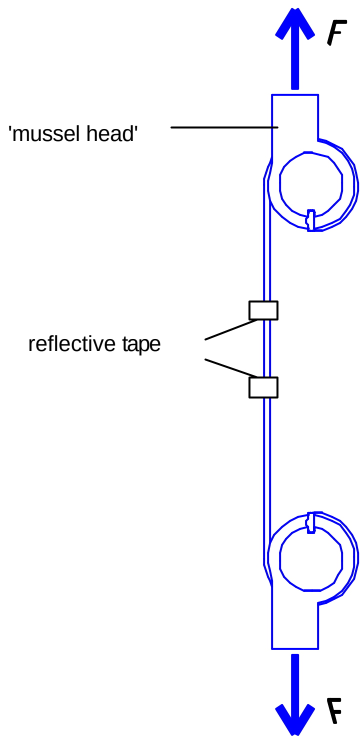

Fig. 4 simple tension test

4.1.2 Asymmetric arrangement

For this static Test the layout of the drop apparatus (DODERO) is transformed to the static tension machine. (s. Fig. 5)

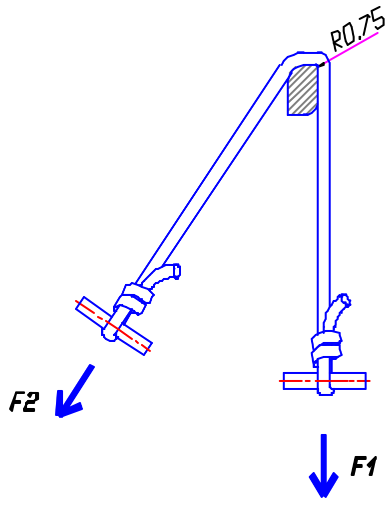

Fig. 5 Asymmetric arrangement

With the asymmetric arrangement the rope is moving over the sharp edge, e.g. we have friction between the sharp edge tool and the rope.
The test samples are attached with an overhand-knot. To be able to compare the results of static and dynamic tests, we had to use this attaching method on all test series.

4.1.3 Symmetric arrangement

Fig. 6 shows the symmetric arrangement:

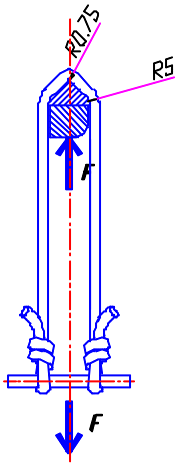

Fig. 6 Symmetric arrangement

Both rope ends are attached to the moving traverse of the machine, i.e. we measure the double force. The speed must be doubled, because the rope elongation is double as much.

The comparison of the two arrangements (static and dynamic) allows us to rate the influence of friction and movement on the DODERO apparatus.

4.2 Dynamic

To measure the energy absorption the rope has to break when loaded over a sharp edge at the first drop. For this we increased to weight of the falling mass to 100kg and set the maximum falling height (4.8m)

4.2.1 Asymmetric (analogue DODERO)

Figure 7 shows the asymmetric arrangement at the drop test apparatus. Analogous to the static test, the samples were fixed with overhand knot to the bollard. The initial free rope length between the sharp edge and the attachment point (2.5m) is set after 60 seconds static load (100kg).

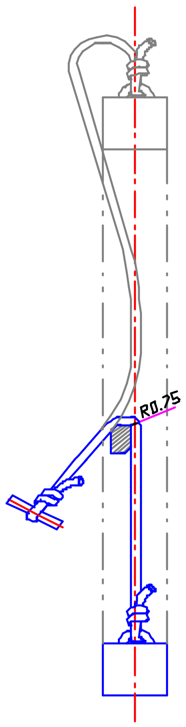

Fig. 7 Dynamic, asymmetric arrangement

4.2.2 Symmetric

The following figures show the symmetric arrangement in the drop test apparatus. The sharp edge tool was fixed to the catch plate and the catch plate to the falling mass! The weight of the falling mass increased to 105kg. For the second attachment point a special framework with a second bollard was attached to the drop test apparatus.

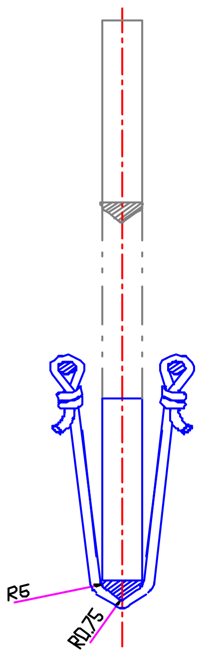

Fig. 8,9 Dynamic, symmetric arrangement

5 Results

5.1 Energy absorption

The energy absorption (AV) of a rope can be calculated with the following formula:

$$AV = \int_{H=FH}^{H=H_{\min}} F dh$$

$H=H_{min}$ minimal height at time of rope breakage
H=FH falling height

For practical calculation of the energy absorption the values are imported into MS Excel and calculated with the following formula

$$\sum_{n=1}^{n=x} ((H_n - H_{n-1}) \cdot (F_{n-1} + F_n)/2)$$

n=1 1. value with force signal
n=x last value with force signal

The following figure shows as an example the force signal vs. position of the falling mass at the sharp edge test.

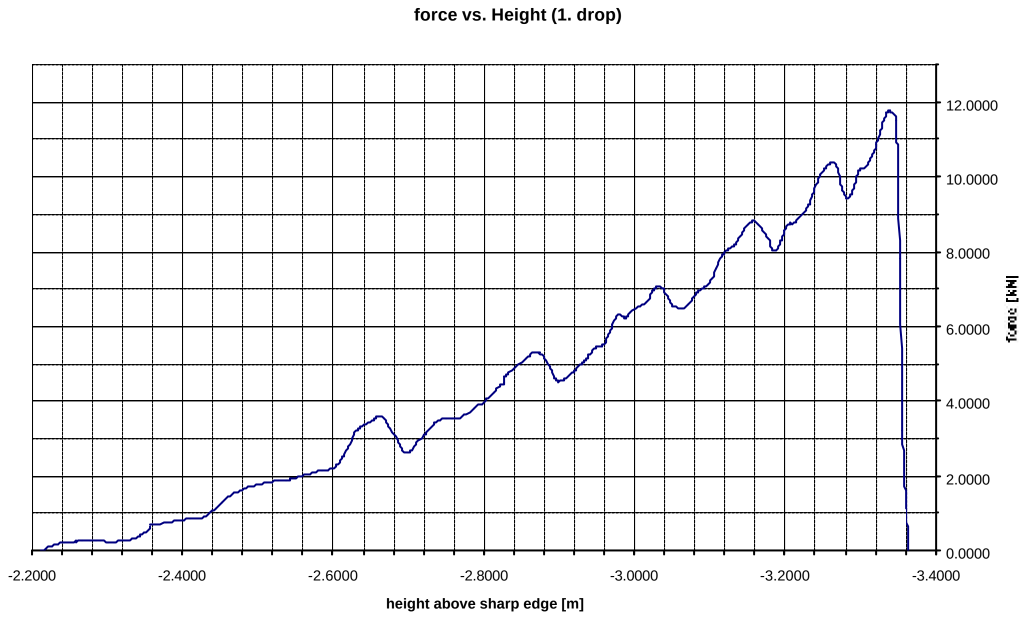

Fig. 10 sharp edge test, force vs. position of falling mass

5.2 *Comparison: ropes as a function of diameter*

5.2.1 Static

Figure 11 shows the comparison of the breaking forces with the three different arrangements:

A – simple tension test
B – asymmetric
H – symmetric

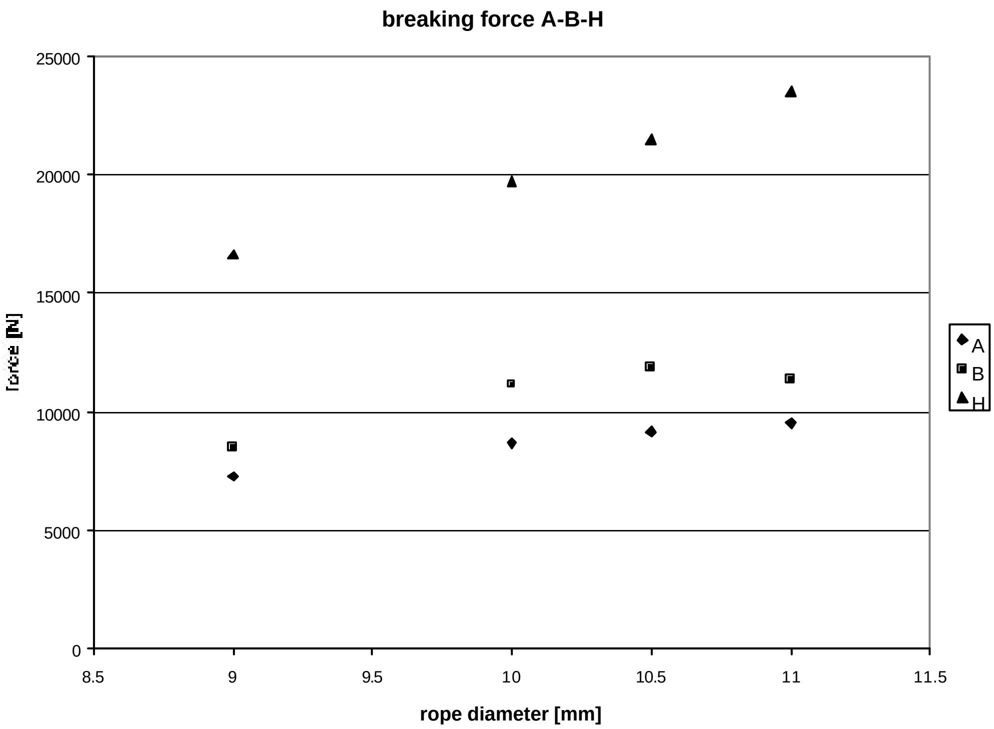

Fig. 11 Static, breaking force

The stress concentration on the sharp edge reduces the measured breaking forces of the symmetric and asymmetric test significantly. Compared to the simple test, the relative breaking forces of the symmetric test reach the following values:

∅ 9 mm	=>	44 %
∅ 10 mm	=>	44 %
∅ 10.5 mm	=>	43 %
∅ 11 mm	=>	41 %

For the asymmetric test we calculate:

∅ 9 mm	=>	51 %
∅ 10 mm	=>	57 %
∅ 10.5 mm	=>	55 %
∅ 11 mm	=>	48 %

The comparison of the breaking energy between simple test and asymmetric test shows a very similar behaviour:

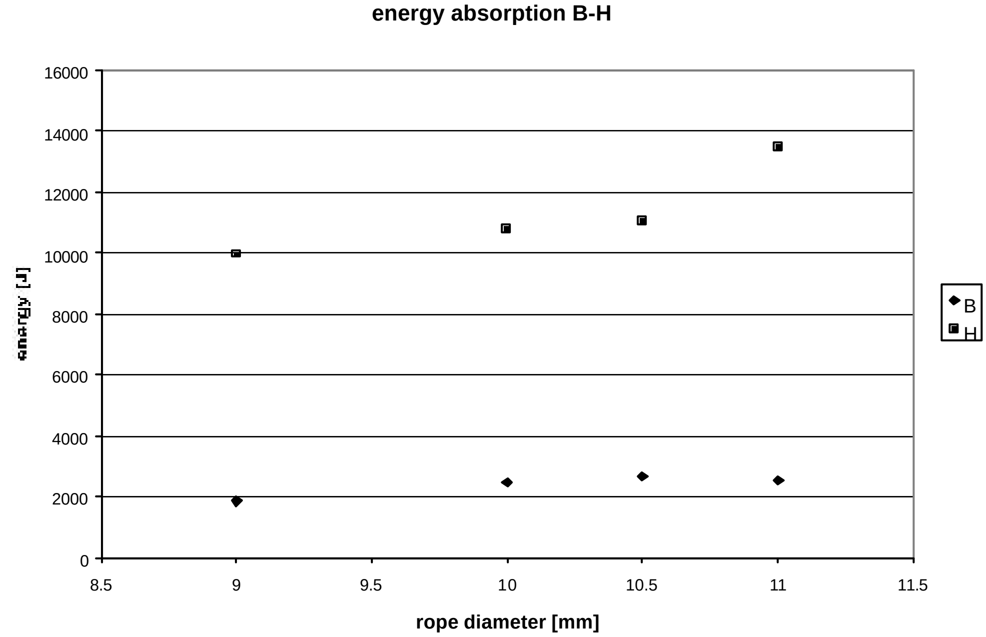

Fig. 12 Energy absorption, simple test (H) vs. asymmetric test (B)

We can see, that at the simple test (H) - without stress concentration – the energy absorption is increasing with the rope diameter. The values of the energy in the asymmetric test are much lower and there is only a low increase with the rope diameter. Compared to the simple test, the relative energy absorption of the asymmetric test reach the following values:

∅ 9 mm	=>	19 %
∅ 10 mm	=>	23 %
∅ 10.5 mm	=>	24 %
∅ 11 mm	=>	19 %

The comparison of the energy absorption symmetric test vs. simple test gives us very similar results (s. Fig. 13):

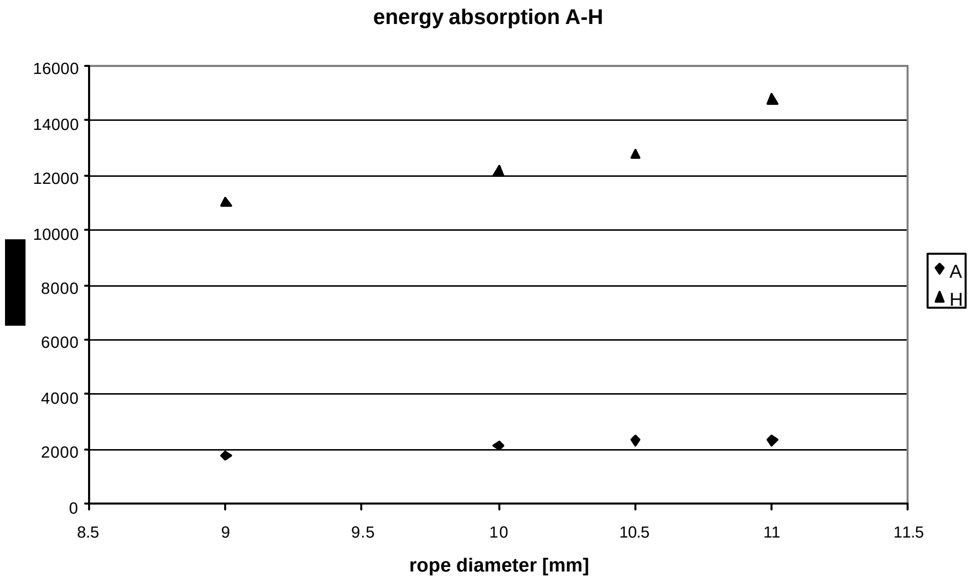

Fig. 13 Energy absorption, simple test (H) vs. symmetric test (A)

Ratio of energy absorption symmetric test vs. simple test:

∅ 9 mm	=>	16 %
∅ 10 mm	=>	17 %
∅ 10.5 mm	=>	18 %
∅ 11 mm	=>	16 %

Conclusion:
The concentration of stress at the sharp edge leads to a big drop of energy absorption of about ~80%.

5.2.2 Dynamic

Fig. 14 compares the breaking forces of symmetric test (G) vs. asymmetric test (EY).

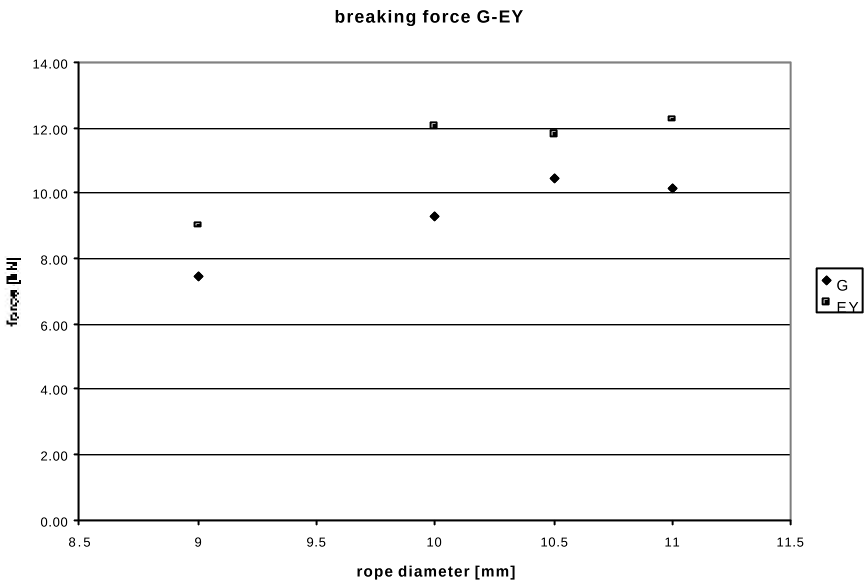

Fig. 14 Dynamic, breaking forces, symmetric (G) vs. asymmetric (EY)

Figure 15 shows analogue the results of energy absorption for both arrangements.

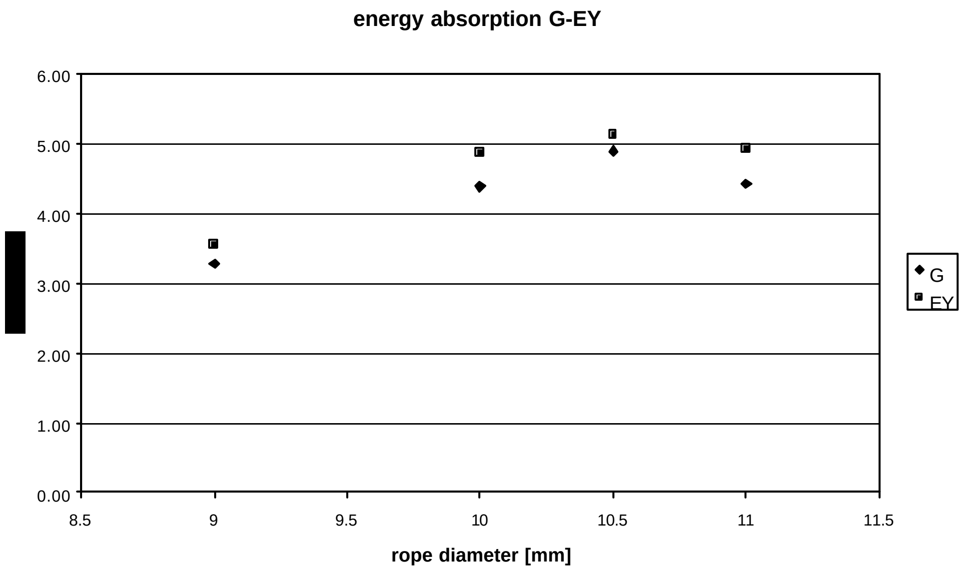

Fig. 15 Dynamic, energy absorption, symmetric (G) vs. asymmetric (EY)

Conclusion:
Independent from static or dynamic tests, the values of energy absorption of the asymmetric test are always higher than for the symmetric test.

5.2.3 Influence: attaching method DODERO

Concerning EN 892 the sample has to be attached to the drop test apparatus by winding the rope three times round the bollard and securing with a clamp.

Figure 16 shows the comparison of energy absorption of both attaching methods.

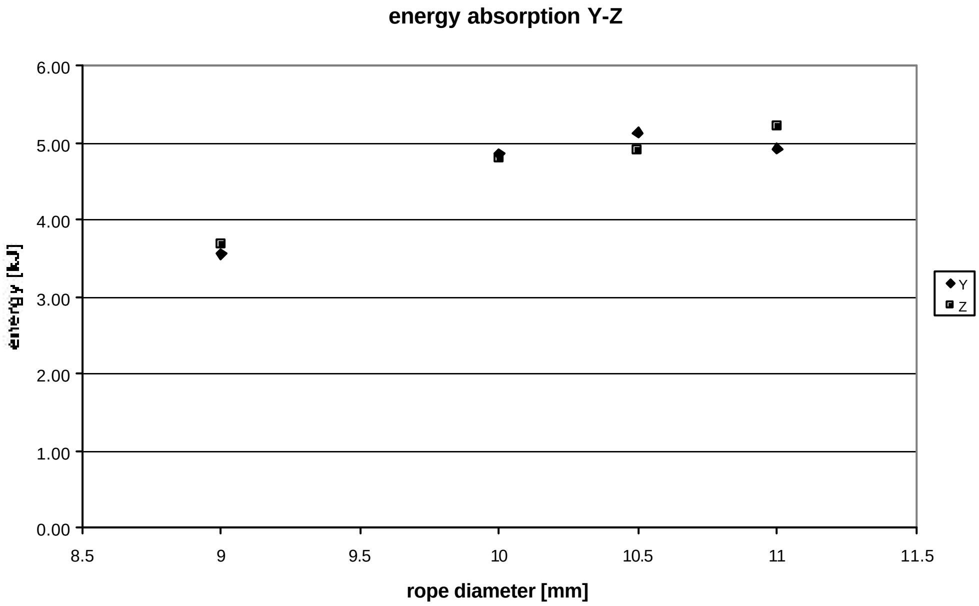

Fig. 16 Energy absorption, bollard (Z) vs. overhand knot (Y)

The deviation of the results of energy absorption between the two attaching methods is maximum 5%.

5.3 Analysis of the breakage surface

The macroscopic analysis of the broken parts of the dynamic tested ropes shows the following details:

asymmetric	long stripes (6-8cm) of melted yarns on sheath before breaking point
	big area (~3-4cm) of melted and bonded cores (twists)
	hardened rope near the breakage point
symmetric	clean breakage surface, rectangular to rope axis
	minor bonding of cores with each other
	short area of hardened rope near breakage point

Apart from the macroscopic analysis, additional pictures were made with an electronic microscope (REM). In Figure 17 one can see very clear melted fiber ends of a rope sample from the asymmetric test. Even with a very glossy surface of the sharp edge there is enough friction to produce local melting.
The second picture (Figure 18) shows the ends of the fibers from the symmetric test. In comparison one can see that the ends of the fibers look like being cut or mechanical broken.

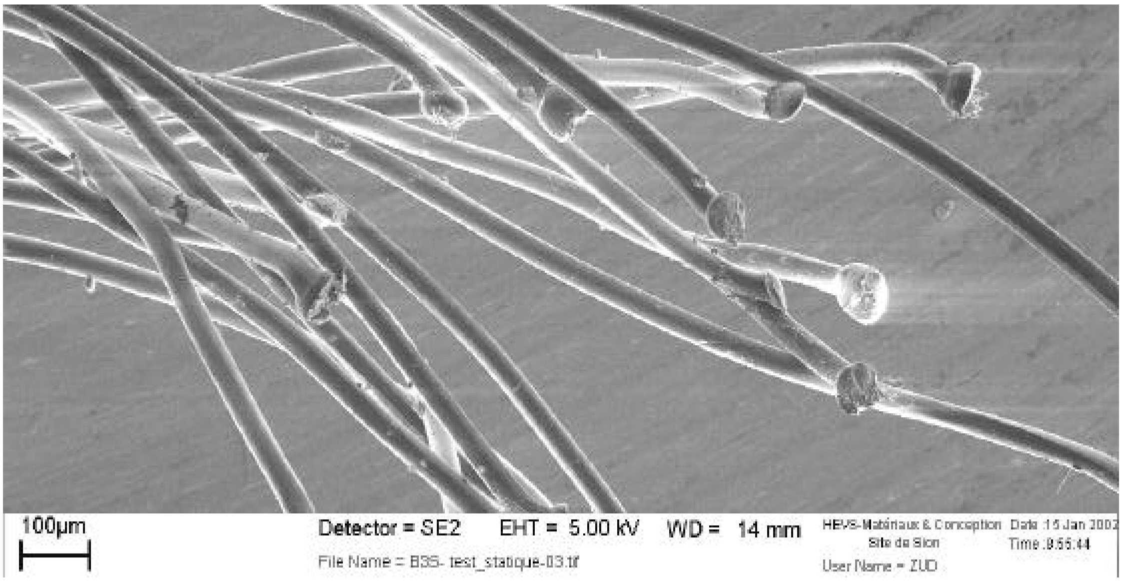

Abb. 17 REM, dynamic - asymmetric

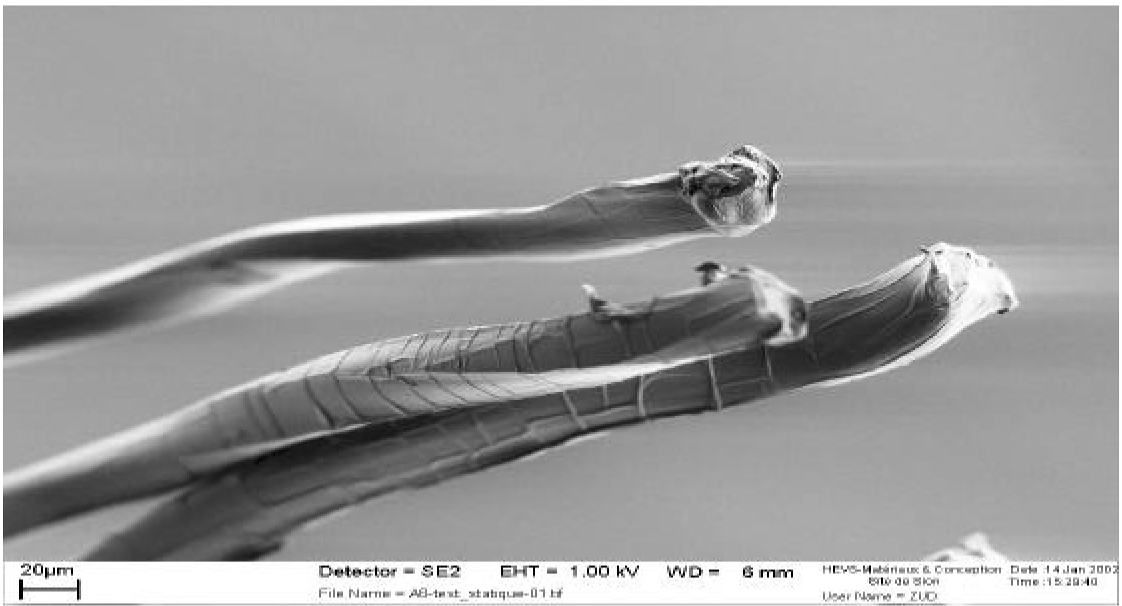

Abb. 18 REM, dynamic - symmetric

5.4 Comparison of 'sharp edge proof' ropes

The following Table shows the technical data of four different ropes from different manufactures. All of them are available on the market and declared as 'sharp edge proof' ropes (e.g. the hold 1 drop over a sharp edge).

rope	Diameter	weight per meter	number of drops	peak force	knotability	core construction
	[mm]	[g/m]	[-]	[kN]	[-]	
8	10.6	74	8	9.5	0.6	4 cores (braids) braided with monofilament
9	10.8	75	10	9.5	1.0	11 twists, 7 twists braided with monofilament
10	10.5	71	11	9.0	0.7	14 twists
4S	10.2	68	11	8.8	0.8	13 twists

Table 2 technical data of different rope constructions

All ropes were tested on the DODERO (asymmetric test). In the following Figures one can see the results of breaking force and energy absorption:

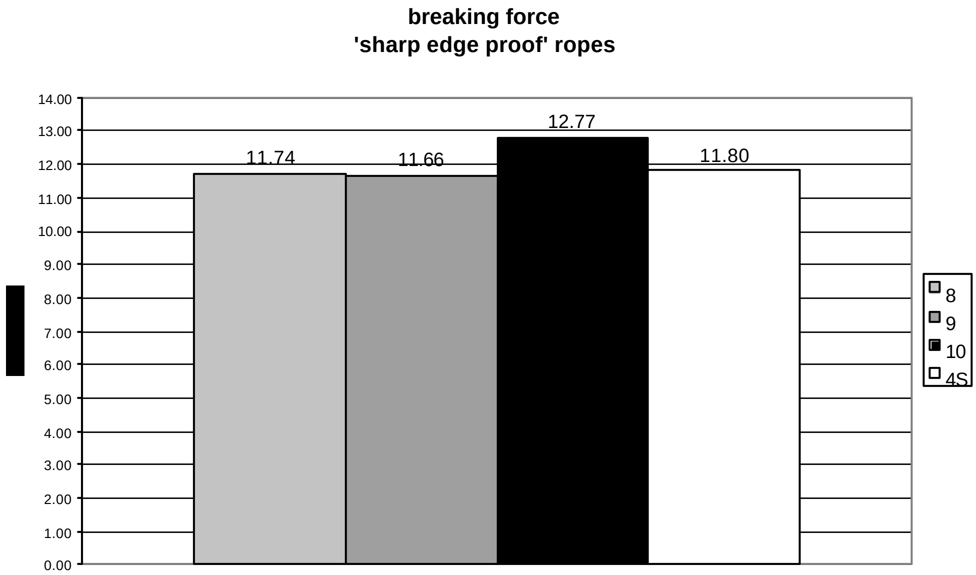

Fig. 19 DODERO, breaking force – 'sharp edge proof' ropes

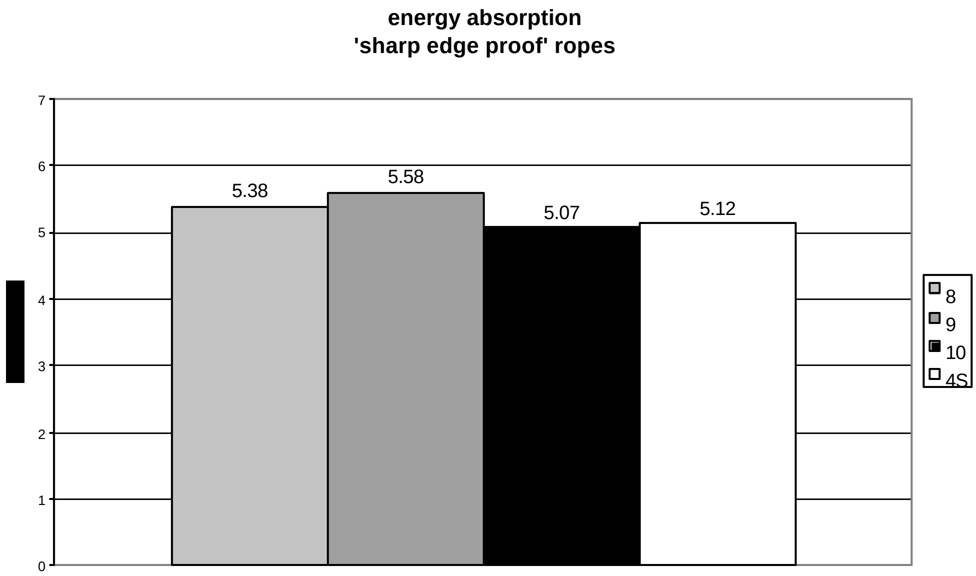

Fig. 20 DODERO, energy absorption – 'sharp edge proof' ropes

For the rope sample no.10 with the highest breaking force we measure the lowest energy absorption of all samples. Rope sample no. 9 behaves in the opposite way.

Apart from the very different core constructions, the maximum difference between the lowest and highest values of breaking force and energy absorption is less than 10%!

6 Conclusions

The breaking behaviour of a rope loaded over a sharp edge is a complex event. We realise that there are more than one failure mechanism, e.g.:

- local stress from bending and contact
- cutting from lateral movement
- melting from friction

Up to now it has not been possible to combine these mechanism and to calculate them, but with the actual investigation we gained a better understanding.

The measurement of breaking forces and energy absorption under sharp edge contact leads us to the following conclusions:

- The stress concentration from the sharp edge reduces the energy absorption by ~80% compared to the simple tension test.
- The rope sample 11.0mm reaches in all test arrangements lower values of energy absorption than the 10.5mm sample.
- The energy absorption is not directly proportional to rope diameter whereas breaking strength is proportional to rope diameter.
- The comparison of different 'sharp edge proof' rope constructions shows that the measured energy absorption differs by only 10%.
- The comparison of a not 'sharp edge proof' rope (Mammut 10.0mm) with the 'sharp edge proof' ropes leads to a difference of only 4-13%!
- The asymmetric test leads to slightly higher values of energy absorption (1-10%) compared to the symmetric test.
- The symmetric test arrangement is not more selective than the DODERO (asymmetric) arrangement.

As a result of this investigation it is on principle possible to define 'sharp edge proof' (s. Chapter 1.3) with a limit value of energy absorption, e.g. 5.5kJ. On the other hand we realise that there is a very small difference between 'sharp edge proof' or not. It is also reasonable to take into account fluctuations and tolerances of measurement.
For this we have to consider that the basic demands for an accepted test method (s. Chapter 1.3) are not fulfilled with the chosen test methods!

Another point of view maybe the formulation of the following question:

> Do we already have 'sharp edge proof' ropes available or must they be developed in the future?