

Safety Loss of Mountaineering Ropes by Lowering Cycles in Toprope Climbing

Wolfram Vogel and Folker Bocksch, Institute of Mechanical Handling University of Stuttgart. Presented at the conference on Nylon and Ropes, Turin, March 8 - 9, 2002. The complete version of this paper was first published in EUROSEIL, Deutsche Seilerzeitung, 1996, #2.

1. Introduction

On short sport climbing routes, artificial climbing structures and so on, a climber can find short routes of all degrees of difficulty. Toprope climbing is then used frequently by belaying from the ground. In [Fig. 1](#) the rope arrangement in toprope climbing, by belaying from the ground, is shown. The climber is connected with the rope to his harness. The rope leads from the climber to the upper end of the route, where the direction is changed at the carabiner and is led back to the belay device. Because of this arrangement, the fall factor, which describes the relationship of fall height to the paid out rope length and, therefore, the force on the climber in the case of a fall, is small. When the climber reaches the end of the route, the belayer will lower the climber. During lowering the rope is bent over the upper carabiner as well as in the belay device.

Dynamic mountaineering ropes are commonly used in toprope climbing. Such ropes are stressed dynamically by leader falls. The measurement of the safety of a rope is the number of break-free norm drops, which is determined in a drop test by using an unused rope and testing it in accordance with DIN EN 892 (UIAA Standard 101). A rope is also exposed to mechanical, thermal and chemical demands while in use. These individual stresses act together on the rope and reduce its original capacity. The reduction of this capacity results in a loss of safety of a used rope, which is expressed by the reduction of the number of break-free drops held.

Considerably mechanical stress in toprope climbing results from the bending around the upper carabiner during lowering as well as in the belay device under the rope force. In this investigation ropes are exposed exclusively to the bending during lowering cycles and their safety loss (number of falls) is examined. Three different belay devices are employed.

2. Bending during the lowering cycles

In toprope climbing the direction of the rope changes during the lowering cycle around the upper carabiner as well as in the belay device. The Munter hitch, figure eight descender and Grigri, used in toprope climbing, are shown in [Fig. 1](#).

The Munter hitch and the figure eight descender are designated as dynamic belay devices. In these belay devices, the hand power of the belayer is needed to brake the fall. The term dynamic belay device is derived from the braking effect, since during a fall, the impact force can be reduced by rope-slip through the device. In the Munter hitch, the direction of the rope is changed twice with rope-carabiner-contact and twice with rope-rope-contact. In the figure eight descender the rope experiences three bends with rope-metal-contact.

The Grigri is a representative of a static belay device. The rope is placed around an eccentric with a groove. Using a lever, the eccentric can be positioned in such a way that during climbing, rope can be paid out. During lowering, the position of the eccentric and, therefore, the

braking force can be varied, although not as smoothly as with the other devices. The brake functions automatically, i.e. no hand power is needed. A dynamic brake effect arises with the Grigri only with a movement of the belayer, who may be lifted up.

The bending around the upper carabiner with a radius of 5 mm takes place with an angle α , between 160° and 180° , depending on the horizontal distance the belayer is from a vertical line passing through the upper carabiner.

3. Rope forces during lowering

The rope force during the lowering cycle is dependent on the mass of the climber and the position of the rope in the safety chain. The rope force F_2 between the upper carabiner and the belay device and the force of the braking hand F_H has been measured for the dynamic belay devices, the Munter hitch and figure eight descender, during the lowering with a solid mass of 80 kg. The experimental arrangement is shown in [Fig. 2](#). The wrapping angle in the upper carabiner is about 170° in these measurements. The measurements have been carried out with an unused mountaineering rope and a used mountaineering rope with a furry rope sheath. The measured rope forces are shown in Table 1. The rope force F_1 between the climber and the upper carabiner is equivalent to the mass of the climber. The rope force F_2 , between the upper carabiner and the belay device, is 56% of the lowered mass, m for a new rope. For the used mountaineering rope the force F_2 is, as expected, smaller and amounts to only about 46% of the mass, m . The force of the braking hand F_H depends on the choice of the dynamic belay device. In the figure eight descender, about 11% and in the Munter hitch 4% of the mass, m has to be held with a new rope. For the used rope, the hand force goes back to 7.6% and 2.5%, respectively, of the force produced by the mass, m .

4. Ropes

Altogether, eight different single ropes were tested. Most of the tests were carried out on three single ropes, which were made available by European mountaineering rope producers (AROVA-MAMMUT AG, CH; EDELMANN + RIDDER GMBH + CO., D-Isny i.A.; MARLOW ROPES LTD., GB-Hailsham). All of the ropes were examined and tested when new in accordance with DIN EN 892 at the Institute of Mechanical Handling, University of Stuttgart.

5. Test procedure

The testing is performed in two steps. First, the ropes are aged by N lowering cycles using the different belay devices and then they are tested in the drop test according to DIN EN 892.

5.1 Aging test of ropes by lowering

The lowering procedure in top rope climbing with belaying from the ground is simulated in the laboratory. Thus, a test stand ([Fig. 2](#)) was erected, in which the relationships in top rope climbing are simulated. Additional degradations such as rubbing at edges or environmental influences are excluded. The belay devices are fixed on the hall floor with a short sling.

A lowering cycle is designed as follows: the mass, m is hoisted up with a crane to the height of the upper carabiner using another rope. The test rope is pulled behind, force free and

the mass, m is transferred to the test rope. The mass, m is then lowered to the hall floor. The speed of lowering is about 1 m/s. The lowering procedure is repeated $N = 20$, $N = 40$, $N = 60$ and $N = 80$ times. After each aging test, two samples with a length of 3.8 m are removed for the drop test. One part of the rope is bent only over the upper carabiner and the other part of the rope is only bent in the belay device N -times. After the aging tests, no damage to the sheaths of the ropes could be determined.

When belaying with the Munter hitch and figure eight descender, the mass, m can be deposited nearly shock free on the hall floor as the rope is completely unloaded. This is possible, because the force of the braking hand and, therefore, the lowering speed can be finely adjusted. In belaying with the Grigri, the lowering procedure can only be roughly influenced. Before reaching the hall floor, the mass, m has to be sharply slowed down. In doing this, the rope receives an additional dynamic load. In [Fig. 3](#) the measured rope force in a typical lowering cycle with the Grigri is shown. After the rope is stopped in the Grigri, the maximum rope force is approximately 2.8 times of the force produced by the lowered mass, m .

5.2 Drop tests

The drop tests with the aged ropes are carried out in accordance with DIN EN 892 on the drop test stand at the Institute of Mechanical Handling, University of Stuttgart. The drop test stand is provided with a guided falling mass. The mass used to test a single rope is 80 kg. A 3.8 m long rope is required for each test. The sections of ropes tested were taken from the portions, which passed over the upper carabiner as well as through the belay device. The test sample is connected to falling mass. The rope is passed through the orifice (the test edge with a radius of 5 mm, equivalent to the radius of the upper carabiner) and then tied, three times, around an anchor pin and finally fixed between a clamp plate. The test sample is then loaded statically with the mass and after one minute the free length of (2500 ± 20) mm is adjusted. During the drop test the mass falls freely for approximately 5000 mm before the rope stretches and absorbs the energy produced by the falling mass. The impact force is measured and recorded during the first fall. After the drop, the rope has to be unloaded within one minute. Between two consecutive falls the time span has to be (5 ± 0.5) minutes. The drop test is repeated until the rope breaks.

6. Number of drops without breakage

All the ropes were tested when new in accordance with DIN EN 892. The tests were carried out on three test samples. The minimum requirement of the standard requires each sample to hold at least five falls without breaking. The mean value of the number of drops without breaking of these test samples is designated as n_u (on the graphs n_u with a mean value bar over the n). The mean value of the number of drops without breaking of the aged test sample is referred to as n_g . The relative number of drops without breaking n_g/n_u is plotted against the number of lowering cycles N . [Figs. 4](#), [5](#) and [6](#) show the ropes bent only in the belay devices. For the Munter hitch ([Fig. 4](#)) and the figure eight descender ([Fig. 5](#)) the relationship between the relative number of drops without breaking and the number of lowering cycles is nearly linear. The rope degradation is more severe for the Munter hitch than for the figure eight descender because of the higher number of bends, the more severe radii and, moreover, the rope-to-rope contact. Rope sections, which were exposed to 80 lowering cycles in the Munter hitch, have already lost more than 50% of their original capacity. For rope sections, which were bent in the Grigri ([Fig. 6](#)), the relative number of drops without breaking decreases steeply after some

lowering cycles and is then reduced only slightly. The reduction, with increasing number of lowering cycles, is smaller than with the Munter hitch or the figure eight descender. This behaviour is a consequence of the additional dynamic demand to which the rope is exposed at the end of the lowering procedure.

The plot of the relative number of drops without breaking against the number of lowering cycles for rope sections, which are only bent in the upper carabiner, is shown in [Fig. 7](#) for the dynamic belay devices, the Munter hitch and the figure eight descender, and in [Fig. 8](#) for the Grigri. For both belay methods the quotient n_g/n_u decreases with the increasing number of lowering cycles. For the dynamic belays, the relative number of drops without breakage decreases linearly with increasing number of lowering cycles. The reduction of n_g/n_u is, despite the high rope forces at the upper carabiner, regularly smaller than for rope sections, which were bent in the dynamic belay devices. For the static belay with the Grigri, the already known behaviour of n_g/n_u against N , as a consequence of the additional dynamic demand, is shown.

The relative number of break-free falls determined in the tests, as a result of rope bending during the lowering cycles in top rope climbing, is evaluated in a regression analysis. A linear starting equation is chosen for the dynamic belay with the Munter hitch and the figure eight descender

$$(n_g/n_u) = a_0 + a_1 N \quad (1)$$

For the static belay with the Grigri an exponential equation is chosen.

$$(n_g/n_u) = b_0 N^{b_1} \quad (2)$$

For the regression calculation, equation (2) is changed into the logarithmic form

$$\lg(n_g/n_u) = c_0 + c_1 \lg N \quad (3)$$

The regression calculation yields the constants a_0, a_1 and c_0, c_1 . In Table 2 the constants a_0 and a_1 , the standard deviation (*derivation*), s and the coefficient of determination (*determination measure*), $B = r^2$ are listed for the dynamic belay devices. Table 3 includes the constants found for the static belay device. The results of the calculation are plotted in [Fig.4](#) to [Fig. 8](#) as solid lines. Additionally the 95 % confidence interval is shown as a dashed line. The test results are above this calculated statistical limit.

7. Summary

The drop tests carried out on mountaineering ropes, which were aged in lowering procedures (top rope climbing), have shown that with an increasing number of lowering cycles the number of drops without breaking strongly decreases. Rope sections, which were bent in the figure eight descender or in the Munter hitch, for only 80 lowering cycles have only about half, or less than half, of the capacity of a new rope left. This safety loss occurs customarily after few days of top rope climbing. By superimposing other factors of rope degradation upon those caused by the bending in the belay devices and the top carabiner, one can expect a further decrease in the number of drops held without breaking. The safety loss is of no consequence for a rope used solely as a top rope because fall factors are small but is critical for lead climbing, when larger fall heights are possible.

Table 1: Rope Forces during lowering

Designation of the Rope force	Rope force [N]		
	Unused rope	Used rope	
At upper carabiner	F_1	785	785
	F_2	440	360
Hand force F_H belay carabiner	30	20	
Hand force figure eight descender F_H	90	60	

Table 2: Constants of regression calculation (dynamic belay devices)

	Constants		Derivation s	Determination measure B
	a_0	a_1		
Belay carabiner	0,998	$-6,99 \cdot 10^{-3}$	0,057	0,928
Figure eight descender	0,976	$-5,43 \cdot 10^{-3}$	0,091	0,757
Upper carabiner	0,965	$-3,3 \cdot 10^{-3}$	0,106	0,483

Table 3: Constants of regression calculation (static belay device)

	Constants		Derivation s	Determination measure B
	c_0	c_1		
Grigri	-0,1215	-0,0618	0,052	0,848
Upper carabiner	-0,1023	-0,0347	0,069	0,708

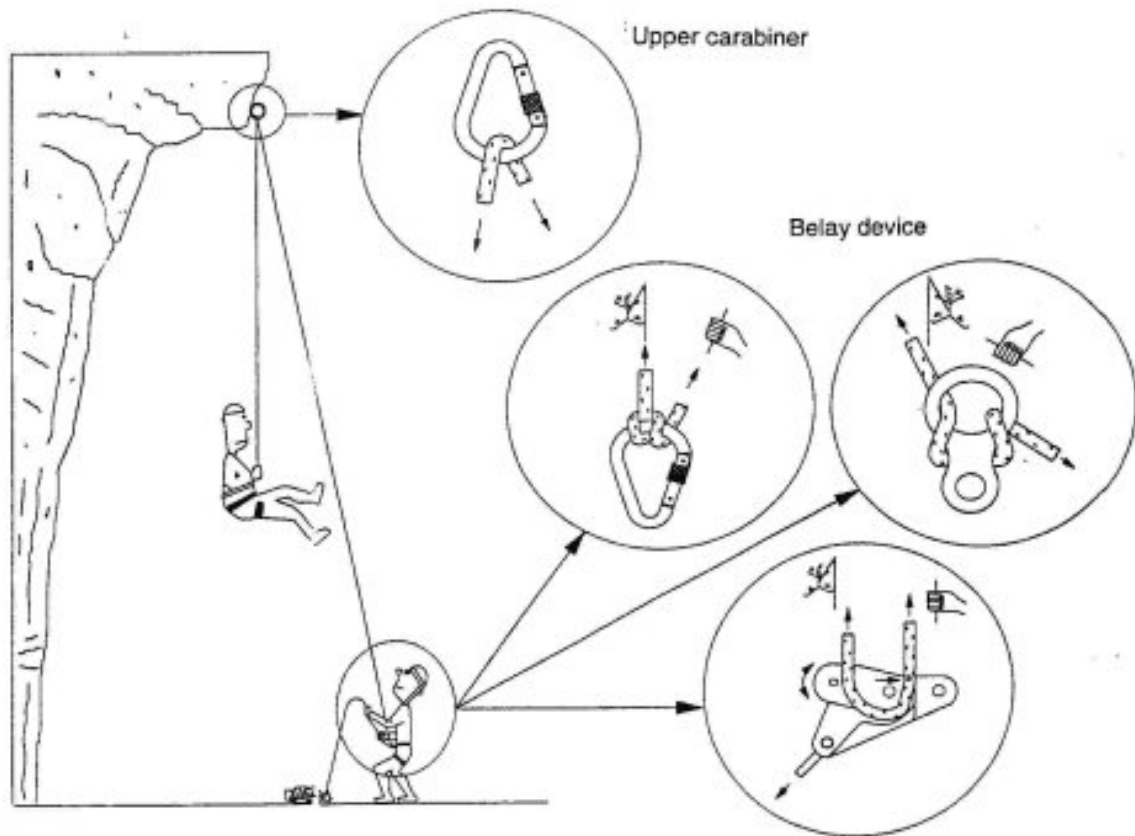


Fig. 1: Rope line in top rope climbing

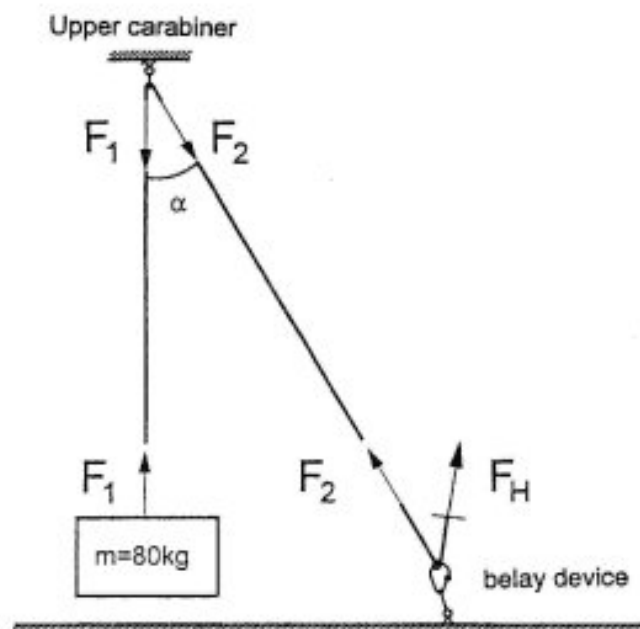


Fig. 2 Rope forces during lowering.

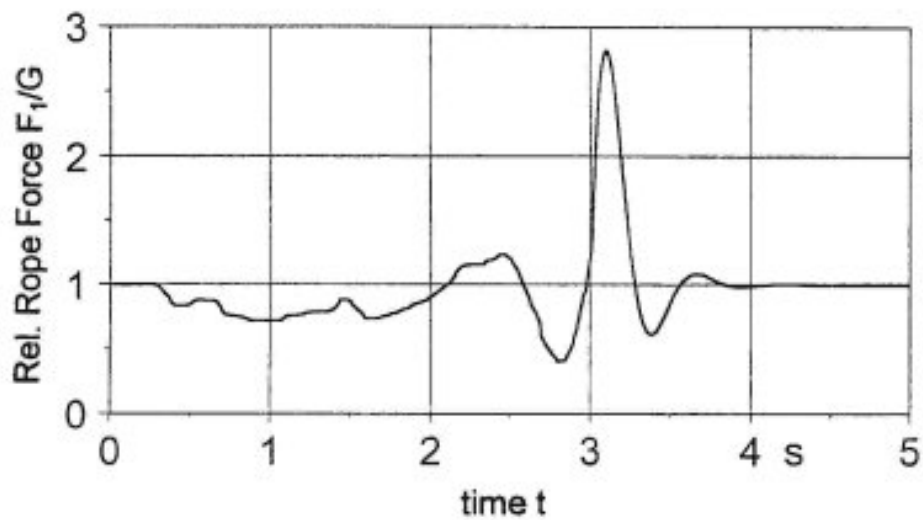


Fig. 3: Dynamic Force at the end of lowering - belaying with grigi

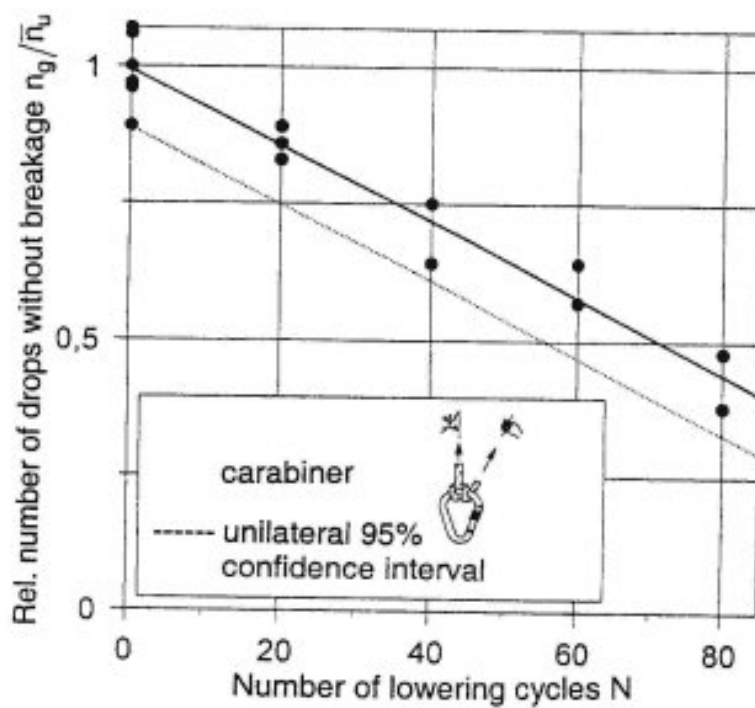


Fig. 4: Relative number of drops – bendings in the belay carabiner

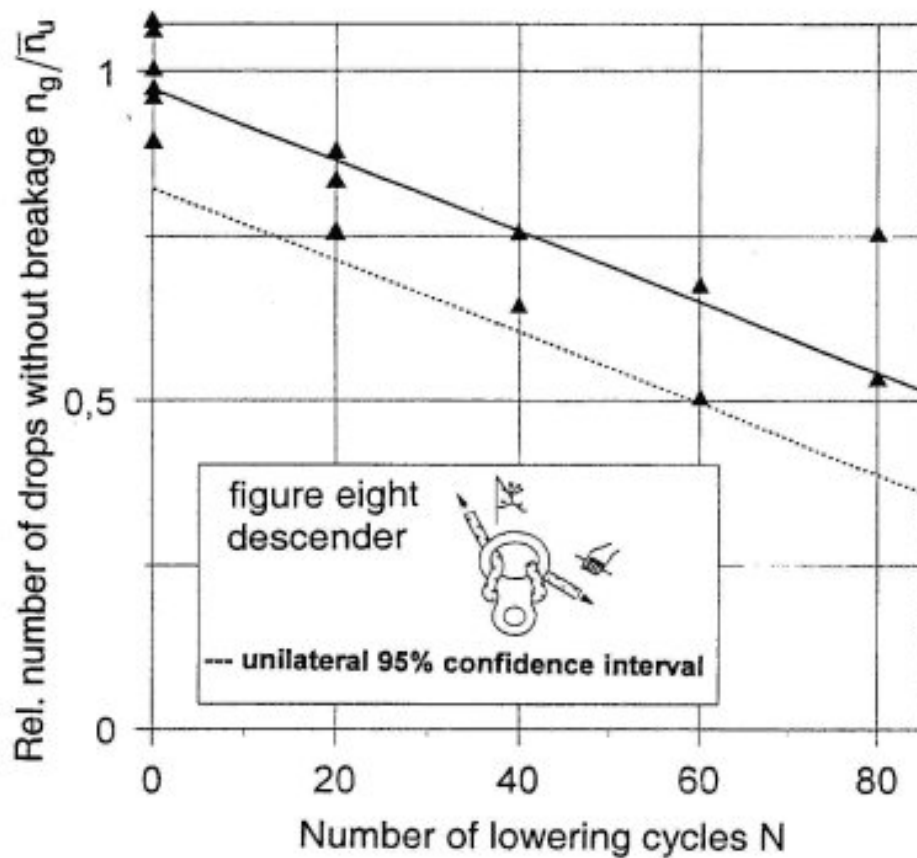


Fig. 5: Relative number of drops – bendings in the figure eight descender

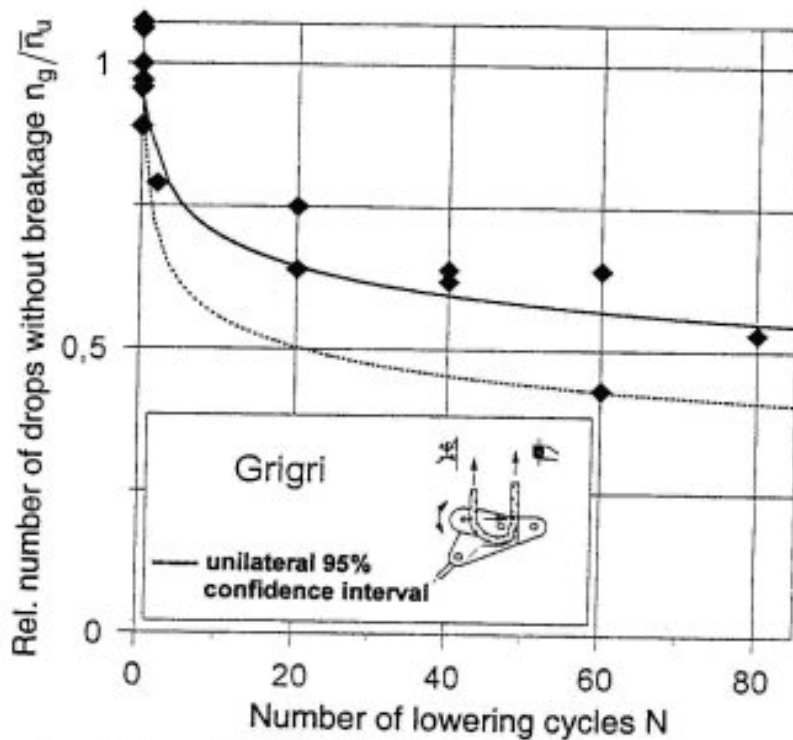


Fig. 6: Relative number of drops – bendings in the grigri

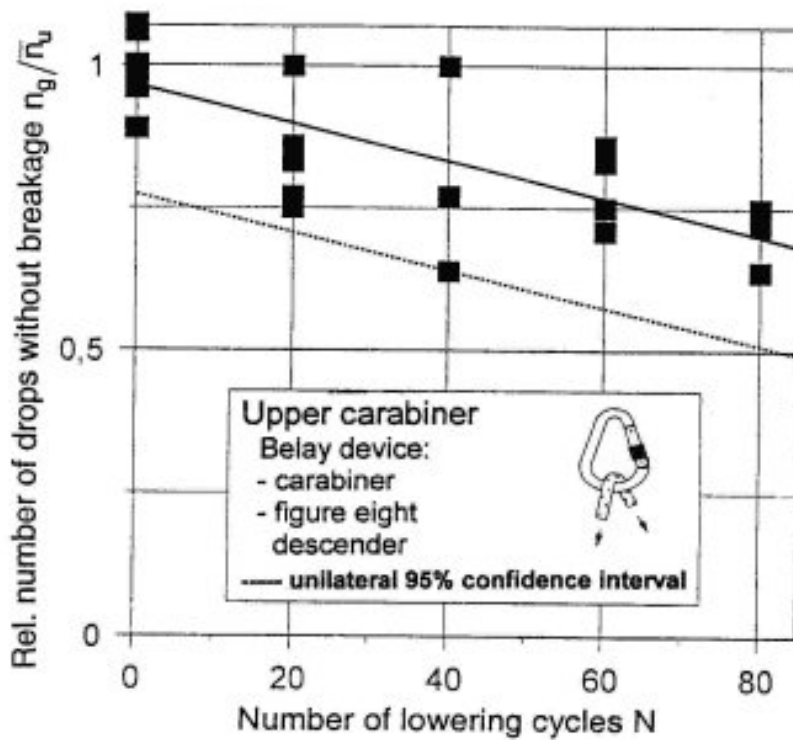


Fig. 7: Relative number of drops – bendings in the upper carabiner combined with the belay devices carabiner and figure eight descender

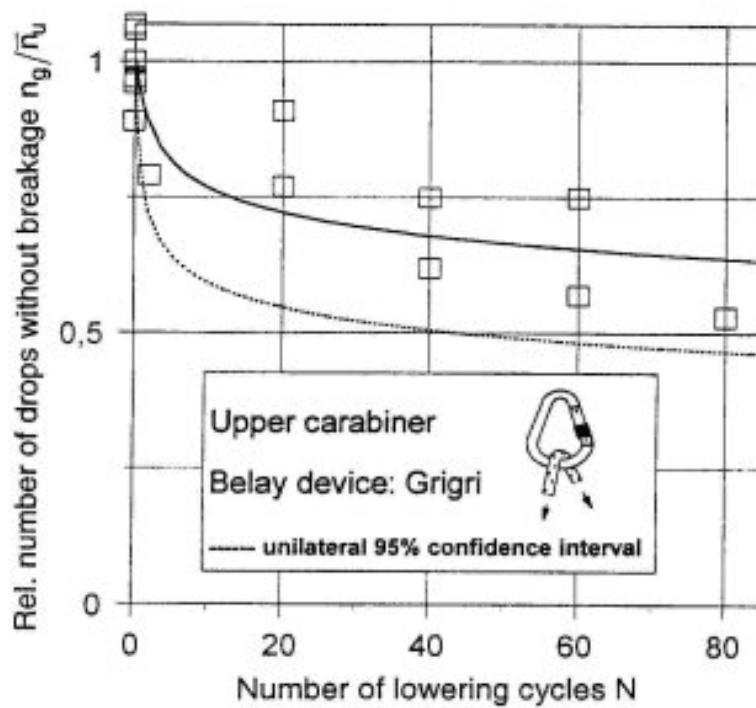


Fig. 8: Relative number of drops – bendings in the upper carabiner combined with the belay device grigri