Safety loss of mountaineering ropes by lowering cycles in toprope climbing

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1. Introduction

In climbing gardens, artifical climbing structures and so on the climber can find short routes of all degrees of difficulty. Here the toprope climbing is used frequently by belaying from the ground. In picture 1 the rope line in toprope climbing by belaying from the ground is shown. The climber is connected with the mountaineering rope by his harness. The mountaineering rope leads from the climber to the upper end of the route where the direction is changed within the carabiner and is lead to the belay device. Because of this special rope line the fall factor which describes the relation of fall height to the displayed rope length and therefore the force on the climber in the case of a fall are small. If the climber reaches the end of the route he will be lowered by the belaying person. During the lowering the mountaineering rope is bend over the upper carabiner and in the belay device.

In toprope climbing usually mountaineering ropes are used (fiber ropes in kernmantel-construction made by polyamid fibers). Mountaineering ropes are stressed dynamically by drops in climbing. As a measurement for the safety of a mountaineering rope, the number of break-free norm drops, which are determined in a drop test by using unused mountaineering ropes according to DIN EN 892 is valid. A mountaineering rope is exposed to mechanical, thermical and chemical demands while in use.

The individual stresses are effective as a collective on the mountaineering rope and reduce its application characteristics. The reduction of the application characteristics is at the same time connected with a loss of safety, which is expressed by a decline of the number of drops without breakage of used ropes. A considerably mechanical stress in toprope climbing results from the bendings during lowering around the upper carabiner and in the belay device under a rope force.

In this investigation the safety loss of mountaineering ropes at drop test is examined, which are exclusively exposed to the bendings during the lowering cycles with different belay devices.

2. Bendings during the lowering cycles

In toprope climbing the direction of the mountaineering rope is bend during the lowering cycle around the upper karabiner and in the belay devices. The belay devices carabiner, figure eight descender and grigri used in toprope climbing are shown in figure 1.

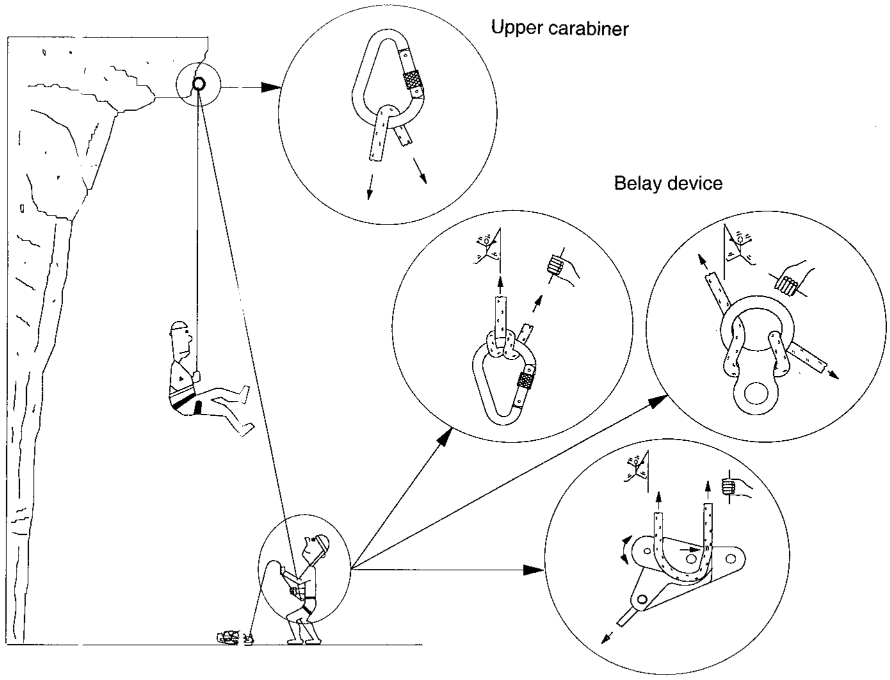

Fig. 1: Rope line in toprope climbing

The carabiner and the figure eight descender are designated as dynamical belay devices. In using these belay devices, the hand power of the belaying person is needed to be able to brake. The term dynamical security device is derived from the braking effect, as during the drop the drop force by handing out the rope can be reduced. In the carabiner, the direction of the mountaineering rope is changed two times with rope-karabiner-contact and two times with rope-rope-contact. In the figure eight descender the mountaineering rope experiences three bendings with rope-metal-contact. The grigri is a representative of the static belay devices. The rope is laid around a eccentric provided with a groove. In using a lever the eccentric is positioned in such a way, that in climbing the rope can be handed out by using the grigri. With the help of the lever during lowering, the position of the eccentric and therefore the braking force roughly varies. If the lever in lowering is released, the eccentric turns through the friction force between rope and eccentric groove. The rope on the hand side is trapped between the edge of the eccentric and the case. The brake functions itself, i.e. no close hand power is needed. A dynamic brake effect arises with the grigri only by the movement of the belaying person, who carried along at a drop.

The bendings around the upper carabiner with a radius of 5 mm takes place with a angle α between 160° and 180°, dependent on which horizontal distance the belaying person from the plumb, judged from the upper carabiner, has.

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 carabiner and figure eight descender during the lowering with a solid mass of 80 kg. The experiment assembly is shown in figure 2.

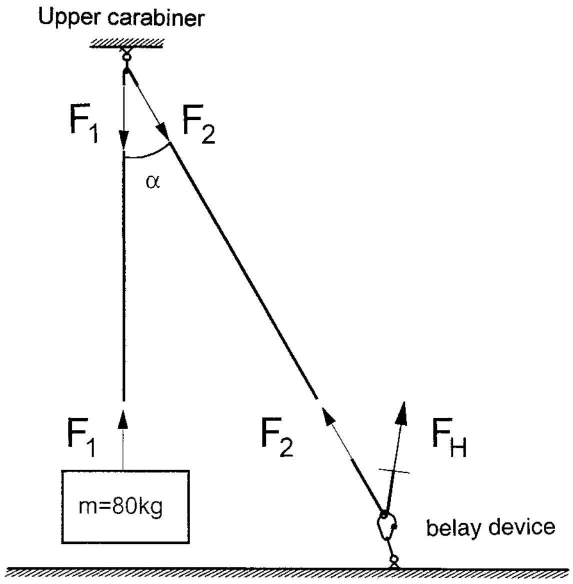

Fig. 2: Rope forces during lowering

The wrapping angle in the upper carabiner has about 170° in the measurements. The measurements have been carried out with a unused mountaineering rope and an used mountaineering rope with a furry rope casing. The measured rope forces are concluded in table 1. The rope force F_1 in the part of the rope between the climber and the upper carabiner is equivalent to the weight force of the climber. The rope force F_2 between the upper carabiner and the belay device is by using the unused rope about 56% of the force produced by the lowered mass m. By using the used mountaineering rope the rope force F_2 is, as expected, smaller and amounts to only about 46% of the force produced by the lowered mass m. The force of the braking hand F_H is dependant on the choice of the dynamic belay device. In the figure eight descender, about 11% and in belaying with the carabiner about 4% of the mass force had to be hold with the unused rope. In using the used rope, the hand force goes back to 7,6% or rather to 2,5% of the force produced by the mass m.

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

4. Ropes

Altogether, eight different simple ropes are used as testing ropes. Most of the examinations have been carried out with three single, which were made available for this examination 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 have been examined in new condition according to DIN EN 892 at the Institute of Mechanical Handling, University of Stuttgart.

5. Testing enforcement

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

5.1 Use of the test ropes by lowering

The lowering procedure in toprope climbing with belaying from the ground is simulated in the laboratory. Therefore, a wearing test bed (figure 2) has been erected, in which the relations in toprope climbing are copied. Additional demands like i.e. rubbing at edges or environmental influences are excluded. The security 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 over a helping rope. The mountaineering rope (test rope) is pulled behind force free and the mass m is handed over to the test rope. Now the lowering of the mass m to the hall floor follows. The speed of lowering is about 1 m/s. The lowering procedure is repeated N = 20, N = 40, N = 60 or N= 80 times. After each wearing test, two samples for the drop test with a length of 3,8m each exist.

One part of the rope is bend only over the upper carabiner and the other part of the rope is only bend in the belay device N-times. After the wearing tests, no damages to the sheath of the mountaineering ropes could be determined.

In belaying with carabiner and figure eight descender the mass m is nearly landed shock free on the hall floor and the rope is completely unloaded. This is possible, because the force of the braking hand and therefore the lowering speed can be finely dosed. 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 by getting stuck of the rope in the grigri. In doing this, the mountaineering rope is additionally dynamically demanded. In figure 3 the measured rope force in a typical lowering cycle with the grigri is shown. After the mountaineering rope got stuck in the grigri, the maximal rope force amounts to approximately a force 2,8 times of the lowered mass m.

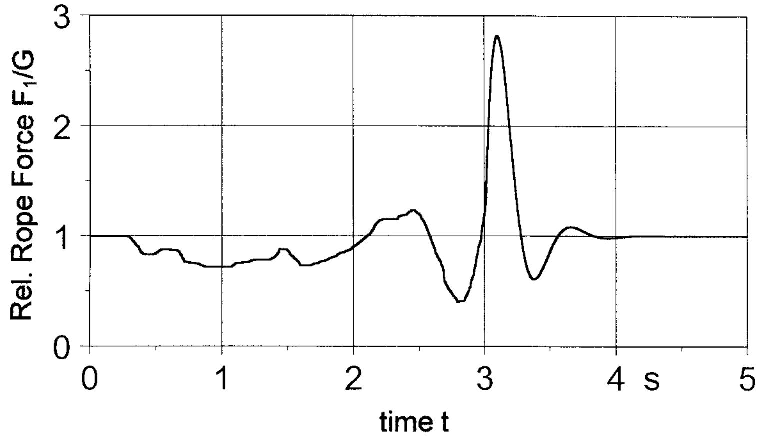

Fig. 3: Dynamic Force at the end of lowering - belaying with grigri

5.2 Dynamic tests (drop tests)

The dynamic tests with the aged mountaineering ropes are carried out according to DIN EN 892 on the drop test device at the Institute of Mechanical Handling, University of Stuttgart. The drop test device is provided with a guided falling mass. The falling mass to examine single ropes is 80kg. To be able to do a drop test, a rope length with a length of about 3,8m is needed. The length of the rope length for the falling test is equivalent to the rope part which is bend in the lowering cycles in the upper carabiner or in the belay device. The test sample is fixed with the knot in accordance to the rules with an interior loop length of (50+/-10) mm at the fixing bow of the falling mass. The mountaineering rope is tied around over the round testing edge with a radius of 5 mm (equivalent to the radius of the upper carabiner), three times around a poller and fixed behind a screwed up clamp plate. Then the test sample is loaded statically with the falling mass and after one minute a free length of (2500+-20) mm is adjusted. At the drop test, the falling mass falls free approximately 5000m, before the rope stretches. The drop force transmitted to the falling mass over the rope and slows it down. The drop force is measured, tightened and recorded during the first fall. After the drop, the rope has to be unloaded within a 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

From the mountaineering ropes used in this examination, the number of drops without breakage in new condition out of tests according to DIN EN 892 are known. According to the DIN EN 892, the drop test has to be carried out in new condition until the break at three test samples. Each test sample has to bear at least five norm falls without a break. The mean value of the number of drops without breakage of the three unused test samples is designated as n_u. To be able to compare single ropes of different construction and of different rope diameters, the number of drops without breakage of the aged test sample n_g is referred to n_u. The relative number of drops without breakage $n_g/\overline{n}_u$ over the number of lowering cycles N is for rope parts applied on in figure 4 to figure 6, which are only bend in the belay devices. At the carabiner (figure 4) and at the figure eight descender (figure 5) the relative number of drops without breakage with the number of lowering cycles is nearly reduced linear. The relative number of drops without breakage at the carabiner is regularly stronger reduced than the figure eight descender, because of the higher number of bendings, moreover with rope-rope-contact. At rope parts, which were bend times in the carabiner the number of drops without breakage is already gone back to less than the half of the new condition.

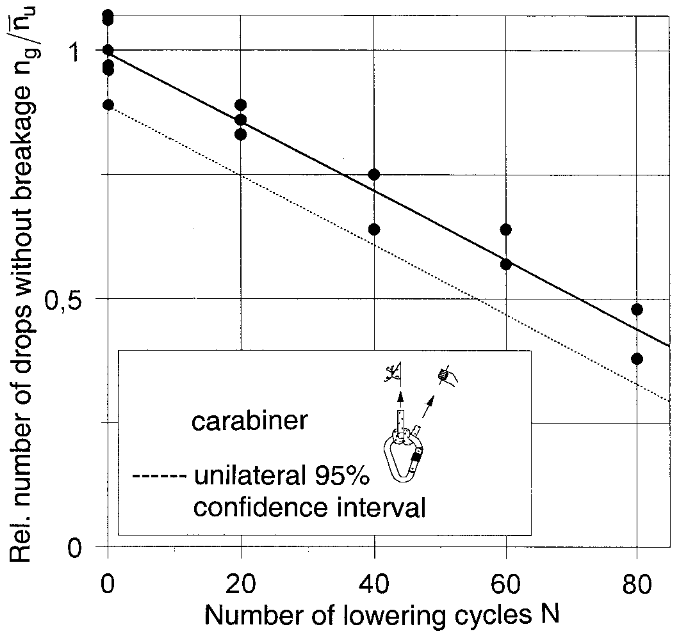

Fig. 4: Relative number of drops – bendings in the belay carabiner

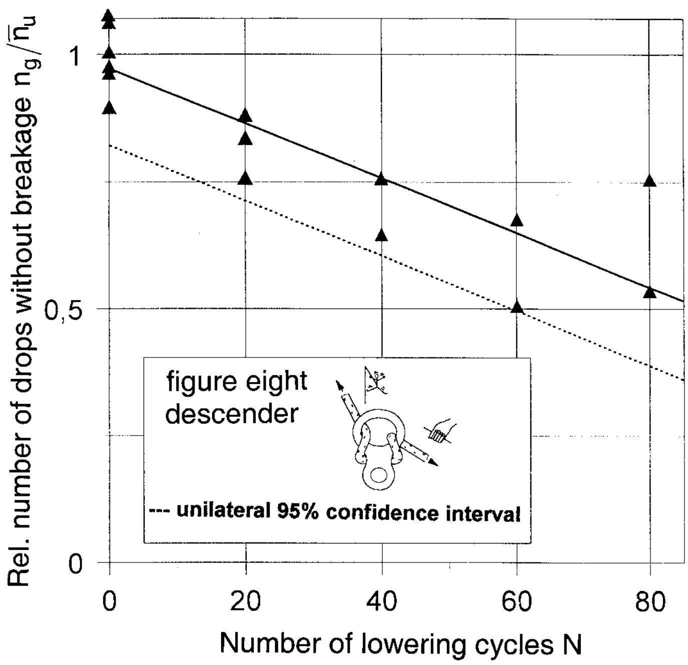

Fig. 5: Relative number of drops – bendings in the figure eight descender

At rope parts, which were bend in the grigri (figure 6) the relative number of drops without breakage is high after some lowering cycles and is then reduced only slightly. The reduction is with an increasing number of lowering cycles smaller than at the carabiner and the figure eight descender. This course of the relative number of drops without breakage over the number of lowering cycles is a consequence of the dynamic additional demand, to which the ropes are exposed at the end of the lowering procedure. The relative number of drops without breakage falls over the number of lowering cycles of rope parts, which are only bend in the upper carabiner, is shown in figure 7 with dynamic belaying carabiner and figure eight descender and in figure 8 with static belaying. For both belaying methods the quotient $n_g/\overline{n}_u$ decreases with the increasing number of lowering cycles. At a dynamic belay, the relative number of drops without breakage decreases symmetrically with the increasing number of lowering cycles. The reduction of $n_g/\overline{n}_u$ is despite the higher rope forces at the upper carabiner regularly smaller than at the rope parts, which were bend in the dynamic belay devices. At the static belaying security with the grigri, the already known process of $n_g/\overline{n}_u$ over N as a consequence of the dynamic additional demand is shown.

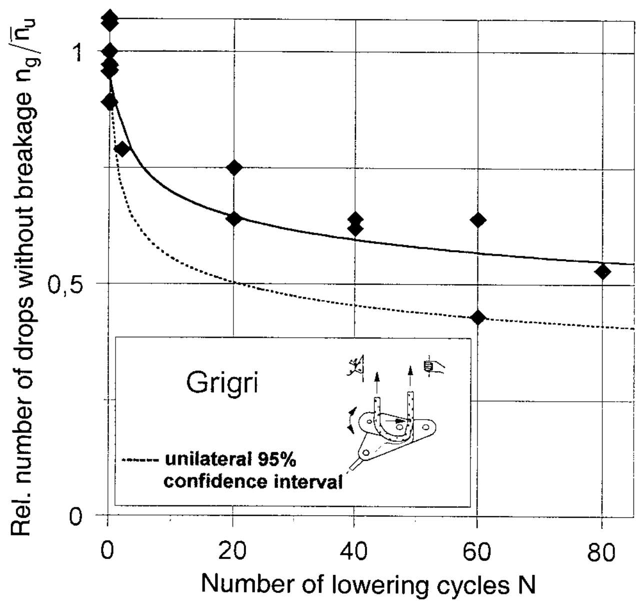

Fig. 6: Relative number of drops – bendings in the grigri

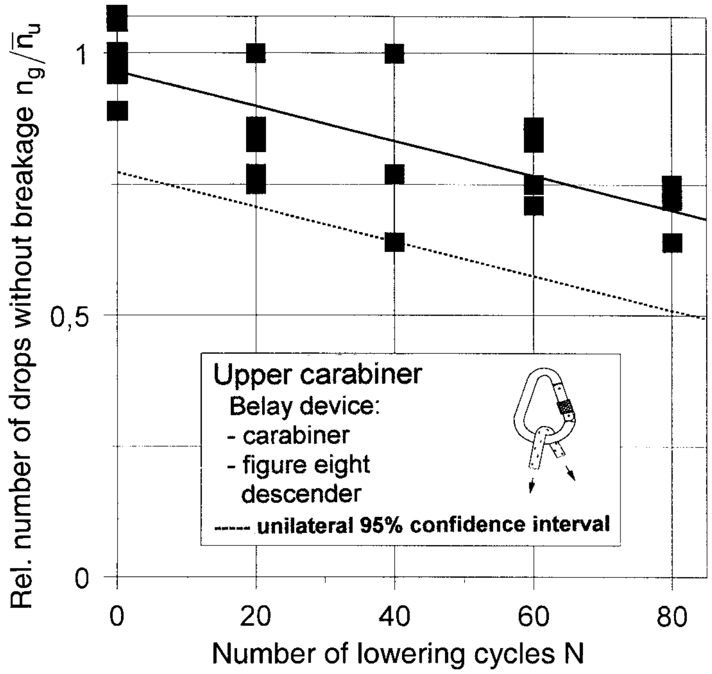

Fig. 7: Relative number of drops – bendings in the upper carabiner combined with the belay devices carabiner and figure eight descender

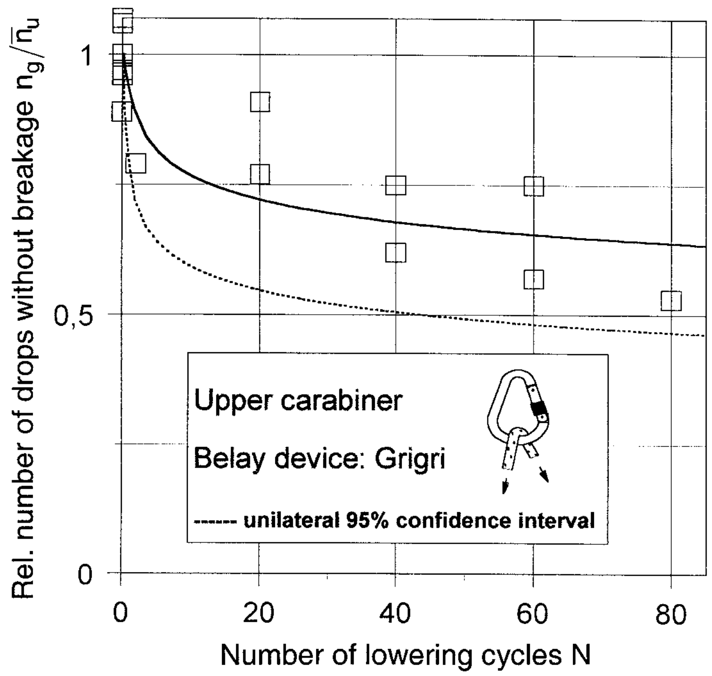

Fig. 8: Relative number of drops – bendings in the upper carabiner combined with the belay device grigri

The relative number of break-free bearing falls determined in the test after bendings during the lowering cycles in toprope climbing is evaluated in a regression calculation. As regression equation at the dynamic belay with the carabiner and the figure eight descender a linear equation

$$\left(\frac{n_g}{\bar{n}_u}\right) = a_0 + a_1 N \qquad (1)$$

is chosen. At the static belay with the grigri a potential equation is chosen.

$$\left(\frac{n_g}{\bar{n}_u}\right) = b_0 N^{b_1} \qquad (2)$$

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

$$\lg\left(\frac{n_g}{\bar{n}_u}\right) = c_0 + c_1 \lg N \qquad (3)$$

In using the regression calculation the constants a_0, a_1 and c_0, c_1 are calculated. In table 2 the constants a_0 and a_1, the standard derivation s and the determination measure B are listed for the dynamic belay devices. Table 3 includes the constants found with the static belay device. The results of the calculation are plotted in figure 4 up to figure 8 as solid lines. Additionally the unilateral 95 % confidence interval is shown as dashed lines. The test results are practical in all cases above this calculated statistical limit line.

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 10^{-3}	0,057	0,928
Figure eight descender	0,976	-5,43 10^{-3}	0,091	0,757
Upper carabiner	0,965	-3,3 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

7. Summary

The drop tests with mountaineering, which were altered in lowering procedures as normal in toprope climbing, have shown that with an increasing number of lowering cycles the number of drops without breakage compared to the new condition of the rope strongly decreases. With rope parts, which were only bend in the figure eight descender or in a carabiner, already after 80 lowering cycles only about half or less than half of the number of drops without breakage of the new condition, unused rope. This safety loss occur in praxis after few top rope climbing days. By overlapping the bendings in the belay devices with other stresses of the collective one has to calculate with further decrease of number of drops without breakage. The safety loss is uncritical for further use as a toprope rope because fall factors are small but critical when a big fall height is possible.