Sharp edges and rope cuts

This document is an English language translation of the original 'Skarpe kanter og taukutt", produced in Norwegian by the Norges klatreforbund (NKF)/Norwegian Climbing Federation (NCF), a UIAA full member. The document is produced in collaboration between the safety commissions of the NKF/NCF and the UIAA.

The climbing rope is the backbone of the protection system in sport climbing, mountaineering and ice climbing. If the backbone breaks during climbing, we find ourselves at the mercy of gravity. A fall during roped climbing will very likely cause serious injury or death to the climber.

Requirements for climbing ropes
The rope is so important that it must not break under any circumstances. Other strict requirements also apply to all ropes intended for climbing. The most important one is the rope's ability to stretch and provide dynamics in the case of a fall. For low stretch ropes the breaking strength is also important. However, there are no requirements regarding the rope's ability to resist shear over sharp edges.

What is a sharp edge?
This is a fundamental and important question that has no simple answer. Non-identical sharp edges were one of the factors that led to the scrapping of the UIAA sharp edge test (please refer to fact box #2). Putting tests and standards aside for a moment, imagine yourself on a rock face. After a series of delicate moves, you get up to an overlap that is the crux of the route. You know that the moves are marginal compared to what you are capable of, but your anchors are solid and falling should be safe. But the rope will be loaded against a bevelled edge if you fall on the crux. Is the edge sharp? How sharp is sharp? Is the edge too sharp to risk a fall with subsequent loading of the rope against it? How can you gauge the sharpness of an edge up on a rock face?

Now let us leave the rock face and look at the UIAA 101 fall test (please refer to fact box #1). In this drop test, a carabiner with a diameter of 10mm is used, i.e. a radius of curvature of 5mm. A possible definition of a sharp edge could be to say that anything sharper than the test carabiner constitutes a sharp edge. At the Norges Høgfjellsskole (Norwegian High Mountain School), the carabiner was from its establishment in 1967 used as a point of reference for sharp edges. Some will probably argue that this is a conservative definition of a sharp edge, but a conservative definition gives us a margin of safety, and a carabiner is always available on the climbing harness for reference when you are on the rock face. But no structure on a rock face is the same. Some edges are sharp, some are smooth, some are rough, and some edges have crystals on them.

Fact box #1: Certification of climbing ropes
The International Climbing and Mountaineering Federation (UIAA) has developed a standard for climbing ropes (UIAA 101), which has in turn been adopted by the European standardisation body CEN into a common European standard for climbing ropes (EN 892). Climbing ropes are to be considered personal protective equipment (PPE) according to EU Regulation 2016/425. The EU regulation sets special requirements for PPE designed to protect against falls to a lower level. This is defined as PPE category III, which is the strictest category. Climbing ropes fall in this category. The standard sets requirements for testing and marking of the climbing rope. When the formal requirements have been met, a declaration of conformity must be issued for the climbing rope, and it must be CE marked before it is allowed to be sold. Ropes that do not meet EN 892, that are not correctly marked or have not been issued a declaration of conformity are not permitted to be sold as climbing ropes in European countries.

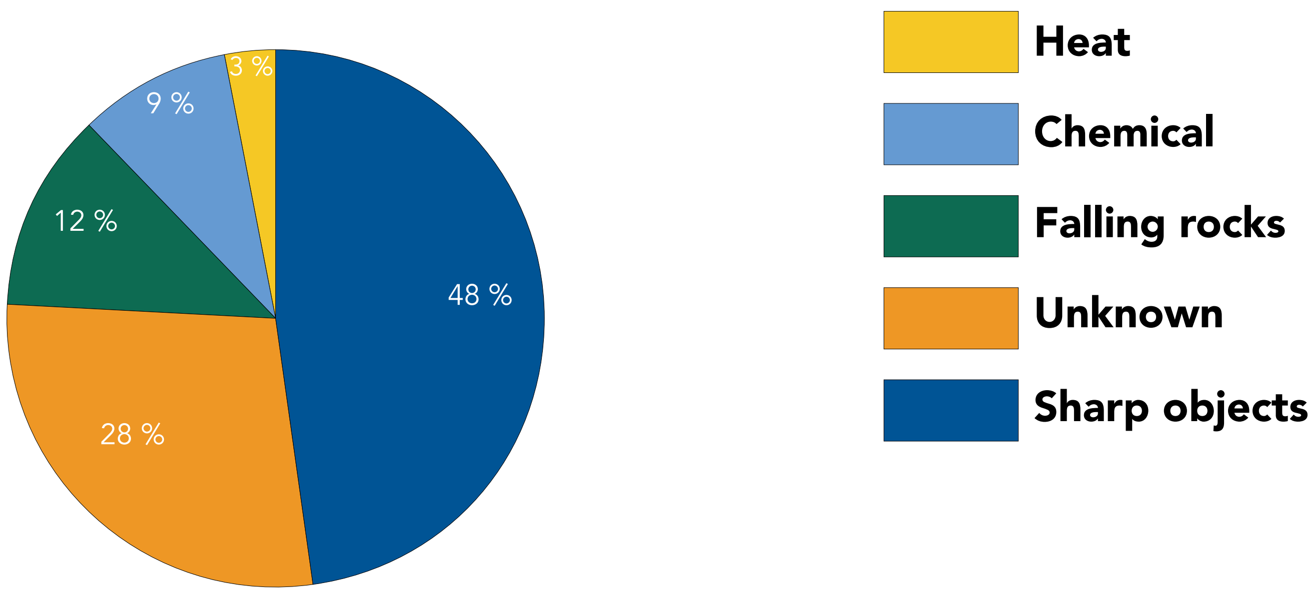
Fact box #2: UIAA's sharp edge test - the test that had to be scrapped

Climbers with good memories who have been climbing for over 20 years may remember that for a short period between 2002 and 2004, ropes were certified according to the UIAA's sharp edge test. This was a test that the UIAA had developed to test the rope's ability to sustain loading over a sharp edge. Ropes could be legally sold without passing the test, as it was a voluntary test that rope manufacturers could apply to prove that their ropes had good sharp edge resistance. However, the test soon proved to be unreliable. Identical ropes gave different results when tested at different laboratories. The reason owed to problems with the consistency of the sharp edge that the ropes were to be tested against. In the UIAA 101 drop test the rope is loaded over a 10mm diameter carabiner. In the sharp edge test, this carabiner was replaced with a 90 degree sharp edge. Mathematically, it is easy to describe a 90 degree angle, but in real life the edge consists of metal where the atoms sit in a crystal structure. Exactly how the atoms are arranged in relation to each other at the very tip of the "sharp edge" determines the actual sharpness. Every single time a rope is tested on this edge, some atoms disappear and make the edge less sharp, even though it still appears to be a perfect 90 degrees. A good analogy here is a sharp knife versus a dull knife - these can rarely be distinguished from each other with the naked eye. The UIAA sharp edge test was also criticized for being unrealistic, as it did not test the rope's strength under lateral load over a sharp edge. As of 1 July, 2004, this standard was scrapped as it was deemed redundant.

When the rope breaks

Fortunately, climbing ropes rarely break. However, it has happened often enough that we can form a picture of the different mechanisms that can lead to a rope break. In the 1960s, the safety pioneer Pit Schubert from the Deutscher Alpenverein (DAV)/UIAA Safety Commission started collecting data on rope breaks and their causes. Between 1969 and 2018 (50 years), the DAV collected information on a total of 53 cases. Adding data from the American Alpine Journal and other sources, there are 128 cases of known rope breaks in this period, i.e. just over two rope breaks per year on average. The accident causes are distributed as shown in the figure below. In 28% of the cases there is not enough information or data to determine the cause. The dominant cause is cutting against sharp objects (48%). This can be sharp edges on the rock face, carabiners that are so worn down that sharp edges have formed in the metal, or more exotic causes such as the rope being cut by an ice screw crank that was not tilted up after placement. Rockfalls account for 12% of the incidents, and contact with chemicals 9%. Acids, especially battery acid, are very harmful to the rope and such damage can be difficult to see. On the other hand, gasoline, Coca Cola, urine, seawater and UV radiation have little effect on ropes, according to tests carried out by Pit Schubert. After 1982, Germany saw a noticeable decrease in fatal rope breaks as a result of the majority of alpine climbers switching to double ropes, which provided redundancy in the belay system.

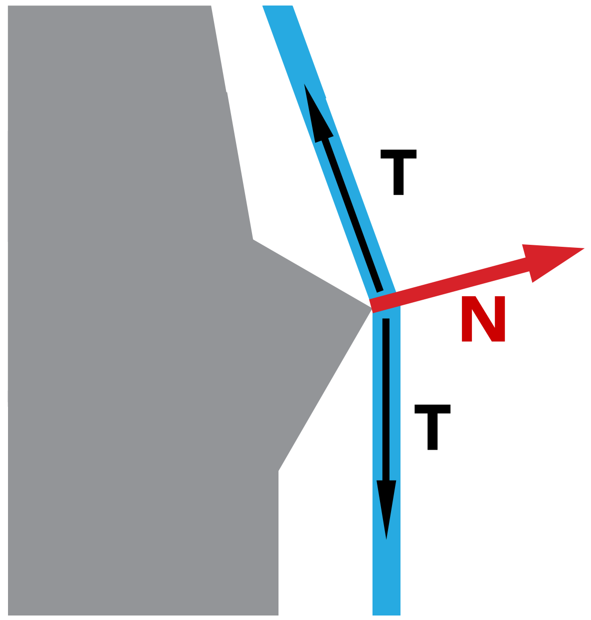
Causes of rope breaking



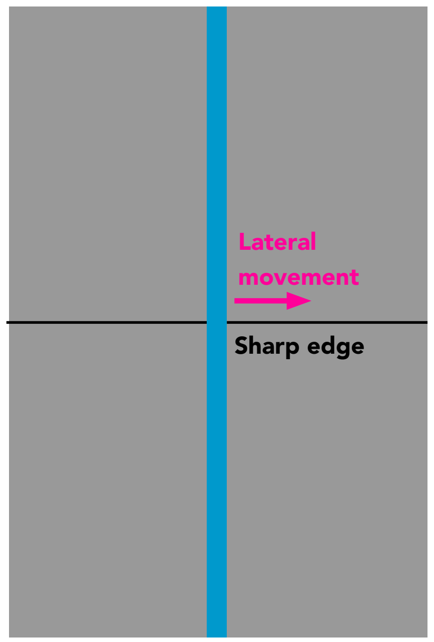
The sharp edges

We will now focus on rope breakage caused by sharp edges. There are mainly two mechanisms, or types of force, that come into play when the rope is loaded against a sharp edge.

Cutting force: When the rope rests against a sharp edge, the edge will assert a normal force (N) perpendicular to the rope. The other force at this point is the tension (cord tension) of the rope (T). For those who listened closely during their physics classes at school, it is obvious that the greater the tension of the rope, the greater the normal force from the sharp edge on the rope will be. See the figure below.

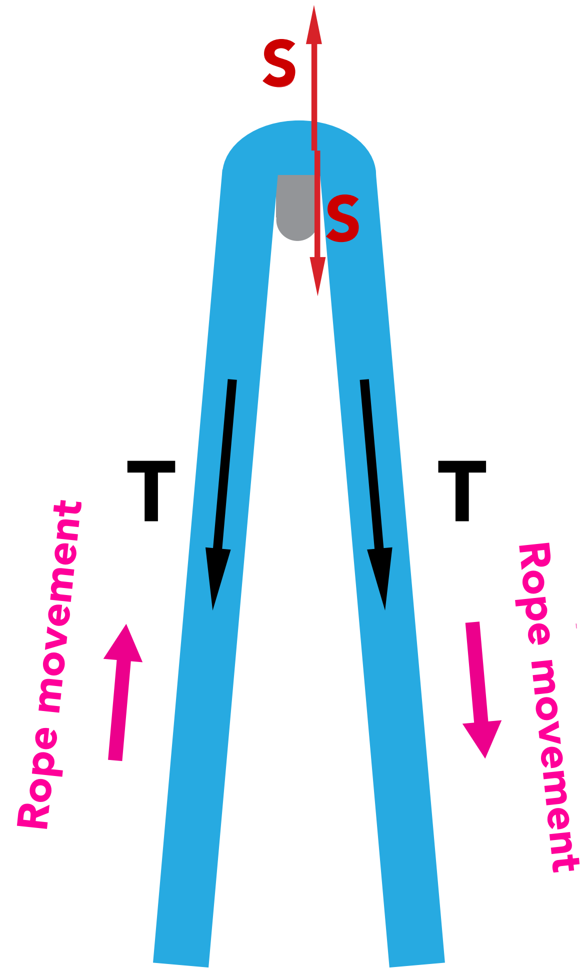


If the same point on the rope now moves laterally along the sharp edge, the normal forces will make the rock cut into the rope in the same way as when cutting it with a knife.



How much lateral movement it will take to fully cut the rope in this way will depend on the rope load. Greater load gives greater rope drag which in turn gives greater normal force and thus a shorter sliding distance before the rope is completely cut. Experiments done at Edelrid's laboratory show that increasing the rope load from 80kg to 160kg reduces the sliding distance before a cut happens to 1/4. Increasing the rope diameter appears to have some effect on the sliding distance before cutting occurs, but the diameter of the rope matters much less than the rope load.

Shear forces: These are internal forces in the rope that act perpendicularly to the length of the rope. In any cross section of the rope, the part of the rope to one side of the cross-section will be subject to shear forces from the part to the other side of the cross section. Again, if you paid close attention during your physics classes at school, you know that Newton said that such forces are equal in magnitude and opposite in direction, and that they act on every part of the rope. A pair of shear forces (S) are shown in the figure where a loaded rope is bent over a carabiner, as happens if you fall or if you are lowered from an anchor.



Shear forces commonly occur in the belay system, but they become very dangerous if there are sharp edges on the metal that the rope slides over. Especially carabiners that have been in place on a route for a long time will wear from repeated lower-offs. Deep grooves can form in the carabiner material, and sharp edges can be found in these grooves. Such grooves often form in carabiners on the first and second bolt on the route, or under overhangs where the rope changes direction. Such edges do not necessarily feel sharp when touched with a finger, but they could be more than sharp enough to damage a rope that is forcefully loaded over the edge. In the worst case, it is cut completely. The carabiner pictured below belonged to a permanently placed sling that was taken down from the route Aloha on the crag *Beachen* in 2022. The risk of rope damage or rope cuts on this carabiner is very real.

In many cases, cutting forces and shear forces will occur simultaneously. Both types of forces can contribute to rope cuts when a rope is in contact with sharp edges.

The accident database at ulykkesdatabasen.no contains 17 cases of complete rope cuts. The causes of these rope breaks are distributed as follows:

- Rockfall (10 incidents)
- Load against sharp object (5 incidents)
- Combination sharp/melting (1 incident)
- Unknown (1 incident)

Rope breakage due to rockfall

This is the dominant cause of cut climbing ropes in Norway. Rocks that hit the rope are either released by the climbing team itself, by other climbers or by natural causes.

Rope cut by falling rocks at the Hetta climbing crag in Vaksdal. The picture above shows the cut rope. The picture below shows the rock that came loose when the climber stepped on it.

That the rope can be cut by rockfall is quite obvious (in contrast to ropes that are loaded over edges). If we count the number of rockfalls that have caused damage to ropes without the rope being completely cut, the number is much larger than ten. Rockfalls can of course also cause injuries to the climbers, and we must do our utmost to avoid them while climbing. For the climbers, this is primarily about assessing handholds and footholds before loading them, as well as making wise route choices on the mountain. For those developing sport climbing routes, it is essential to do a thorough cleaning job before the climbing route is opened.

Non-rockfall rope cuts

We will dig into the details of the seven reported rope cuts that were not related to rockfall and take a closer look at what caused each one of these.

June 2003, Sunnmøre

A low stretch rope rigged for a Tyrolean traverse broke when a teenage student reached the end of the traverse. When the braking rope was about to stop the final movement, the rope of the Tyrolean bounced a little up and down and broke at the top anchor. The anchor at the top was rigged at an angle so that the rope was not allowed to run freely. Instead it was pressed against the edge of the pulley. At the same time, the telephone pole forming the lower anchor yielded a little and kept swaying back and forth. This led to continuous small tugs on the taut rope while students were being lowered down. At the point of breakage, there were signs of melting 2-3mm into the rope, before the remaining fibres in the core had failed, partly cut off and partly torn. The rope had seemingly been grating against the sharpened edge of the pulley. Eventually this generated enough frictional heat for the edge of the pulley to melt through the sheath of the rope and into some of the core fibres. The rope snapped when the remaining fibres could no longer support the load. No one was injured. The pictures on this page show the cut rope and the pulley that was used.

This Tyrolean traverse was improperly rigged, and the rope was repeatedly subjected to adverse load from the pulley, which weakened the rope and eventually made it snap. A separate report has been prepared about this accident.

June 2003, Hornaksla, Romsdalen

A climber on the route *Philipshave* took a controlled fall on an apparently well placed camming device. The cam came out when it was loaded. One half rope, an almost brand new 8.5mm rope, was loaded against the edge under a small corner and was cut. Since only this rope was connected to the top three anchor points, the fall was extended to 15m. The climber tumbled, hit his head on the wall and had his forehead cut. The pictures below show the cut rope. The edge that cut the rope was identified afterwards, by a lot of remaining fibres from the rope sheath. When pulled taut by the fall, the rope had been dragged across a 30cm long layback edge. The half ropes had not been put to optimal use, which resulted in the fall being unnecessarily prolonged. However, the use of half ropes prevented a more serious outcome. In the climber's opinion the half ropes were too thin.

September 2003, Florø

During supervised climbing a rope broke when two climbers were abseiling simultaneously, when they were a metre above the ground. The break was triggered by a jerk when they hit a figure-8 descender left behind on the rope by the previous abseilers. No one was injured.

This rope break happened when a timid participant abseiled together with an instructor on a single fixed rope. The abseil went down an overhang 10m above the ground. Towards the end, due to the dynamics, the rope was seesawing over a rough edge with crystals on it, above the overhang. The point of failure indicated that the rope was sawn off by the seesawing due to friction against the rock. The weight of two persons rather than one on the rope adds to the rope's vulnerability to cuts. Unfortunately, we have not been able to find any pictures of the rope in this accident.

June 2005, Hardangerjøkulen

An 11mm rope broke during a rescue exercise with a 1:3 hoist during a glacier instructor course. The rope was placed over a bag near the crevasse rim to prevent it from digging into the snow. The hauling was heavy, and two people were pulling at the top with all their might when the rope broke sharply. The point of failure was above the crevasse, between the bag and the person standing closest to the crevasse. The person hanging in the crevasse was caught by a separate safety rope and no one was injured. The rope was not in visible contact with any sharp objects where it broke. The bag was examined for sharp objects, but none was found. The cause of the rope break remains unknown. The rope's age, history of storage and history of usage could not be determined. There were no visible colour changes or colour variations on its surface around the point of failure. The broken section did not appear to have been cut, but looked more like it had been torn. The fibre length at the break varied with long fibres in the middle and short one towards the outer edge. There was no heat damage to the fibres. One hypothesis is that the rope had undetected prior damage, either mechanical or chemical. Another hypothesis is that there was a sharp edge on the bag at the rim, which was either not detected or not considered sharp enough to cause a rope cut when examined.

The picture below shows the cut rope at Hardangerjøkulen

June 2008, Vardø

A climber on a top rope fell into pendulum swing after a controlled fall. As a consequence the rope was dragged across a sharp edge two or three times and then broke sharply. The climber was two metres above the ground and escaped with no injuries except for a sprained arm.

Lateral movement and cutting forces applied to a single point on the rope caused the cut. We do not have any pictures of the rope from this accident, but the pictures below show the crag, and the sharp edge is marked with a red ring.

January 2021, Jaklefoss, Ringkollen

During drytooling with natural protection, one of the lead climber's half ropes was run over a sharp edge. When the climber fell one half rope was cut. The other half rope prevented a ground fall. The left picture shows the edge that cut the rope and remains of rope fibres (green). The right picture shows the cut rope.

In a video of the fall, we can see the rope moving along the sharp edge and breaking during this movement. The usage of half ropes prevented a more serious fall in this case.

There is a link to the video on the last page.

May 2023, Staup, Voss

During a supervised abseil, the rope breaks sharply as a teenage student jumps off and the rope hits the edge. The tight rope probably moved laterally over a sharp edge and was cut. She fell 12 metres and suffered a broken back, a dislocated collarbone, and a torn knee ligament. Jumping over the edge creates a large force on the rope, and when the rope under tension slides sideways against a sharp edge, a clean cut is made. The pictures show the cut rope and some of the sharp edges at the scene (note the remains of rope fibres). A separate accident report has been written about this accident.

Summary and recommendations

Seven rope cuts that are not due to rockfalls over a period of 21 years is fortunately not a lot, but very dramatic for those involved. Fortunately, there are no fatalities among these seven incidents. We can see from the various images of cut ropes that there are different mechanisms involved in the rope breakages. Cutting by lateral movement at one point of the rope is evident in the images from Staup, Voss (2023). This type of cut was also recorded in the incident from Vardø (2008). In the images of the broken ropes from Hornaksla (2003) and Jaklefoss, Ringkollen (2021), we can see that the yarns have been cut in different places. This indicates that the rope has been moving over the sharp edge so that the yarns have not been cut in the same place. We have not recorded cuts caused by loading over a ground down carabiner in Norway, but we are aware of incidents from abroad.

It is worth noting that two of the incidents happened during supervised abseiling on a fixed single rope. It is therefore timely to question this practice. A similar incident has been recorded in Switzerland where a rope was cut when two persons were abseiling on a single rope during a self-rescue course for mountain guide training. Two persons and/or bouncing on the rope increases the load, which makes the rope much more vulnerable to loading over sharp edges.

Two of the Norwegian incidents occurred during climbing with double ropes, where one rope broke and the other rope prevented far more serious outcomes.

To avoid rope cuts, climbers must be aware of the danger and know the different mechanisms that can cause rope breaks. The Norwegian Safety Committee would like to give some simple recommendations to reduce the chance of cut ropes.

Advice for abseiling:

- Do not use fixed single ropes for supervised abseiling. Use two ropes or a rope laid double (which can often be fixed on top). This provides redundancy. If one rope breaks, there is a chance that the other one does not. The load is also halved, making the ropes much more resistant to sharp edges than a single rope would be.
- Examine the abseiling location, and avoid places where there are sharp edges.
- If abseiling on a fixed single rope (for route development, maintenance and instructor work), use a low stretch rope and put on rope protectors where the rope is in contact with the rock.
- Avoid bouncing while abseiling, as this creates increased loads making the rope more vulnerable to sharp edges.
- During self-rescue practice when two persons load the rope, there is a dramatic weakening of the rope's resistance to sharp edges. Again, always use two ropes in combination with rope protectors where needed.

Advice for route developers:

- Clean the route thoroughly. Knock on all imaginable and unimaginable holds and remove what sounds loose with your hands, hammer, crowbar or similar. If it is impossible to remove loose material and make the route safe, find another place to establish a route.
- When placing bolts, try to analyse and visualise where the rope will go against the rock. Place the bolts in such a way that the rope will run cleanly with minimal rock contact, and in any case make sure that the rope is led away from any sharp edges. A controversial tip is to knock off dangerously sharp edges with a hammer.

General advice

- Use half ropes when climbing ice, mixed, alpine and longer routs in the mountains. This is a good precaution against rope cuts caused by rockfalls and sharp edges.
- If you consider an edge to be sharp, try using a longer sling to pull the rope away from it in the event of a fall. You can also choose to turn around and climb back down if the risk of falling is high.
- If there are permanent slings on the route you are going to climb, check if the carabiners are worn, and if so replace them with undamaged carabiners.
- Take care of your ropes and treat them gently. Store them safely, and make sure they are not in contact with chemicals or acids. Keep them away from batteries as these can leak battery acid.
- Replace the rope when it becomes visibly worn or, if possible, cut off and discard the worn part of the rope. A worn rope is much more vulnerable to sharp edges than a new rope.

Although there is currently no formal test for rope resistance to sharp edges, this is a problem that rope manufacturers are working to solve. On this page, there is a link to a couple of video clips from the rope manufacturer Edelrid, which is trying to find a standardized setup for testing the resistance of ropes to lateral loading against sharp edges.

Recommended video clips

Video of the cut rope at Jaklefoss
https://www.youtube.com/watch?v=V0Zqnjhk8g0

Michele Caminati's rope breaks as he falls on the Elder Statesman route
https://www.youtube.com/watch?v=K9Wzx-9JzsI

Edelrid's knowledge base on climbing ropes and cut resistance - Part 1
https://www.youtube.com/watch?v=WGjvW8_wLuE

Edelrid's knowledge base on climbing ropes and cut resistance - Part 2
https://www.youtube.com/watch?v=IL2r_f2g4Sw

Hard is Easy analyses the cut resistance of climbing ropes
https://www.youtube.com/watch?v=dpmUFQhMdbI

What is the UIAA Safety Label?
https://www.youtube.com/watch?v=mfXDLcgZeWs

Important pages

https://www.theuiaa.org/safety/
The work of the UIAA - International Climbing and Mountaineering Federation to improve the safety of climbers and mountaineers.

https://www.sikresider.no/
Portal for safety-material related to climbing.

https://www.theuiaa.org/accident-reporting/
Registration of accidents, near misses and unwanted incidents in climbing/mountaineering in the world. Freely available accident reports.

https://www.facebook.com/theuiaa
https://www.instagram.com/uiaa_official/
Follow the UIAA on social media to get regular news about climbing safety in your feed.

https://www.facebook.com/sikresider/
Follow "sikre sider" on Facebook to get regular news about climbing safety in your feed.

Prepared special reports

Sunnmøre (2003)
https://api.ulykkesdatabasen.no/storage/uploads/vooEpNPa0zAWzl9UnHdsvo5VGiNjkTxENNN-bTAxi.pdf

Staup, Voss (2023)
https://api.ulykkesdatabasen.no/storage/uploads/HSdWkNBbp00WWjM65kVL9ADEcm4Jy1y-D3cReWR7b.pdf