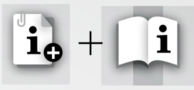
DYNAMIC ROPES

Experience



• This Product Experience document is a supplement to the Instructions for Use, which provides feedback from field experience and tips for using your product
• It must be used in conjunction with the Instructions for Use

Important / remember

• Read the Instructions for Use carefully before looking at the following techniques
• You must have already read and understood the information in the Instructions for Use to be able to understand this supplementary information
• Mastering these techniques requires specific training
• Work with a professional to confirm your ability to perform these techniques safely and independently before attempting them unsupervised

Failure to heed any of these warnings may result in severe injury or death.

Table of contents

Each piece of information is listed according to the technical level required for its application. Respect your own level when choosing your techniques.

FOR BEGINNER — **Beginner technique**
Technique usable by a trained practitioner of the activity.

NOT FOR BEGINNER — **Technique for a certified practitioner**
Technique for a person trained and certified in the activity.

EXPERT ONLY — **Expert technique**
Technique only for experts in the activity.

Icons legend

user	mass of user
climber	hand
victim	anchor
rappel	mass
victim + rescuer	small mass
fall	harness

After many laboratory fall tests with metal masses, we noted a significant difference between forces in the laboratory and forces in the field. We wanted to understand these differences through a variety of measurements in real conditions. These tests were correlated with tests on metal masses.

Understanding real falls is somewhat complex as many variables come into play. We give you the results we obtained with a maximum of transparency, while simplifying the data.

Good reading and good climbing

1. Understanding falling

1.1. Theory

Fall factor and impact force are two important concepts in the physics of climbing falls.
To understand a climbing fall, it is important to recall a basic law of physics: when an object falls, it stores kinetic energy.

Impact force

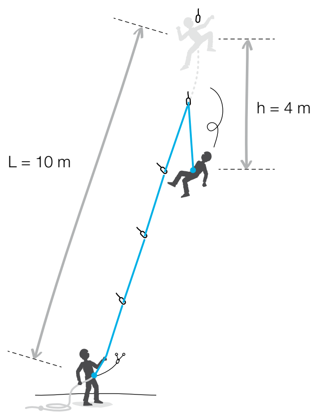
During fall arrest, this energy is dissipated by elongation of the rope, displacement of the belayer, the climber's body... Energy is transmitted to the belay chain in the form of force. This is the impact force. For the climber, it's the impact experienced during fall arrest. We are often interested in the impact force transmitted to the climber, the belayer, and the redirect point.

This value relates to all of the important factors in energy absorption: rope elongation, belayer displacement, the climber's body, rope sliding through the device...

The impact force indicated on a rope corresponds to the maximum force measured on a metal mass (a climber) in the standard test conditions (chapter 2.1).

Theoretical fall factor

The fall factor is often used to quantify the severity of a climbing fall.
It can have a value between 0 and 2 in climbing.

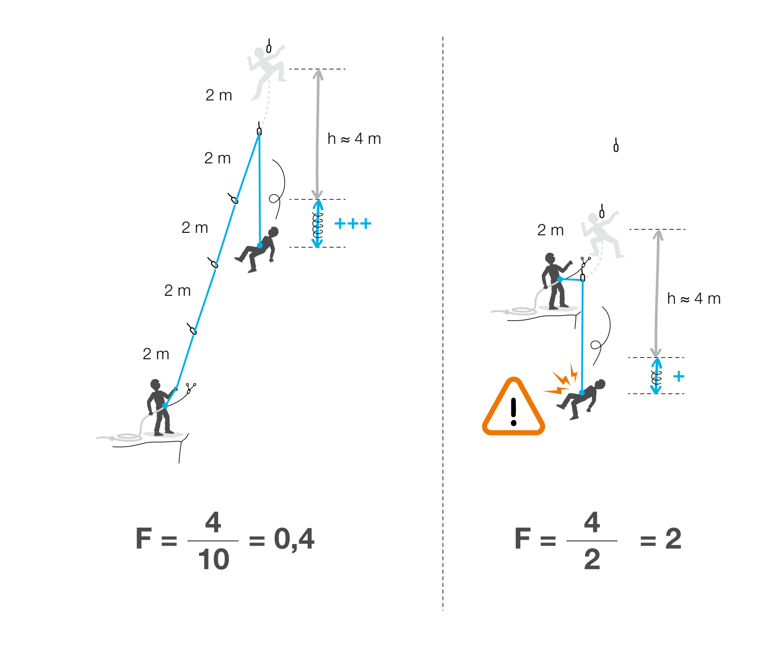


$$F = \frac{4}{10} = 0{,}4$$

$$F_{th} = \frac{\text{Fall length}}{\text{Rope length}}$$

Fth = theoretical fall factor
Fall length = length of the climber's fall
Rope length = length of rope between belayer and climber

The fall factor is the ratio of fall length to rope length.
In climbing the severity of the fall does not depend on the fall length, as the longer the rope, the more energy it can absorb.
In these two cases, the severity of the fall increases. The free fall length is the same. There is the same amount of energy to absorb, but the system is less dynamic.



Case 1
rope length = 10 m, fall length = 4 m so fall factor = 4/10 = 0.4.
The rope length is significant, so the absorption capacity is significant. The severity is low, so the impact force is low.

Case 2
rope length = 2 m, fall length = 4 m so fall factor = 4/2 = 2.
The rope length is short, so the absorption capacity is low. The severity is significant.

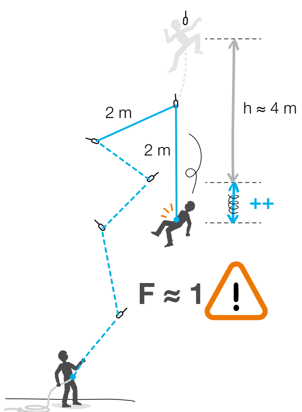
To learn more:

In theory, the higher the fall factor, the higher the forces generated. **The concept of severity as a function of fall factor is useful only with a dynamic rope.** The longer the rope, the more energy it can absorb. The fall factor model is rather simplistic, as it does not take into account important factors such as rope drag, type of belay device, belayer displacement... In the following chapters, we will see the impact of some of these factors.

Actual fall factor

The theoretical fall factor does not take into account the rope friction against the rock and in quickdraws. This friction prevents the rope from stretching over its entire length. Thus, only a part of the rope (solid line) will absorb the energy of the fall: this is called effective rope length.
It is therefore useful to talk about the actual fall factor.

It is clear that if a climber does not take the necessary steps to avoid rope drag, the actual fall factor can quickly increase. In this case, the fall will be more severe for the climber.



$$F_{th} = \frac{\text{Hauteur de chute}}{\text{Longueur de corde efficace}}$$

Fth = facteur de chute théorique
Hauteur de chute = hauteur de chute du grimpeur
Longueur de corde = longueur de corde entre assureur et grimpeur

1.2. What are the forces at work in a fall?

The values of the forces at work in a climbing fall that one finds in the literature or on the Internet are mostly derived from tests and numerical models based on the standard model (chapter 2.1)(rigid masses, falls on a fixed point…). So reported values are high, as they are the product of harsh tests.

In order to determine the forces actually encountered in the field, we performed a series of fall tests with the climbers in three configurations, corresponding to higher and higher fall factors.

The results shown are valid only on the tested configurations and can not be generalized to all situations. However they help us evaluate falls involving real people. To ensure repeatability of our protocol, each test was repeated at least three times.

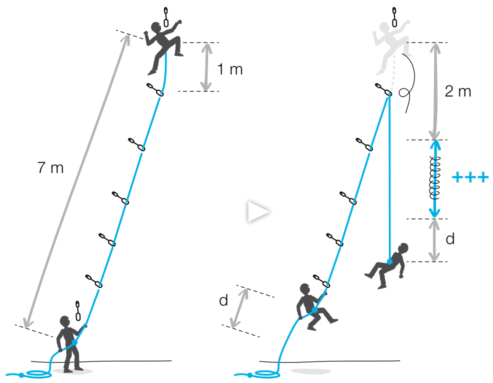
Notes

Despite our desire for a rigorous protocol, measurement uncertainty related to these results is significant. We can estimate at + or _ 0.3 kN. The forces presented are thus the result of the average of the tests, rounded to 0.5 kN.

We made the choice to focus on the forces on the climber, the belayer, and the redirect point. However, the force value alone does not characterize a fall. Other factors come into play to quantify the severity of a fall, notably the force rise time and the direction of pull. These different factors are not studied here and will be the subject of a future publication.

Fall factor 0.3

This first series represents a common climbing situation.



Test conditions

Climber: 80 kg
Belayer: 80 kg
Rope length: 6.9 m
Fall length: 2 m
Rope: VOLTA 9.2 mm
Belay device: GRIGRI 2

To ensure a certain repeatability, the climber always falls from the same position and the belayer is neutral (non-dynamic belay).
For this test, we chose not to clip the first quickdraw, in order to avoid blocking belayer displacement.

Results

Climber
Impact force ≈ 2.5 kN
The climber experiences the fall as a soft catch.
Note the significant climber displacement, despite the short fall distance.

Belayer
Impact force ≈ 1.5 kN
For the belayer, the fall is easy to stop.

Anchor
Impact force ≈ 4 kN

Note:

Despite the short fall distance, the climber ends up not far from the ground. This significant displacement is explained by two points:
- the line was straight, with little friction in the quickdraws.
- the first quickdraw was not clipped, so belayer displacement was not limited.

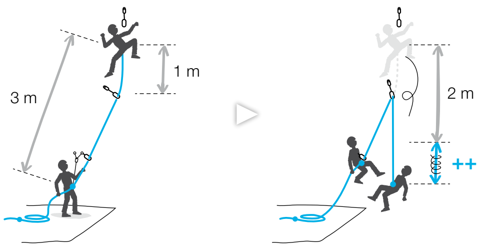
This situation is common in the gym, where the main hazard is a ground fall.

Advice

Systematically clipping the first quickdraw reduces the chance of a ground fall, by limiting belayer displacement.

Fall factor 0.7

This second configuration represents a fall on a multi-pitch climb, at the start of a pitch.



Test conditions

Climber: 80 kg
Belayer: 80 kg
Rope length: 3 m
Fall length: 2 m
Rope: VOLTA 9.2 mm
Belay device: GRIGRI 2

The belayer is tethered to the belay with an 80 cm lanyard. This pitch was chosen according to the location of the belay station: the belayer is below an arete, the 80 cm lanyard helps limit belayer displacement.

The belay station has no freedom of movement - it is equivalent to a fixed point. We made this choice to increase the repeatability of the test. A more common belay station gives the belayer more freedom of movement and thus yields lower forces. By contrast, the redirect point has significant freedom of movement; with a shorter anchor, the forces would be higher.

Results

Climber
Impact force ≈ 3 kN
The fall is impressive for the climber, but not painful.

Belayer
Impact force ≈ 2 kN
The force is not significant, but the belayer is stopped harshly at the belay station. Stopping the fall can be difficult if the belayer is surprised.

Anchor
Impact force ≈ 5 kN

Note:

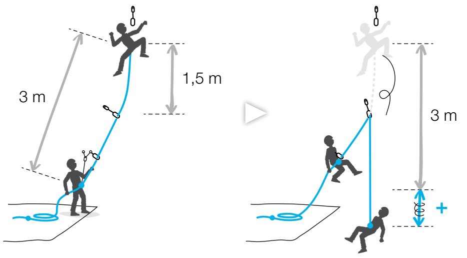
An initial series of tests was conducted without a redirect point on the belay. As the first anchor point was offset to the right of the belay, the belayer was pulled sideways in the fall, then stopped harshly by his lanyard. Sustaining such a load is hard on the human body.

Advice

A redirect point in-line with the belay (or otherwise on the belay) helps ensure a good direction of pull on the belayer, which makes stopping the fall less painful, and thus easier.

Fall factor 1

This configuration represents a fall on a multi-pitch climb when leaving the belay.



Test conditions

Climber: 80 kg
Belayer: 80 kg
Rope length: 3.6 m
Fall length: 3.6 m
Rope : VOLTA 9.2 mm (Impact Force: 8.6 kN)
Belay device: GRIGRI 2

The belayer is tethered to the belay with an 80 cm lanyard.
The belay station has no freedom of movement - it is equivalent to a fixed point.

Results

Climber
Impact force ≈ 4 kN
Such a fall is impressive for the climber and is rare in the field. However, the force is quite bearable.

Belayer
Impact force ≈ 2 kN
As with the factor 0.7, the belayer is stopped harshly at the belay station: arresting the fall can be painful and difficult.

Anchor
Impact force ≈ 6 kN

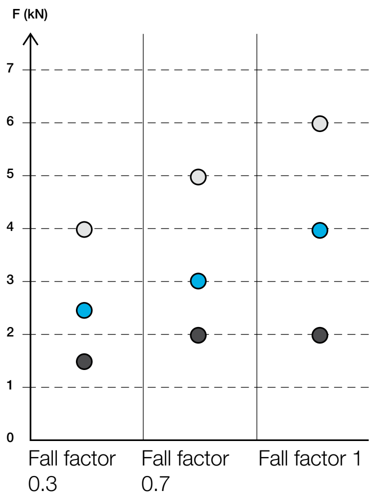
Note:

The force on the anchor is significant.
Such a pull is no problem for a solid fixed anchor.
However, it would be critical on a dubious point such as a small wire or poor piton.

Advice

Belayer movement helps dissipate the fall energy and thus limits the force. Thus the belayer is advised to have a long tether to allow displacement. Obviously, the length must be suitable for the situation.

The first point after the belay must be solid.



○ Force on the anchor
● Force on the climber
● Force n the belayer

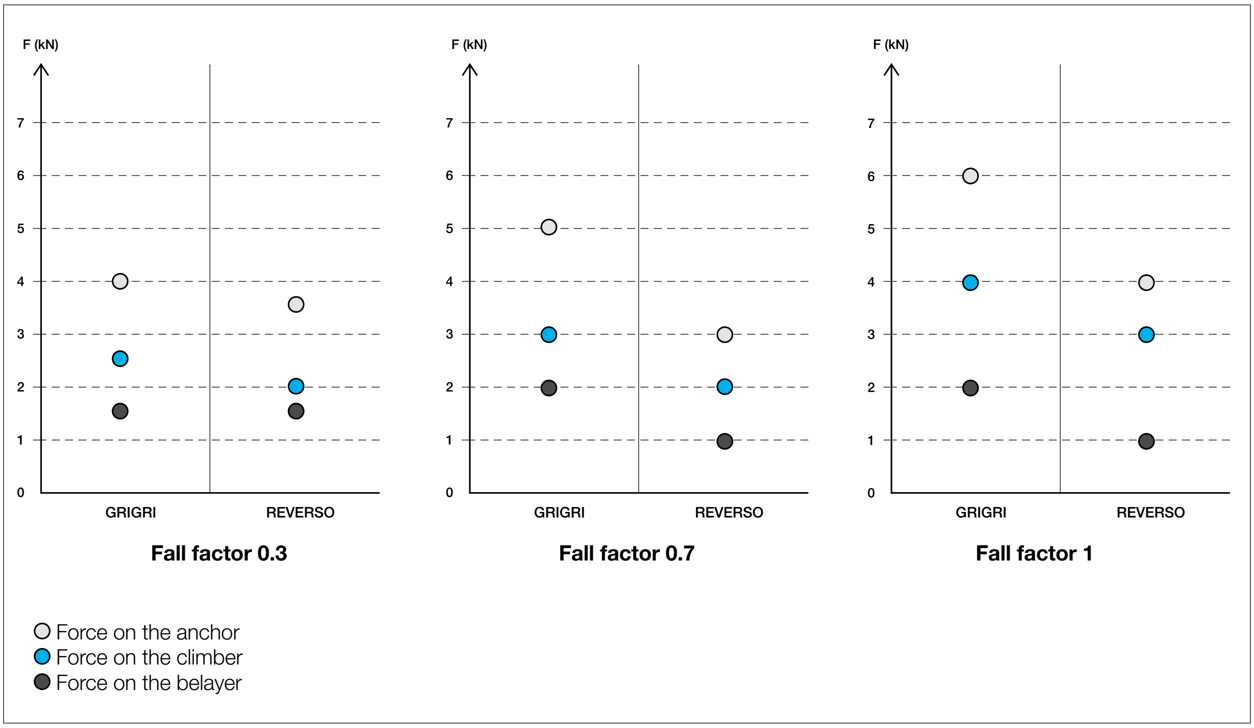
Conclusion

These tests have enabled us to put values on falls involving real people. These values will serve as a basis to study some particular points of the fall.

1.3. What is the influence of the belay device?

The results presented above correspond to falls belayed on a GRIGRI 2. In order to determine the influence of the belay device, the same falls were redone with a REVERSO 4 replacing the GRIGRI 2.
The test protocol is unchanged: the only variable is the belay device.

The results are influenced by slippage in the belay device and therefore by the belayer's grip. Variability is thus high: these results can not be generalized to all situations and allow us only to quantify, in a broad sense, the influence of the belay device.



Notes

Slippage in the REVERSO 4 has the effect of limiting the forces at work. The difference between GRIGRI and REVERSO 4 can be significant: up to 30% less force on the anchor.
The climber experiences a softer catch with the REVERSO 4 in these configurations.
The impact on the belayer is reduced, the force is weaker due to rope slippage. However, control of the rope, and thus stopping the fall, remains dependent on the belayer being very alert.

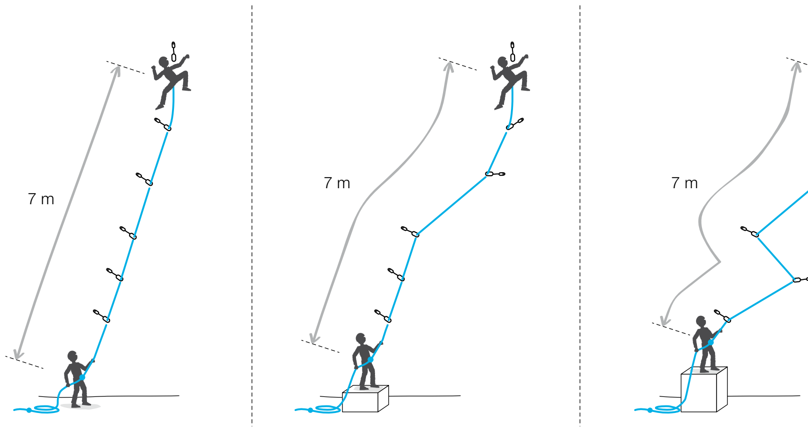
Advice:

The belay device should be suited to the situation.
Slippage in the REVERSO 4 increases climber displacement: one must be especially vigilant where there is a risk of hitting the ground or a ledge. This slippage can make stopping a fall particularly difficult for the belayer: gloves must be used, especially with a new skinny rope.

1.4. What are the consequences of poor rope drag management in a common fall?

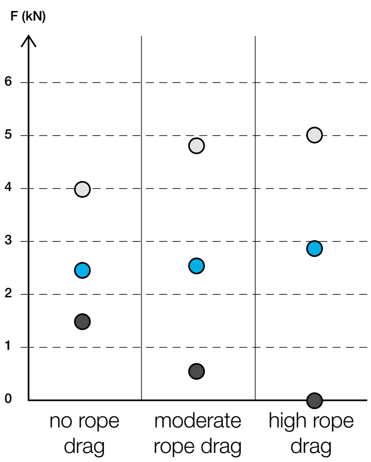
The first series of tests represent configurations with very little friction (protection points aligned). This configuration is common in the gym, but it is rare to find aligned points on single or multi-pitch climbs, where poor rope management can create significant drag.

It thus seems important to study the influence of drag on a common fall. We did a series of falls with different rope paths.



Only the drag was changed, the other parameters were constant.
The belayer was gradually raised to keep the same rope length regardless of the rope path.

It is important to note that the drag is greatly exaggerated, in order to highlight its influence. In practice, it is rare to face such significant drag.



Fall factor 0.3

○ Force on the anchor
● Force on the climber
● Force on the belayer

Notes

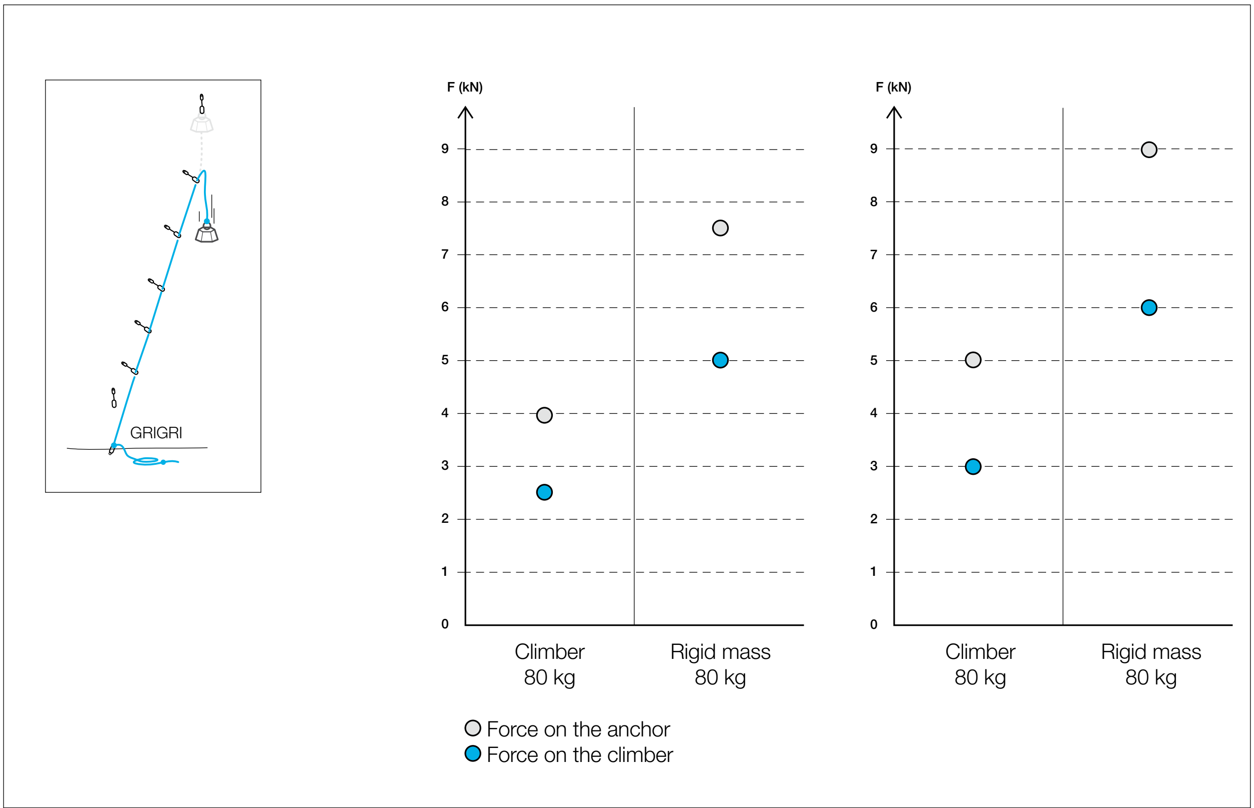
- Significant drag prevents the full length of the rope from absorbing the energy of the fall. Only the last section of rope stretches, the actual fall factor increases.
- The effective rope length being shorter, the climber has the sensation of getting a hard catch when the fall is arrested.
- The belayer is pulled less (or not at all) during the fall: his displacement does not contribute to dissipating a part of the energy in play.
- The effect is to slightly increase the forces on the climber and the redirect point.

Advice:

Anticipating the rope path and extending offset anchor points helps avoid situations with high rope drag.

1.5. What would be the results with a rigid mass?

The tests presented above were designed to help us evaluate falls involving real people.
For comparison, we redid the same series of falls based on the standard model: rigid mass with a GRIGRI 2 fixed to the anchor.



These tests revealed very significant differences between the two protocols: the force on the climber increases by up to 70% with a rigid mass.
These differences are explained by the many factors, other than the rope, that contribute to fall energy dissipation: the absorption of the two bodies, belayer displacement, rope slippage in the device...

Conclusion

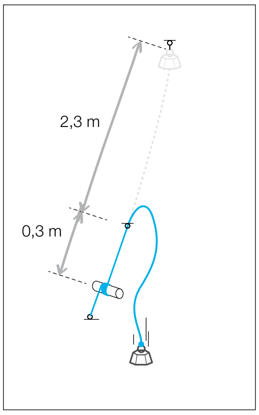
These tests help us evaluate falls involving real people.
Such measurements necessarily carry a high degree of uncertainty, but help provide important information:

• The forces at work in a real fall differ greatly from the results of standard testing.
• In practice, factors other than the rope contribute to dissipating the energy of a fall.
• To understand a fall, one must take into account all of these factors and not focus only on the rope.
• It is difficult to control all of the factors that dissipate fall energy. However, it is easy to influence the potential for belayer displacement.
Belayer displacement helps dissipate a significant part of the energy and thus limits the forces at work. On the ground, it is essential to allow displacement to occur for a dynamic belay. At the belay station, it is wise to use a long tether, when the situation allows it, to allow displacement to occur.

2. Standards: how are ropes tested?

The standard tests are done to ensure that the rope meets the given standard. These standard tests are established to prove that the rope is suitable for climbing. They are designed to be easily repeatable, but can be far from realistic.

2.1. Impact force



The dynamic test in the EN 892 standard consists of dropping a metal mass guided by two vertical rails. All dynamic ropes are subjected to this test.
The mass is 80 kg, except for half ropes where it is 55 kg. This 80 kg mass represents the weight of an average user with his equipment.
The fall simulates a factor 1.77 fall on a fixed point.
The force transmitted to the mass, when the fall is arrested, is limited to:

- 12 kN for single ropes (one strand of rope)
- 8 kN for half ropes (one strand of rope)
- 12 kN for twin ropes (two strands of rope)

2.2. What is the impact force of a rope?

The impact force of a rope is the force transmitted by the rope to a mass in the standard test. The measurement is made at the falling mass, climber side. This impact force is not representative of actual forces encountered in a climbing fall. The dynamic test of the standard is an extreme test, as it simulates a factor 1.77 fall with a metal mass, with the rope attached to a fixed point.
In practice, numerous factors can limit these forces: energy absorption by the climber's and belayer's bodies, rope slippage in the belay device, belayer displacement, deformation of the harness...

Rope type	Test mass	Max. impact force	Number of falls
1 Single rope	80 kg	12 kN	5
Twin rope (on 2 strands)	80 kg	12 kN	12
½ Half rope (on 1 strand)	55 kg	8 kN	5

Explanation of table:
The single rope on a single strand must withstand 5 successive falls. The impact force in the first fall cannot exceed 12 kN.

2.3. How was the max. impact force of 12 kN determined?

This value comes from military studies on paratroopers: the human body can withstand a maximum deceleration of about 15 G, or 12 kN for an 80 kg mass.

2.4. Why the 55 kg test mass for half ropes?

The half rope dynamic test is done on a single strand, as the strands can be used separately. However, it is not a single rope and is not designed to withstand multiple hard falls on a single strand.
On one strand with 80 kg, a half rope holds between 1 and 2 falls; it is difficult to differentiate between ropes with such a small number of falls.
And in reality, on a big fall, both ropes usually come under tension before the climber's fall is arrested. In this case each rope supports part of the user's weight.
For these reasons the standards committee decided: half ropes must hold 5 falls at 55 kg.
The 5 falls at 55 kg prove that a half rope is suitable for climbing.
Attention, this does not mean that you can belay a climber on one strand of a half rope.

2.5. Why the 8 kN impact force for half ropes?

The impact force of 8 kN comes from the max. deceleration sustainable by the human body of 15 G, or 8 kN for a 55 kg mass.

2.6. What would be the results of tests done with 80 kg on one strand of a half rope?

The impact force for factor 1.77 standard falls:
TANGO 8.5 mm on 1 strand with 80 kg, F = 9.2 kN, max. number of falls before break = 3.
SALSA 8.2 mm on 1 strand with 80 kg, F = 9 kN, max. number of falls before break = 2.
PASO 7.7 mm on 1 strand with 80 kg, F = 8.5 kN, max. number of falls before break = 2.
This means that with half ropes, it is possible to separate the 2 strands and clip only one strand several times to limit drag on a route, and be able to fall in this situation.

Attention: this does not mean that the belayer can easily stop a big fall on a single strand. It is also essential to beware of sharp edges.

2.7. Elongation

Two types of elongation are measured in the standard testing.

Static elongation

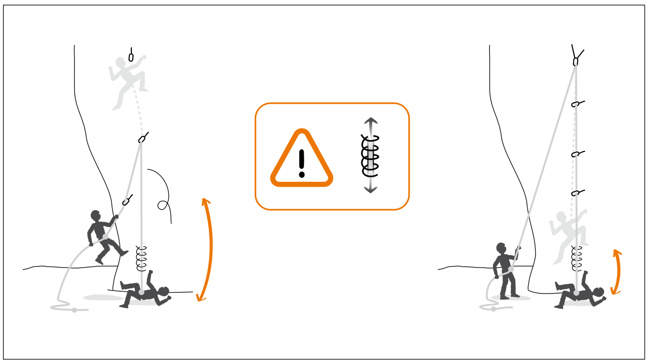
Static elongation is the amount of rope stretch under an 80 kg load. The test is done on one strand for single and half rope, two strands for twin rope.
It is limited to:
- 10 % for single ropes (one strand of rope)
- 12 % for half ropes (two strands of rope)
- 10 % for twin ropes (two strands of rope)

In use, static elongation is important mainly in a slingshot top rope situation. When working a route, less stretch can be more convenient, to avoid finding yourself below the spot you want to work!
A low static elongation also helps avoid ground falls at the start of the climb.

Dynamic elongation

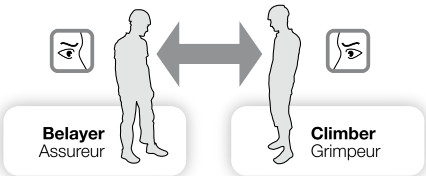
Dynamic elongation is the amount of rope stretch produced by the standard dynamic test. It must be less than 40%. As this test is extreme, it should be assumed that this is the maximum elongation. This maximum value will always be less in the field.

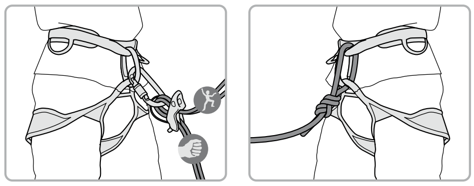
For a climbing fall, the dynamic elongation of the rope is between 10 and 40%.
A large dynamic elongation increases the risk of falling to the ground or on a ledge.



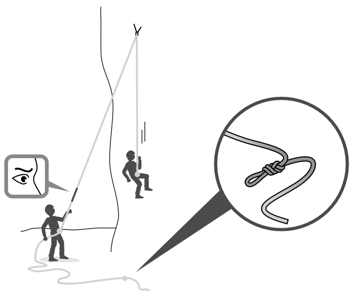
3. What are the primary dangers when using a rope?

• Incorrect tie-in, knot incompletely tied or tied in to the wrong place on the harness.
Solution: partner check or mutual verification.

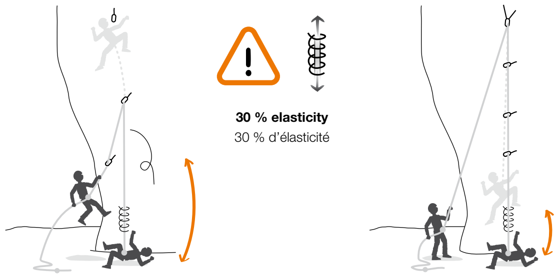




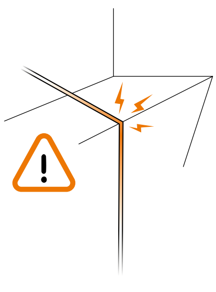
• Rope too short. Solution: always tie a knot at the end of the rope.
And check the length of the route on the topo.



• Ground fall due to rope stretch and a bad belay. Solution: spot, then remain extremely mindful of ground fall potential while the climber is low on the route. Always keep a critical eye on your surroundings (ledges) when considering rope stretch (on lead or on top rope).



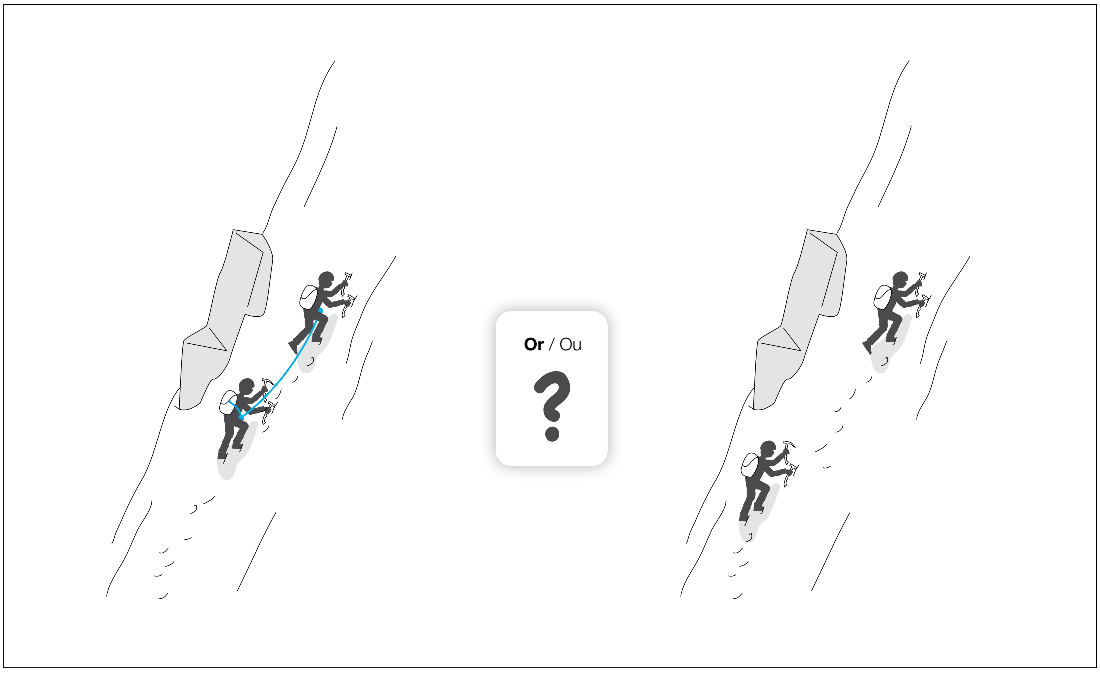
• Each year there are multiple incidents in which the rope is cut. For example on sharp rock edges, from rockfall or on fixed carabiners with sharp edges from excessive wear...



• Avoid climbing with the rope behind your leg.

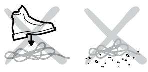
• Take the time to verify that your rope is compatible with your belay device. Compatibility obviously depends on the diameter, but also on the treatment, texture, density, flexibility... Two ropes of the same diameter can perform very differently in a belay device. Do some tests a few meters off the ground, especially with new, slick ropes, or with skinny ropes.

• Being tied in does not guarantee your fall will be arrested! Certain situations demand weighing the pros and cons of whether to use a rope or not. Steep snow slopes are a perfect example...

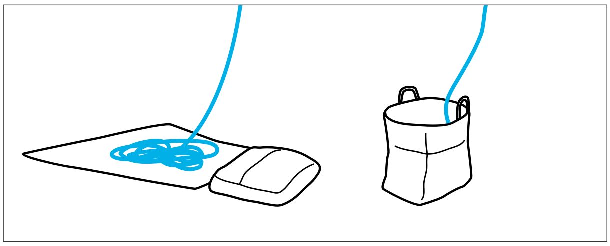


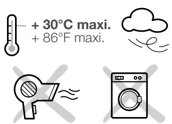
4. How to protect the rope?

As the rope is a relatively vulnerable component in the belay chain, it is important to take care of it.
Here are some tips for optimizing the life of your rope:



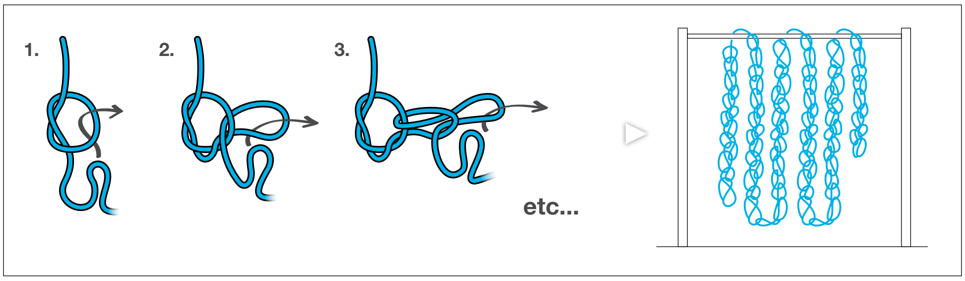
• Use a rope bag.
When the rope is in contact with the ground, dirt gets into the rope and accelerates wear. The rope bag keeps the rope off the ground.
A rope bag also removes the need for coiling: it is stored stacked, which helps reduce twists.



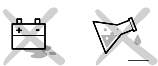


• A rope should not be stored wet.
Before storing, it should be dried in a ventilated area, away from UV.

Chaining the rope for efficient drying.

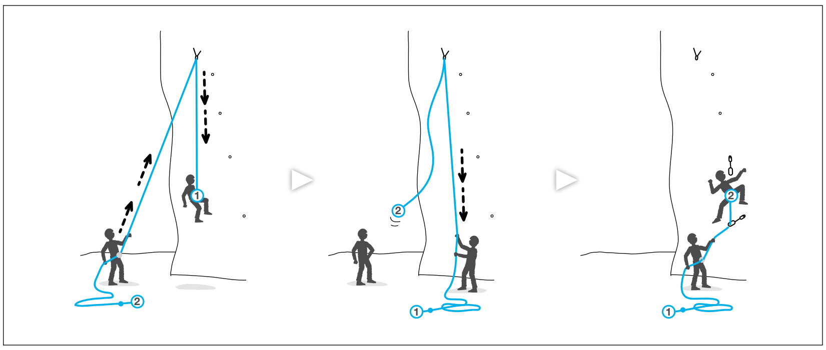


• Do not store a rope in a car trunk in the heat.

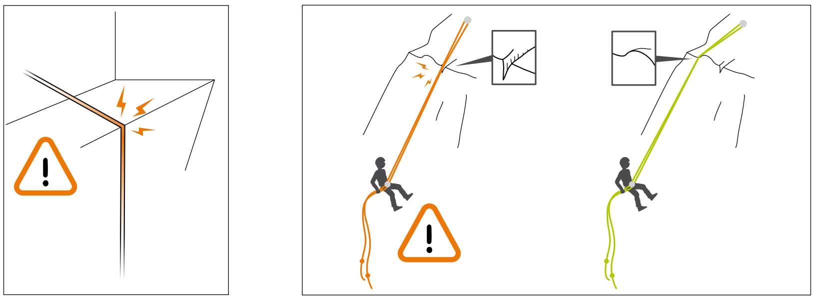


• Keep your rope far away from chemicals.
The most dangerous chemicals are acids (beware of battery acid, for example).

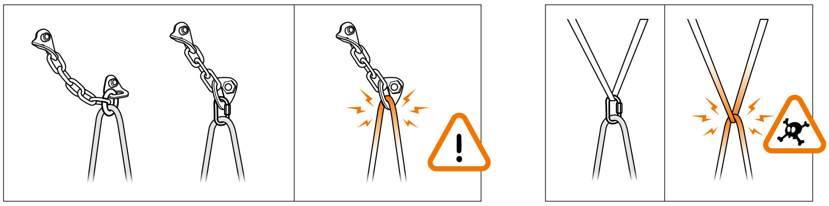
• Alternate usage between the two ends to limit twists and wear on just one end.



• **Avoid rubbing against edges and avoid positioning the rope in a crack when rappelling.**



• **Rope-on-rope or rope-on-webbing friction is forbidden.**



Coiling the rope

Carefully coil your rope to avoid twists.

Shoulder

Hand

Butterfly coil:

- Easy to learn, this coil reduces twists.
- The loops can snag on branches when carrying

It is also possible to coil a doubled rope, but this technique requires careful uncoiling.

Backpack coil:

It is also possible to coil a doubled rope, but this technique requires careful uncoiling.

Mountaineers coil:

- Very practical for carrying
- Requires more skill to avoid twists.

How should my rope be cleaned?

Cleaning a rope when it is too dirty helps prolong its life.
- Soak it in lukewarm water with a mild soap or rope-specific product. Brush gently if necessary.
- Dry it away from UV and heat sources. The rope can be spread out in large loops or chained.

When should my rope be replaced?

- When you no longer have confidence in it.
- If the sheath is too worn
- If any irregularity is showing, such as a hernia.
- If it has been subjected to a major fall (or load).
- If it has come into contact with chemicals
- If it is more than 10 years old