A History of Rock Climbing Gear Technology and Standards

An Undergraduate Honors College Thesis

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Dedication

This paper is dedicated to the individuals whom, through experience and intellect, have helped make rock climbing and mountaineering activities for the masses, often times at great personal cost.
Acknowledgements

Special thanks go to Ryan Hawkins and Zachary Eubanks, two fellow mechanical engineering rock climbers who were always willing to listen to my current research and ask great questions. I would also like to express appreciation Dr. Larry Roe and Mr. John Hamilton for affording me the opportunity to study a subject in which I have a deep interest.
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Abstract

Humans have been climbing for thousands of years for survival, with the first development of special mechanical tools appearing in the 15th century. Advancement in this field came to a standstill until the mid-19th century when materials and technology advanced enough to become useful. Safety was vastly improved by the transition from natural to synthetic fibers, the increased knowledge of metallurgy, and implementation of standardization for all climbing gear. All standards from the European Committee for Standardization and the International Climbing and Mountaineering Federation are based upon research of the human body and subsequent survivable loading magnitudes. Safety system component design requirements are therefore all dependently defined. Per capita, climbing accidents have drastically decreased due to these advancements. While virtually all standards have existed at least in part since the 1960s, no standards are in place for abrasion resistance in dynamic kernmantle rope. As a central component of climbing safety, the aforementioned component dependency raises concern for totally system reliability. Most climbing accidents have been linked to poor education, fatigue failure, and catastrophic rope abrasion for the better part of a century. Better rope design and abrasion testing standards could greatly reduce the number of incidents. In an effort to understand why no such standards exist and to quantify the possible impact in system design, this paper details the history of technological advancement for all system components and further comments on the shortcomings of current abrasion testing measures. A deeper understanding of this most basic component is required to improve the current system.
I. Background Research

Advances in Climbing Gear and Route Difficulty
Vertical standards of difficulty and equipment evolution have historically been mutually dependent upon each other. In the same spirit as the ascent of Mont Inaccessible, most modern advancements at the end of the 19th century were isolated events carried out by the occasional individualist. As American climbers began their own developments of safety techniques and equipment in preparation for the first ascent of the Grand Teton in 1989, Europe comparatively displayed a markedly advanced union of technology and climbing. The changes initially occurred in hardware. This was followed by rope and harness advancements. No actions ensured the safety of climbers, the longevity of crags, and the rampant advancement in modern rock climbing greater than the development and standardization of harnesses, hardware, and ropes.

A History of Climbing-Specific Gear Development and Standardization
The European Standards (EN) are implemented by one of three European Standards Organizations (ESOs)—CEN, CENELEC, or ETSI. These organizations made rope testing a standard process in the 1960s. The physical basis for all standards for rope and other gear is based upon the resilience of the human body. We know Earth’s gravitational field is 1 G, or 9.8 m/s². A safe fall arrest distance lies between 1/10 (physics) and 1/5 (UIAA) of the active rope distance by current UIAA/CE dynamic rope standards. In this scenario enough force is generated for the human body to take approximately 12 kN of force. This number comes from an old US Military specification for paratroopers and parachute deployment. Harnesses are designed to take a minimum 15 kN. A factor two fall, with a climber impact force of 12 kN, can easily propagate a force of 20 kN onto the carabiner. This is due to the fact that the belay side takes up to 1/3 of the force-decrease on to the carabiner. Thus, carabiners are required to have a minimum breaking force of 20 kN.
Harnesses

The UIAA Standard 105 / EN 12277 defines material selection, test methodology, and performance criteria for all harnesses manufactured for mountaineering. The most common type of harness in mountaineering is the Type C Sit Harness. Waist-belt strength is tested at 10 ± 0.1 kN. The complete harness is tested by cyclically applying a force gradually increasing to 15 ± 0.3 kN over a time period of 1 ± 0.25 minutes, resting for a maximum of 1 minute, and reapplying the same force for 3 ± 0.25 minutes. The most common mode of failure is due to buckle slippage. Most buckle related accidents occur due to poor maintenance or improper use. Improper use can include, but is not limited to, incomplete buckle fastening and failure to tie-in at the belay loop. Many manufacturers produce harnesses with a permanently ‘double-backed’ buckle, minimizing the likelihood of misuse. Gear loops on over 99% of harnesses are not rated to take a fall. As a safety consideration, standard documentation both in packaging and on the harness instruct climbing to never tie in to a gear loop.
Pitons

In the days before carabiners, a cord tied around the piton ring and the rope provided a static means of safety. At the turn of the 20th century, the first pitons were designed to fit into cracks in the rock in Europe. These were little more than iron spikes with rings connected to the flat end. This ring style piton was primarily designed for descent and for use as an additional foot or hand hold on a route for the style of aid climbing, where standing on or pulling oneself upwards by means of fixed or placed protection is required. This style of piton was typically hand forged.

In 1910, Hans Fiechtl invented and manufactured the modern piton made of mild steel with an eye rather than an attached ring. This eliminated the risk of a ring failure under tensile loading. Standards did not officially exist for these pieces of gear because the method of fabrication resulted in huge inconsistencies. Today, UIAA 122 sets the standard for hardness factors for hard and soft pitons, as well as 3-plane maximum loading limits for standard and safety pitons.

Geographic expansion of climbing was also a driving factor for technological advancement. 1927 brought two changes to protection; one in America and a more advanced change in Europe. Joe and Paul Settner ordered ring-angled pitons from Munich, headed to Colorado, bought a rope at the local hardware store, and procured the first ascent on the east face of Long’s Peak. This ascent marked the first instance of mechanically protected climbing in America. The soft lead and then mild steel pitons of Europe and Colorado were no match for hard Yosemite granite. In 1946, climber/blacksmith John Salathe used high-carbon chrome-vandium Model T axles to forge ultra-strong pitons that could be installed in the granite without buckling and getting mangled.
In Europe, the use of pitons had been the norm for quite some time with mountaineers beginning to develop more advanced techniques to provide themselves with protection. In the same year as the Settner’s ascent of Long’s Peak French mountaineer Laurent Grivel invented and manufactured the rock drill and the expansion bolt. These pieces of gear were bound for a famed future-- they are the primary means of adding permanent protection to climbing routes around the world today. In spite of the revolutionizing implications, the official inclusion of this gear into the climbing world did not come for many generations.

**Carabiners**

The problem with pitons was followed up by the invention of the carabiner, from the German word “karabinerharken” and the Italian “carabiner.” This was the name of the connectors used by German and Italian soldiers around the 1900s for securing carry straps to rifles.

**First Attempt at Standardization**

1919 saw the first efforts in climbing technique standardization with Guido Rey’s publication, Aplinisme Acrobatique. After the First World War, international climbing organizations easily exchanged this information to remote areas where climbing was taking hold. This standardized usage of the “artificial” techniques utilized the now easily available pitons and carabiners. The post war era also brought higher quality woven ropes and stronger carbon steel for carabiners.

**Carabiner Types**

![Figure 4 Basic Carabiner Types](image)

1 UIAA 121, Connectors
**Snap Gate**

Snap gates can be operated quickly. The advantage of this is in rock climbing is clear. This design is also lighter as there is no locking mechanism on the device. This advantage also has a very apparent disadvantage—the fact that they open easily during correct operation makes them susceptible to accidental opening during use. This led to a number of incidents, causing the changes in carabiner standards and design over the years. Using a locking carabiner can almost eliminate an accidental opening or failure.

**Wire Gate**

Wire gates are basic non-locking carabiners with a gate made from martensitic, precipitation hardenable 17Cr-4Ni stainless steel with an average diameter of 2.3 mm. They emerged in the early 1990s, pioneered by Black Diamond. The climbing community was generally skeptical since the gate resembled a paperclip. As with many advancements in climbing gear, they eventually became popular for good reason. These carabiners are lighter in weight, the gates are stronger, and they are less liable to open gate failures due to the gates flicking open because of their low inertia in shock loading.

**Screw Gate**

The most common style is a screw gate. This design consists of a threaded gate and an internally threaded sleeve that affixes onto the gate. When the sleeve is undone, this device operates as a typical snap gate carabiner. However, screwing the sleeve up the gate and securing it against the nose of the carabiner can lock the gate. Failure of the screw gate is typically due to vibrations caused by the wind or the rope running over the unweighted carabiner.

**Twist Gate**

More sophisticated closure mechanisms have been developed, for example, the ‘twistlock.’ When the gate is in the closed position, it is always locked as the locking sleeve is sprung in a torsion axis around the long axis of the gate. To unlock the gate, the sleeve is swiveled and the gate is pulled open. In some designs, this type of mechanical closure can be operated much more rapidly than the screw gate. In other designs, the spring-loaded sleeve can be a real pain. A potential disadvantage is the ease of opening the sleeve. For instance, if it is caught and twisted by the rope it could open accidentally as the sleeve only needs to be
rotated 90° compared to the screw gate, which often requires several turns to allow the gate to open.

**Material Details**

Today the majority of carabiners used for mountaineering are made from 7000 series aluminum alloys. These are wrought age-hardened alloys, based on the Al-Cu, Zn, Mg, Cr system; typically 7075-T6 is used for the carabiner bodies and gates. The gate is hollow and spring-loaded using a spring pusher with a spring mounted on the end. The spring pusher is typically pressed from a stainless steel strip regardless of body material choice. The gate is attached to the carabiner using a stainless steel rivet, and the gate generally locates on the nose of the carabiner with a second rivet pin. The closure systems on locking carabiners are metallic, again typically 7075, or polymeric, typically injection-molded nylon for the push button.

Carabiners made from austenitic stainless or alloy steels, micro-alloyed steels containing B and Mn, are used in certain situations where weight saving is not a primary concern. In certain applications the higher corrosion or wear resistance makes the materials more suitable. Some examples of this are caving, top roping or industrial use.

**Process and Testing**

The carabiners are tensile tested at a crosshead velocity of 20-50 mm per minute, with the carabiner loaded using steel bars of a 12 mm diameter. The pressure required to open the gate is also specified, and must be between 5 and 15 kN. The standard also specifies the minimum clearance between the gate and the nose when the gate is fully open, and carabiner surfaces must be free from burrs.

*Figure 5 Carabiner Anatomy*

2 *Choosing the Right Type of Carabiner, Foxfire Mountain Adventures*
Most simply shaped carabiners are made from circular cross-section wrought wire. The c-shape of the carabiner is bent while the material is in soft, annealed condition. Relatively minor modifications in the cross-section are achieved by cold forging in press tools. The most profile is punched out and rivet hole(s) drilled. Hot forging produces more dynamic and innovative carabiner shapes as more of the alloy can be moved and deformed.

After forming, the carabiner is heat treated by solution treatment, quenching into water, and finally an aging heat treatment. This results in a fine dispersion of hardening precipitates. The carabiner is ground and polished to remove sharp edges. Gates and metallic sleeves are made by turning, milling and drilling, and similarly ground and polished. Soft color anodizing is used for color-coding or cosmetic/brand recognition. This is helpful because knowing that a certain piece is on a purple carabiner makes it readily distinguishable either on a gear rack or when laying on the ground next to a climbing partner’s gear.

**Standards**

Carabiners today must pass three certification standards—NFPA, ANSI, and CE in the United States. They are classified by the general shape of the device and by whether the gate is a simple snap gate or has a more elaborate gate locking mechanism. The first standard by UIAA Safety Commission came in 1965. Most recently, EN 12275 details seven types of connectors with tensile testing procedure specification for the carabiners. They must be tested along the major axis closed gate, open gate and along the minor axis with the gate closed. Overall, good metallic climbing gear must exhibit the following qualities:

1. Good strength to weight ratio
2. Good hardness and fracture toughness
3. Good resistance to impacts
4. High fracture propagation resistance
5. Corrosion resistance

**Ropes**

Before specific hardware was developed for climbing, rope was used by itself as a means of connecting a team of climbers. This rope was quite a simple, non-specialized static rope
typically made of animal or plant fibers. The materials would have been either woven by hand or spun using a Cordelier. The issues in this design were intrinsic to the manufacturing process. Being made by hand, uniformity was impossible to achieve. As opposed to modern dynamic nylon rope, natural fibers resulted in a bad strength to weight ratio, poor durability, unnecessarily high stiffness, and close to zero elasticity. These ropes were spiral-braided, adding strength but also adding to the existing problem of rope management. The rope was guaranteed to twist upon itself and bind, creating a safety hazard. This was an era in climbing when not many of the top climbers lived past 30. Clearly, new safety measures would have some merit.

**Introducing Nylon**

Post WW1 ropes remained heavy, but comparatively more reliable. The world saw the first hawser-laid ropes, due to DuPont Chemical Company’s invention of nylon. Nylon was patented in 1935 and was first used in climbing rope in America in the early 1940s. The first nylon climbing rope made its way to Europe in 1949. This was a key factor in rock climbing emerging as a sport and the benefits were instantly apparent. The nylon ropes were more elastic, aiding in fall protection. In addition to the introduction synthetic materials, cordage machines had also evolved to allow for tighter, more consistent weaves and stronger ropes. However, the twisting required in the rope still reduced the handling. The ropes were also lighter and stronger—key factors in an application where most decisions about gear heavily depend upon strength-to-weight ratio.

**Kernmantle**

While nylon made a marked improvement in rope performance, no development was more significant in climbing rope history than the kernmantle design first implemented in 1953 by the German company Edelrid. This revolutionary design placed a strong synthetic rope core within a braided nylon sheath. These ropes had further increased elasticity and strength, and solved two major aesthetic problems climbers faced—namely, untwisting and rope wear. Because kernmantle rope featured a core and sheath design, un-twisting was all but eliminated. The sheath minimized the problem of rope wear, as well as adding improved handling and an intrinsic ability to absorb less water. As ropes rubbed on rocks and climbing gear, the sheath protected the inner core—the portion of the rope that provided the majority
of the strength (roughly 80%). This rope design quickly became an industry standard. In fact, UIAA standards for Dynamic Mountaineering Rope only cover this construction type.

Nylon fibers are hydrophilic, meaning they absorb water. Recent studies have shown that the most advanced nylon ropes lose up to 50% of their strength when wet. In 1966, Edelrid again made history when they produced the first water-repellent kernmantle rope. Rope core and sheath, the two major components of dynamic mountaineering rope, are very different by design. Further discussion of these components is warranted.

**Core**

Construction begins with nylon filaments being turned to yarn. These yarns are twisted to form a ply, which are twisted together to form a bundle. Several of these bundles are then twisted together to form the core. At each stage there is a specified level of twist, and each of these help determine the final elongation and energy absorption properties. Hence, the material and the manufacturing process determine the rope’s ability to absorb impact force. The kinetic energy of the climber is then converted into heat within the rope, due to the friction between components. The core comprises the majority of the cross-sectional area and mass in most dynamic ropes, with the sheath acting as a protective sleeve.

**Sheath**

While the sheath is the strongest protection against abrasion, it also greatly defines handling properties. Factors of consideration include:

1. Number of yarns used
2. Amount of twist in yarns
3. Sheath braid pattern
4. Tightness of weave

![Figure 6 Kernmantle Rope Anatomy](image)

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A higher number of yarns lends the rope to better handling, but decreases abrasion resistance. A greater level of twist decreases impact force, but increases rope elongation. According to the British Mountaineering Council, the most common weave pattern for dynamic ropes is 2 yarns over 2. This design has better handling and abrasion resistance versus the 2 over 1 design more common to accessory cord. The tightness of the weave also affects abrasion resistance. All other things equal, a tighter the weave correlates to a more abrasion resistant rope.

**Rope Manufacturing**

Current rope manufacturers employ the use of continuously drawn nylon filaments - the most basic unit in any nylon rope. These filaments are twisted to form yarns, which in turn gives the rope dynamic properties. This results in strengthening and stiffness as molecular chains of semi-crystalline polymer become orientated. Nylon rope can be spun to create a low-stretch high-strength rope or for arresting falls. In this application, the drawn nylon is heat-treated to approximately 120°C in a very complex temperature and pressure cycle. Chain orientation and crystalline properties are diminished as a result of the annealing process, resulting in a reduced Young’s Modulus. These yarns are combined in a multitude of possibilities, all of which affect the end properties of the product.

**Dynamic Rope Core Twisting Technique**

Combined with the partial twisting of the core, the dynamic rope has increased energy absorption properties, allowing a lesser impact force on a climber’s body during fall arrest. Since the 1960s, all ropes have been made from UV-stabilized nylon in this fashion. The fibers of the core are twisted in S and Z configurations (clockwise and counter clockwise) in order to minimize rope twisting. Incorporating two directions of twist gives the rope balance. This balance translates into a rope that will not cause a climber or rescuer to spin when they load the rope by climbing or falling on it. The angle of twist is also set such that individual rope fibers are still in line with tensile loading.

**Twist Relation to Elongation and Feel**

Core strands receive two levels of twist. The first twist dictates the rope’s level of elongation. It also affects the overall strength of the rope. The second twist combines several yarn bundles producing a finished core. The level of second twist greatly affects the overall hand
and knotability of the finished rope. It is important to remember that the core of a kernmantle rope is upwards of 80% of the total strength of the rope and also handles the majority of impact absorption in static and dynamic ropes.

**Static vs. Dynamic Rope**

Dynamic ropes have high levels of twist in the cores, acting like a spring when shock loaded, increasing the elongation and impact absorption. At the end of a fall, a climber does not oscillate, so a critically damped spring is a more fitting model. Conversely static ropes have much lower twist in the cores creating a rope with much less elongation, which translates to less impact absorption. For this reason, static ropes are not suitable for lead climbing, where pieces of protection are placed below the climber. A fall that would be considered safe and comfortable on a dynamic rope could easily break a climber’s back if sustained on a static rope. To accomplish greater tensile strength, manufacturers increase in the number of bobbins used during the manufacturing process. This increases the dynamic ability but lowers the abrasion resistance. Therefore, finding a balance of these two properties requires finding a compromise. There are currently no tests in place to rate and therefore specify abrasion resistance.

**Rope Standards, Environment and Use**

The EN 1891 specification requires all such ropes to have a minimum tensile strength of 6000 lb. while wet. The strength of nylon is significantly reduced when it absorbs moisture. Significant findings from a series of EN and UIAA entities have shown a strength reduction corresponding to 30% of the number of falls being held in drop tests compared with a new dry rope. Thorough drying of the rope leads to a recovery of the dynamic properties. An important conclusion was that “a used rope in good condition, say a rope which can still hold four to five falls in the standard drop tests might only hold one or two falls when soaked.”

**Table 1 Average Dynamic Rope Properties**

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Average Weight</th>
<th>Typical Impact Force*</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1 mm</td>
<td>42 g/m (0.45 oz/ft)</td>
<td>6 kN (1350 lbf)</td>
</tr>
<tr>
<td>9.8 mm</td>
<td>63 g/m (0.67 oz/ft)</td>
<td>8 kN (1800 lbf)</td>
</tr>
<tr>
<td>11 mm</td>
<td>78 g/m (0.84 oz/ft)</td>
<td>9 kN (2000 lbf)</td>
</tr>
</tbody>
</table>

* Calculated from manufacturer data of UIAA Certified test results.
the test, the rope is held statically and passed over a 10 mm diameter edge, 300 mm from the anchor. The falling mass is dropped to give a fall factor of 1.78. This is considered by many to be impossible to recreate in consumer use. To pass the standard, the drop test is repeated five times and the impact force on the first drop must not exceed 12 kN for a single rope (10-11 mm diameter) and 8 kN for a half rope (8-9 mm diameter). While the rope is required to withstand five such tests, ropes that can withstand at least 10 falls can be marketed as a “multi drop rope”. Other factors such as knotability, sheath slippage and static elongation are measured and have minimum requirements. In practice today, these efforts to improve rope quality and performance have made failure at the carabiner, the knot, or the belay device virtually impossible on a rope in good condition.

Rope failure today is mostly caused by abrupt abrasion from rock or hardware, internal abrasion due to grit particles imbedding in the rope, and by contamination with corrosive materials before use. An extraordinary fact is that no kernmantle rope construction of 9, 10, or 11 millimeter diameter has failed simply because of a falling climber, even in the 1960’s when ropes would only survive two drop tests.
II. Goal and Objectives

After reviewing the relevant data, it is apparent that rope abrasion resistance is a subject that is not understood and has not been developed. Considering that most fatal accidents occur due to rope shear and failure, the researcher proposes that further study of this subject is warranted. Several organizations have tried to develop abrasion resistance standards, and all methodology has been rebuffed. Reasons vary, but most include at least partial disagreement with system design or relevance. The goal of this study is to propose testing scenarios and discuss one ‘best’ method. The caveat being that all such decisions are based on current data and knowledge, none of which is considered complete nor has been personally observed in practice by the researcher.

Figure 7 Minimize This Problem

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4 Primary Dangers When Using a Rope, Petzl
III. Rope Test Design Proposals

Quasistatic Tensile Test with Manual Abrasion

A fundamental method used to test materials for tensile strength is by means of a universal test machine. In this proposed test design, a section of dynamic rope is mounted in the machine at two connection points as pictured. The rope is wrapped around two 10 mm OD rods in accordance with fall test standard EN 892 / UIAA 101. The rope is fixed together with u-shape wire rope clips. Care should be given to ensure each fixture has smooth edges to minimize the likelihood of rope failure at the points of attachment. A solid saddle is recommended for this reason. The minimum length of the free section of rope shall be 200 mm per EN 564 / UIAA 102, the standard for testing accessory cord (Appendix A). This same standard depicts an alternative fixture apparatus which may be employed if the aforementioned connection radius is sufficiently small to cause failure at the fixture. By increasing radius and number of wraps, this concern can be mitigated.

With the goal of quantifying the effect of abrasion, for which almost no data exists, rope samples shall be manually abraded to differing levels of severity from 0% to 100% destruction to be tested incrementally. Undamaged rope core and sheath should also be tested individually. Each rope design has an even number of carriers for sheath construction. The researcher suggests focusing on the two by two weave pattern, as this is universally believed to better withstand abrasion. 32 and 48 carrier count sheaths should be examined with identical methodology.

Uniform abrasion is most similar to damage from repeated use while concentrated abrasion more accurately models the effect when rope is dynamically pulled across a
sharp edge. Therefore, the location of such manual destruction is of interest. The proposed test includes testing rope with distributed and concentrated carrier damage around the sheath. A 32 carrier rope has 16 weave groups in a two-by-two pattern. 50% abrasion, for instance, would be simulated by severing 16 groups in various configurations ranging from side-by-side to evenly distributed, and also by cutting one carrier in each weave group.

All of the previous options lend themselves to make lacerations in a 2D plane perpendicular to the length of the rope. Yet another pattern would be to choose a fewer number of carriages on the cross-section and cut all crossing carriages in different ways. Repeating a similar set of tests for varying levels of damage would help to better understand failure propagation. Yet with as much precision and accuracy as possible, this test will not give data regarding the dynamic nature of high stretch kernmantle rope construction and how it reacts to dynamic loading and abrasion.

**Dynamic Load Cycle Abrasion Test**

This test is proposed in an effort to more effectively and accurately simulate a dynamic fall. Simply put, in this scenario the rotating drum is released from a stationary position, the force of gravity acting on the mass unwinds the system, and as the mass falls the rope sheath is damaged by a hardened abrasive surface with a specified roughness and profile while various measurements are obtained in real time. This process is repeated until rope failure, with the counter recording how many cycles are required to meet the objective.
With a known rope length and fall distance, the fall factor can be calculated by the following equation:

\[
\text{Fall factor} = \frac{\text{Length of fall}}{\text{Length of rope}}.
\]

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5 Figure by Petzl
The UIAA uses a fall factor of 1.78 for all standard drop tests. Through proper component dimensioning, mass increase (above the standard 80 kg), or mechanically accelerated drop force, this loading scenario could be adapted to simulate the same load magnitude, impact force, and rope tension of such a fall at a minimum. It should be noted that the use of a rigid mass of 80 kg versus the use of a human body of 80 kg is significant. Studies have shown that the difference in using a fixed point and dropping a solid mass increases the loading at the anchor by as much as 70% when compared to the results of two human bodies on either end of the rope. Numerous other factors exist, such as: rope slippage in the belay device, energy absorption by the climber’s and belayer’s bodies, deformation of the harness, and belayer displacement (Petzl).

A rope’s physical response to dynamic loading is a very difficult thing to model. This is especially true when the rope makes contact with any surface other than one fixed, static anchor. Yet in use, a rope almost always is in contact with more than one surface. Each point of contact absorbs some of the kinetic energy produced from a falling mass; therefore every section of free rope has a unique loading scenario. Kinetic energy within the system is primarily decreased through friction in junction with a foreign surface and also within the rope itself.

No two rope designs are identical, even from the same manufacturer. Designing a testing apparatus that can account for relatively intricate differences in an assemblage of variables and isolate them would make a huge impact in not only abrasion resistance studies, but in the understanding of dynamic rope reactions in general. To that end, it is necessary to append additional components to the given diagram for data acquisition, improved repeatability, and variable isolation. Some suggested components that are not pictured for simplicity above are:

1. An accelerometer mounted to the rope-mass interface.
2. A pressure transducer on the drum-stop for measuring impact force.
3. A heat exchanger built and installed in close enough proximity to the abrasive surface in conjunction with a thermocouple to isolate and measure thermal effects.
4. A load cell located under the abrasive surface to record the force exerted onto the edge by the weighted rope.

5. Two metal rails to guide the mass downward, resulting in a safer more repeatable test.

6. A high-speed camera to observe rope failure.

While only further studies will show the necessity of these and possibly other components, the objective here would be to isolate each given variable and experimentally define all relationships through dimensional analysis. The optional components for the given design which are included in the diagram are present for just that. In order to avoid subjecting the rope to the abrasive surface on cycle reset the pressure relief rollers would deploy outward. The hoist would also be used to lift the large mass on reset so as not to impose great stress on the system components and give time for dynamic property restitution. It would also serve a purpose in measuring static and dynamic elongation per EN 892 / UIAA 101. For single rope, static elongation is limited to 10%, while dynamic elongation must fall within the range of 10 – 40%.

The researcher recommends using this in conjunction with the first test design proposal.
IV. Discussion

Outside of the recreational world, many industries depend upon rope on a daily basis. Several industrial environments for dynamic rope have begun the search for more abrasion resistant methods of construction, even going so far as to abrade rope and test the effects of dry treatments on the construction. This industry is on in which climbing rope manufacturers also compete.

As a climber, the researcher is very much interested in the future of standardization. As it currently stands, there is not a single UIAA certified lab in North America. As an entity on the cusp of technology in materials science, there is a case for the University of Arkansas to develop such a lab. The researcher’s plans are to continue to study methods of computer methods, PDEs, and material science in order to further this research. There are many questions remaining regarding the reactions of dynamic rope under dynamic loading.

The relationship between technology and climbing follows a very traditional pattern. As each new technology develops, there is an initial resistance. Some tools are rejected outright, some fade into obscurity, and others are used sparingly until accepted with the new standard that is created. Generally, the element of risk is reduced with each new technological advancement. Detractors will speak out against the new ideas and push themselves harder to prove the lack of necessity of new tools. But eventually new tools become mainstream. Climbing challenges have always seemed limited as a resource, but new and bolder challenges always appear. Is there a limit? One thing is certain: No one can predict the future technology and the limits to the human will.
V. References


Zeitlin, Joel. "Rope Strength under Dynamic Loads: The Mountain Climber's Surprise."
Appendix A - UIAA Mountaineering Equipment Standards

<table>
<thead>
<tr>
<th>EN-892</th>
<th>DYNAMIC MOUNTAINEERING ROPES</th>
<th>UIAA-101</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: This representation of EN 892 and UIAA 101 does not contain the full details of the test methods and requirements in these standards; it gives only a simplified pictorial presentation. For full details, EN 892:2004 and UIAA 101:2008 should be consulted. © UIAA, Pit Schubert, Neville McMillan, 2009

Designed by Georg Sober
EN-892  DYNAMIC MOUNTAINEERING ROPES  UIAA-101

This representation does not provide full details. Read the note at the head of page 1.
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Sheath slippage test

Sheath slippage test after the 5th pull ≤ 20 mm

pull 2 m
repeat 5 times
(on one 2 m specimen)

50 N

50 N

50 N

the forces 50 N are spaced 120° apart radially

Static elongation test

5 kg

80 kg

1.00 m

static elongation

single rope ≤ 10 %
half rope ≤ 12 %
twin rope (double strand) ≤ 12 %

Marking

single rope  

half rope  

twin rope

Designed by Georg Sojer

Additional UIAA requirements

• If the middle of the rope is marked, the mark shall be within 1 m of the real middle.
• If a single rope or a half rope withstands 10 or more test drops, the manufacturer can claim it is a “Multi drop rope”.
• The diameter stated by the manufacturer on the hang-tag and in the information supplied shall be within ± 0.3 mm of the diameter measured in the test.
• In the information for use there shall be a warning to the effect that ropes may shrink during normal use.

All tests shall be done after conditioning as follows:
24 h (50 ± 5)°C and ≤ 10 % rel. humidity, after that 2 h (20 ± 2)°C and ≤ 65 % rel. humidity, after that 72 h (20 ± 2)°C and (65 ± 2) % rel. humidity.

There are no constraints on rope diameter or mass per unit length, but both are measured by standard methods and given in the information for use.
The diameter of accessory cord shall have a whole number value between 4 and 8 mm with tolerances of \(\pm \frac{1}{8}\) mm.

The minimum strength shall be as shown in the table:

<table>
<thead>
<tr>
<th>nominal diameter mm</th>
<th>minimum strength kN</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3.2</td>
</tr>
<tr>
<td>5</td>
<td>5.0</td>
</tr>
<tr>
<td>6</td>
<td>7.2</td>
</tr>
<tr>
<td>7</td>
<td>9.8</td>
</tr>
<tr>
<td>8</td>
<td>12.8</td>
</tr>
</tbody>
</table>

If accessory cord is supplied on a drum, it may not be one continuous length. In this case, the number of pieces shall be stated on the drum, and the ends of the pieces shall not be joined together.

Additional UIAA requirement
Currently no requirement
Any cross section of tape is possible. The strength shall be marked with stripes on one side of the tape (see below) in accordance with the table:

<table>
<thead>
<tr>
<th>Number of Stripes</th>
<th>Minimum Strength (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.0</td>
</tr>
<tr>
<td>2</td>
<td>10.0</td>
</tr>
<tr>
<td>3</td>
<td>15.0</td>
</tr>
<tr>
<td>4</td>
<td>20.0</td>
</tr>
</tbody>
</table>

In general only the tape with 3 stripes is usual.

Marking with stripes (on one side of the tape)

If tape is supplied on a drum, it may not be one continuous length. In this case, the number of pieces shall be stated on the drum, and the ends of the pieces shall not be joined together.

**Additional UIAA requirement**

Currently no requirement
Any kind of sling, and any form of sling closure, and any permanent means of connecting the tape ends, are allowable.

The sling shall be labelled with the tensile strength and the year of manufacture.

Stripes on the tape have no meaning concerning the strength.

**Additional UIAA requirement**

If slings are made from tape by stitching the tape, at least 50% of the visible area of the stitching shall contrast with the tape in colour.

If slings are made by stitching textiles, the visible area of stitching shall contrast with the tape in colour or surface appearance.

Designed by Georg Sejer
EN-12277  HARNESSSES  UIAA-105

Note: This representation of EN 12277 and UIAA 105 does not contain the full details of the test methods and requirements in these standards; it gives only a simplified pictorial presentation. For full details, EN 12277:2007 and UIAA 105:2007 should be consulted. © UIAA, Pá Schubert, Neville McMillan, 2009

Minimum tape width
in contact with the body

Main parts
a = at least 43 mm
(for small body version and chest harness 28 mm)

Shoulder straps
b = at least 28 mm
(for small body version 23 mm)

Dummy for strength tests

For all:
slippage at the buckle
20 mm max.

Strength test of full body harness

Strength test of chest harness

Strength test of sit harness

All harnesses shall be labelled with the year of manufacture.

15 kN
10 kN small body version
7 kN

Additional UIAA requirement

Where threads in load bearing parts are visible, at least 50% of the visible area of stitching shall contrast with the tape in colour.
<table>
<thead>
<tr>
<th>EN-12492</th>
<th>HELMETS</th>
<th>UIAA-106</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Note:</strong> This representation of EN 12492 and UIAA 106 does not contain the full details of the test methods and requirements in these standards; it gives only a simplified pictorial presentation. For full details, EN 12492:2002 and UIAA 106:2004 should be consulted. © UIAA, Pi Schubert, Neville McMillan, 2009</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Energy absorption test</strong></th>
<th><strong>Energy absorption test</strong></th>
<th><strong>Penetration test</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>vertical</td>
<td>frontal, lateral</td>
<td></td>
</tr>
<tr>
<td>5 kg falling mass</td>
<td>5 kg falling mass</td>
<td>3.0 kg falling mass</td>
</tr>
<tr>
<td>2.0 m</td>
<td>0.5 m</td>
<td>1.0 m</td>
</tr>
<tr>
<td>impact force</td>
<td>impact force</td>
<td></td>
</tr>
<tr>
<td>EN ≤10 kN</td>
<td>EN ≤10 kN</td>
<td></td>
</tr>
<tr>
<td>UIAA ≤ 8 kN</td>
<td>UIAA ≤ 8 kN</td>
<td></td>
</tr>
<tr>
<td>The peak of the cone shall not touch the head form</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Strength test of chin strap</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>500 N</td>
</tr>
<tr>
<td>no breakage extension ≤ 25 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Slippage test</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>frontal and dorsal</td>
</tr>
<tr>
<td>550 mm</td>
</tr>
<tr>
<td>175 mm</td>
</tr>
<tr>
<td>550 mm</td>
</tr>
<tr>
<td>10 kg falling mass</td>
</tr>
<tr>
<td>marking on the Headform</td>
</tr>
<tr>
<td>The helmet shall not leave the headform</td>
</tr>
</tbody>
</table>

Designed by Georg Sojer
The general term "Connectors" is used to include all types of karabiners and also quicklinks ("Maillon rapides").

Type B (Basic)
Connector for normal use

Type D (directional)
Connector for Quickdraws

Type X (oval shape)
Connector for Aid climbing

Type H (HMS)
Connector for belaying

Type K (Klettersteig)
Connector for "Via ferrata", "Klettersteig"
Type K Connectors shall have an automatic locking device

Gate opening

Gate opening force
(for all types)

Designed by Georg Sojer
Additional UIAA requirements
(continued)
for all connectors with a locking device

1. After applying a force \( F = 1 \text{ kN} \) for 90 secs the gate-locking device must still be functional.
2. The maximum force required to open the gate by 3 mm shall be more than 2 kN.

These requirements apply to a frontal force (see figure above), and a side force in either direction.
Note: This representation of EN 569 and UIAA 122 does not contain the full details of the test methods and requirements in these standards; it gives only a simplified pictorial presentation. For full details, EN 569:2007 and UIAA 122:2008 should be consulted. © UIAA, Pit Schubert, Neville McMillan, 2009

Strength requirements

Minimum load in kN in the three directions as shown

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>R</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety piton marking &quot;S&quot;</td>
<td>25,0</td>
<td>10,0</td>
<td>15,0</td>
</tr>
<tr>
<td>other pitons (without marking)</td>
<td>12,5</td>
<td>5,0</td>
<td>7,5</td>
</tr>
</tbody>
</table>

all dimensions in mm

Design requirements

The eye shall be large enough that a bolt as shown can be inserted

Marking

There are two categories of pitons depending on their hardness. The design requirements are as follows:

Hard steel pitons shall have a hardness of at least HRC = 38
The surface finish shall appear dark

Soft pitons shall have a hardness of less than HRC = 22
The surface finish shall appear light

Pitons with a hardness in between 22 and 38 HRC are not acceptable.

Additional UIAA requirement

Currently no requirement.

Designed by Georg Sojer
Design requirements

Minimum length five times the diameter of the drilled hole

Minimum length 70 mm

The requirement for smooth edges applies to all edges, which can be touched by fingers after installation in the rock.

The eye shall be large enough that two bolts as shown can be inserted.

Designed by Georg Sojer
Strength requirements

for all types of rock anchors
(not only for samples as shown)

Concrete:
ISO TR 9492
compressive strength 50 N/mm²

All parts of the rock anchors shall be manufactured from the same material.

Additional strength requirement for glue-in bolts

Torque min. 150 Nm for 60 s without any rotation of the bolt

Additional UIAA requirement
Material of the rock anchors: corrosion-resistant to at least number 1.4307 in accordance with EN10089-3 (but not material 1.4305)
Note: This representation of EN 12270 and UIAA 124 does not contain the full details of the test methods and requirements in these standards; it gives only a simplified pictorial presentation. For full details, EN 12270:1998 and UIAA 124:2004 should be consulted. © UIAA, Pi Schubert, Neville McMillan, 2009

Definition of width

\[ b_{\text{max}} = \text{largest width as shown} \]
\[ b_{\text{min}} = \text{smallest width as shown} \]

Design requirements

The sling for clipping in a karabiner shall be large enough to insert a pin of 15mm diameter.

Strength requirement

for all types and sizes at least 2 kN

If a Chock can be placed in different positions all positions shall be tested.

Calculation of the distance of the jaws

\[ s = b_{\text{min}} + [(b_{\text{max}} - b_{\text{min}}) / 3] \]

Strength test

all dimensions in mm

The manufacturer has to mark on the Chock the minimum load in kN, he guarantees.

Designed by Georg Sojer
If a Chock cannot be fixed in the jaws as shown on page 1, two parallel jaws shall be used with a ledge as shown.

all dimensions in mm

Additional UIAA requirement

If there is a textile means of attachment, whose strength is dependent on the integrity of the stitching, then at least 50% of the visible area of the stitching shall contrast with the background in colour.
**Measurement of the range**

- \( b_{\text{max}} = \) largest width
- \( b_{\text{min}} = \) smallest width

**Design requirements**

- The sling or the eye for clipping in a karabiner shall be large enough to insert a pin of 15mm diameter.

**Additional UIAA requirement**

- If there is a textile means of attachment, whose strength is dependent on the integrity of the stitching, then at least 50% of the visible area of the stitching shall contrast with the background in colour.

**Strength requirement**

- for all types and all sizes at least 5 kN
- Each Frictional Anchor shall be tested in two different positions, large and small, as shown.

**Calculation of the two positions**

- Large position: \( b_{\text{min}} + \frac{(b_{\text{max}} - b_{\text{min}})}{3/4} \)
- Small position: \( b_{\text{min}} + \frac{(b_{\text{max}} - b_{\text{min}})}{1/4} \)

- If the difference between \( b_{\text{max}} \) and \( b_{\text{min}} < 5\text{mm} \), only one position shall be tested:
  - position: \( b_{\text{min}} + \frac{(b_{\text{max}} - b_{\text{min}})}{1/2} \)

**Strength test**

- The manufacturer must mark on the Frictional Anchor the minimum load in kN, he guarantees.

all dimensions in mm

**Note:** This representation of EN 12276 and UIAA 125 does not contain the full details of the test methods and requirements in these standards; it gives only a simplified pictorial presentation. For full details, EN 12276:1998 and UIAA 125:2004 should be consulted. © UIAA, Pål Schubert, Neville McMillan, 2009
Design requirements

The holes for clipping in a karabiner shall be large enough to insert a pin with diameter of 13 mm.

all dimensions in mm

Strength requirements

The load shall be applied five times, one after the other.

If the rope is damaged in such a way, that it cannot be used any longer, a new rope shall be used.

Additional UIAA requirement

When tested as shown, the rope clamp shall not move along the rope.
**Design requirements**

The pulley shall be large enough to accommodate (as shown above) a pin of diameter 1 mm greater than the maximum diameter of rope with which the pulley is intended to be used.

The holes for clipping in a karabiner shall be large enough to insert a pin of diameter 12 mm.

**Strength requirements**

Under a static load of 2 kN the pulley shall move in both directions as shown and no deformations shall appear, which can impair its function.

After the test as above the load is increased up to 15 kN. The rope shall not be completely released, but deformation is allowed.

**Additional UIAA requirement**

Currently no requirement.