# Long-life bolts-what are the options?, which is the best one?

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Placing bolts in caves has an impact; so the ethically minded caver considers the options carefully, only placing bolts if suitable naturals can't be found, or if a bolt (or bolts) are needed to avoid some hazard (e.g. waterfall, dangerous rocks). However, in the past even so-called ethically minded cavers haven't necessarily thought about the long-term situation and have placed comparatively short lived bolts. It would be good to address this issue, so that we can be confident that any bolt placed will have a useful life of something like 20-50 years or even more!

I found that I wanted to learn more about this subject, so did a bit of research on the subject. Note that I don't claim to be any sort of expert, but did think that others might also be interested in what I discovered. If anyone has more to tell, especially in relation to their own practical experiences etc., then I for one would be interested to hear from them (contact details at the end).

## 1. An historical Introduction-a Tasmanian perspective

The first "standard" for bolts used in Tasmanian caves was the large eye-bolts (made from 1/2" diameter galvanised rod), screwed into galvanised Loxin anchors (thin-walled expansion casings). These were installed in the 60's and early 70's for anchoring ladders. At that time, the only available welded and galvanised eye-bolts available were large in size (1/2" diameter, 5" long), and so the large diameter Loxins (requiring a 7/8" diameter hole, 2 & 1/2" deep) were chosen to suit. The hole was drilled by hand (with a star drill and a club hammer-watch your thumbs!), each bolt taking around 1-2 hours to drill and place, which was the major disadvantage. The following quote from Stuart Nicholas (1998), summarises this pretty well. *"Installing a bolt was something that one never undertook without some considerable search first for natural belays and anchor points. Bolting trips were a major source of Forward Programme entries as I recall but not too many people went on them after their first time . . . normally a choofer stove was to hand and someone made the tea/soup/coffee while others drilled, and swapped turn about. It was a welcome respite from the bone chilling cold when one's turn to drill came up!!!!"* The eye-bolt could be removed and regularly inspected, although the actual Loxin could not be accessed.

This bolting system has stood the test of time, many of these bolts still exist (e.g. in Midnight Hole, Khazad Dum, Niagara Pot) and are regularly used (when loaded they do flex somewhat, this is consistent with the fact that the captive nut into which the bolt is screwed resides in the bottom of the Loxin). Being large chunks of steel, they are long lasting and hard wearing (the one's in Midnight Hole have been used regularly for trips for over thirty years, although those on the last two pitches are now showing significant wear (~30-40 % worn through) due to the large number of pull-through trips). Apart from the placement (i.e. back from the edge of the pitch), in many respects this bolting system resembles some of the more robust systems that are in use today.

Sources of the eyebolts dried up in the mid-70's, which was the main reason for discontinuing their use, (Nicholas, 1998). About this time, with the advent of SRT (a faster way to cave), a faster method for installing bolts was called for. Cavers looked to rock-climbers to see what sort of bolts they were using. At the time rock-climbers were using the so called Australian Rock Bolt, or Carrot bolt (basically a 5/16" diameter, 2 & 1/2" long high tensile bolt with a head; the thread was ground to a partial square taper to make it pointy with ridges of thread between; the bolt was then generally pounded in with a hammer). Stuart Nicholas says *". . . these were fraught with hazard of course as you never knew what internal/structural damage you were doing to the bolt while it was being driven in. . . . always provoked some level of fear seeing the bolt head bend and twist as it was pounded with a hammer!!!!"* A keyhole style hanger (or a small wired chock or a sling) was used to attach a krab to the anchor. These bolts were comparatively short lived and many of the heads have rusted/broken off. Some can still be seen (e.g. top 2nd and 6th pitches in Dwarrowdelf, top of the big pitch in Three-forty-one, at the top of the third pitch in Mini-Martin). Indeed the one in Mini-Martin is still regularly used! Both rock-climbers and cavers moved on from these sorts of bolts in the 70's. New technology from overseas provided better (generally better due to ease and efficiency of installation, as opposed to strength and longevity!) options.

The defacto international standard bolt for caving then became the 8 mm self drilling bolt-casings, knows as "Spits" or "Terriers" or simply just "Bolts", as shown at right. The casing is 30 mm long, 12 mm diameter, has a toothed drilling end and is threaded internally to accept an 8 mm diameter bolt. A larger (10 mm) size Spit (15 mm diameter casing, 40 mm long, accepting a 10 mm diameter bolt) was also available but was rarely used in Tasmania. The casing is held in place by the spreading of the inner end against a metal cone compressed against the bottom of the hole. Such a bolt can be installed in 10-15 minutes by someone who knows what they are doing and so allowed pitches to be rigged quickly. When properly installed they have a shear strength of around 1400-2200 kg in good rock, 700 kg in soft rock-Warild (1988). The casings are made from steel but have a coating (i.e. plated steel) to prevent corrosion. Of course, they still do corrode, the plating is damaged when installation occurs. Generally an Aluminium alloy hanger is fitted to the casing by a high tensile 8 mm diameter steel (Grade 8.8) bolt (a twist hanger is shown at left). Some cavers leave the hanger in-situ, others remove it and leave a plastic marker (so the spits can be found again) in it, others just remove the hanger and don't mark the casing (in which case, if another caver doesn't find the existing casing, they may install their own!). Leaving the hanger in situ enhances the corrosion potential of the anchor; Aluminium and steel in close proximity in a wet environment leads to electrochemical corrosion.

In relation to these self-drilling anchors, it is interesting to note that they are definitely out of flavour with the climbing fraternity, as evidenced by the following quote by Hirst (1998). *"The self drilling bolt set-up is about the worst system you can still buy . . . you wind up with about the weakest bolt on the market. These come in two sizes, Worthless (8 mm) and Lame (10*

*mm) . . . The small self-drive bolt is "officially" approved for caving and not for climbing. If you own such a kit, sell it to a caver."*
Of course, rock-climbers generally use their bolts in a different way than cavers. For climbers, bolts are for protection; they are generally not loaded, but if/when they are the loading is generally a higher shock load transmitted through a fall on an attached dynamic rope. For cavers the bolt is statically loaded at a comparatively low level via abseiling and prussiking on an attached static rope.

Anyway, the fact is that these self-drilling bolts gradually decay and the integrity and safety of the anchor begins to diminish. Many of the spits in Tasmania have were installed in the heady days of the 70's or early 80's and so many of these have been installed for one to two decades. Some have had hangers left in them (to assist in relocation), these are more likely to be in a worst state due to electrochemical corrosion (see below). I have not heard of any failing (yet), but from experience overseas, this will gradually begin to occur. Incidentally, many of the original installations were done for speed, not safety and so often you will find a pitch-head equipped with a single bolt, the rope being tied back to another anchor. In these types of situations, if the bolt at the pitch head fails the consequences are more severe. (In the ideal world, two bolts would have been installed at the pitch-head for safety). Also, the 'speed' often meant that the casings weren't greased (as recommended) to prevent the ingress of water and the onset of corrosion.

So, very soon many of these ageing spits will need replacing. It would be good to replace them with some longer lived type of anchor. In addition, since the spits are often in the best position (w.r.t. rope hang), it would be good to re-use the existing location (if possible) for the replacement anchor.

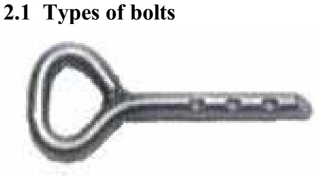
There are several different contenders to use for replacing them. Cavers in different countries use different devices; often rock-climbers and cavers in the one area use different methods (of course, the bolts often serve different purposes). There is not an easy answer to the question: "What is the best system to use?" as the several possible systems each have their own good and bad points. I thought that I'd scan the literature (and Internet) to see what sorts of systems are in use about the place and present the information so that we can make a more informed decision about what is the best method to use.

These days, the existence of high-powered portable drills means that a substantial hole can be drilled quite quickly, and as a result the bolts of this modern day era tend to me much more substantial (like the eye-bolts of old, those oldies did seem to do it properly!).

## 2. Some background

Prior to having a look around and seeing what sorts of bolts are in contemporary use, it is instructive to have a look at some basic concepts, to get a feel for some of the potential problems that a good bolting system will have to deal with.

### 2.1 Types of bolts



Bolts can be divided up into two sorts by the methods used to fix them to the rock. Bolts can be either mechanically fixed (e.g. via expansion cone(s), expansion sleeve, compression ridges, or simply a friction fit) or chemically bonded (e.g. epoxy resin, commonly referred to as 'glue') to the surrounding rock. An example of a mechanically fixed bolt (expansion sleeve) is shown at right, whilst an example of a chemically fixed eyebolt is shown at left. Mechanically fixed bolts are the most appropriate for hard rock, whilst chemical bolts are best suited to soft rock. If a mechanically fixed bolt is used in soft rock, then it is only held in place by a comparatively small surface area (e.g. the flared area around a cone), if the rock fails in that area the bolt can come out. A chemically fixed bolt is held everywhere along the glue-rock and bolt-glue interfaces, and thus is less likely to be affected by localised failure. Because of this large surface area of holding power, chemically set bolts have a very high pull-out strengths (which also means that it can be hard to remove them if you want to!). In fact properly prepared chemically fixed bolts are only limited by the quality of the surrounding rock. Chemically fixed rocks obviously will work well in hard rock as well. Sometimes mechanically fixed bolts are specially made so that they don't rely on a single mechanical fixing (e.g. a double expansion bolt), which makes them safer in soft rock than bolts with a single mechanical fixing.

### 2.2 Forces on bolts

The two main forces on bolts are an outwards force parallel to the rock (tension) and a breaking force perpendicular to the bolt (shear). If the tensile force is exceeded, the bolt will be pulled out of the rock. If the shear force is exceeded, the bolt will break off. When the "strength" of a bolt is quoted, people are usually talking about the shear strength. When a bolt is loaded in caving (or climbing applications), it is generally primarily loaded parallel to the rock surface, but there may also be a small outwards loading, as shown in the diagram opposite. (Sometimes, e.g. for a bolt in a roof, the loading might be primarily in tension, in which case a suitable hanger (ring) must be used!).

| Component | Typical Strengths |
|---|---|
| 10 mm diameter Stainless steel anchors | 25-29 kN, Shear.<br>23-40 kN, Tensile (mechanically fixed bolts).<br>25-50 kN, Tensile (chemically fixed bolts). |
| 10 mm diameter karabiner/maillon | Various (long axis, gate closed) in the ranges 18-32 kN (alloy), 22-45 kN (steel) |
| Static rope | Various in the range 18 kN (9 mm diameter)-30 kN (11 mm diameter) |
| Tape | Various in the range 11 kN (14 mm wide)-21 kN (26 mm wide) |

In relation to strengths, it is worth keeping in mind that the anchor is only as strong as the weakest component in the system. Typical ratings of the various components normally used are shown in the adjacent Table. Modern day stainless steel bolts are generally the strongest parts of the anchor system; in the event of a fall the bolt will be the least likely component to fail.

**2.3 Strength of limestone**

A few physical properties of different rock types are shown in the table below. Limestone when compared to other types of rocks has a low hardness and will withstand less compressive force. Consequently limestone is generally regarded as a soft rock. The quality of the limestone in Tasmania can be quite variable, but most seems to be reasonably hard beneath the often weathered surface. The vast majority of bolts used in Tasmanian caves have been mechanically fixed ones.

For a given type of natural rock there can be a substantial variation in physical properties (see opposite Table), thus it can be difficult to make hard and fast rules about the types of bolts best suited to different types of rock. In general, the softer the rock, the beefier the bolts need to be for the same holding power. Shorter mechanically set bolts may be adequate for hard rock, but for softer rock, longer chemically set bolts are better suited.

| Material | Density[1,2] (kg/m$^3$) | Hardness[1] (Mohrs Scale) | Load (kg) to cause a standard test cylinder to compressive failure.[3] |
|---|---|---|---|
| Concrete (anchor testing grade) | 2700-3000 | | 1800 |
| Gypsum | 2320 | 2 | |
| Limestone | 2680-2760 | Calcite 3/Marble 3.5 | 400-2000 |
| Dolomite | 2840 | 3.5 | |
| Sandstone | 2140-2360 | | 400-9000 |
| Granite | 2640-2760 | | 1800-18000 |
| Dolerite | 2890 | | |
| Quartzite | 2647 | 7 | |

Notes. 1 from CRC (1996)
2 from CRC (1997)
3 from Raleigh (1989)

**2.4 Stresses placed on rock by bolts**

When a bolt is placed in rock, stresses are placed upon the rock. For uniform rock, the so-called stress zone resembles a cone radiating outwards from the bottom of the hole to the surface of the rock, the radius of cone at the surface being about the depth of the hole. When a bolt is loaded, it will stress the rock in this cone of influence; a shorter bolt means a smaller volume of rock is stressed and thus it is less secure than a deeper bolt, where the stress can be spread over a larger volume. Expansion bolts further stress the rock by the deformation of the cone to hold the bolt within the rock. Chemical bolts do not have this added stress mechanism.

Because of the consequences of failure, it is advised that when bolts are used, a minimum of two are used. To ensure that the failure of one bolt doesn't affect the integrity of the backup bolt, it is desirable that the stress cones are not overlapped. Various statements are made about the minimum spacing, e.g. no closer than 20 hole diameters apart, or no closer than 25 cm to each other. I have seen a pitch bolted (not in Tasmania, I'm pleased to say) with two spits placed right next to each other, under 5 cm apart. In this case two spits are probably less secure than one alone!

Any rock that is weathered will be weaker near the surface, and so a deeper bolt will be more secure than a shallower bolt. Similarly, a bolt with some mechanical gripping will be more secure if the gripping is deeper in the hole. The standard spit has the gripping at the end of the hole, in the best possible position. Compression bolts (see below) grip the hole mid-way along the hole, where the rock could be weaker. A chemically set bolt grips the hole everywhere along the glue-rock interface.

**2.5 Materials for bolts and hangers**

Generally bolts are made from high tensile steel, or stainless steel. Hangers are made from the same materials, but can also be made from Aluminium alloys. Aluminium is weaker than steel, and so hangers made of it are thicker than those made from steel. For example, a Petzl twist hanger is about 4 mm thick, whereas an RP steel hanger is about 2 mm thick.

There are many different grades of steel and alloys used for different components. Steel components could be standard mild steel, or high tensile steel (Grade 8.8), or a so called austentitic stainless steel, (which comes in many different varieties; types, 303, 304, and 316 are common classes). Types 304 and 316 are commonly used in climbing protection (Law et al. (1992)), but 316 (commonly known as Marine Grade) has better corrosion resistance and a better choice than 304 in coastal environments.

Many of these modern alloys have been specially treated (e.g. through controlled heating and cooling processes such as tempering, annealing) when being made, and often again after being fabricated into the end products (e.g. some high strength karabiners). Any modifications (e.g. bending, hammering, drilling, grinding, welding) to the end product may modify the strength and/or corrosion properties of these, and so should be avoided as much as possible. If any modifications need to be done, then it is best to do them gently and avoid heat as much as possible, this may necessitate doing the work in small stages and quenching in between.

**2.6 Corrosion**

When two different metals (or grades of the same metal) are in contact, especially when moisture is involved there is a potential for electrochemical corrosion (i.e. galvanic coupling). A stainless steel expansion bolt might be fitted with components made from different grades of stainless steel. Aluminium alloy hangers are fitted with a high tensile steel bolt. Often components made of steel (e.g. bolt casing) are plated with another material (e.g. Cadmium or Zinc (i.e. galvanised)) to prevent/slow corrosion. So, any particular anchor can have a variety of metals in intimate contact. Ideally all components in an anchor will be made of the same material.

Sharp bends and deformities (e.g. crevices, welding dags) can encourage local corrosion. Thus it is good to avoid these by choosing well designed and well finished products, i.e. those with only large radius bends and free from welds; or if welded, well finished welds.

Stainless steel does still corrode, it just does it at a much slower rate than normal mild steel. In sea-water, where a mild steel will corrode at a rate of about a millimetre every six years, an austentitic stainless steel will corrode about a millimetre every 200 years. This corrosion can be greatly accelerated by galvanic coupling when two different grades remain in contact. Hellyer (1988) reports that in Thailand, on seeping limestone sea cliffs, (where climbing is popular), six year old stainless bolts have already begun to show visible signs of corrosion. There have been several failures causing several serious injuries.

Obviously the corrosion potential in an inland Tasmanian cave will be a lot lower than by the sea in Thailand, but it is still present. Many existing spits have obviously rusted (exacerbated by them not being greased when installed?); and of course you can only examine the internal thread, not the remainder of casing. In some caves, hangers have been left in-situ for a more than a decade and anchor could be in a very bad condition (e.g. the hanger on the rebelay on the 55 p in JF371, was recently examined after 14 years residence, the hanger was very badly pitted, but both the bolt and thread in the casing appeared to be okay). Karabiners that have been left in a cave for 6 months can often show substantial surface corrosion. One way of minimising this corrosion potential is not to leave hangers installed in casings, but to instead to insert a greased and non-metallic plug, which prevents the ingress of moisture and also aids the relocation of the casing. (This is the current practise in Tasmania, the nylon bolt being fitted with a reflective marker.)

**2.7 Thermal cycling**

When on the surface, bolts can undergo large thermal cycling. This regular heating up and cooling down leads to thermal expansion and contraction of the bolt, which can lead to loosening the mechanical fixing and make the bolt subject to failure. Fortunately, apart from in the entrance region, the cave environment is very stable and so any sort of thermal cycling problem should be minimal.

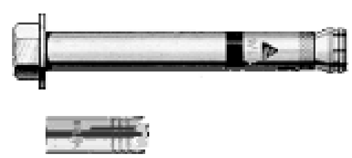
## 3. The types of 'long-life' bolts used around the world

I don't claim this to be exhaustive, but it probably represents a reasonable assessment of the different types of long lasting bolts used around the world. Note, that I have excluded spits because of their relatively temporary nature and lower strengths. They (even if available in a stainless steel form) just don't measure up with many of the more substantial types of bolting hardware available around the world.

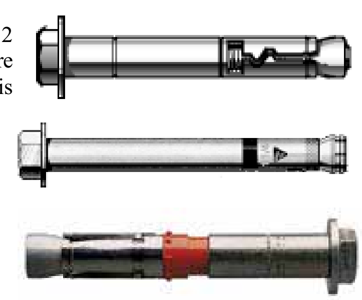
**3.1 Mechanically set bolts**

Most of the these types (and there are a multitude of different shapes, styles, sizes, materials, mechanisms) of bolts on the market have been designed for fastening things to concrete. Acceptable loads for the different types of bolts are carefully stipulated by Construction Codes for specific grades of concrete. The appropriate loads in natural rock aren't specified. These types of fasteners are most suited for use in hard rock. Some fasteners are more suitable for use as caving or climbing anchors than others. A few types have been specifically made for caving/climbing anchors.

Fasteners used for permanent anchors in cliffs or caves are substantial pieces of metal (say 60-100 mm long, 10 to 12 mm diameter, made of stainless steel), with some sort of expansion mechanism to allow the bolt to be held firm in the rock. When compared to a spit (see the scaled diagram opposite) there is no comparison!, the spit looks like a total safety compromise!



The mechanical fastening can be made by many different mechanisms; these are briefly described below:



- **Sleeve:** have an outer sleeve (along the full length of the bolt, but sometimes this is in 2 parts) around the bolt and a cone at the end. Some types are fitted with a bolt, others are threaded to accept a nut. The standard Dynabolt is a very low technology example of this type of bolt and the holding power and security of a Dynabolt is low compared to some of the other types; some of which are designed to hold in concrete with cracks in it (e.g. the top of the three bolts shown at right). For the higher tech. models (e.g. Rawl '5-piece' or equivalent), as the bolt is screwed into the cone the end of the sleeve deforms outwards to grip the rock. Further tightening causes a nylon compression ring between the two parts of the sleeve (e.g. as in the lower two of the three bolts pictured at top right) to deform and bind to the rock. For this particular example, the actual bolt and outer part of the sleeve is removable, but the bound portion of sleeve and cone isn't. Rock-climbers in the USA extensively use this type of bolt, Hirst (1998). For sleeve bolts, the diameter of the hole is greater than the diameter of the actual bolt to allow space for the sleeve, and the diameter of the hole must be selected to match the diameter of the bolt.

Petzl (France) make a permanent anchor that instead of having a nut on the end has a captive hanger and a protruding pin, to set the bolt (expand the end) the pin is driven in. Once installed, it is not removable, hence the name. Presumably cavers and climbers in Europe use this bolt, but it is expensive.

- **Wedge:** are basically a solid stud, threaded on the outside end to take a nut, and machined into a wedge on the inside end to accept a small wrap around sleeve. When the nut is tightened, the wedge forces the sleeve to bind to the rock. Once they are in and the sleeve is deformed, that’s it and they won’t come out. However, if the hole is over-drilled (i.e. deeper than the bolt) by about two centimetres, then the actual bolt can be bashed in and the bolt hidden. Some bolts may have more than one wedge/sleeve pair, as shown in the lower example (made by Fixe in Spain). The hole is drilled to be the same diameter as the bolt, which gives the maximum shear strength in relation to hole size. Fixe double expansion bolts of this type have been used in the first stage of rebolting pitches in Ice Tube, Hawkins-Salt (1998a). Rock-climbers in New Zealand use wedge bolts (e.g. Hilti HSA or Ramset Tru-bolt) for hard rock, Newnham (1995); these models have good expansion reserves (see below).

- **Compression:** are split shaft studs which compress for a spring fit when pounded into drilled holes. The hole is drilled to be the same diameter as the bolt. Supposedly they are fairly strong when new, but lose their grip after about ten years. With the application of some force (e.g. through leverage) they are removable, or if the hole is over-drilled, they can be bashed in and hidden. Note that from the outside of the rock, wedge and compression bolts look the same. I haven’t found evidence of the availability of these bolts, let alone availability in stainless steel. Various people, e.g. Child (1995), recommends against using them, except for alpine climbing when a quick and light bolt is required. Apparently a 1/4” diameter version (non-stainless steel) were very popular in the USA in the past, but these rusted badly and the grip weakened resulting in them readily failing (for this reason they are referred to as “coffin nails”).

Collectively, Sleeve and Wedge mechanism bolts are known as Expansion Bolts. Law et. al (1992) talks at length about these, and divides them up into two types, deformation-controlled and load-controlled. The deformation-controlled type (e.g. spit) once in are in and cannot be tightened, they have no expansion reserves. The load-controlled type (e.g. Sleeve) have a reserve of expansion holding power, i.e. they can be nipped up to counter any changes in the rock (e.g. local failure). Note that these bolts have a specified torque that they should be tightened to. The long and short of it is that Deformation-controlled bolts are recommended against (another nail in the coffin of the spit), and only the Load-controlled expansion bolts that have a high expansion reserve are recommended.

The properties for all these types of bolts (in stainless steel) is summarised in the Table below.

| **Mechanism** | **Typical hole size required** | **Longevity and how limited.** | **Relative[1] Shear Strength** | **Relative[1] Tensile Strength** | **Expansion Reserve[2]** | **Removability** |
|---|---|---|---|---|---|---|
| Sleeve | 2 mm wider than bolt, 50-75 mm deep | ?? years due to corrosion. | 64 % | > 100 % | Medium-High | MOSTLY, the internal bolt and outer sleeve section can be removed. |
| Wedge | same diameter as bolt, 50-75 mm deep | ?? years due to corrosion. | 100 % | 100 % (> for double wedge) | High | NO, but it can be bashed in if the hole is deep enough. |
| Compression | same diameter as bolt, 50-75 mm deep | ?? years due to corrosion, but even less to spring fatigue? | 100 % | < 100 % | None | YES, with force. Can also be bashed in if the hole is deep. |

Note: 1 For a 10 mm diameter hole in the rock
2 For a good high tech. example

A summary of the different types of stainless steel mechanically fixed bolts that are in use (or are available in outdoor gear shops) is shown in the Table below:

| Brand name/origin | Mechanism | Typical Sizes Used | | Hole | Strength[1] | | Notes/ Applications etc. |
|---|---|---|---|---|---|---|---|
| | | Diameter | Length | Diameter | Tensile (kN) | Shear (kN) | |
| Petzl /France | Sleeve | 12 mm | | 12 mm | | 25 | Integral hanger |
| Coast /USA | Wedge | 3/8” | 2 1/4-3 3/4” | 3/8” | 24 | 18 | MEC-Canada. Climbing. |
| Fixe /Spain | Twin wedge | 10 mm | 98 mm | 10 mm | 31 | 23 | Several countries. Climbing, Caving |
| Rawl | Sleeve | 10 mm<br>10 mm | 65 mm<br>90 mm | 10 mm<br>10 mm | 32-37<br>38-40 | 23-28<br>25-34 | USA-Climbing |
| Ramset Trubolt | Wedge | 10 mm<br>12 mm | 75 mm | 10 mm<br>12 mm | | | Good expansion reserves. NZ-Climbing. |
| Hilti HSA | Wedge | 10 mm<br>12 mm | 75 mm | 10 mm<br>12 mm | 23<br>38 | 27<br>43 | Good expansion reserves. NZ-Climbing. |

Notes. 1 from Manufacturers specifications or Equipment Suppliers catalogues, unless otherwise shown

### 3.2 Chemically set bolts

Chemically set bolts were initially designed to hold rock, or concrete together, e.g. at dam sites, road cuttings, in mines. With some adaptations, mainly to the shape of the fastener, this system has been adapted for use as caving or climbing anchors.

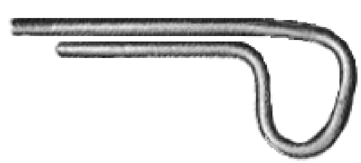
Again, as with the mechanically set bolts, chemically set bolts are substantial pieces of metal. There are two types of chemical set bolts; bolts which take a hanger and 'hangerless' bolts where the design results in a loop of steel protruding from the rock.

The chemical setting agent (the 'glue') is generally a two part epoxy resin, discussed below. Some of these resins will even set underwater whilst others are tolerant of a damp environment. The hole for the bolt has to be larger (2-4 mm in diameter, e.g. 10-12 mm hole for 8 mm bolt) than the bolt to allow an annular space for the resin. The cleanliness of the hole is paramount to the adhesion of the resin to the rock surface, all traces of dust/rock powder must be removed. The safety of glue-in bolts is critically dependant on the installation being done correctly. Some of the References at the end of this article go into much more detail about this, see CNCC (1998).

For the 'hangerless' variety, there is only one piece of metal, which means that the problem of galvanic corrosion doesn't occur. Also, for this variety of bolt, the surface is generally roughened, or deformed (e.g. with dimples), and/or the ends are bent to increase the bonding between the glue and the metal. In addition, the ends of glue-in bolts are generally sharpened/angled to assist in preventing air pockets forming around the bolts as the bolts are pushed into the glue. Hellyer (1998) reports that in the early days of chemically set bolts, there were several accidents due to failure of the resin to adhere to the smooth steel shafts of Staples. The thread on machine bolts and threaded rod allows the glue to get a better grip on these bolts, which are rotated as they are inserted to ensure good adhesion of the glue.

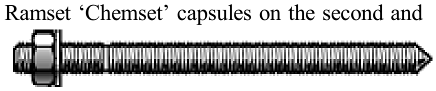
The bolt itself can have many different shapes and forms, the main ones are described below:

- **Staples:** are made out of 8 mm marine grade stainless steel (316) rod bent into a "U" shape such that the two straight ends or "legs" are parallel. Overall the U is about 90 mm long; with one leg about 10 mm shorter than the other. The long leg is embedded about 60 mm, the short 50 mm. The internal gap between the two legs is about 30 mm. One hole is needed for each leg; care must be taken to keep the holes parallel! The commercially produced version (as shown at right) is shaped to give a nice position for an attached karabiner; in addition, the entrance to the bottom hole is shaped so that where the leg curves, it sits hard on the rock. The home-made version is generally just a straight "U", and so an attached karabiner is forced to rest against the rock-face. Home-made "U" anchors of this type have been used by local rock-climbers at a number of locations (e.g. Coles Bay, Fruehauf Quarry, Adamsfield), over the last 5 years. Two glues/systems (see below) have been used: the Hilti "HY-150" injection system, and a hand-mix/syringe system using "Megapoxy HT"; Parkyn (1988).
- **P Hanger:** This is basically a variant of the Staple ("U"), where both legs are placed in the same hole to give a "P" shape. The DMM Eco-hanger (shown at left) is made from a single piece of 8 mm marine grade stainless steel (316) rod, which is installed into a single massive (18 mm diameter, 100 mm deep) hole. This style of hanger is extensively used by the Caving fraternity in the UK, CNCC (1998).



- **Eyebolts:** are generally made out of 10 mm stainless steel (or bigger, e.g. the Petzl Batinox is made from 14 mm diameter rod). A single hole, 2 mm larger in diameter than the bolt shaft diameter is used. A few examples are shown here. Shapes for the eye vary, the closer the hanger sits to the rock surface, the less leverage and the stronger the anchor. Again, as with staples, some custom shaping of the hole allows the bottom of the eye to be recessed slightly, this prevents any rotational force on the hanger, which would tend to twist the hanger out.

- **Bolts that take a hanger:** basically these are the glue-in equivalent of mechanically set bolts, but with an increased holding power in soft rock. Bolts with heads (and thus captive hangers) can be used, as can threaded rod. The only glue-in bolts that the hanger can be removed is the headless variety (e.g. threaded rod). Stainless steel (316) machine bolts (10 mm by 120 mm) with captive stainless steel hangers were installed (in 1996) with Ramset 'Chemset' capsules on the second and third pitches of Slaughterhouse Pot by John Hawkins-Salt (1998b).



The properties for all these types of chemically set bolts (in stainless steel) is summarised in the Table below.

| Type | Typical hole size required | Longevity and how limited. | Relative[1] Shear Strength[2] | Relative[1] Tensile Strength[3] | Removability | Volume[4] of resin (ml) |
|---|---|---|---|---|---|---|
| **Staple ("U")** | 2 holes, 10 mm diameter, 50 mm & 60 mm deep. | Life of the resin. | 100 % | 69 % | NO | 9 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Eyebolt** | 2 mm wider than bolt, 70-100 mm deep | Life of the resin. | 78 % | 71 % | NO | 9 |
| **"P" hanger** | 18 mm diameter, 100 mm deep | Life of the resin. (bolts in the UK have been in use for ~10 years to date) | 100 % | 100 % | YES, drill down the sides of the hanger (5 mm bit), and with a big bar through the eye rotate it out. | 19 |
| **Machine Bolts** | 2 mm wider than bolt, 70-100 mm deep | Life of the resin, or corrosion. | 78 % | 71 % | NO | 9 |
| **Threaded Rod** | 2 mm wider than bolt, 70-100 mm deep | Life of the resin, or corrosion. | 78 % | 71 % | NO | 9 |

Notes: 1 For the normal sizes used, e.g. 10 mm rod for bolts/rod/eyebolts, 8 mm rod for staples/P hangers and for the maximum sizes shown in Column 2.
2 Based on the cross-sectional area of the bolt material.
3 Based on the surface area of the bolt material.
4 Assuming a wastage of 20 %.

A summary of the different types of stainless steel chemically fixed bolts that are in use (or are available in outdoor gear shops) is shown in the Table below:

| Brand name/origin | Type | Typical Sizes Used Diameter | Length | Hole Diameter | Strength[1] Tensile (kN) | Shear (kN) | Notes /Applications etc. |
|---|---|---|---|---|---|---|---|
| DMM Eco-hanger/UK | P | 2x8 mm | 100 mm | 18 mm | 18-54[2] | | Cavers in the UK and elsewhere |
| Fixe /Spain | Eyebolt | 10 mm | 100 mm | 12 mm | 36 | 40 | Cavers |
| Home-made | U | 2x8 mm | 60 mm | 2x12 mm<br>2x10 mm | 18[3]<br>32[4] | | Rock-climbers in several countries |
| Petzl | Eyebolt | 10 mm<br>14 mm | | 12 mm<br>16 mm | | 25<br>50 | France-cavers and climbers |
| Threaded Rod | rod | 10 mm<br>10 mm | 60 mm<br>115 mm | 12 mm<br>12 mm | 30<br>50 | 29<br>29 | Rock-climbers |
| Machine Bolts | bolts | 10 mm | 120 mm | 12 mm | ~50 | ~29 | Rock-climbers/cavers |

Notes: 1 from Manufacturers specifications or Equipment Suppliers catalogues, unless otherwise shown
2 CNCC testing, range for pull-out of DMM bolts, for all types of hole preparations. Hanger deforms at 19 kN.
3 from Hellyer (1998), a single test.
4 Parkyn (1998), a single test. with two U anchors in series. Failure was ductile in nature.

### 3.3 Chemical Setting agents

Various different types of chemical setting agent (i.e. the 'glue') are used, the main ones being two part epoxy resin; the resin itself and a hardener. The resins available were designed for any number of industrial and construction applications, for example the insertion of steel reinforcement rods into concrete.

There are several different types of resin, e.g. Epoxy, Polyester, Urethane. Polyester resins (according to reports) are much easier to work with as they have a lower viscosity. However, manufacturers specifications show that Polyester resins are not as strong as the Epoxy resins.

Which is the correct resin to use for which rock type is the subject of much debate and is more often dictated by what is locally available. A summary of the different commonly available stronger resins, and who uses them is shown in the table below. Note that Hellyer (1998) reports that a large amount of research has been carried out by the UK National Caving Association (NCA), concentrating on resins suitable for limestone. Please note that some internationally distributing companies sell different products in different countries. Also, the use of proprietary brand names, (which often sound similar) can cause some confusion. The manufacturers specifications need to be carefully checked.

| **Resin Brand name/ type** | **Made in/ Available from** | **Recommendations** | **"Rucksack" sport users** | **How available** |
|---|---|---|---|---|
| Exchem Resifix 3 Plus | Exchem, UK | Recommended by the UK National Caving Association (UK-NCA) for massive limestone. [Formerly Hilti C50 resin was recommended, but no longer is due to environmental concerns.] | Cavers in the UK [CNCC (1998)], Canada [Horne (1998)] | dispenser pack |
| Vivacity Megapoxy HT | Vivacity Engineering, NSW | Epoxy Resin. Australian Rock-climbers. Manufacturers claim this glue to be hydrophillic. | Rock climbers in Aust. [Parkyn (1988)] | bulk |
| Ramset Epoxy-Set | Ramset, Australia | Epoxy resin. Manufacturer recommends for concrete, solid brickwork and stone. Excellent | Rock climbers in NZ [Newnham | capsule or dispenser pack |

| | | | | |
|---|---|---|---|---|
| | | resistance to alkali and moisture. Capsules can be used underwater. | (1995)] | |
| Hilti HY 150 | Hilti, Australia | Manufacturer recommends for concrete and hard natural stone. No problem with wet environments. | Some rock climbers in Aust. [Parkyn (1988)] | dispenser packs |
| Hilti HVU | Hilti, Australia | Styrene free Vinyl Urethane resin. Manufacturer recommends for concrete and hard natural stone. | | sachets |
| Rawl Kemfix | Rawl, Australia | Manufacturer recommend for solid concrete and masonry materials. | | capsule |
| Rawl Foil Fast | Rawl, Australia | Manufacturer recommends for concrete and other solid base materials. | | dispenser packs |

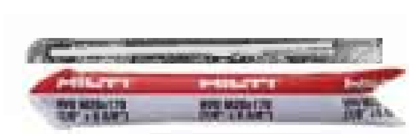
The life of the installed resin is somewhat open-ended or ill-defined. Many of the applications that cavers/climbers are using it are outside the normal commercial/industrial types of use. Resin in caves is not subject to ultra-violet light, but conditions are generally more humid. The longevity of the resin is an unknown; they certainly last a significant time; they may last 50 years. No one really knows, only time will tell. Some bolts installed by the NCA have been in use for ~10 years without showing any signs of old-age.

The resins generally have a low shelf life (some are 2 years, others 12 months), and so one needs to get fresh stock and use it quickly.

It is crucial for the resin and hardener to be properly mixed. Like most chemicals, the vapours and the material itself are dangerous (avoid breathing or skin contact or exposing to flame).

Once mixed the resins have a setting time that is primarily temperature dependant. Setting times are also dependent on the volume of resin used, i.e. shorter for greater volumes. Typical gelling times are, 20 minutes@20°C, 30 minutes@10°C, 1 hour@0°C and 5 hour@-5°C. Some manufactures recommend that temperatures be above 5°C for best results and that if used for lower temperature on-site testing be carried out.


Resin comes in either bulk packs (e.g. Expellable containers, or tins) or single shots. Some bulk packs are designed for use in special dispensing guns which expel the resin and hardener from a the pack in the appropriate ratios and mix it via nozzle equipped with many spiral baffles. Between jobs you may need to replace the nozzle and you are set to go again. Often a colour change is used to indicate complete mixing. Other bulk resins come in tins/containers. This system is a Batch system, where you measure out the appropriate amount of resin and hardener, mix it, then dispense it via a caulking type gun/syringe etc. You have to use the entire mixed batch before it sets (typically 30 minutes). Single shot resin packs consist of resin and hardener in either a glass ampoule or foil sachet. The ampoule or sachet (sachets don't fall out of downward pointing holes) is inserted into the hole. The stem of the bolt is then driven into the resin container and mixing is effected by rotating the bolt (e.g. via an attachment to a drill). This system can't be used for Staples; asymmetric hangers would be difficult to spin as well.




There are a variety of advantages/disadvantages between the Bulk and Single-Shot Systems, these are summarised in the table below.

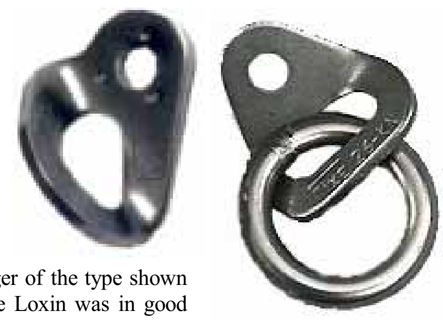
| **System** | **Methods** | **Advantages** | **Disadvantages** |
|---|---|---|---|
| Bulk (Gun Dispenser) | The resin is automatically mixed as it is injected into the hole. The hole is 2/3 rd's filled, from the back. The bolt is placed in and any excess resin is cleaned up as it exudes. | - The cartridge holds enough glue for many bolts.<br>- Accurate dispensing ratio of resin and hardener.<br>- Via the clear mixing nozzle, have a visible indication (colour change) of correct mixing.<br>- Easy to take a sample of resin home to ensure it sets. | - Potentially messier.<br>- Have to install a large number of bolts to make the best use of the larger amount of glue. |
| Bulk (Batch Mix ) | Measure out resin and hardener, thoroughly mix it and transfer to an injection gun, then proceed as for the Dispenser Gun; however all the mixed resin needs to be used before it sets. | - The least expensive method.<br>- Can mix as much resin as is required. | - Much messier and there is a lot more mucking around and potential for spilling etc.<br>- Potentially more wastage of resin.<br>- Potential for inaccurate ratios of resin/hardener. |
| Single-Shot (Ampoule or Sachet) | The ampoule is inserted into the hole, the stem of the bolt is inserted through the ampoule | - Easy to do a single bolt at a time.<br>- Can purchase a single shot of resin at a time, so it's up to date. | - Can't see how well the resin is mixing. |

| | | | |
|---|---|---|---|
| | and rotated to mix the resin. | a time, so it's up to date.<br>∉# Less waste of resin.<br>∉# Less potential for polluting the cave environment.<br>∉# Accurate amounts of resin and hardener. | ∉# Resin is contaminated by Ampoule/Sachet debri.<br>∉# More expensive. |

Temperatures in Tasmanian caves being in the 4-14°C range means that gelling times will be 30-40 minutes. This is not a long period, especially if you have to move between pitches. As a result one needs to be well organised and spare mixing nozzles carried just in case. The quick thinkers will have realised that other anchors will have to be used for the installation process. Newly installed chemically bonded anchors are normally allowed ~ 24 hours before use.

Once installed, the resin sets harder than rock and is thus difficult to remove. The P hangers can be removed via drilling 5 mm holes along both sides of the stem and then by rotating the hanger via a bar through the eye. Some two part resins soften with heat (e.g. Araldite), and so it may be possible to use a blow torch or similar to heat the hanger and soften the glue, thus allowing it to be removed?? This is something that would need to be checked by practical testing.

**3.4 Hangers and Anchor Systems.**
All the Mechanically fixed bolts (presented in Section 3.1) and the non-hanger integral chemically fixed bolts (discussed in Section 3.2) need to have hangers affixed. Ideally these should be of the same material as the bolt, to minimise the potential for galvanic corrosion.



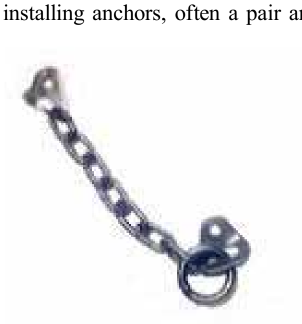
There are many good and strong hangers around, some come equipped with one or two stainless steel rings to facilitate pull-through style trips. Some are even available in environmental colours to make them blend in with the rock.

Systems with replaceable hangers have an obvious advantage in that if a hanger (or ring attached to it) becomes worn, it can be easily replaced. It should however be noted that stainless steel is very hard wearing. The large eyebolts in Midnight Hole have probably seen the most use of any bolt installed in a Tasmanian Cave. After over thirty years of trips (mostly pull-through trips), the mild steel eyebolts on the longer pitches are showing significant wear, about 30-40 % of the way through the 1/2" stock. The time is near to replace these, a hanger of the type shown above (captive ring, made from 10 mm diameter material) would be ideal. If the Loxin was in good condition, a 1/2" diameter bolt could be used to affix one of these hangers (with the hole enlarged) to the existing Loxin anchor as a short term solution.

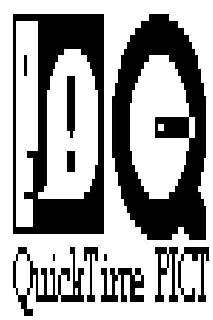
Most of these hangers are very strongly rated. The two Fixe hangers above are rated at 40 kN (Twist hanger) and 26 kN (Flat hanger with Ring, itself rated at 40 kN).

Nuts for any of the threaded bolts may loosen up with time, so it makes sense to use locking nuts (i.e. those with nylon inserts), or use some sort of proprietary Loc-tite material. Note that the outside end of the a threaded bolt is generally tapered to allow it to be tapped into the hole without burring the thread, and so it is not possible to simply burr the end of the bolt over to ensure the nut stays on.

When using artificial anchors the accepted practise is to use at least two, i.e. to never put ones faith in a single anchor. When installing anchors, often a pair are thus required. In the case of the hangerless variety, this generally means installing two bolts (no less than 20 hole diameters (e.g. 240 mm for 12 mm holes) apart!), and the rope is threaded through both. Note that the "eyes" should be oriented with due consideration to where the rope will lie and the direction of pull.



Some manufacturers make abseil stations, which include a pair of bolts, joined by a 25 cm long section of stainless steel chain (itself rated at 26 kN). Two examples are shown here, for both mechanically and chemically fixed bolts. These are probably more suited to rock-climbing situations (as abseil stations), than for caving situations, however, the rope drag on a single ring will be less than that for two anchors.




**3.5 Prices of Hardware.**
This section has been removed to reduce the size of this article. Details are available from the author; Contact details at end.

## 4. The Best Option is????
To my way of thinking, the ideal bolt should:
∉# be absolutely secure,
∉# be well situated,

- be easily locatable (unlike some unmarked spits),
- be long lasting (i.e. corrosion resistant),
- be replaceable,
- cause minimal impact on the cave environment (e.g. no nasty chemicals being spilled during installation or leaching out afterwards) and the installer (e.g. no nasty fumes or dangerous chemicals),
- be reasonably priced (i.e. inexpensive over it's lifetime),
- be easily installed,
- and have a known history (i.e. records kept of the installation and periodic checking).

A comparison of all types of permanent anchors presented in this article is shown in the table below.

| **Type of bolt** | **Sleeve** | **Wedge** | **Comp-ression** | **"U"** | **Eye** | **"P"** | **Mach-ine bolt** | **Thread-ed Rod** |
|---|---|---|---|---|---|---|---|---|
| Amount of drilling | SMALL-MEDIUM | SMALL | SMALL | MEDIUM (2 holes) | SMALL-MEDIUM | LARGE | SMALL-MEDIUM | SMALL-MEDIUM |
| Installation difficulty | LOW | LOW | LOW | HIGH | MEDIUM | HIGH | MEDIUM | MEDIUM |
| Biological Impact | LOW | LOW | LOW | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM |
| Tensile Strength | MEDIUM-HIGH | MEDIUM-HIGH | LOW-MEDIUM | HIGH | HIGH | HIGH | HIGH | HIGH |
| Shear Strength | HIGH | HIGH | HIGH | HIGH | HIGH | HIGH | HIGH | HIGH |
| Expected Long-evity | MEDIUM | MEDIUM | SHORT-MEDIUM | LONG | LONG | LONG | MEDIUM-LONG | MEDIUM-LONG |
| Replace-able hanger | YES | YES | YES | NO | NO | NO | NO | YES |
| Remove-ability | PART-IALLY | NO (but can bash in) | YES | NO | NO | YES | NO | NO |
| Cost per anchor | MEDIUM | LOW | ?? | MEDIUM-HIGH | MEDIUM | HIGH | MEDIUM | MEDIUM |
| Approp-riate for limestone | MEDIUM | MEDIUM-HIGH (if 2 wedges) | LOW | HIGH | HIGH | HIGH | HIGH | HIGH |
| **Overall Rating** | **GOOD** | **GOOD** | **POOR** | **GOOD** | **GOOD** | **GOOD** | **GOOD** | **GOOD** |

You can devise all sorts of rating schemes using the data above to try and work out which bolt is best, but to me it is not immediately obvious that any one method outshines the rest. However, there certainly is a case against continued use of the 8 mm spit in any cave that is going to have more than infrequent visitation.

Law et al. (1992) state that Glue-in bolts are at present the best answer to the all-round bolt; they are strongest in the widest range of rock and the integral stainless nature gives them high life expectancy.

In the UK, where they have significantly more cavers than here, the decision (based upon extensive research and testing by the NCA and the CNCC Technical Group) has been to go with the chemically fixed "P" hanger (DMM Eco hanger). Of all the glue-in bolts, the P hanger is the only one that is easily removable, which gives it the edge-i.e. it is replaceable when the time comes.

## 5. The Next Steps??

To me the following seems a logical sequence to follow:

- Ensure our knowledge of the options is complete and accurate,
- Gain some practical* experience; preferably hold a practical workshop* where we get some "experts" (e.g. company representatives, people with considerable practical experience etc.) to come along and provide sound instruction to people likely to be involved in installing bolts, (this is one proposal I have suggested for the Down To Earth Conference the VSA are running early next year; however it could equally be held at an ASF conference, or as a special event somewhere that interested cavers can get to). [*For the chemically set bolts there are quite a few points that need to be strictly adhered to (no pun intended) in order to achieve a high quality result.]
- Have a trial of some of the different bolting systems in a couple of different caves,
- **Plan out** a rebolting program; targeting the more popular caves (e.g. for Tasmania) such as Midnight Hole, Khazad Dum, Dwarrowdelf etc.

Any feedback from out there would be appreciated, contact details below. Thanks for the time and considerable space!

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**Acknowledgements:**
Nearly all diagrams were taken from the Internet, see the various Web addresses below.

**References:**

Child G., (1995) "Climbing, the Complete Reference"
Council of Northern Caving Clubs Technical Group (CNCC), (1998) "Permanent Resin Bonded Anchors".
CRC (1996) CRC Handbook of Physical Properties of Rocks.
CRC (1997) CRC Handbook of Chemistry and Physics, 79th Edition.
Hawkins-Salt J., (1998a) "An Incident in Ice-Tube", in Speleo Spiel 307, pp10-11.
Hawkins-Salt J., (1998b) Personal communication. "New glue in bolts in Slaughterhouse Pot", was to be published in Speleo Spiel 299, 1996, but this issue was never published.
Hellyer N., (1998) "Bolting Sport Routes-An Unofficial Guide", http://www.lbell.demon.co.uk/technical/bolting
Hirst E., (1998) "Bolting Sport Climbs-A Primer", http://www.dtek.chalmers.se/climbing/hardware/howtobolt.htm
Horne G., (1998) Personal communication.
Law M., Matheson M., Mudie D., (1992) "Bolting", in Rock 17, pp 23-29
Newnham L., (1995) "Drilling a cliff-tower", in Climber (NZAC magazine), Winter 1995, pp 29-30.
Nicholas S., (1998) Personal communication.
Parkyn R., (1998) Personal communication.
Raleigh D.,(1989) in "Climbing" magazine (August 1989)
Warild A., (1988) "Vertical".

**Websites with good information:**

| | |
|---|---|
| CNCC | http://web.ukonline.co.uk/members/andy.mccarron/cncctech.htm |
| Dragon | http://www.dragon-speleo.co.uk/ |
| Hilti | http://www.hilti.com |
| Inglesport | http://www.inglesport.co.uk/accessor/boltfixe.htm |
| Petzl | http://www.petzl.com/english/dir/climbacnhors.html |
| Ramset | http://www.itw-epcon.com |
| Rawl | http://www.rawl.com |
| REI | http://ww.rei.com/shopping/store3/climbing |