# Artificial Rigging Anchors for the Present and Future

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IF CAVES ARE TO BE MAINTAINED in natural condition then visitors must try to minimize their impact. We tolerate minor exceptions to this rule that will return relatively large rewards in terms of more documented passage, or a reduction of hazard. The exceptions are most obvious in vertical caving, where either exploration or visitation may require artificial anchors to be placed for rigging. There are analogies to the physical infrastructure (roads, bridges, etc.) that is built and maintained for the common good. Our intent here is to provide some reliable advice on where and how these investments are appropriate and how they should be maintained. An important theme is that of false economy: cheap materials and/or laziness will waste effort, will result in more damage to the caves, and can result in hazard.

We began with three simple observations:

1. At some percentage of vertical drops there is no way to secure ropes to existing cave features to minimize abrasion, and thus artificial anchors must be installed;

2. Artificial anchors will deteriorate over time, particularly if they are not maintained properly;

3. Cavers can come to rely excessively on artificial anchors, placing them even where natural anchors exist;

**OUTLINE**

From here we tried to assemble information that would help the caver to make responsible decisions. This is an account of both research and exploration. What resulted was a complete re-assessment of both the published English-language literature and our own beliefs. The result is that we may have to reconsider how we build our infrastructure in the future, and regard past investments with increasing caution.

## *TRENDS IN ARTIFICIAL ANCHOR TECHNOLOGY*

Why is the population of anchors increasing, and what will the effects be as this population ages? Which anchors will be most reliable for which applications? To consider these questions, we must first examine two trends.

### The Increased Availability of Anchors and Hardware

Over the past 10 to 15 years there has been a gradual increase in the number of artificial anchors used in caving. The reasons are numerous. In part, we are pushing more difficult caves further. In part, we are more aware of expedition caving and aid climbing where artificial anchors have played a large role. And there is definitely a difference in availability: anchors, a variety of hangers, hammers, etc. are all available from caving equipment dealers. So there is much more chance that “Joe Caver” will have a “bolt kit” and use it.

In the early 1970s increased availability resulted from interest in rock climbing. Petzl and Troll marketed products aimed specifically at cavers. To understand these effects, one must consider the vertical caving techniques of European and British cavers. The earliest experiments with SRT occurred in France during the 1930s and 1940s, but ladders (and winches for long drops) were favored into the 1960s (Worthington, 1989). Alpine conditions, cold water and thinner ropes have since given SRT and artificial anchors a major role. This approach has allowed small teams to push cold, remote caves to depths of over 1000 meters. When the same approach has been attempted by less competent cavers in heavily-visited caves, there have been problems with poorly placed, deteriorating, or simply unnecessary anchors.

### Rechargeable Hammer Drills: Painless Drilling

The second important change is the introduction of battery-powered hammer drills. According to Peter Ludwig (1988) the original AC-powered hammer drill was developed by HILTI Company of Liechtenstein. This was superior to the traditional “impact drill” incorporating a rotating serrated disk that alternately pushes the drill bit forward as it turns. It was necessary for the user to push the impact drill hard to make it work. However, the hammer drill has a solenoid that operates a pneumatic cylinder to hammer at about 4000 impacts per minute (Hilti, 1989). It puts most of its energy into impacts (about 1 Joule each), and it does not have to be pushed hard by the user (Gebauer, 1986). After HILTI's patents expired, it was Bosch of West Germany who produced the first DC (battery-powered) hammer drills. Others, including HILTI, quickly followed.

Using a rechargeable hammer drill, a caver can set an anchor in less than a minute and a power pack will last for 10 to 20 holes (depending on various conditions like rock hardness, ambient temperature, etc.) Clearly this 4 kg (9 lb) tool has the potential to change the way in which we cave, because it makes placing artificial anchors so easy.

Effects of the Trends

The result of these two trends is that we have to re-examine what we know about anchors and how we use them. Due to the marketing and convenience, we have tended to use self-drill anchors over the past 10 years (*self-drill* refers to anchors which have drilling teeth on them; they are both a disposable drill and an anchor). For drilling holes by hand, self-drills are the choice of many experienced cavers. Other “sleeve-type” anchors with internal threads are also in common use. But these are all turning out to be more prone to deterioration than might have been expected. Interestingly enough, they have long been out of style for surface climbing. Now the hammer drill provides the opportunity to drill holes easily, even with awkward orientations. Should we set other anchors that will last longer? In what orientation should anchors be set? What hangers should be used?

## *OBJECTIVES FOR ARTIFICIAL ANCHORS*

What is an Artificial Anchor?

To begin, anchors fall into two broad classes. Each is a metal fitting that goes in a hole drilled in rock (Figure 1). The self-drill has teeth that allow it to first be used as a drill. An expander cone is then placed in the open end, and the anchor driven home. A set screw, usually called a “bolt,” attaches a hanger to the anchor and the rock surface.

Hangers connect the caving rope to the anchor. This is usually through a carabiner or Rapid-link, although some hangers support the rope directly. Hangers are of two basic types: those that are radially loaded and those that are omnidirectional.

The stud is driven into a hole drilled with a bit. Some type of protrusion then acts as a barb to keep it from being withdrawn. The end of the stud is threaded, and a nut is used to hold the hanger against the rock. There are variations and hybrids on these themes, but this is sufficient for general discussion. Later, we will give a more complete classification of anchors.

What is a Safe Anchor?

To be safe, an anchor must provide not just a place to hang a rope, but also for the avoidance of hazards. A good anchor allows the caver to be on rope while staying away from features of the cave which are judged to be hazardous: sharp and/or abrupt lips, loose rocks, water, etc. It should be strong enough to take the dynamic loads that would result from failures of other equipment or errors on the part of the cavers. And it should be reliable for users who do not know its history,

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To be reliable, the placement must minimize susceptibility to deterioration if the anchor is left in place. Both the anchor design and the anchor placement must be damage tolerant. The strength of a newly placed anchor is almost irrelevant. More important is the strength of the aging anchor and the detectability of its deterioration.

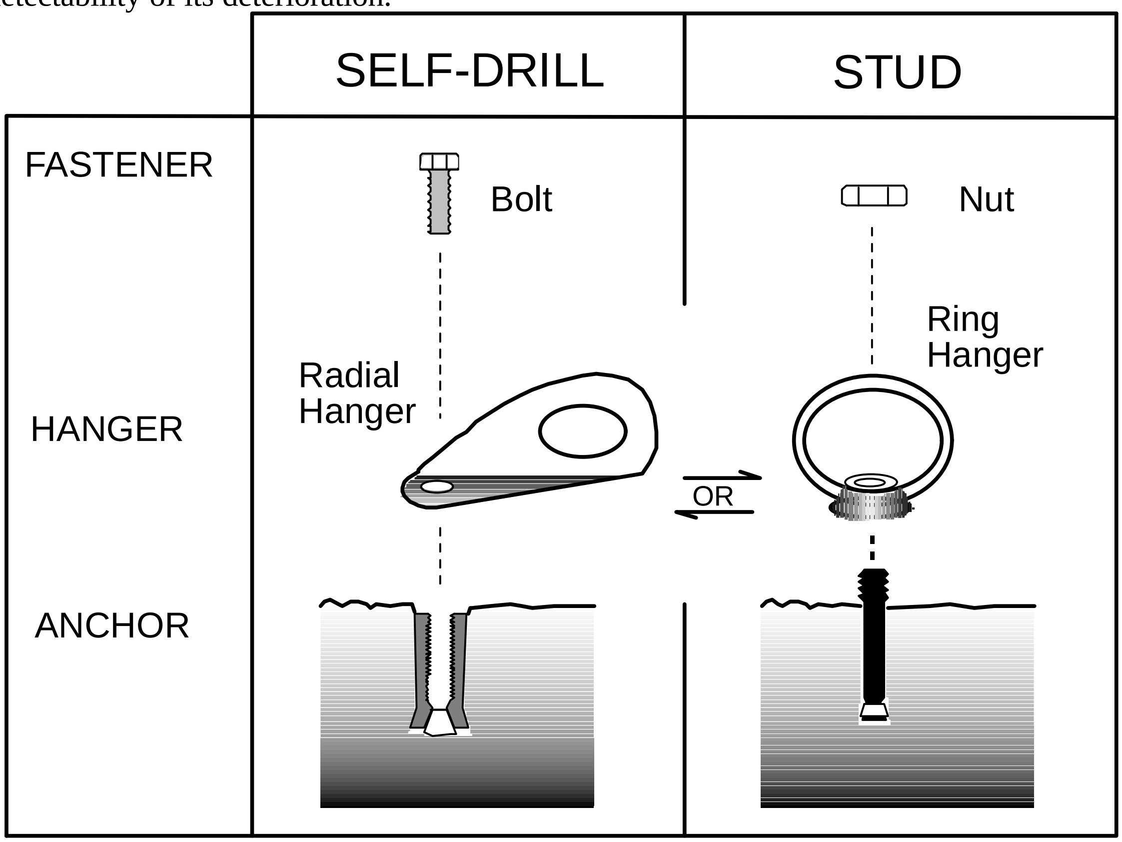



Figure 1: The two basic categories of artificial anchors, and related terminology

How strong should an anchor be?

Anchors, artificial or natural, should be at least strong enough to hold the maximum loads that a caver could survive. Eavis (1981) suggests 1200 kgf (2640 lbs) as a maximum force survivable in a harness. (This force would be exerted by a 77 kg (170 lb) person taking a 15.5 g fall, i.e. decelerating at 15.5 times gravity). For very short durations, accelerations of 35 g's have been survived, but 15 g's is an accepted limit where the back bends forward to limit motion (Damon and Stoudt, 1966).

A Brief Mechanics Tutorial

1 Loading

Judging the quality of an existing anchor requires some knowledge of the mechanics of the system. When the anchor (except for the adhesive types discussed below) is secured in its hole, a large compressive force is developed along the anchor-rock interface. This force provides the friction that resists pullout (axial direction, tensile force). The importance of a tight fit for pullout loading is thus obvious.

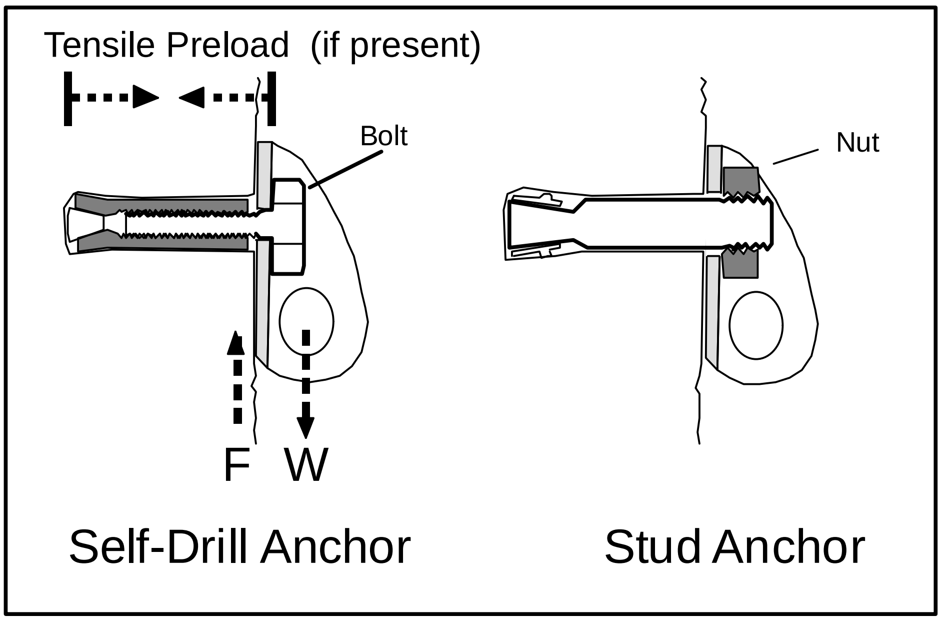



Figure 2: Idealized self-drill and stud anchors in tight holes. Axial preload enables the rock/hanger interface to oppose the load applied by the rope (W), with friction force (F). Note that the self-drill anchor is optimally placed just below the rock surface.

The rock stress from this compressive force exists with no applied load. If an axial load is applied, the rock stress increases until the rock breaks along a conical plane of maximum stress. Shear loads will cause a slightly different failure shape.

Most small anchors are stronger in the pullout direction than in the perpendicular or radial loading (shear force) which is more common in cave use. This applies for both anchor failures and rock failures. Still, there are several reasons radial loading is preferred. While undesirable, it is possible to use a radially loaded anchor which is loose (Brook, 1965), with the hanger bearing directly on the anchor or bolt. Many combinations of anchors and hangers result in the hanger being coupled fairly tightly to the wall. Thus minimal bearing occurs and in normal loading the “shear” loading actually results in little applied shear stress to the anchor. Tables of anchor shear strength are thus often mis-applied. A common misconception (e.g. Seddon, 1986; Meredith and Martinez, 1986) is that the stress due to applied shear loading and torquing are directly additive.

In most anchor systems, a nut or bolt is torqued down, squeezing a hanger against the flat rock surface (Figure 2). This squeezing is called tensile preload, since it is a tension or pull induced in

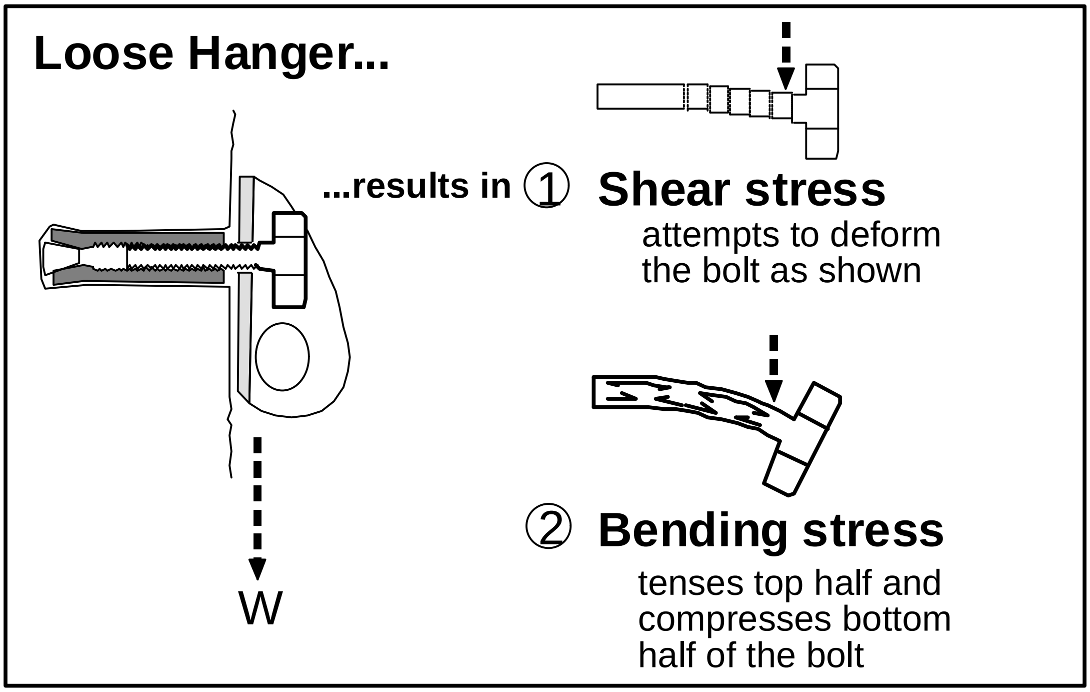



Figure 3: A self-drill anchor with a loose hanger resulting from a lack of preload. The hanger bears on the bolt directly. If the hanger is thin, the bearing stress is very high. Shear and bending stress also occur, and result in extension and compression within the screw. There is no pure axial tension.

the anchor before it is loaded by the caving rope. This preload results in a frictional interface between the hanger and rock wall, which supports part of the load. As long as this coupling is maintained, the only significant force (and resulting stress) in the anchor is the tensile preload.

Unfortunately, maintaining this coupling requires that the preload, resulting from torquing, be somewhat higher than the applied load. A fall, the failure of another anchor, or possibly high loads during ascending may result in decoupling the hanger from the wall. This results in the hanger bearing down on the bolt or stud directly. A much different stress state then exists.

The new stress state is complex, a combination of shear, bending and compression (bearing). Shear stress, from the radial loading, attempts to deform the anchor as shown in Figure 3. Bending stretches the top half of the anchor, adding axial tension.

Unfortunately 8mm (1/4-inch) bolts are often not strong enough to withstand the preload that would be required to prevent decoupling under the loads established above. It is difficult to imagine that optimum preload could be applied or maintained in the cave environment. We conclude, as have most others, that 8mm (1/4-inch) bolts are risky and should not be used as rappel anchors.

In the case of self-drills, a similar stress state will exist if the bolt is torqued, with the hanger coupled to the anchor instead of the wall when the anchor is slightly underdrilled (Figure 4). The test results of Brindle and Smith (1983) (Figure 5) show the results of increased bending stress from a 2mm protrusion.

Studs have some advantages where stress is concerned. First, the preload is distributed over the entire hole diameter, not just the central bolt in a self-drive or sleeve-anchor. Second, the need for high preload is reduced because of this greater bearing area. For a more detailed discussion of the relationship between bolt preload, stress and shear load capacity, we suggest an engineering design textbook such as Juvinall (1983).

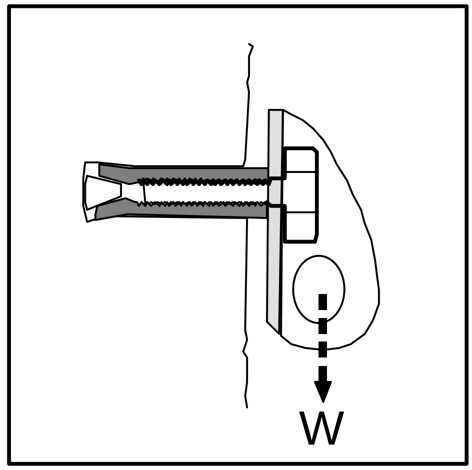



Figure 4: A self-drill that is underdrilled, but has a torqued bolt. Since a preload exists, it experiences only axial tension, bending, and shear.

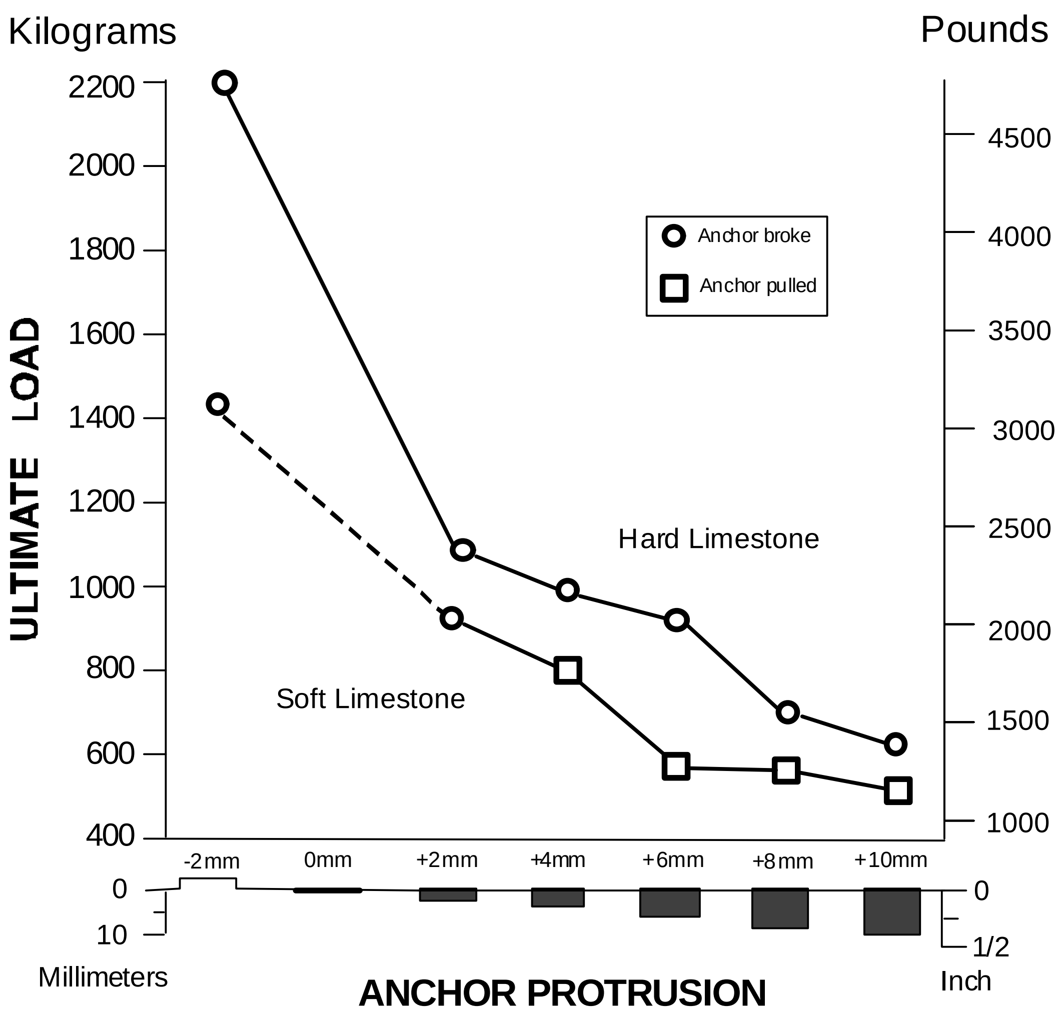
2 Axial and Other Loading Angles

In cases where various load angles are basically directed at the head of the bolt (Petzl Clown and Petzl Ring, for example) the anchor strength will vary predictably between that achieved in radial and axial loading. Some older hanger designs cause leverage tending to increase anchor loads as mentioned for axial loading. The newer Petzl designs greatly reduce this tendency. On the basis of our stress analysis, and testing by Brindle and Smith (1983), small variations from straight radial loading do not significantly affect anchor strength.

Because radial loads are always applied at some small distance from the wall, there is a tendency for the hanger to pivot about its bottom end. This results in leverage and some axial (pullout) component to any applied radial (shear) load. Lawson (1982) and Brindle and Smith (1983) have noted that the minimum net axial force will result from load application at some angle between radial and axial directions. This varies from straight axial by 15 to 40 degrees depending on hanger geometry. We agree with their observations on minimum net axial force but disagree with the conclusion that they represent “optimum loading angle.” Loading at these angles will result in minimum stress only if no shear or bending is present in the anchor/bolt. Achieving such an “optimum loading angle” in caves would often mean placing anchors in overhanging walls where drilling is difficult and the consequences of poor placement are severe. We support Lawson's contention that increasing the load angle beyond “optimum” rapidly increases stress to dangerous levels, and feel that this is a further argument for anchor placement that results in loading which is close to straight radial.

3 Adhesive Anchors: A Special Case

Adhesive anchors, discussed in detail below, consist of a stud glued into a hole. Manufacturers of adhesive anchors claim that no expansion stress is placed on the rock and that true bonding of the anchor to the rock occurs. Their strength testing in weak concrete supports this. Until a load is




For Troll anchor and hanger. Bolt: 8mm (5/16-inch) Anchor: about 12mm (1/2-inch). Source: Brindle and Smith, 1983

Figure 5: How strength decreases in an improperly placed anchor

applied to adhesive anchors, induced rock stress around the hole is essentially zero. This obviously leaves a larger percentage of the rock's strength to withstand applied loads.

Understanding Corrosion

Some popular corrosion fallacies exist in caving circles; one of these is stress corrosion. Stress corrosion cracking is a well known phenomenon where some metals, in a state of high mechanical stress, undergo accelerated electrochemical decay. The mechanism is complex and interesting, but largely irrelevant to caving. Stress corrosion is not observed in the combinations of alloys, heat treatments, stress levels, and environments encountered when commercial anchors are used in caves (ASTM Committee on Wrought Stainless Steels, 1978; Scharfstein, 1977).

## Anatomy of a Corrosion Incident

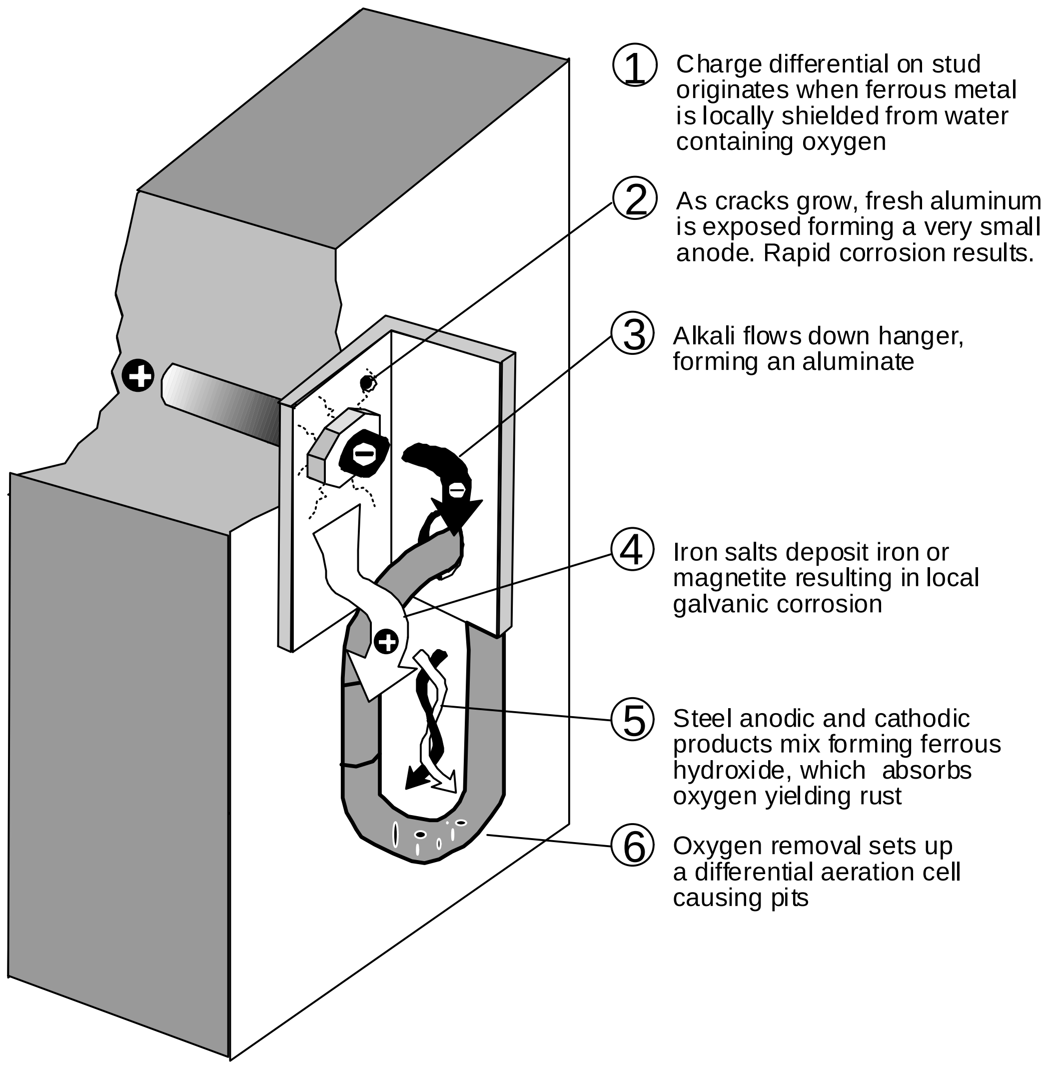



Figure 6: An aluminum hanger and carabiner attached to a carbon steel stud. The diagram shows the probable sequence of events leading to degradation each component. A stainless stud would help the situation. Note that the effects of "galvanic corrosion" are secondary; electrically insulating the parts would not reduce corrosion rates. Items 1, 2 and 3 can occur independently-- the sequence is not necessarily a cause-effect relationship. The progression from 3 to 6 is definitely causal.

Another corrosion myth results from the table of electrode potentials found in chemistry and physics books. It is commonly held that the corrosion susceptibility of an anchor is a consequence of the difference in electrode potentials of the various materials (bolt or nut, hanger, anchor, etc.) (e.g. Riley, 1984a,b). While combinations of greatly different materials are undesirable, this belief is inaccurate. On the basis of electrode potentials, steel pivot pins in aluminum carabiners should not corrode, but they do. The conditions for which the table is valid (film-free metals in solutions with their normal activity of ions) rarely exist in cave environments. While beyond the scope of this article, the reasons for this are well documented (Evans, 1960).

For fasteners in caves, electrical cells may be set up even if all materials are the same. An electrical current may result when the portion of the anchor buried in rock limits the flow of water and oxygen to the metal surface. Oxygen exhaustion creates a small anode and the large exposed anchor surface becomes a cathode; corrosion follows (Evans, 1960). In such situations, the presence of grease is beneficial because it reduces ionic activity.

Corrosion mechanisms are intricate. Corrosion rates are greatly affected by the presence of trace quantities of salts and metals in solution. One part per 50 million of copper in water will cause pitting of aluminum, when calcium bicarbonate, oxygen and a chloride are present (Porter and Hadden, 1953). Carbonates and bicarbonates sometimes inhibit and sometimes facilitate steel corrosion (Wallen and Olssen, 1977). It has been found that 100 parts per million (ppm) of calcium carbonate in groundwater can reduce corrosion of mild steel (Coburn, 1978). It is almost impossible to predict what will occur outside of carefully controlled laboratory conditions.

A more productive approach for cavers is to employ the history of industrial applications for guidelines. The majority of anchors in caves today are pre-expanded studs, self-drills and other similar sleeve anchors. Conservation considerations aside, for short-term exploration these may be adequate; for longevity they definitely are not. These fasteners are zinc plated or galvanized carbon steel, typically 1020 or 1030 alloys. Industrial experience tells us, beyond any doubt, that these will eventually corrode. The mechanism is not complex. They just rust away, progressively losing strength. Our testing of old pre-expanded studs from a rock climbing area indicates a loss of strength directly predictable from the loss of section thickness (Storage, 1980). It is inevitable that a significant percentage of anchors will be unsafe after 10 to 20 years of service. How old are they now?

The corrosion of aluminum hangers is much less predictable than that of steel bolts and anchors used in caving. We have some samples with uniform, multicolored corrosion products and others with a few deep pits. Several alloys used for hangers (2000 and 7000 series) corrode severely in cave environments. Stress corrosion at low stress levels is observed in these alloys even under surface conditions. The corrosion may be intergranular in nature, with extensive subsurface damage. The presence of steel anchor corrosion products accelerates the aluminum corrosion. A significant loss of strength can accompany a negligible loss of mass.

As is often the case, the strongest alloys are among the worst in terms of corrosion susceptability. It is ironic that our single-minded quest for high strength has sometimes left us with inferior products. Conscientious manufacturers have selected weaker alloys with better corrosion resistance, despite competitive pressures to increase strength. We conclude that, while their light weight is useful for some applications like aid climbing, even the best aluminum hangers have no place in permanent rigging.

Since carabiners are left with fixed rigging in some parts of the world, the same concern applies. They are designed for strength, not corrosion resistance. Thin anodizing is merely ornamental, and probably accelerates aluminum corrosion rates where it is scratched. We have samples of deeply pitted carabiners which have sat in caves for a few months (Figure 6). Steel rapid-links corrode more evenly and predictably, and thus we consider them to be a safer choice. Stainless steel rapid-links are even better.

From a corrosion position alone, stainless steel seems to be the obvious choice. However, strengths of materials must be considered. A discussion on balancing strength and reliability appears below.

## *THE MAJOR OPTIONS IN ANCHORS*

Terminology

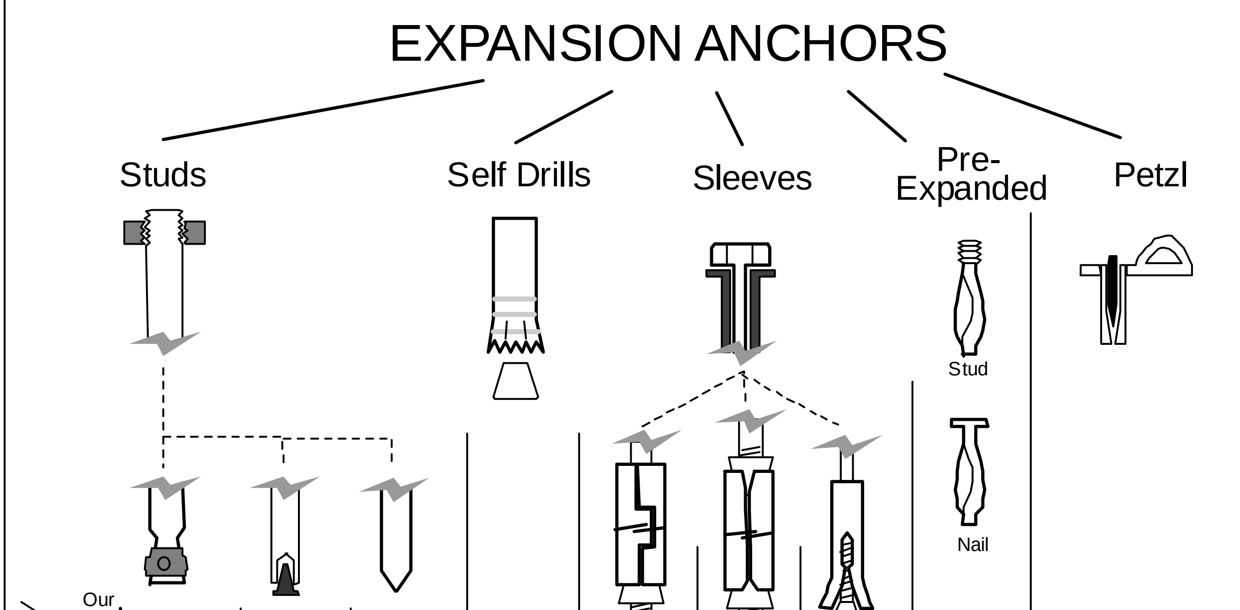
The first order of business is to agree on a vocabulary. There are many types of anchors available for a range of uses in construction and industry. Brand names only add to the confusion, because they tend to be inconsistent. Here we will use generic names that refer to the way that the anchor works (Figure 7).

1 Self-Drill Anchors

**Overview** Rock is hard. It can only be drilled by tools made of even harder steel, which even then become dull fairly rapidly. A popular solution has been the “self-drilling” anchor, which carries its own disposable drill. Once set, the anchor accepts a bolt and a hanger to which a carabiner or rope is rigged. Although marketed for securing machinery and other fixtures to masonry, this has been seen as a reasonable system for artificial anchors in caves. The “overhead” is a hammer and a driver to hold the anchor so that it can be hammered. The supply of sharp anchors is whatever the cavers want to carry. Instructions on setting self-drill anchors appear in a variety of publications.

**Underdrilling and Overdrilling** Occasionally one will see the results from a caver who apparently got tired in the middle of drilling a hole and set the anchor anyway. The assumption seems to be: Half in means half as strong and that's plenty. This is completely wrong. Unfortunately the placement will probably hold for the fool that set it, and then lie in wait for the naive caver who comes along later. This underdrilling leaves the anchor and hanger sticking out from the wall, resulting in a tremendous increase in bending stress. As can be seen in Figure 5, underdrilling by just 2mm can cut the strength of the whole system roughly in half (Brindle and Smith, 1983). Strength is also reduced if the lip of the hole is irregular and cone-shaped.

The other extreme is overdrilling. Fortunately, an anchor that is placed too deep produces less serious consequences. Assuming that the expander cone is still well in place, the loss of strength is due to loss of contact between anchor and screw. In these situations, high thread stress contributes to thread damage, an increasing concern in Britain (George, 1990).




| Brand \ Our Term | Collar | Wedge | Epoxy-Mounted | Self-Drill | Non-Caulking | | Sleeve | Pre-Expanded |
|---|---|---|---|---|---|---|---|---|
| **Emhart** (Molly) | *Parabolt* | | *Parabond* | | | | *Parasleeve* | *Split Bolt* |
| **HILTI** | *Kwik Bolt* | | *HVA* | | | | *HSL Sleeve Anchor* | |
| **ITW** | *Trubolt Wedge* | *Stud Anchor* | *Redi-Chem* | *Self-Drill* | | | *Dynabolt Sleeve* | |
| **Rawl** | *Rawl-Stud* | *Set-Bolt* | *Chem-Stud* | *Saber-Tooth* | *Single* | *Double* | *Lok-Bolt* | *Rawl-Drive* |
| **Star** | *Wedge Anchor* | | | *Self-Drill* | | | *Sleeve Anchor* | *Driv-In* |
| **Wej-It** | *Stud/Wejit* | | | | | | *Sleeve Anchor* | |

Figure 7: Anchor types and terminology. All illustrations are stylized to demonstrate how the anchors work. The products of two widely-available manufacturers are given as examples.

**How much torque?** Lawson (1982) warns that one should not “overtighten the bolt since doing so can drastically reduce the load it can support.” This concern is valid, although it seems unlikely that bolt yielding and loss of strength would occur without being obvious (i.e. the bolt head twists off). Jim Smith (pers. comm.) reports that several 1/4-inch bolts have been broken in Sistema Huautla by overtorqing. Our testing supports Smith's observations. However, we were unable to break 8mm or larger bolts with the wrenches that we use underground.

Small diameter bolts are not strong enough to take the preload (and torque) necessary to maintain hanger/wall coupling and prevent shear and bending stress. Large diameter bolts can withstand the shear and bending, so the preload is unnecessary for stress considerations. Considering the difficulty of knowing what torque is actually applied under cave conditions, this is another argument against small self-drill anchors.

**Reports of Failure** While some anchors are unreliable to begin with and some are visibly deteriorating, reports of failures have been scarce until recently. The majority are almost certainly unreported. Most that are reported seem to be non-catastrophic, i.e. a caver noticed the problem before loading the anchor and removed and/or replaced it.

In a rare reported instance of short-term failure, cavers had chosen to do a pitch despite “all the signs of [it] having been rigged by a half asleep caver in the middle of the night” (Warild, 1988). After exploration to -945 metres, the cavers were ascending quickly through water when an anchor pulled out, dropping one a short distance onto a ledge. The caver above repaired things, then he in turn fell 2 metres and “just above him swung the belay [rig point], a football-sized rock still attached by the tie-off sling.” Clearly errors due to caver fatigue and time constraints played a major role in this situation.

Reports of failure in older anchors that are used heavily are beginning to appear. Apparently, threads are suffering in high-traffic caves where each party installs their own bolt and anchor. Nigel Robertson (1990) had passed beneath a rebelay in Rowten Pot when the bolt pulled out of the anchor, dropping him 2 metres and resulting in a broken back. In subsequent testing, the bolt “jumped the threads” when tightened into the anchor. Robertson concludes that “this damage seems to be caused solely by abuse (i.e. gross negligence and irresponsibility). Overtightening of bolts, using bolts with dirty or damaged threads will all damage the threads in anchors.” While warning against these same practices, Dave George (1990) also states that “Many of the existing anchors have been in place for over 10 years and are simply wearing out.”

The problem undoubtedly stems from both causes. Anchors rust over time. Rusty anchors are more susceptible to damage. A single negligent or inexperienced group can seriously damage the entire set of anchors in a cave, destroying the investment of time and money they represent.

We believe that no self-drive anchor can withstand the repeated insertion and removal of bolts in these high-traffic caves. Even stainless studs will suffer from the abuse to their threads. Perhaps the best solution would be to install anchors such as the Petzl P38/P39 (discussed below) which have a captive hanger. While more expensive at the outset, these anchors will neither require nor permit any fiddling or abuse by subsequent visitors. While the technology is available, a change in mindset will be required on the part of cavers if this investment in new infrastructure is to succeed. If there is an anchor in the cave, it might as well be of stainless steel with a highly reliable hanger affixed permanently to it. This tiny difference in visibility and aesthetic appearance must be balanced against the inevitable alternative: multiple, rusting anchors, abandoned holes, failures and accidents. Surely in high-traffic caves there can be little debate over which is the lesser of these two evils.

**Maintenance** Like most things, anchors will last longer and be more reliable if they are maintained. This is particularly important in the case of self-drills since lubricant will reduce deterioration of low alloy and carbon steel dramatically. To service an existing anchor, the bolt should be carefully removed. The threads in the anchor can then be blasted out with a jet of spray lubricant. This will remove rock dust and rust, displace water and penetrate into the inner parts of the anchor. The anchor should then be squirted full of grease (Elliot, 1985). This can be petroleum jelly in a squeeze tube. Heavy bearing grease is even better. This can be loaded by using a spatula to fill a hypodermic syringe (with an enlarged nozzle) and then squirting this into the squeeze tube for transport into the cave.

Of course it is even better to grease the anchor when it is first installed. Sealing with silicone when the anchor is inserted may also be effective in protecting the metal/rock interface from deterioration. The best solution by far is to use stainless steel anchors, thus avoiding the need for grease altogether.

2 Studs

The stud anchor is an opposite approach to the self-drill; it provides a protruding threaded shaft for the hanger, which is held on by a nut (see Figure 1). There are several advantages. The stud is monolithic; a single piece of steel extends from the back of the hole to the hanger. The result, generally, is that a 6mm stud equals the strength of a 12mm OD self-drill anchor with an 8mm bolt. In addition, the stud is never abused as a drill (Gebauer, 1986). The stud has no internal opening to allow water to reach the inside of the anchor, nor will it fill with mud or other sediment. Finally, studs are available in 302, 303, 304 (all roughly equivalent) or 316 (a more expensive form for marine applications) stainless steel from a variety of sources. This alone is an important advantage over self-drill anchors.

The disadvantages are that a drill bit must be carried for drilling the holes. Since diameter control is often critical to the strength of the anchor, drilling with an impact hammer will produce better results. Drilling must be done very carefully with the manufacturer's recommended bits.

**Collar Studs** There are several types of studs. Those used commonly in caving are what we term *Collar* studs. Expansion comes from a collar which encircles the stud. The collar is spread by the cone-shaped portion of the stud just above the base. Depth control is not critical, and in fact the hole can be intentionally overdrilled so that the stud can be hammered in to close off the hole after use (often desirable in aid climbing).

**Wedge Studs** Wedge studs are expanded like self-drills. Unlike collar studs, depth control is critical. For a given diameter, these anchors have nearly the same strength as collar studs. We are not aware of any available in stainless steel.

3 Adhesive-Mounted Studs

Another option is to make custom studs from stainless steel bolts or rod which do not expand in the hole. Alan Brook (1989) has a set of these anchors, made from 1/2-inch rod, which are in good condition after 10 years at the entrance to Jingling Pot. Alan uses industrial-grade Araldite Epoxy Resin (Ciba-Geigy Plastics) to secure the studs. The epoxy is not affected by water and most chemicals; Alan remarks that it is used to secure roof bolts in mines. Given a source of fairly cheap stainless steel rod, this appears to be an attractive option for high-traffic caves. Petzl offers a “Ring” (P40) that apparently is set with an epoxy (Petzl, 1988?).

Most manufacturers of expansion anchors now market adhesive anchor systems to be used with

3/8 to 1/2-inch rod or bolts. In very soft rock (under 900 kg/cm2 [1000 psi]) these anchors offer markedly increased strength, due to the more even load distribution along the buried portion (Raleigh, 1989). A 3/8-inch by 2-inch adhesive mounted stud, properly placed in 3400 kg/cm2 (4000 psi) rock can withstand shear loads of over 2700 kg (6000 lbs).

To use these anchors, a hole slightly larger in diameter than the stud is drilled and then a glass capsule is inserted. The capsule contains the correct proportions of epoxy (vinylester or polyester resin), sand and hardener in separate chambers. The stud, with a properly beveled end, is then used to fracture the capsule and mix the contents. This must be done very rapidly by using a hammer drill (with the impact turned off) to spin the stud.

Some suppliers also market the adhesives separately. These can be used to seal and reinforce normal expansion-type studs. Although discouraged by the manufacturer because of the tendency for the adhesive to splatter everywhere as the stud is driven into the hole, this combination will greatly reduce water seepage, corrosion and rock deterioration.

4 Petzl Long-Life Anchor System (P38/P39)

Petzl has recently introduced a combination anchor/hanger made of stainless steel. The P38 requires a 12mm hole, the P39 a 1/2-inch hole. The P37 is a double-expansion version for soft rock which requires a 14mm hole. Strengths are high (2100 kg [4800 lbs]). While somewhat expensive and requiring large holes, these anchors are very well engineered, with obvious forethought into minimizing bearing and bending stresses. A wrench is not required for installation and no parts are removable after placement. For high-traffic caves where artificial anchors are proliferating, these appear to be excellent choices to provide long-term reliability.

5 Non-Calking or “Sleeve” Anchors

When an anchor expands into its hole, it is said to “calk” (e.g. Rawl, 1981). This refers specifically to the placement of soft metal (typically lead) anchors which greatly deform in the hole and are *not* safe for life support. Here we use the term “non-calking” to refer to anchors that are removable after they have been placed. This is an attempt to clarify terminology: in Britain these are often called “Rawlbolts.” They have also been called “sleeve anchors” by Padgett and Smith (1987). Montgomery (1976) describes two models, Centurion and Austin McLean.

The idea behind the non-calking anchor is that it may be removed periodically, inspected and greased (Brook, 1985). In some British caves, cavers provide their own anchors for existing holes. The disadvantage to this is that the large holes (1/2-inch) had to be drilled by hand. Today the holes could be drilled with hammer drills, and the anchors have performed well, but the monolithic stainless steel studs are certainly more attractive alternatives. In cases where rapid rock deterioration is a concern, non-calking anchors can be removed for periodic hole inspection. However, this approach does nothing to prevent hole weathering and frequent anchor removal in soft rock will undoubtedly cause wear and increase the rate of deterioration.

6 Pre-Expanded Nails or Studs

These were some of the earliest and most popular anchors used in caving and aid climbing. They are simple, a one-piece stud split in the middle and then hardened so that two opposing flanges are bent and compressed as it is driven into the hole. The stud is threaded; the nail has a head and is not removable. Again, these terms are misused and interchanged often in the literature. These anchors have declined in popularity because they tend to pull out, sometimes under very little force (Davison, 1977). The problem seems to arise in several ways. Some limestones may not be hard enough to fully depress the flanges. While tests in granite gave very good results (Montgomery, 1976), data from Molly (Emhart, 1989) indicates extremely low pullout loads in soft concrete. In other cases weathering and solution, sometimes after the anchor is placed, may make the rock too soft to hold the anchor. Dozens of climbing accidents have occurred from use of these anchors (Leeper, 1977). Thus pre-expanded studs are not recommended for long-term placements.

## *CHOOSING ANCHORS: BALANCING STRENGTH AND RELIABILITY*

Having established a reasonable working load for anchors of roughly 1200 kg (2500 lbs) earlier (see *What is a Safe Anchor?* above), we must now think about how to actually achieve this goal with confidence underground. Margins of safety are used in design for two main reasons. The first involves the level of confidence that the strength of an individual item is the same as the samples that were tested and analyzed. Obviously, we have limited confidence in the rock strengths. The second reason involves deterioration and reduced strength as the item ages.

Fastener manufacturers, such as ITW Ramset/Redhead (1989), recommend 25% of measured ultimate (breaking) load as a safe working load, to account for strength scatter and imperfect placement. The International Congress of Building Officials (1988) recommends an additional 50% reduction where inspection is impossible.

These recommendation result in a desired safety margin of 8 (or a theoretical 9000 kg [20000 lbs] capability). This would require unacceptably large anchors; a 1-inch self drive drilled deep into very strong rock, for example.

Redundancy is a better approach. If parallel redundancy, or shared loading as described in a variety of publications is used, the applied load to each anchor is halved. The probability of simultaneous failures is low, and the likelihood of either failing is reduced because of the divided load.

We feel that two anchors, each intended to be capable of taking the 1200 kg (2500 lbs) load, is a safe system, provided that they do not suffer significant loss of strength over time.

In general this means a 10mm stud of a suitable stainless steel, placed properly. The strength of smaller SAE grade 8 (a stronger material than stainless) bolts may be adequate, but these corrode quickly. Since self-drives cannot be made from stainless (it generally cannot be heat treated), studs have a clear advantage for long-term placements.

The preference for stainless steel eliminates many studs from consideration. The wedge stud design is acceptable, but they do not seem to be available in stainless. Stainless sleeve studs are available, but for a given hole diameter they will always be weaker than collar or wedge studs. Sleeves offer somewhat better load distribution than collars in soft rock, but nowhere near that of adhesive-mounted studs. Stainless collar studs and adhesive-mounted studs emerge as obvious winners for permanent placements.

## *THE ETHICS OF ARTIFICIAL ANCHORS*

Anchors beget more anchors. Cavers sometimes place them poorly and even the best deteriorate. The next cavers come along, don't like the placements or deterioration or sizes, and set still more anchors. Where does it end?

Perhaps the most serious problem is somewhat unobvious; the decline of good caving skills. Cavers who learn that caving is pounding in anchors, or get in the habit of seeing them at every drop tend to lose the ability to recognize and use natural anchors. Dave Elliot (1983), a caving instructor who is a major proponent of artificial anchors, has said, "In contrast to the fertile imaginings of the purists among us, there are in fact very few natural belays in caves suitable for SRT, artificial anchors are necessary on almost every pitch." Clearly a judgement has been passed; don't bother looking because you won't find anything. Once these beliefs about how drops are to be rigged spread, they can go to ridiculous lengths. Paul Lydon (1986) has reported finding two easy 4-foot climbs rigged from an anchor. Dave Brook (1987/88) remarks in reviewing Elliot's rigging guide for the Yorkshire Dales that "the authors love messing about on rope, but don't like certain aspects of caves such as climbs, crawls and especially water."

The other side of the story comes from the Oxford cavers (Rose, 1983) who have descended numerous deep systems in Spain using artificial anchors on less than half the pitches. Kevin Downey (1987) reports on trips to several deep European systems that have been rigged using rebelay techniques, but with no artificial anchors. Explorers of Mexico's Sistema Huautla have noted that about 70% of its roughly 600 pitches have been rigged with natural anchors.

Naturally a lengthy and heated debate has ensued, but to us some points seem worth noting. Anchors can be thought of by less-experienced cavers as "hard core" and applied indiscriminately. Anchors can be hammered in (often badly) by anyone who can buy a kit. Terry Raines (1986) has noted that Sotano de la Golondrinas was descended regularly for 16 years before the first anchor was placed. Now there are over a dozen. An anchor is a permanent defacement of the cave, so poor technique affects everyone.

Some drops unarguably require anchors to be descended safely. In other cases, it is a judgement call and the skilled caver can manage with careful use of natural anchors, rope pads, etc. Steve Foster (1986) gives a good introduction to natural rigging, and more articles on this topic are needed in the caving literature. Like mountaineers and rock climbers, we may begin to see separate ethics for artificial aid near home and far away (Mitchell, 1983). On Everest, just about anything goes; on the local climbing face, a single anchor might be considered very poor form. Too much technology can destroy the experience of caving. As Mike Boon (1980) has observed, "How many bolts are needed before the exercise becomes pointless is a matter for individual judgement." Ultimately it is a question of using technology to enhance, but not overwhelm, the aesthetic experience of working within the challenges of nature.

## *SOME SUGGESTIONS FOR CONSIDERATION*

- Learn to find and use natural anchors safely
- Set anchors responsibly, as an investment for the caving community
- Use stainless steel studs
- Use stainless steel hangers and bolts for existing self-drives, and sleeve-anchors where anchors are removed.
- Use grease on all self-drill anchors
- Anchors, bolts and hangers should be placed well and left in place. Subsequent visitors should not remove the bolts and hangers.
- Don't use 1/4-inch anchors or studs
- Don't leave aluminum hangers in caves

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Anchoring is understood to be a subconscious or semiconscious phenomenon, while adjustment around the anchor is very much a conscious decision. The mechanism that drives the anchoring effect is related to a similar concept called suggestion. Anchoring via suggestion. An adjacent idea to anchoring is the idea of suggestion.Â  The valuation for the properties showed an anchoring index of 41%. It was only marginally better than business school students with no real estate experience who demonstrated an anchoring index of 48%. Anchoring and Adjustment Effect in Finance. Anchoring and adjustment can be seen in many situations in finance. For example, one may get anchored to the result of a valuation model and make decisions or negotiate around it. Anchoring operations are planning consists of information, instructions, and actions that contribute to a procedure for maneuvering the vessel to the designated anchor position and successfully anchoring in a safe, seamanlike manner taking the prevailing weather conditions and sea state into consideration. Improper anchoring has a consequence. The ship may get into colliding with other vessels, or she may run aground and cause damage to property and environment. It is, therefore, for the best interest of all concerned anchoring should be done safely. Proper planning and teamwork are the basis Artificial intelligence is impacting the future of virtually every industry and every human being. Artificial intelligence has acted as the main driver of emerging technologies like big data, robotics and IoT, and it will continue to act as a technological innovator for the foreseeable future.Â  Regardless, the impact artificial intelligence is having on our present day lives is hard to ignore: Transportation: Although it could take a decade or more to perfect them, autonomous cars will one day ferry us from place to place.Â  Preparing for the Future of AI. Helpful or Homicidal: The Fantastical Possibilities of Artificial General Intelligence.