Artificial Anchors

For the Present and Future

By John Ganter and Bill Storage

OUTLINE

IF caves are to be maintained in natural condition, then visitors must minimize their impact. We tolerate minor exceptions to this rule if they return big 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 reliable advice on where and how these investments are appropriate and how they should be maintained. An important theme is that false economy: cheap materials and/or laziness can waste effort, 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, 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.

From here, we tried to assemble information that would help the caver to make responsible decisions. What resulted was a complete re-assessment of both the published literature and our own beliefs. While cavers have managed to use anchors effectively, it turns out that much of the underlying "theory" is completely wrong or simply does not exist.

Trends in Artificial Anchor Technology

Why is the use of anchors increasing, and what will the effects be as these anchors age? Which anchors will be most reliable for which applications? To consider these questions, we examined two trends.

The Increased Availability of Anchors and Hardware

During the past 10 to 15 years, there has been a gradual increase in the number of artificial anchors used in U.S. caving. The reasons are numerous: we are pushing more difficult caves or difficult sections of known caves; we do more expedition caving and aid climbing where artificial anchors play a large role; and equipment is more available.

In the early 1970s increased availability resulted from interest in rock climbing (particularly "big wall" aid climbing) and the marketing efforts of Chouinard, Leeper, SMC, etc. Later Petzl (and Troll in England) marketed products aimed specifically at cavers. To understand these effects, one must consider the vertical caving techniques of Continental (French, German, Belgian, Italian, et al.) 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). Then in the late 1960s U.S. success in descending Golondrinas attracted the attention of the French and British. Since then, however, SRT has evolved on divergent courses (Mixon 1987).

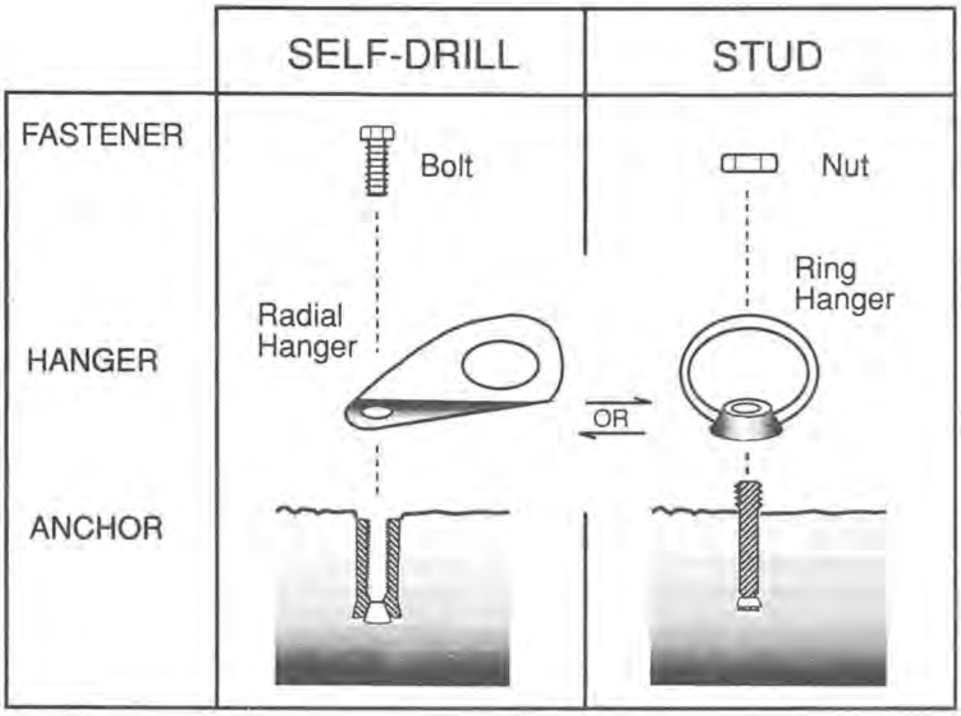


Figure 1. The two basic categories of artificial anchors, and related terminology.

In Europe, alpine conditions, cold water and thinner ropes have given 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 just plain 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 is 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 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 reexamine 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 most experienced cavers. But they are 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 cap 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 omni-directional.

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 reliabile for users who do not know its history, and who may be less competent than those who installed it.

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. Most important is the strength of the aging anchor and the detectability of its deterioration.

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 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

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.

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 tightly to the wall. Thus minimal bearing occurs and 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 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 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 most of the load. As long as this coupling is maintained, the only significant force (and resulting stress) in the anchor is the tensile preload. For many combinations of thin hangers and small diameter bolts, this coupling is the only reason that the system can support loads of a few hundred pounds.

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 1/4-inch bolts are not strong enough to withstand the preload that would be required to prevent decoupling under the loads established earlier. It is difficult to imagine that optimum preload could be applied or maintained in the cave environment. We conclude that 1/4-inch bolts are risky.

In the case of self-drills, a similar stress state exists when the bolt is torqued, but the hanger is coupled to the anchor instead of the wall because the anchor is slightly underdrilled (Figure 4). The test results of Brindle and Smith (1983) in Figure 5 show the results of increased bending stress from a 2-mm 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. Second, the need for high preload is reduced because of this greater bearing area. Some studs, such as the Petzl P38/P39, achieve very high strength with no preload. 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).

Axial Loading—The problems of an axially loaded anchor are severe. Depending on the situation there may be no benefit from high preload. This will depend on spring rates of the anchor, fasteners and rock. It appears that self-drives may be among the worst possible choices for axial loading. Hanger bending and prying can result in anchor loads exceeding those applied by a caver on rope if the wrong hanger is used. The potential fall resulting from extraction of an anchor is a subject requiring a separate discussion of shock absorbers, redundancy, etc., but it is guaranteed to be unpleasant.

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 (leverage component plus preload) will result from load application at some angle between radial and axial directions. This varies from straight axial by 15 to 40° 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 the "optimum loading angle" in caves would

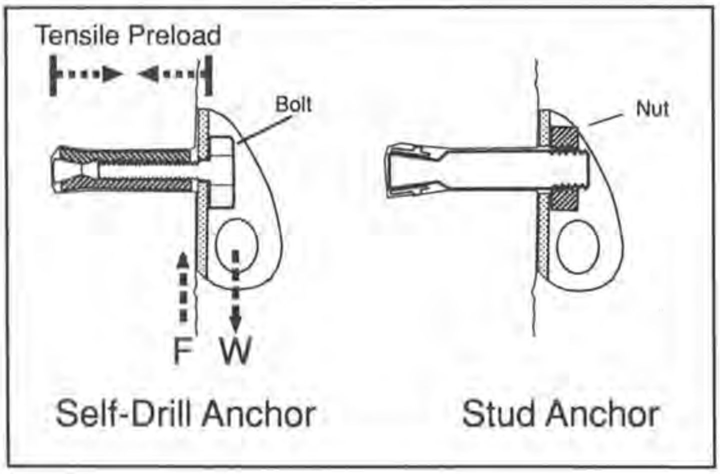


Figure 2. Idealized self-drill and stud anchors in tight holes. Axial preload enables the rock/hanger interface to oppose the load applied by the rope (W), with friction force (F). Note that the self-drill anchor is optimally placed just below the rock surface.

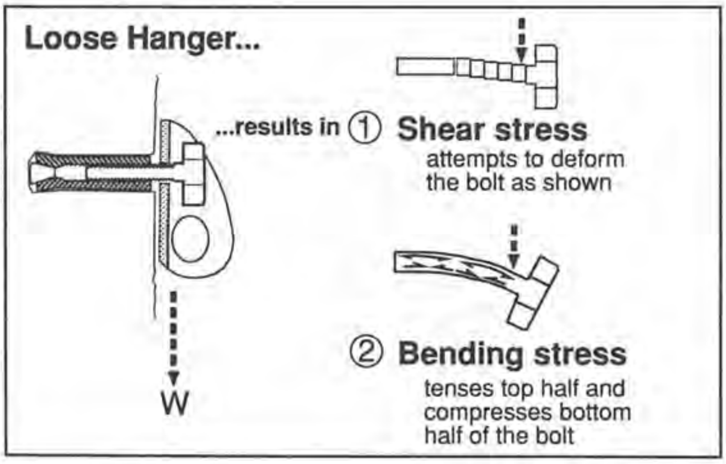


Figure 3. A self-drill anchor with a loose hanger resulting from a lack of preload. The hanger bears on the bolt directly. If the hanger is thin, the bearing stress is very high. Shear and bending stress also occur, and result in extension and compression within the screw. There is no pure axial tension.

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 loading close to straight radial.

Adhesive Anchors: A Special Case—Adhesive anchors, discussed in detail later under "Adhesive Anchor Studs", 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 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 electro-chemical decay. The mechanism is complex and interesting, but largely irrelevant to caving. There is no evidence of stress corrosion of steel in caving applications, despite some rumors. Nor should there be, on the basis of our study. Stress corrosion is not observed in the combinations of alloys, stress levels, and environments encountered when commercial anchors are used in caves (ASTM Committee on Wrought Stainless Steels, 1978; Scharfstein, 1977).

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 incorrect. 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) do not 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.

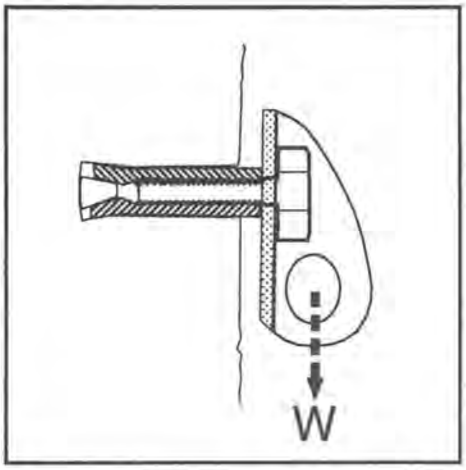
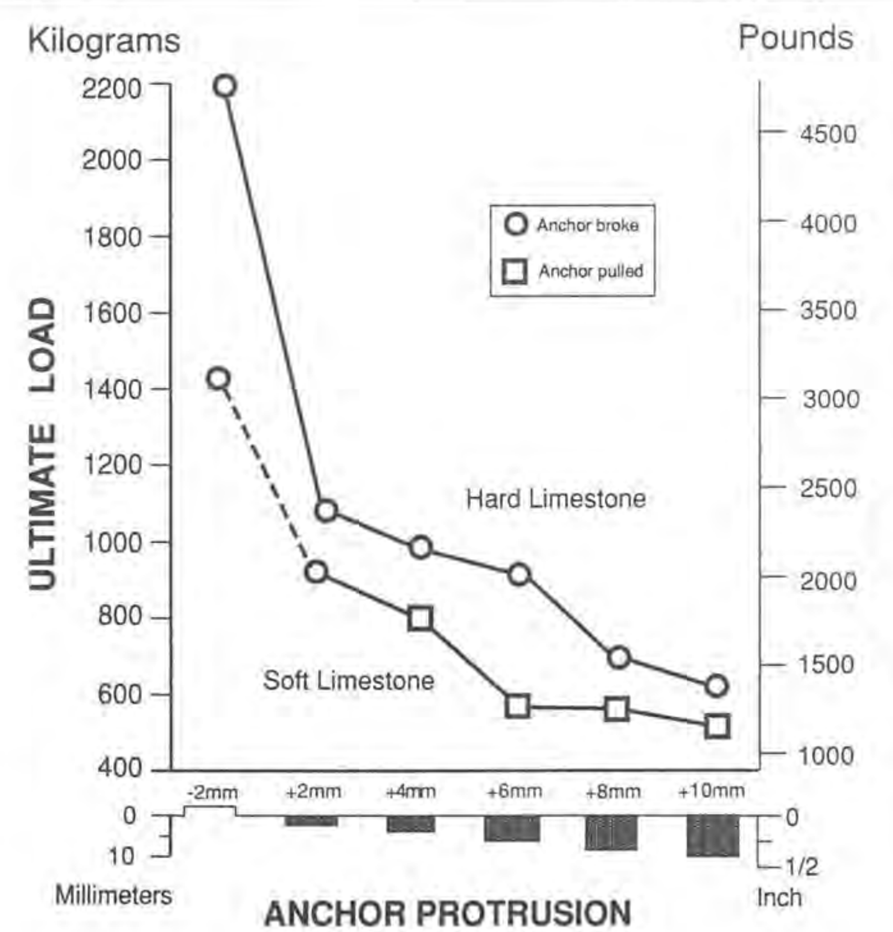


Figure 4. A self-drill that is underdrilled, but has a torqued bolt. The bolt is not loaded in bearing, but it experiences combined axial tension (due to preload) and bending, plus shear.

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 and self-drills. For short-term exploration these may be adequate; for longevity they definitely are not. These fasteners are zinc-plated or galvanized carbon



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.

Anatomy of a Corrosion Incident

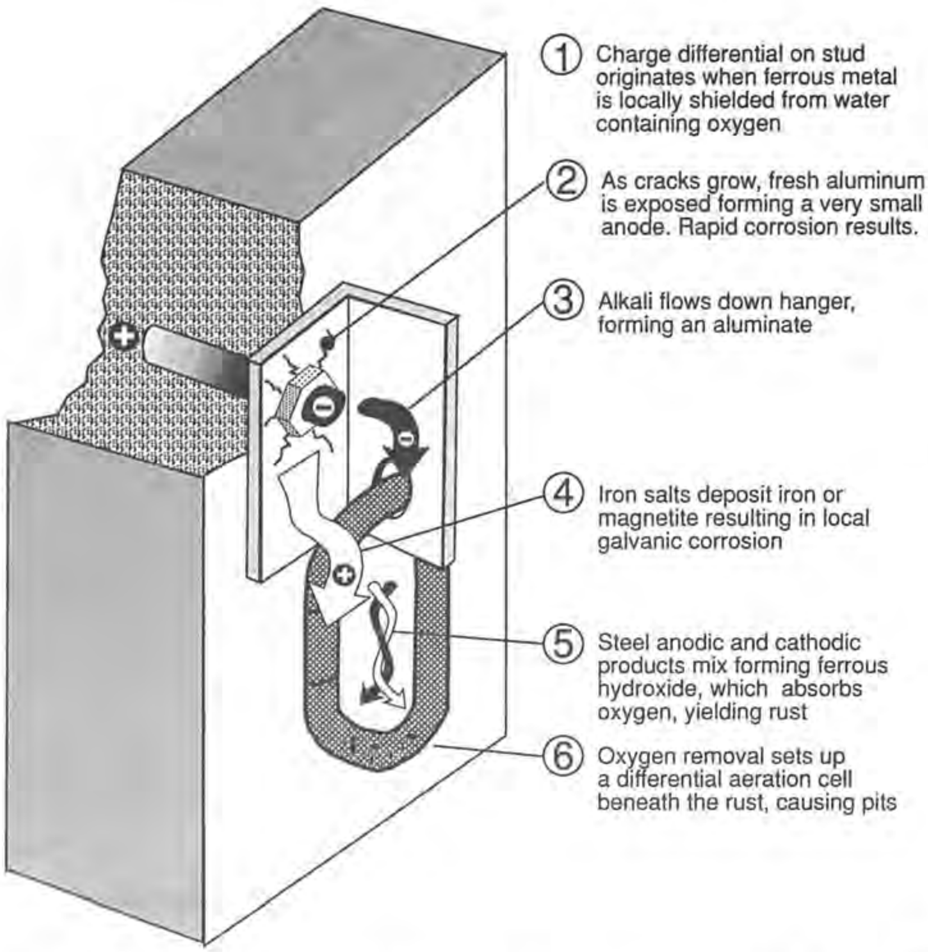


Figure 6. An aluminum hanger and carabiner attached to a carbon steel stud. The diagram shows the probable sequence of events leading to degradation of each component. A stainless stud would help the situation. Note that the effects of "galvanic corrosion" are secondary; electrically insulating the parts would not reduce corrosion rates.

steel, typically 1020 or 1030 alloys. Industrial experience tells us, beyond any doubt, that these will corrode. The mechanism is nothing fancy. They just rust away, progressively losing strength. Our testing of old pre-expanded studs from a rockclimbing 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. "Overaging" (heat treating past the point of maximum strength) can greatly reduce corrosion rates with a slight reduction in strength (e.g. using 7075-T74 alloy instead of 7075-T6). It is ironic that our single-minded quest of high strength has left us with inferior products. Ron Simmons (pers. comm.) fabricates his hangers from 6061-T6 aluminum—a weaker material but one acknowledged for superior resistance to atmospheric corrosion (Van Horn 1967). We conclude that, while their light weight is useful for aid climbing, aluminum hangers have no place in permanent rigging.

Since carabiners are often left with fixed rigging, the same concern applies. Several manufacturers boast of using corrosion-prone 7075-T6 alloy for its high strength. The thin annodizing 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 Quick-links corrode more evenly and predictably, and thus we consider them to be a safer choice.

From a corrosion position alone, stainless steels seems to be the obvious choice. However, strengths of materials must be considered. A discussion on balancing strength and reliability appears later under "Choosing Anchors."

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 the anchor works (Figure 7).

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. One clever solution is the "self-drilling" anchor, which carries its own disposable drill. Once set, the anchor accepts a bolt and a hanger to which it is rigged. Although marketed for securing machinery. and other fixtures to masonry, this is a reasonable system (at least in the short term) 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.

Setting Self-drill Anchors—Good instructions on setting self-drill anchors appear in *On Rope*, and a variety of British and European publications. Cavers should study these carefully and practice the techniques in concrete blocks, etc. before placing anchors in caves. Here we will discuss some subtle yet important details of anchor placement and how they affect reliability.

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 2 mm 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.

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 overtorquing. Our testing supports Smith's observations. However, we were unable to break 5/16-inch 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.

Self-drill Placement with a Hammer Drill—To save labor, a hammer drill may be used to drill the holes for self-drill anchors. If this is done, two precautions must be observed (although as we will suggest below, a stud-type anchor is actually preferable). First, the depth gauge should be used on the hammer drill to assure that the hole is the correct depth. Second, the bottom of the hole may need to be squared since the drill bit will leave it concave (Danilewicz 1987). This can be done by completing the hole witth the self-drill anchor, which leaves a flat, square bottom. Otherwise, the expander cone may not fully seat in the anchor. In one instance, all the anchors set in a deep cave with a Bosch drill had to be replaced by hand when they began to pull out (Danilewicz [?] 1989). This may have been the cause, although it may be that the anchors were studs and the holes were too large.

Reports of Failure—While some anchors are unreliable to begin with and some are visibly deteriorating, reports of failures are scarce. 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 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 m, 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 m and "just above him swung the belay, 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.

In 1988 two 1/2-inch-diameter anchors were reported to have broken in Ellisons Cave, Georgia (Fischesser 1988). The report suggested that they broke under very little force. It was surmised that either the bolt was over-torqued by twisting of the hangers and/or there was a "molecular reaction between metal differences in the hanger and bolt." He reports that anchors were removed in December 1987 for "testing and analysis" and that "additional failures from anchors in other caves have also been reported."

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 WD-40 or other 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; the 1 oz. size is handy. 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.

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 (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 6 mm stud equals the strength of a 12 mm OD self-drill anchor with an 8 mm 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 for $2 to $3 in 302, 303, or 304 stainless steel from Molly, Wej-It and ITW Ramset/Redhead. 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. The Wej-It Wedge Anchor is a minor variation on the collar, which uses wires to hold the deforming sections in place.

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.

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?).

Molly, Rawl, HILTI and ITW Ramset/Redhead all market adhesive anchor systems to be used with 3/8- to 1/2-inch rod or bolts. In very soft rock (under 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 4000 psi rock can withstand shear loads of over 6000 pounds.

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 (e.g. Molly) 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.

Petzl Long-life Anchor System (P38/P39)

Petzl has recently introduced a combination anchor/hanger made entirely of stainless steel. The P38 requires a 12-mm hole, the P39 a 1/2-inch hole. The P37 is a double-expansion version for soft rock which requires a 14-mm hole. Strengths are high (4800 lbs.). While somewhat expensive (about $8) 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. A similar anchor, without a hanger and reportedly removable (Middendorf 1988), was marketed by HME Corporation in the U.S. We were unable to locate the manufacturer in preparing this article.

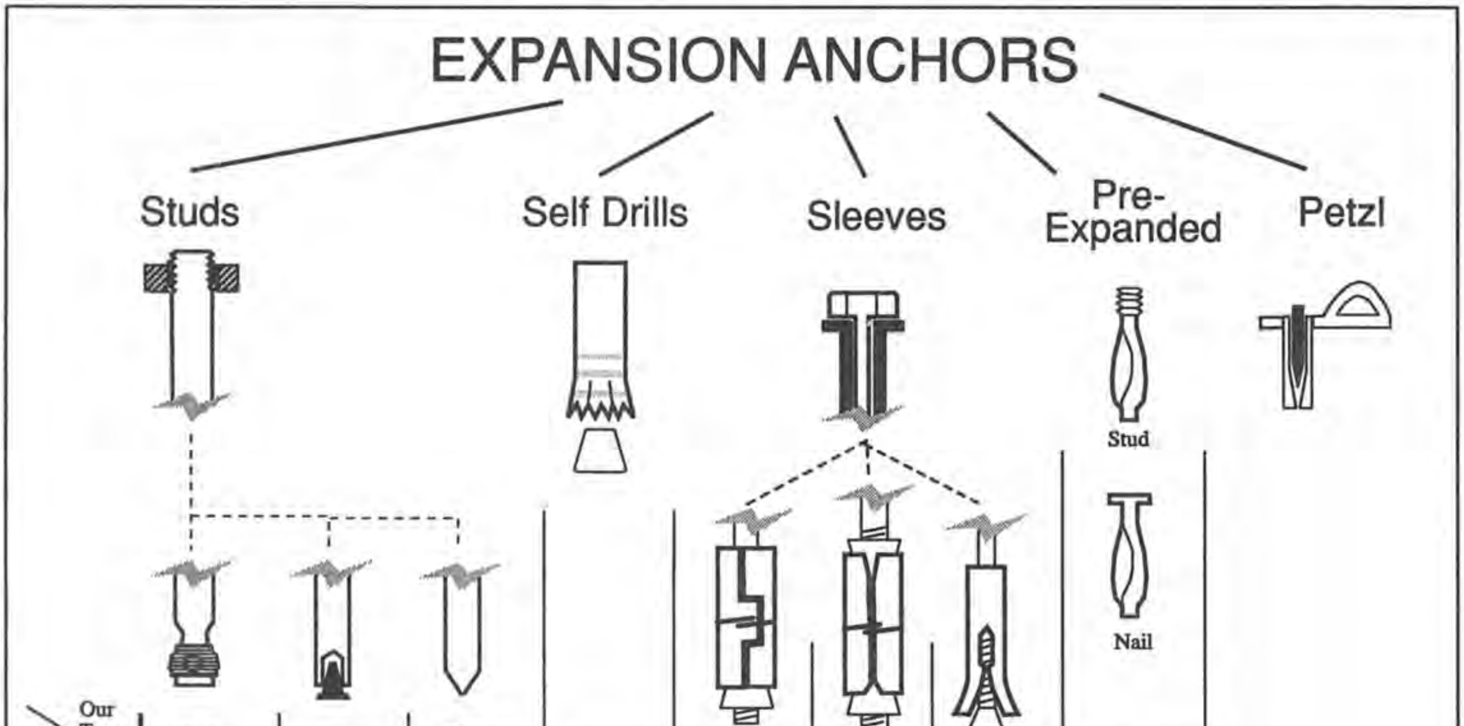
Non-calking or "Sleeve" Anchors

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: the British (e.g. Brook) use "Rawbolts." They have also been called "sleeve anchors" by Padgett and Smith (1987). Montgomery (1976) describes two models, Centurion and Austin McLean, neither of which seem to be in common use in the U.S.

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 probably more attractive alternatives. In cases where rapid rock deterioration is a concern, non-calking anchors can be removed for periodic hole weathering and frequent anchor removal in soft rock will undoubtedly cause wear and increase the rate of deterioration.

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



Our Term / Brand	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.

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 2500 lbs earlier ("What is a Safe Anchor?"), we must now think about how to actually achieve this goal with confidence in the rock strengths. The second reason involves deterioration and reduced strength as the item ages.

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

These recommendations result in a desired safety margin of 8 (or a theoretical 20,000-lb 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 at length in books like *On Rope* 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 2500-lb load, is a safe system, provided that they do not suffer significant loss of strength over time.

In general that means a 3/8-inch 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 we did not find them 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 British 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 four-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 that several deep European systems have been rigged using rebelay techniques, but with no artificial anchors.

Naturally, a lengthy and heated debate has ensued, but to us U.S. cavers 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 las 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 the STC is planning future articles on this topic. 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 esperience 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, especially if you use a hammer drill.
- Use stainless steel hangers and bolts for self-drives.
- Use grease on all self-drill anchors.
- *Don't* use 1/4-inch anchors or studs.
- *Don't* leave aluminum hangers in caves.

Acknowledgements

Alan Brook generously shared his knowledge from many years of placing artificial anchors. Ed Leeper and Steve Worthington contributed information and comments, but do not necessarily agree with our opinions. Bill Torode (NSS Librarian) and Ray Paulson (British Cave Research Association Librarian) were very helpful in tracking down articles. Tom Davinroy brought recent rock climbing literature to our attention.

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Appendix: Addresses of Manufacturers

Emhart (Molly) Industries Inc., 504 Mt. Laurel Ave., Temple, PA 198560. 215-929-5764
HILTI, P.O. Box 21148, Tulsa, OK 74121. 918-252-6000
ITW Ramset/Redhead, 1300 N. Michael Dr., Wood Dale, IL 60191. 312-350-7985
The Rawlplug Co. Inc., New Rochelle, NY 10802. 914-235-6300
Star Expansion Co., Pleasant Hill Dr., Mountainville, NY 10953. 914-534-2511
Wej-It, P.O. Box 521120, Tulsa, OK 74152. 800-343-1264

Obituary

Véronique Le Guen
NSS 27196
1956—1990

"The speleologist Véronique Le Guen, 33 years old, committed suicide on Thursday, 18 January, in her automobile in the garage in front of her home in the 19th arrondissement of Paris."

Through this announcement on radio, on television, and in the press, France learned of the death of our comrade. During 1988, Véronique had become known to the general public by her participation in an isolation experiment underground during which she stayed 111 days from 18 August to 29 November 1988 in the large room of the cave of Valat-Négre, Millau, France. The absence of clocks and other temperal clues made it possible to collect a large amount of data pertaining to fundamental human biologic rhythms. The experiment was directed by Michel Siffre who himself had remained isolated in the same conditions for seven months in Midnight Cave, Texas, in 1972.

A member of the Spéléo-Club de Paris, Véronique was also an active cave diver. She helped Francis Le Guen in his most difficult explorations, such as in Cocklebiddy Cave, Nullarbor Plain, Australia. Recently, she was with him at the end of the Gouffre de Padirac, Lot, where they discovered three kilometers of virgin passages in this major underground system in Central France.

After the isolation experiment, Véronique wrote *Seule au fond du gouffre* (Paris: Arthaud, 1989). In this candid and realistic book, one finds the speleologist "who has joined Cousteau in the heart of the public," with her charm, her humor, her angers, but also with the fears and anguish that assailed her during her long sojourn underground.

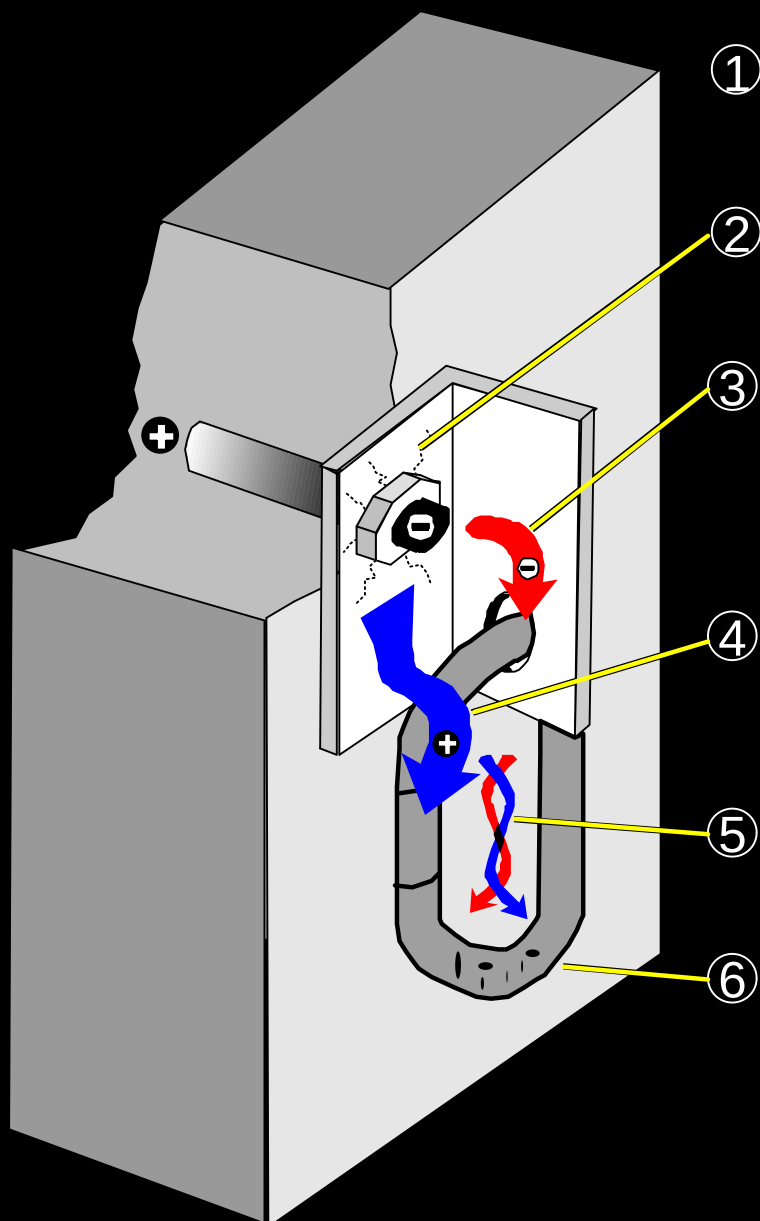
—Jacques Chabert

ACCIDENTS/INCIDENTS

Send reports to:

American Caving Accidents
505 Roosevelt Street
Oregon City, OR 97045

Anatomy of a Corrosion Incident



Conceived and sketched by: Bill Storage
Produced by: John Ganter