Mechanical Bolts
The Nuts and Bolts

by Duane Raleigh

You're thrutching the bad moves, vein worms pulsing in your forearms. You sweat and shake, then calm yourself by checking the last bolt, which is down by your feet. Calling to your belayer for slack, you launch for the exit bucket. And miss.

Falling you wait for your ratty rope to come taut as it has hundreds of times before. But it never does - the bolt pulls. As you hit the ledge it dawns on you that maybe those bolts you snagged at the army surplus store weren't such a bargain after all.

There's a litany of bolts for fastening in concrete and stone and climbers use them all. Most climbers assume all the bolts are bomber, too. Yet when you a bolt you don't really know what you're getting. Making matters worse, the person who drilled the anchor probably didn't know what they were getting either. Fact is, most bolts are better at anchoring Pizzeria sign post like they are designed to than catching leader falls.

To sort the good from the bad, we tested every type and brand we could find. We pulled them in concrete blocks custom made to simulate soft and medium rock, then checked those results by testing again in sandstone, marble, and granite. When their hydraulic puller finally creaked to a halt we had broken 325 bolts.

You can't just look at the charts, though, and start drilling away. To select and set a solid bolt you have to know what hardness of rock you're dealing with, and understand how bolts work.

Even then, bolting may not be for you. Good bolts and hangers are expensive, and bolting is hard work. If you aren't up to the task - and if slapping up a new route means more to you than doing good work, leave the job to someone else.

A Rock and a Hard Place

A bolt is only as solid as the rock you put it in. And rock can be iron hard, or so soft you can carve it with a stick. You'll know when rock is hard - your dulled bits and quickly drained Hilti battery will tip you off. Soft Rock is easy to define, too: even with a hand drill you can punch a big hole with little effort. It's the rock consistencies in between that raise questions.

You can get an idea of how well a bolt should hold in different hardness of rock by checking its strength as supplied by the manufacturer for tensile (pull-out) and shear (straight down load, as a bolt on a vertical wall) in 2000-psi (medium) and 4000-psi (hard) concrete. (2000 psi means that it takes 2000 founds to crush a one - inch cube of that rock or concrete.) The best bolts for climbing are usually the ones with the highest strengths in the lowest psi concrete. Our chart lists manufactures strengths (for simplicity we bumped some concrete strengths to the nearest 500-psi), and based on our own tests, notes whether bolts are suited for use in soft, medium, or hard rock.

For construction purposes 1000-psi concrete is too soft, so bolt companies don't bother testing their anchors in this material. Still, this concrete is about as hard as the soft rock in many climbing areas, so we tested in 1000-psi concrete that we had specially made. These blocks could be scratched with a fingernail, and were about as hard as the limestone swells around Dallas and Austin, Texas, and the volcanic rock at Cochiti Mesa and the Enchanted Tower in New Mexico. (The rock in these areas seems harder, though, because a tough outer crust belies the soft substrate underneath.)

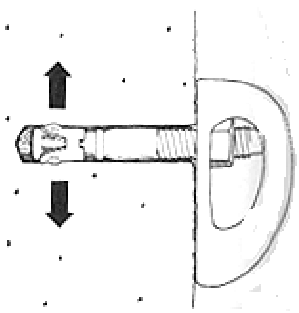
Our "medium" blocks consisted of 2000-psi concrete. We couldn't scratch these blocks with our nails, but the "rock" still drilled easily by hand and had a consistency similar to the rock in Penitente Canyon, Colorado and Smith Rock, Oregon. For "hard" rock, we tested bolts is solid tombstone-grade marble and granite blocks and a conglomerate boulder.

You have to be careful when correlating concrete to rock. Concrete is the same consistency throughout, so bolts set in it yield uniform test results. Conversely, rock usually varies in hardness and quality from one bolt hole to the next, making it impossible to predict exactly how strong each placement is. Use out test data and the manufacture's list strengths as rough comparative guidelines only. Every time you drill a hole re-evaluate whether the rock is sound enough for your bolt. If you can't decide what hardness of rock you're bolting into, err on the safe side and assume it's softer.

The works

Mechanical bolts, those that work by either expanding of compressing, grip the rock by pressing against the wall of the bolt hole (Figure 1). The pressing action creates friction between the anchor and the rock; for the bolt to pull out, the applied load has to overpower this coefficient of friction. But more important than understanding how bolts work is knowing how they don't work.

Figure 1. Mechanical bolts, those that work by either expanding or compressing, grip the rock by pressing against the wall of the bolt hole.



A bolt will fail by either breaking , pulling out, or destroying the rock around it. A bolt will break if its holding power is greater than its shear strength. You can virtually eliminate bolt breakage by using a bolt with a shear strength of at least 5000 pounds. The hardest you'll likely ever load a bolt is around 2600 pounds, so a 5000 pound shear-strength anchor gives about a two-to-one safety margin. (For details on fall forces see "The harder you fall" Over two tons of breaking strength may seem like overkill, but it isn't. This safety factor is in fact only half what the bolting industry recommends for bolts used to safeguard life.

If a bolts holding power is less than its shear strength it will pull out before breaking. The typical pull-out follows this scenario: the bolt flexes, crushing the rock beneath it. Without the support of the rock the bolt continues to bend until the developing prying action pulls the bolt out. You can increase a bolt's holding power by using a larger-diameter bolt that won't bend as readily as a smaller one and has a greater rock to metal contact (friction) area. In the case of soft rock or rock that has a flaky or crumbling surface, lengthening the anchor may also improve its holding power by letting the bolt grip into the more solid underlying rock, if there is any.

In hard rock, the bolt or the hanger will usually break before the rock crumbles, but he failure of the rock itself is a concern with any anchor in soft or medium rock. To keep the rock intact, don't place bolts too close to one another at belay/rappel stations. Keep bolts at least one foot apart, and place them equally far from corners, cracks, pockets, and other rock flaws. Before drilling, tap the rock with your hammer. If you hear a hollow sound, place the bolt elsewhere. Watch out, too, not to set a bolt in a block, which may sound solid but could tear loose. Finally, don't be fooled by rock with a hard outer crust. Varnished sandstone, limestone and some volcanic rocks are frequently hard on the outside but soft on the inside. In these cases be sure to use a bolt suitable for soft rock.

Never trust your life to a single bolt. Always double up at belay, rappel, and lowering stations. Bolt companies make millions of bolts a year, and there's no way they can check each bolt for flaws. And sure enough, defective bolts slip through their safety net - in our tests we found bolts that broke well below their list strengths in nearly every brand we tested.

Length and girth

You should always place the fattest and longest bolt that's practical. When you're using a power drill or bolting by hand on rappel there's no excuse for placing a flimsy bolt, and at a minimum you should use a 3/8inch by 2 1/2inch bolt in hard rock, 3/8inch by 3 1/2inches in medium rock, and a 1/2inch by 4 1/2inch glue-in bolt in soft rock.

Bolt design

What makes a good bolt? Climbing bolts should be strong, durable, easy to place, corrosion resistant, have some leeway for user error, and be removable so you can replace them. No bolt fits the entire bill, but various models of sleeve, wedge, compression, self-drill, nail-drive, and adhesive bolts are as good as you can get for now.

Sleeve bolts

These are tapped into a hole and then tightened down with a wrench, drawing a tapered cone into the sleeve, causing the bolt to expand. Sleeve bolts are among the most dependable mechanical anchors in hard and medium rock. Yet you have to be careful as there are two types of sleeve anchors: strong and durable bolts with solid hexheads and internal threads; and weaker sleeve bolts with external threads and an end nut (See "Bolts to Avoid") that can break under the strain of repeated loadings.

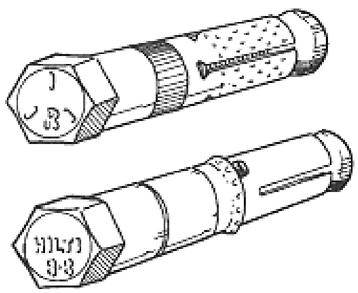


Figure 2. There are two types of sleeve anchors: shown here are the strong and durable solid hex-heads with internal threads. Rawl Bolt (above) and Hilti HSL.

There are three solidhead sleeve bolts that are applicable to rock climbing: the 3/8 and 1/2inch Rawl Bolt, and the 12 millimeter Hilti HSL (model number M8/20). These anchors are easy to place (you tap them in and wrench them down), removable, strong in tension and shear, and fit through standard 3/8inch bolt hanger holes.

The Hilti HSL, proving stronger in our rests, is the better of the two bolts, but costs twice as much as the Rawl Bolt. Additionally, the HSL is metric, requiring an expensive metric drill bit. We called every drill supplier in the phone book, but the only 12millimeter hammerdrill bit we found was from Hilti and cost $57. In comparison, a 1/2inch bit costs around $12.

In our tests the 12millimeter HSL and 3/8 and 1/2inch Rawl Bolts were stronger in hard rock than stainless steel bolt hangers, which usually broke at around 6000 pounds. In medium rock all three anchors pulled out (rather than breaking) at an average of 4100 pounds (HSL), 3700 pounds (1/2" Rawl), and 3400 pounds (3/8inch Rawl), making them the strongest mechanical bolts in this type rock.

We also tested these bolts in soft rock, but their expansion cones, being slightly larger than the drilled hole, sheared away the inside of the hole as the bolt was tapped in, causing the bolt to spin when we attempted to tighten it down. In solid desert sandstone where you can drill a dimensionally correct hole and the bolt tightens down, the 1/2inch Rawl Bolt and Hilti HSL are about twice as strong in shear and pull out as drilled angles.

The HSL and the Rawl Bolt are solid anchors in hard and medium rock, but they have some quirks. The biggest problem is that they require an immaculately clean hole-dust in the hole prevents the expansion cone from setting, preventing you from tightening the bolt down. When you set these bolts be sure you use a blow tube (a piece of 3/8" aquarium tubing works fine) and a test tube brush to clean the hole, and use a fairly new drill bit-worn-out bits will undersize the hole and make tightening the bolt difficult. If you get a spinner, clip a quickdraw to the hanger and pull out on it while you turn the bolt. If this doesn't work you'll have to remove the bolt, and since the spinning bolt won't unscrew you'll have to drill it out. Patch any bolt scar with a mix of polyester resin, like Bondo, and crushed rock.

Hilti, Rawl, and all other bolt manufacturers recommend torquing their bolts to a specific number of foot pounds. You aren't likely to take a torque wrench to the cliff, so prepare in advance by placing some bolts in a block of rock, and use a torque wrench to get a feel for the correct tension. On the cliff the bolt should draw up snug, but not too tight. If you over torque the bolt you might shear the head off, or worse, get it to the verge of shearing. The Hilti HSL and the Rawl Bolt may loosen slightly over time. When this happens, simply retighten them.

Wedge bolts

Wedge bolts have a tapered end with an expansion clip (Figure 3). Other than the Rawl Bolts discussed above, 3/8inch wedge bolts (1/4inch ones are far too weak) are the most commonly used climbing anchors. Their simplicity makes them easy to place and inexpensive (typically 40 to 75 cents apiece). And as an added bonus you can set these bolts with one hand-an advantage over the Hilti HSL and Rawl Bolt, which take two hands to start them in the hole, a sometimes difficult procedure.

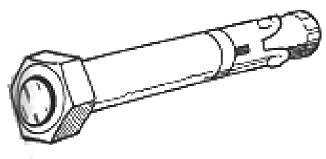


Figure 3. Wedge bolts have a tapered end with an expansion clip.

It's hard to botch a wedgebolt placement in hard rock, as placing one is as simple as drilling a hole deeper than the bolt is long (you can't drill the hole too deep), blowing the hole our, tapping the bolt in, and tightening it down. Tightening the bolt pulls it slightly our of the hole and draws the expansion clip over a cone, creating a friction hold at the back of the hole. If you don't get the bolt quite tight enough, no problem: this "selfenergizing" bolt will tighten itself when it's loaded.

It is easy to botch a wedgebolt purchase, however. We tested seven different brands and found that while some can hold up to 4000 pounds in hard granite, others are pitifully weak or are of erratic quality, and can break at as little as 1500 pounds. Compounding the problem, one wedge bolt looks like the next. If you use wedge bolts, the only way to make sure you know what you're getting is to insist on a sealed box or package. Avoid getting wedge bolts out of a bin where they can be mislabeled, or not labeled at all.

The strongest and most dependable wedge bolts are, in descending order of reliability, the Petzl , Hilti, Ramset/Red Head (also known as Phillips), Rawl, and WedgeIt. In hard rock the Petzl outdid all other wedge anchors by a long shot, proving stronger than the Petzl Coeur bolt hanger. The worst wedge bolts, the ones that can break at only 1500 pounds, are the USE, Star, and "generic" ones.

Because their exterior threads make them prone to work fatigue, wedge bolts aren't nearly as dependable as solidhead sleeve bolts. For that reason if you must use wedge bolts consider 1/2inch diameter ones, which still fit through a 1/2 inch Petzl Coeur bolt hanger, and are far more resilient than the 3/8inch size.

Beware of any wedge bolt that draws our of the hole more than 1/2inch when you tighten it (a common occurrence in soft rock); the expansion clip may be perilously close to slipping off the end of the bolt. You can't remove a wedge bolt, but you can countersink it and patch the hole if it was drilled slightly deeper than the bolt's length.

Compression bolts

Also confusingly called expansion bolts, these anchors are larger than the drilled hole and are forcibly hammered in, compressing as they go. These bolts try to "spring" back to their original size, creating a frictional force that gives the anchors high pullout strengths in hard rock. But the expansion effort can also cause the rock to crack or dinnerplate, and over time the bolt itself may crack from stress fatigue.

The Rawl Drive (Figure 4) is the only compression bolt we found, although Rawl makes a similar, and weaker, anchor called the Spike. Prior to the use of cordless power drills, the Rawl Drive, being fast to place and relatively strong, was the bolt of choice for drilling on lead and on big walls.

Rawl discontinued the 5/16inch Rawl Drive , the best bolt for on-lead hand drilling in hard rock, but continues to produce this bolt in the 1/4 and 3/8inch sizes. The 1/4inch Rawl Drive is too weak to trust even when brand new and set in hard rock. In softer rock or after a couple of years of weathering, the strength of these anchors is reduced to about body weight. If you place a 1/4inch Rawl Drive, plan on coming back and replacing that anchor before anyone has time to get on your dangerous route.

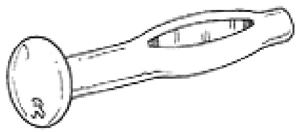


Figure 4. Compression bolts like the Rawl Drive are larger than the drilled hole and are forcibly hammered in, compressing as they go.

The 3/8 by 2inch Rawl Drive is an acceptable anchor for hand drilling in hard rock as it can hold over 5000 pounds in any direction, doesn't require a wrench, and takes a shorter hole, hence less drilling time, than the longer sleeve bolts. Nevertheless, if you have a power drill you've no reason to use the Rawl Drive, and plenty not to: the bolt tends to dinner plate the rock, can stress fracture over time, rusts badly, and is less reliable than solidhead sleeve bolts. And, forget about this bolt in medium or soft rock-in our tests the 3/8inch Rawl Drives pulled out at between 500 and 1000 pounds.

The 3/8inch Rawl Drive comes in two styles: round head and hex head. The roundhead version is more reliable than the externally threaded hexhead, which can crack across the threads. Disadvantages to the roundhead are that it only works with the 1/2inch Petzl hanger, and it isn't removable. (You can't remove the hexhead Rawl Drive either, but if you drill the hole deep enough you can take the nut and hanger offend countersink the bolt.)

Naildrives

Naildrives, such as the Petzl Long Life (Figure 5),expand when you drive a nail through the center of the bolt, expanding the anchor at the back of the hole.

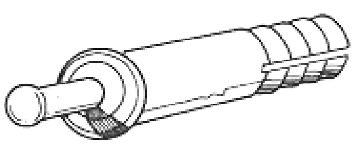


Figure 5. If we had our druthers we'd make everyone use the Petzl Long Life in hard rock, shown here without its included hanger.

If we had our druthers we'd make everyone use the Petzl Long Life for hard rock. Available in 1/2inch and 12millimeter sizes the Long Life is stronger than the Petzl Coeur hanger, which breaks at around 6000 pounds shear and 4000 pounds tensile. Besides having Herculean strength, the Long Life is easy to place, tamper proof so you don't have to worry about some low-rent swiping the hanger, and because both bolt and hanger are stainless steel, is virtually corrosion free. Unfortunately, even with the Long Life's advantages you aren't likely to ever clip many- they cost $9 each, hanger included.

The Long Life is fine in hard rock, but don't count on one in medium rock, where it can fail at under 2000 pounds. Also, don't confuse the Long Life with the fragile all-American, which looks similar and is temptingly available in many hardware stores at about a fourth the cost. You can tell a Long Life from the All American by color: the Petzl bolt is silver; the other is gold.

On our hydraulic puller the 3/8inch all-American sheared off at a paltry 1000 pounds. Even the meaty looking 1/2inch one, rated to 3620 pounds tensile, broke at 2200 pounds-a pathetic performance for a bolt this large. And don't even think about using the 1/4inch jobs: the ones we tested snapped off under a 400 pound load.

Drilled Angles

We were surprised at the high shear strength of drilled angles in hard desert sandstone. Placed with eye pointed down and drilled at a slight downward angle, these anchors held an average of 3500 pounds in rock that was solid to where the pin was difficult to pound into the hole. (Set with the eye facing up, they held about 1000 pounds less.)

Figure 7. In lieu of glue-ins, a 1/2-inch angle piton hammered into a 3/8-inch hole is the most common soft-rock anchor.

Drilled angles aren't a panacea, though, as they are dangerously weak in straight out pulls. In the same rock we used to check shear strength, the 10 drilled angles we tested pulled out at an average of only 1100 pounds, so don't pull out on these anchors at belays or when beginning a rappel. Additionally, drilled angles loosen with age as most anyone who has ever repeated a desert "classic" can attest. Test a drilled angle before weighting it, and even if it seems solid don't bet your life that it is.

In the end, aside from glue-ins, there really isn't a safe anchor that you can place on lead in soft sandstone. The best you can do is to use large sleeve anchors when they will tighten up, and go with a large wedge bolts when they won't.

Adhesive bolts
Glue-in bolts bond molecularly with the rock, giving them the highest pullout strength of any anchor. These bolts are superior to mechanical anchors in many ways. Foremost, they are reliable in soft and medium rock. To see how adhesive bolts perform in these mediums see part two of this article Adhesive Bolts.

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