DRILLS, HANGERS, BOLTS

The Dope for Doing It Right

A treatise revealing the mysteries of bolting will necessarily be controversial. My objective, however, is to help establish a common understanding of the mechanics of bolting systems. This, combined with intelligent consideration of the environmental impacts, can only encourage progress. Of course, opinion varies on the definition of progress. Regardless, bolts should be placed with discretion, for their impact is permanent.

Bolting is inherently dangerous. The information contained within is not absolute, and it is the responsibility of the reader to personally test and evaluate all bolting gear prior to in-field use. Refer to manufacturer's instructions for specific details.

"BAD BOLT JU-JU"

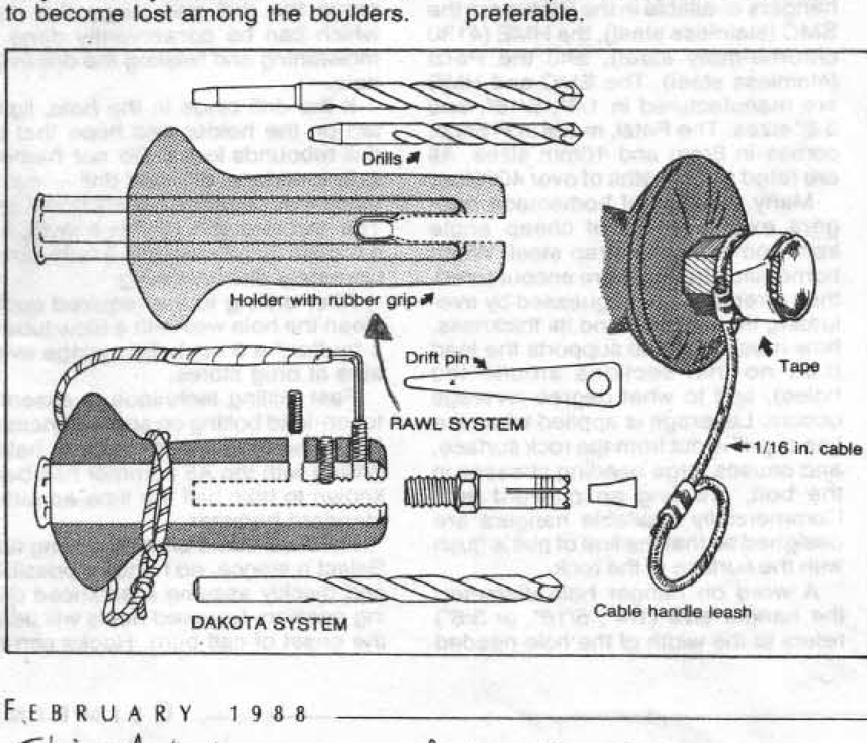
DRILLING SYSTEMS

Rawl. The Rawl system is the historical standard. Its main advantage is simplicity. It consists of a holder (with optional rubber grip), a tapered shank drill, and a drift pin (a wedge for removing drills from the holder). The Rawl uses an archaic drill numbering system for holder diameter: #12 refers to 1/4", #14 to 9/32", and #20 to 3/8". #14 Rawl holders are standard, and accept commercially available 1/4", 5/16", and 3/8" tapered-shank drills with standard #14 taper.

The drills press fit into the holder. Hammering the drift pin into the holder's ejection slot forces the drill out; this is called "clearing the drill." Unfortunately, drill removal is this system's major drawback. Loosening a tight press fit requires considerable hammering on the drift pin, and the drill may suddenly shoot out of the holder to become lost among the boulders.

Another major problem is a lack of manufacturing consistency in the holder's heat treatment and internal taper. Too hard a heat treatment causes holders to chatter with use; too soft a treatment or too large an internal taper and the drill can become fixed deep in the holder, making it impossible to insert the drift pin.

The Rawl rubber grip slips on the holder, and works best if epoxied on. The stock Rawl drift pin is crude, so the Leeper model with its tie-in hole is preferable.



Another important feature of any drilling setup is a leash, which can be fashioned by clove hitching and taping a length of half-inch webbing to the holder. However, a leash system that doesn't wrap around the holder while drilling is preferred — such as the cable handle leash.

Dakota. The Dakota system allows for non-forcible removal of the drill from the holder. Three allenhead screws threaded in the holder are tightened flat against the drill, locking it securely in place. Locktite will help prevent loosening of the screws during use. Internal plug spacers are included and can be inserted into the holder to extend the cutting length of the drill. The properly hardened Dakota holders are shorter (preferred) than the Rawl, and come with an epoxied-on rubber grip, a leash, and a tied-on allen wrench.

Dakota offers two versatile systems: the Quad and the Quint. The Quad accepts 5/16" and 3/8" drills (5/16" shank), while the Quint takes 1/4", 5/16", and 3/8" drills (1/4" shank). Self-drives (1/4" and 5/16") can be used with both systems by inserting a threaded adapter.

The main advantages of the Dakota system are controlled removal of the drill and reliability. The disadvantage is that losing the essential set screws can disable the system.

Self-Drive. A self-drive is a combination drill and anchor (see Bolt section). There are two types of holders: threaded, which uses a bolt with internal threads; and press fit (made by Mammut), which uses chuck-end (aka snap-off), tapered-end bolts, expelled from the drill with a drift pin.

Although there are many self-drive aficionados, I feel these systems are very inefficient compared to conventional bit-and-holder systems. They are more costly (sometimes several "bits" are required to drill one hole), require greater time and effort to drill a hole, exhibit a lower strength to bolt-diameter ratio, and are limited to only self-drive anchors.

Powered. The advent of rechargeable, battery-powered hammer drills has been responsible for a recent proliferation of new routes. Although usually associated with rappel-placed routes, many traditionalists have also used them for on-lead bolt placements. One such climber altered his Bosch Bulldog, enabling him to place a bolt with one hand from stance.

These drills have a dual impact/rotary motion, and use carbide-tipped bits. Holes can be drilled in under a minute. The Bosch Bulldog (model 11213K) is the most popular hammer drill, weighing 7.7lbs (with 24V battery). On a fully charged battery, it can drill ten to 12 holes (3/8" by 3") in gran-

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ite. Hilti makes a heavier (9.3lbs), more powerful version. Other manufacturers (Mikada, Porta-Cable, and Ryobi) make lighter-duty units. And for those interested in trivializing even the remote challenges, Ryobi (12 lbs) and Hilti (16lbs) make gas-powered rotary hammer drills.

DRILLS

The drill is the heart of a bolting system. Proper knowledge of drill design is essential for correct use. The following geometric variables apply:

Diameter, Length, and Shank. The diameter of a drill depends on what size bolt is being used, while length is determined by which system is employed. The shank, the end that fits into the holder, is tapered on a Rawl-type drill, while on a Dakota it is straight.

Body. The body directly effects the degree of binding that occurs while drilling. When the width of the cutting edge is decreased by side wear near the tip, the drill will start a smaller diameter hole. Binding results when the wider part, usually near the tip, jams in the hole.

Invented by Ed Leeper, the reverse taper was thought to reduce binding, compensating for side wear with its 0.3 degree taper. However, the reverse taper more readily creates wide spots 1/8″ to 1/4″ behind the tip. Furthermore, as these drills are sharpened, and thus shortened, they bore successively smaller holes, compounding the binding problem.

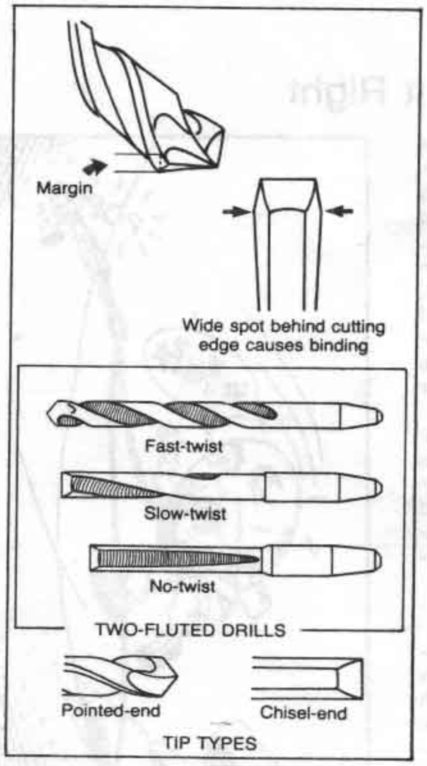
Margin. Margin, a slightly raised shoulder running lengthwise along the edge of the flute, prevents binding by reducing the effect of side wear. Visual inspection of a drill for a worn margin is a good idea to avoid the binding headache.

Flutes and Twists. Two-fluted drills are preferred over three-fluted ones, because they can be chisel-pointed for faster drilling.

I feel twisted flutes are essential for removing rock dust, which can promote binding. They convey dust out of the hole, and come in either fast twist (1 revolution per 2″) or slow twist (1/2 revolution per 2″).

Tip. Tips come sharpened in either a chisel-end or pointed-end. Chisel-end tips drill faster because the effective cutting edge wears more slowly than pointed-end tips. However, it is more difficult to start a hole with a chisel-end tip. They also have a greater tendency to wander, creating an oversized hole.

Three companies manufacture climbing drills: 5.10, Dakota Bolt Works, and Mountain High. 5.10 makes reverse-taper, chisel-tip drills for the Rawl holder. The 1/4″ is a no-twist drill; the 5/16″ and 3/8″ are slow twist. The 3/8″ model needs improvement — both the shank (too short to extend past the rubber grip) and the body (too short to drill sandstone anchoring holes) need to be lengthened.



Dakota modifies industrial metal drills to fit either the Rawl or Dakota holder. These excellent drills have a constant diameter, twisted flutes, and margin.

Mountain High manufactures a 1/4″ reverse-taper, slow-twist drill; it works well and is moderately priced. Drill prices range from $10 to $16.

HANGERS

The only three commercially made hangers available in the States are the SMC (stainless steel), the HME (4130 chrome-moly steel), and the Petzl (stainless steel). The SMC and HME are manufactured in 1/4″, 5/16″, and 3/8″ sizes. The Petzl, made in France, comes in 8mm and 10mm sizes. All are rated at strengths of over 4000lbs.

Many varieties of homemade hangers exist — some of cheap angle iron, some of bent strap steel. When homemade hangers are encountered, their strength can be guessed by evaluating the material and its thickness, how much material supports the load (i.e., no thin sections around the holes), and to what degree leverage occurs. Leverage is applied when the line of pull is out from the rock surface, and causes large bending stresses in the bolt, creating an outward pull. Commercially available hangers are designed so that the line of pull is flush with the surface of the rock

A word on hanger hole diameter: the hanger size (1/4″, 5/16″, or 3/8″) refers to the width of the hole needed for the bolt. Confusion arises with Rawldrive (split-shank) bolts because 1/4″ Rawldrive buttonheads require a 5/16″ hanger (or a 3/8″ with 3% less strength). Likewise, a 5/16″ Rawldrive requires a 3/8″ hanger.

TECHNIQUE

Good drilling technique comes with practice. Experimenting with a variety of techniques and systems will naturally optimize your ability to place a good bolt. Here are the basics:

Location. Pick an area in smooth, solid rock, at least ten bolt diameters away from the nearest fracture or edge, considering at the same time the line of pull and convenience for clipping. Optimize the height of the bolt with ease of drilling, which is efficient at 2/3 of your maximum reach. Test for exfoliated or hollow sections with a hammer. The hanger must sit flush with the rock, so small nubbins should be chipped away. However, beware that excessive pounding will weaken the rock.

Starting and Drilling the Hole. To begin the hole, use the drill as a chisel, cross-hatching to create a shallow circular indentation.

The hole must be drilled perpendicular to the surface of the rock, so it is important to maintain a steady drilling angle to avoid an oversized or non-perpendicular hole. Turn the drill at least 1/8 of a revolution between every hammer blow, and distribute the total number of hits at each orientation evenly with at least 180° rotation.

As the hole progresses, grip the holder loosely, maintaining a steady angle and constant rotation, and allow the drill to rebound slightly (1/4″ or so) after each hit. The resulting pneumatic effect helps displace dust, which otherwise slows drilling and encourages binding. Also, periodically remove the drill and purge the dust, which can be conveniently done by moistening and twisting the drill in the hole.

If the drill binds in the hole, lightly tap on the holder and hope that the drill rebounds loose. Do *not* hammer side-to-side on a bound drill — sometimes even normal use will break one. The "unbreakable drill" is a myth, and a broken bit midway into a hole can be ultimately disheartening.

After drilling to the required depth, clean the hole well with a blow tube or a "puffer," a 3 oz. baby syringe available at drug stores.

Fast drilling technique is essential for on-lead bolting on small stances. A heavy, well-balanced hammer helps; drilling with the A5 hammer has been known to take half the time as with a standard hammer.

Here are some on-lead drilling tips. Select a stance, no hands if possible, and quickly assume a balanced drilling position. Lowered heels will delay the onset of calf burn. Hooks can be

used to unweight the rope, or for aid. Maintain a relaxed, steadfast attitude, and avoid procrastination. Resting frequently and shifting positions are inefficient. Difficult on-lead bolt placement is an uncelebrated art, its perfection requiring boldness, adventurous desire, and repudiation of the spineless, top-down technique.

BOLTS

Nearly all bolts used for rock climbing are designed for industrial anchoring in masonry and concrete, except the HME and Metolius which are designed specifically for rock climbing. There are over 100 masonry fastener companies in the U.S., the main ones being the Rawlplug Company (New Rochelle, NY), Star Expansion Company (Mountainville, NY) and USE Diamond (York, PA). Other suppliers include Redhead-Phillips, Wej-it, and Hilti.

Climbing bolts can be divided into three functional classes. A hammer-in bolt is pounded into the hole; a torque-type bolt is placed in the hole, then torqued with a wrench; and a glue-in bolt is a threaded rod glued into an oversized hole.

Glue-in bolts are common in Europe. Their strength is that of the bond between the glue and the rock, which is sometimes stronger than the rock itself. Glue-ins are also resistant to weathering and should be strongly considered by the top-down "creationists" who can afford the setting time required — 10-20 minutes at 68°F. Polyester resin glue is available in convenient capsule form, such as the Rawl Chem-Stud capsule. These can be simply placed in the hole and mixed while setting the anchor rod with a rotary hammer drill.

Hammer-in Bolts. These bolts come in two styles. Rawldrives have split-shank halves that compress, exerting an outward spring force against the walls of the hole. Friction between the bolt and the rock converts the outward force into a resisting lateral force. Wedge-type hammer-ins utilize a wedge driven into the base of the bolt, expanding its sides outward.

Rawldrives. Rawldrives have been the most common rock climbing bolt. However, they fail with time due to "creep," an engineering concept which describes a time-dependent deformation of material under a constant force.

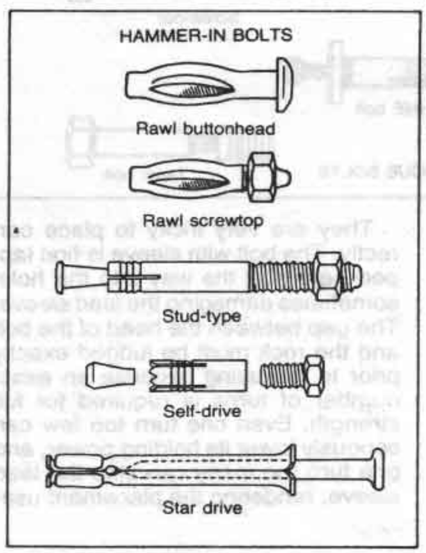
Rawldrives are adequate for hard rock, but not recommended for sandstone. Sandstone deforms too easily, and the split shanks don't compress sufficiently; also, the coefficient of friction between steel and sandstone is low due to thin shear planes, and Rawldrives depend on a high coefficient of friction.

They come in a buttonhead and a screw-top design. The screw-top, which must be placed with the nut prethreaded on, is weaker due to the threads.

When placing a Rawldrive, always orient the split-shanks perpendicular to the line of pull. To prevent cratering, tap the bolt in slowly until the wide part of the shank is in. Do not continue to pound on the bolt if it bottoms out.

Wedge-Type Hammer-Ins. These come in both stud-types and self-drives. Holes for these bolts must be drilled to an exact depth. Stud-types are externally threaded, strong in the 3/8" size, and convenient to place. Self-drives are internally threaded, weak considering the large hole diameter, and difficult to properly place flush with the rock.

Common machine bolts can also be used for rock anchoring, most notably as a cheap and easy aid rivet placed in a 1/2"-deep hole. Proper hole sizing is



very critical when using these because they rely on an interference fit for security. Coarse-thread machine bolts (5/16") are secure in a hole hand-drilled with an exact 0.275" diameter drill. Even a hole oversized by a few thousands of an inch can render the placement useless; obviously, they are not recommended for sandstone. Grade 5 hexagonal head bolts are the best, grade 2 material is too weak, and grade 8 steel is too hard to ensure the required meshing of threads. Aluminum machine bolts hold body weight, and can be the ticket for aid ladders on remote big walls.

Baby Angles. A half-inch baby angle hammered into a 3/8" hole is a commonly used anchor. In fact, they are currently the only anchor suitable for soft sandstone. Desert rat Ron Olevsky certifies that baby angles are "so good that long after the rock has crumbled and eroded into dust, they'll be hanging up in space..." However, proper placement of baby angles is complex, requiring the use of glue and several drills of varying diameter (1/4", 3/8", and 1/2"). Rock quality is the key factor determining this anchor's reliability.

Miscellaneous Hammer-Ins. Star Drives are sleeve- or shield-type bolts, but are barely deserving of mention because they are expensive and relatively weak. Drop-ins (not shown) are similar to the self-drive bolts, but instead have an internal wedge which is set with a special driving tool. They are sometimes used for aid.

Torque Bolts. Torque bolts can be divided into two classes: pull-type, which pull a cone into the expansion section; and push-type, which pushes the expansion section outward. The expansion section can either be a sleeve, or the body of the bolt.

Rawl Bolt. The 5-piece Rawl bolt is in the pull-type class, and is one of the best available. Pluses of the Rawl bolt include high strength, versatility (good for a variety of rock types including some sandstones), and foolproofness (over-torqueing is easy to avoid). For full strength, the Rawl bolt is torqued until the blue plastic sleeve starts to compress, which is apparent when the torqueing force becomes constant (generally after 3 or 4 turns).

Metolius Bolt. Metolius manufactures a 3/8" welded-eye bolt with a three-piece (bolt, wedge, sleeve) pull-type construction. The bolt is made from high-strength (4130) steel rod, bent and welded to form the eye. Structural welds are susceptible to corrosion, hide flaws, and locally disturb the base material's mechanical properties. Nevertheless, these bolts have tested out well and are the best of the hangerless bolts on the market.

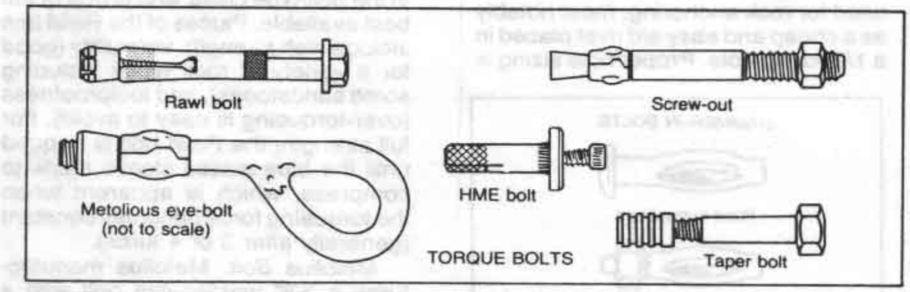
Miscellaneous Torque Bolts. Screw-outs are a common torque-bolt, available in stainless steel.

BOLTS

Type	Manufacturer	Size[1]	Price[2]	Rock Type[3]	Function Index[4]	Strength Index[5]	Manufacturer's Listed Strengths[6] (in pounds)
HAMMER-IN							
Rawldrive	Rawl	1/4", 5/16", (3/8")	1/4"-$.43 5/16"-$.58	HR	medium	medium	1/4" - 2050(+) pullout, 2230(+) shear 5/16" - 3500 pullout, 4850(+) shear 3/8" - 5010 pullout, 7800 (b) shear
Stud-type	Rawl, Star	(1/4"), 3/8"	1/4"-$.53 3/8"-$.85	HR, MR	high	medium	1/4" - 2300 pullout, 1800 shear 3/8" - 3400 pullout, 4100 shear
Self-drive	Rawl, Star	7/16", 15/32"	1/4"-$.68 5/16"-$.91	HR, MR	low	low	1/4" - 2710 pullout 5/16" - 3225 pullout, 4300 shear
Machine Bolt	——	many	$.05-.10	HR	low	medium	A grade 5, 1¼" long, coarse thread machine bolt placed in a #14 diameter hole tested to 3700 shear.
Baby Angle	Chouinard SMC	1/2" angle for 3/8" hole	$4.35	SR	low	high*	——
Dryvins	Star	(1/4", 3/8")	$1.85	NR	low	low	A 3/8" x 2" Stardrive tested to 2000
TORQUE							
Rawl-Bolt	Rawl	3/8"	$.90	HR, MR	high	high	3/8" x 2" - 4840 pullout, 7875 (b) shear 3/8" x 3" - 5590 pullout, 8155 shear 3/8" x 3½" - 5310 pullout, 9055 (b) shear
Metolius	Metolius	3/8"	$6.50	HR, MR	high	medium	3/8" x 2" - 4000 pullout, 4500 (−) shear 3/8" x 3" - 6000 pullout, 7500 (−) shear
HME	HME	1/4"	$6.50	HR	high	medium	n/a
Taperbolt	USE Diamond	1/4", 3/8"	1/4"-$.99 3/8"-$1.52	HR	low	medium	1/4" - 1666 pullout (−), 2425 (+) shear 3/8" - 4030 pullout, 7177 (b) shear
Screw-out	Rawl, Star, USE, others	1/4", 3/8"	1/4"-$.42 3/8"-$.75	HR	medium	medium	½" - 2700 pullout, 2600 (−) shear 3/8" - 4390 pullout, 4320 (+) shear
Sleeve-type	Rawl, Star, USE, others	(1/4"), 5/16", 3/8"	5/16"-$.39 3/8"-$.70	HR, MR	medium	low	1/4" - 1650 pullout, 1550 shear 5/16" - 2400 pullout, 2300 shear 3/8" - 4100 pullout, 3020 (+) shear

[1] ( ) indicates a non-recommended size [2] For 1/4" x 1½" or 3/8" x 3" [3] HR = hard rock, MR = medium rock, SR = soft rock [4] Function index includes versatility, foolproofness, and ease of placement. [5] Strength index considers longetivity, relative bolt diameter, and assumes proper placement. * sandstone only [6] Manufacturer's tests are in 3000-5000 psi strength concrete; (+) = verified by test, (−) = test strengths were less, and (b) = hanger broke first

Sleeve anchors (not pictured), such as the Rawl Lok-Bolt, utilize a wedge which is pulled into a body-length sleeve. Wej-it makes a bolt (not recommended) with two triangular wedges connected to long thin rods running the length of the bolt.



TORQUE BOLTS

HME Bolt. HME manufactures a stainless-steel, push-type bolt. The allen screw, with only one full turn, expands the trisected body outward. Loosening the allen screw allows removal of the bolt, which can be reused. Although exorbitantly priced at $6.50, the HME bolt, outfitted with a thumb screw, would be an extremely handy tool to fill missing bolt holes such as those often found on El Cap's Boot Flake.

Taper Bolts. Taper bolts, manufactured by USE Diamond, have been a popular alternative to 1/4" Rawldrives. They are a push-type bolt; a tapered, threaded section on the bolt is screwed into a lead sleeve, expanding the sleeve outward.

They are very tricky to place correctly. The bolt with sleeve is first tapped nearly all the way into the hole, sometimes damaging the lead sleeve. The gap between the head of the bolt and the rock must be judged exactly prior to torqueing because an exact number of turns is required for full strength. Even one turn too few can seriously lower its holding power, and one turn too many can strip the lead sleeve, rendering the placement useless. Many experienced bolters (even those familiar with the taper bolt) have botched placements. Worst of all, a botched taper bolt is difficult to detect. Furthermore, a taper bolt's pull out strength is minimal, and despite a recently improved lead sleeve design, these bolts are not recommended.

USE Diamond also makes a 3/8" taper eye bolt. It is poorly designed for shear; pull forces with the round eye design are away from the surface of the rock, causing excessive leverage.

GENERAL RECOMMENDATIONS

Selecting a suitable bolt for a particular application requires knowledge of the mechanical properties of the anchoring medium. General recommendations are difficult.

Solid rock anchors exert a large anchoring force with not much expansion. Medium rock anchors must exert the same degree of anchoring force, but with more expansion and so on as the rock gets softer. Anchoring force must continue with time, and compensate for possible rock decomposition. Careful consideration of the bolt's anchoring mechanism will indicate its compatibility with a given rock type.

In general, 1/4" bolts should not be

used as a general protection bolt, and should only considered for special applications where speed is critical and security secondary.

A 5/16" is only available as a Rawldrive and in weaker sleeve types. The 5/16" Rawldrive comes only in 1 1/2" length, limiting its use to hard rock.

The best bolts for free climbing are 3/8", and are available in a variety of styles. The Rawl bolt is a good all-around bolt, as is the 3/8" stud-type hammer-in. These bolts work well in medium (or better) quality rock.

Personal experimentation with bolts is advised. A non-definitive estimate of a bolt's strength can be obtained with the aid of a "funkness device," a strong, swaged cable assembly (3' to 4' long, with end loops). Clipping one end of the cable to the bolt, the other end to a heavy hammer, and swinging hard can create incredible forces (and tendonitis). Commercially made hangers can bend or even break using this test, indicating the bolt is good.

Corrosion and fatigue are factors which weaken a bolt with time. Fixed anchors should be stainless steel, and possibly sealed with glue, especially in more porous rock. When sealing or gluing any bolt, do *not* use epoxy. Recent research indicates "that steel corrosion caused by contact with epoxy occurs" (*Machine Design Trade Magazine*). Furthermore, epoxy has low shock absorbing properties. Polyester resins are better in all aspects.

Testing. Static strength tests of 74 bolts were performed last fall in Yosemite granite. Results of the test are tabulated.

The author encourages independent testing. A reliable test rig can be constructed with a hydraulic cylinder (push/pull type) and a pressure gauge. The hydraulic pressure and pull force are linearly related.

The hydraulic test rig reveals the static strength of an item. Climbing forces are quasi-static (loading rates can be static, quasi-static, or dynamic). The quasi-static strength of common structural materials is not much less than the static strength, so the static strength test gives applicable results.

— *John Middendorf IV*

Manufacturers

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P.O. Box 1390
Glendale, CA 91209
(818) 768-3068

Dakota Bolt Works
1801 Centre Street
Rapid City, S.D. 57701
(605) 348-9109

HME
360 Chestnut #5
Carlsbad, CA 92008
(619) 434-6498

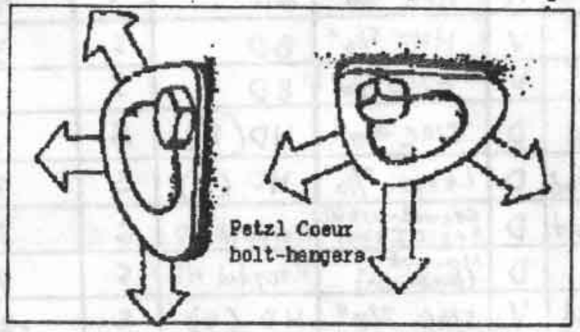
Metolius
63225 Lyman Place
Bend, OR 97701
(503) 328-7585

Petzl/PMI
Box 803
La Fayette, GA 30728
1-800-282-7673

SMC
12880 Northrup Way
Bellevue, WA 98005
1-800-426-6251

Addendum

__New Products:__ **Petzl has a new bolt hanger, the Coeur, which innovates a new standard in bolt hangers. Existing hanger types are well designed to minimize leverage for a shear pull, but pry on the bolt for a straight outward pull load. The Petzl hanger is designed such that for any angle of pull, leverage is minimized.**



The Coeur hanger is available in two sizes: 10mm (model #P34) for 3/8" bolts, and 8mm (model #P36). Metolius has a look-alike version, with similar non-leveraging characteristics (no further info available).

__Update on bolts:__ The Rawlbolt is proving *not* to be as foolproof as originally thought. Rock-dust sometimes gets into the threads where the cone attaches, and the cone may sieze on the bolt, disenabling further expansion. Continuing to tighten the bolt after this happens will cause the bolt to spin in its hole, confirming a useless bolt. For best results, make sure the hole is very clean before placing the Rawlbolt. Also, Rawlbolts generally require 3 to 4 __half__-turns for full strength, rather than the previously stated 3 to 4 full-turns (stop torquing when the blue plastic sleeve starts to compress).

On Taperbolts: Taperbolts aren't recommended due to ease of "botchment". Botched taperbolt placements may be minimized with the use of an accurate torque wrench, and a spacer to determine initial clearance. Proper placement requires __exact__ concordance with manufacturer's (USE Diamond) recommendations on torque.

__Epoxy Update:__ Bob Harn from Seattle has clarified epoxy use with bolts. The corrosion that occurs with epoxied-in bolts is due to crevice corrosion (as opposed to a chemical reaction between the epoxy and the bolt). Crevice corrosion occurs when the epoxy cracks due to thermal and/or shock loads, allowing water and other contaminants to collect in the cracks and initiate crevice corrosion which occurs in the oxygen starved environments. Epoxy has little resilience; a more resiliant glue (like polyester resin) is required for rock climbing applications.

__Bolt Failure:__ The pull-out strength of a bolt (as opposed to its shear strength) is a very important factor of a bolt's overall strength, especially in the 1/4" and 5/16" sizes (hanger failure usually occurs first for 3/8" bolts). When tested in shear, a bolt crushes the rock around its hole in the direction of pull, and the bolt bends. Further pulling on the bent bolt results in both a shear force *__and__* a pull-out force. Most 1/4" bolts pull out of their hole rather than break when tested in shear.

Rawl 1/4" split-bolt Test Results

Test Number	Bolt type, & Length	O (1)	Hanger	Hole (2)	FD (3)	Strength (lb) (5)	Failure Mode (4)	Comments
1	1 1/4" Buttonhead	H	HME 5/16"	HD (J.B.)	S	3614 →	BP, HD	
2	1 1/4" "	D	HME 5/16"	HD (J.B.)	S	3275	BP, HD	popped out 1/2 way pulled out at 2814
3	1 1/4" "	V	HME 5/16"	HD (J.B.)	S	3283	BP, HD	—
4	1 1/4" Buttonhead	H	HME 5/16"	BD		~~4238~~ →	HB(c)	—
5	1 1/4" "	H	HME 5/16"	BD	S	4010 →	HB(c)	hanger broke, bolt then pulled out by hand
6	1 1/4" "	V	HME 5/16"	BD	S	3274	BP, HD	
7	1 1/4" "	V	HME 5/16"	BD	S	4223	HB(c)	rebroke at 1526 lb after hanger broke
8	1 1/4" Buttonhead	D	SMC 3/8"	HD(D)	S	3050	BP, HD	
9	1 1/4" Buttonhead	D	Leeper 5/16"	HD (D)	S	2858	BP,	
10	1 1/4" Buttonhead	D	Second-used (A) Angle Iron	Recycled HD	S	2658	BP—	
11	1 1/4" "	D	No-gud (Aluminum)	Recycled HD	S.	2566	BP—	
12	1 1/4" Buttonhead	V	SMC 3/8"	HD (D)	S	~~2034~~	BP, HD(slight)	Intentionally placed bo[lt] - placed only 1/2 way in
13	1 1/2" Buttonhead	(H)	HME 5/16"	HD (J.B.)	S	4574	HB(c)	rebroke at 1723 lb after hanger broke
14	1 1/2" "	(H)	SMC 3/8"	HD (D)	S	4571	HB(e)	Bolt pulled out by hand after test ✓.
15	1 1/2" Buttonhead	•V•	HME 5/16"	BD		3242	BB(mid-way), HD	
16	1 1/2" "	•H	HME 5/16"	BD	S	~~5163~~	HB(c)	rebroke at 3118 lbs and 1446 lbs after.
17	1 1/2" Buttonhead	V	SMC 3/8"	BD	S	3518	BB(mid-way), HD	
18	1 1/2" "	V	SMC 3/8"	BD		3360	BB(mid-way), HD	Bolt pulled out first 1/2 way
19	1 1/2" "	H	HME 5/16"	BD	S	~~3179~~	BP, HD	
20	1 1/2" "	H	HME 5/16"	BD	S	4099	HB(e), HD	Bolt pulled partially out, then HB.
21	1 1/2" Screwtop	•H	Leeper 1/4"	HD (D)	S	3534	BP, HD	Rock failed at 2858 lb
22	1 1/2" Screwtop	H	SMC 1/4"	HD (D)	S	2846	BP	
23	2" short-thread screw-top	H	HME 1/4"	BD	S	4854	BB(threads) and HB(c)	Hanger broke - pulled through...
24	2" long-thread screw-top	H	SMC 1/4"	BD	S	3162	BB (threads)	Bunk bolts - cannot be placed w/out defor[ming]
25	1 1/4" Buttonhead	H	HME 5/16"	BD	P	1258	BP	Cratered hole in placement
26	1 1/4" "	H	SMC 3/8"	BD	P	1762	BP, HD	
27	1 1/4" "	H	SMC 3/8"	BD	P	1303	BP, HD	
28	1 1/2" Buttonhead	H	SMC 3/8"	BD	P	2363	BP, HD	Hanger bent @ 1120 lbs
29	1 1/2" "	H	SMC 3/8"	BD	P	3875	BP, HD	Hanger bent @ 2538 lbs
30	1 1/2" "	H	HME 5/16"	BD	P	2414	BP HD	Popped first, finally pulled at 1462 lbs
31	1 1/2" "	H	SMC 3/8"	BD	P	3182	BP, HD	

Notes:

(1) Orientation of Splits
H = horizontal
V = vertical
D = diagonal

(2) Hole
HD = hand-drilled (w/ Dakota 1/4" bit)
BD = Bosch-drilled

JB = Jim Bridwell
D = Deuce

(3) Force Direction
S = shear P = pull-out

(5) Subtract 200-250 lbs from all forces ←

(4) Failure Mode
BP = Bolt pulled
HB = Hanger broke
e — at eye
c — at clip-in
HD = hanger deformed
BB = bolt broke
at threads
at head
mid-way

ave 1 1/4": 3281
ave 1 1/2": 3874

Notes
(A) Chopped: from Powerfingers

Many Thanks to Hal Murray, John Dill, Dimitri Barton, Kurt Smith, and Jim Bridwell for their help and participation in this test.

Test Info

subtract 200-250 lbs from forces

Test #	Bolt type, description	Hanger	Strength		Failure Mode	Comments
	Miscellaneous					
	5/16" Rawl, Horiz. orient.	SMC 3/8"	5179		bolt pulled	
	" "	"	4998		hanger broke	
	5/16" Self Drive (STAR)	SMC 3/8"	4630		Rock crumbled, sleeve popped and broke at threads.	
	3/8" Bolts		weld broke	ultimate strength		
1	Metolius long (Placed w/ 3-4 turns ~25 ft-lbs torque)	—	6062	5866	eye opened	Placed w/ 1/4" clearance from rock
2	" "	—	6571	>7500	" "	Placed w/ 1/4" clearance from rock
3	Metolius short	—	4219		BB (threads)	Placed w/ 1/4" clearance from rock
4	" "	—	5902		BB (")	Placed w/ 1/4" clearance from rock
5	Rawl 3/8" screwtop	SMC 3/8"	6838		HB	Bolt barely phased.
6	Taper 3/8" 2 1/2" long	SMC 3/8"	5474		HB	Bolt was in mint replaceable
7	3/8" Screw-out ~2-3"	SMC 3/8"	4618		BB (threads)	catalog
8	Sleeved Rawl ~2-3" cheap sleeve 3 1/2-4 turns	SMC 3/8"	3642		BB (threads)	check catalog for type
9	Hammer-in type-long	SMC 3/8	4530		BB (threads)	
10	Hammer-in type-short	SMC 3/8	5427		BB (threads)	
11	Taper Eye-Bolt 3/8"	—	4819		BP w/ sleeve	Bent @ 2538 - pulled out in stages
12	Short-sleeved ~~Rawl~~ Star drive	SMC 3/8"	2302		BP in pieces	semi-botched in placement
13	Rawl bolt - short 2 1/4" max tighten	SMC 3/8"	5974		HB (e)	Good Bolt!
14	Stardrive - botched long	SMC 3/8"	2644		BP in pieces	botched (1/2 way in)

notes: length of bolt must be checked (catalog)

Metolius bolts are 4130 steel HT to RC 38/42

Photos of Metolius bolts at noted strengths 5206 (BW), 6558 (color)

Test Info

Subtract 200-250 lbs from strengths

Test #	Bolt type, description	Hanger	Hole	FD	Strength	Failure Mode	Comments
	Machine Bolts						Test #1-5 - all hangers placed tight
1	Grade 5, 1 1/4", coarse thread	SMC 3/8"	#14	S	4006 -	pulled out	
2	Grade 2, 1 1/4", "	SMC 3/8"	#14	S	2979	sheared at nut	
3	Aluminum, 1", "	SMC 3/8"	#14	S	1658	sheared at nut	
4	Grade 5, 3/4", "	SMC 3/8	#14	S	2954	pulled out	
5	Grade 5, 3/4", "	RP key hole	#14	S	2718	pulled out HD	unbelievable
6	Grade 5, 1 1/4", "	SMC 3/8	1/4"	S	2842	pulled out	placed 1/2 way in, as is
7	" " "	SMC 3/8	1/4"	S	1714	"	placed 1/2 way in, threads mash
	Taper Bolts		BD ↓				
1	1 1/4" New style, 4 1/2 turns (K)	SMC 3/8"	BD	S	3066	BB (midway)	spinner
2	1 1/4" New, 5 turns (K)	SMC 1/4"	BD	S	4668	BB (head)	tight
3	1 1/4" New, 2 turns (K)	SMC 1/4"	BD	S	2950	BP w/sleeve	Tight, intentionally placed w/ few turns
4	1 1/2" Old, 5 turns (K)	SMC 1/4"	BD	S	3890	BP, sleeve left at hole edge	Tight, rock broke • at ~2000 lbs
5	1 1/4" Old, 5 turns (K)	SMC 1/4"	BD	S	2798	BP, sleeve disintegrated	• tight
6	1 1/2" Old, 6 turns (K)	SMC 1/4"	#14	S	3166	BP, sleeve @ hole edge	Rock broke first: pulled @ 3146
7	1 1/4" New, 6 turns (K)	SMC 1/4"	HD (kurt)	S	4682	BB (head), bolt pulled out, too	Rock broke, then bolt broke @ 32?
8	1 1/4" Old, 4 turns (D)	SMC 1/4"	BD	P	934	BP w/ broken sleeve	Lame
9	1 1/4" Old, 4 turns (D)	SMC 1/4"	BD	P	770	BP w/ broken sleeve	"
	Miscellaneous 1/4"						
1	Cassin Wedge	—	BD	S	1306	BP	1/2 way-in catalog rating?
2	~1" Hammer in	SMC 3/8"	BD	S	2180	BB (threads)	
3	~1 1/4" screw-out	SMC 3/8"	BD	S	1938	BB (threads)	see catalog for types
4	"	"	BD	S	2076	"	
5	"	"	BD	S	1838	"	
6	"	"	BD	S	2242	"	
7	1/4" Stardrive	"	BD	S	1384	Hanger pulled - too small	Hanger too big
8	long Z-mac	SMC 3/8"	BD	S	1550	BB	Bolts pulled out first, then sheared. Nail pulled out w/ head.
9	short Z-mac	"	BD	S	1355	BB	
10	long pin thing (this is a blind rivet)	"	BD	S	1391	BB	