CHOOSING Concrete Anchors

To avoid failures, match the anchor to the type and condition of the substrate

by Clayton DeKorne

Concrete anchors have always been a mainstay of commercial and industrial construction. But for residential contractors who aren't always handed a set of plans from a specifier, choosing the right fastener can be a challenge. To make that selection easier, this article describes how different anchors work and which applications each type fits best.

Performance Data

The first step in choosing a structural anchor is making sure it's strong enough to support the loads it must bear. All anchor manufacturers publish design values based on testing in concrete and masonry.

While most structural connections require engineering, there are many applications that don't typically fall under an engineer's scrutiny yet still deserve a "structural" anchor. For example, anchors that hold siding to concrete walls or sleepers to slabs are subject to periodic changes in humidity and temperature that can affect holding power. Similarly, anchors for door and window jambs are subject to twisting, low-level vibrations, and shock loads. Before selecting any concrete anchor, it's vital that you understand how a particular anchor responds, not just to immediate structural loads, but also to long-term use and conditions. Unlike wood, concrete is unforgiving, so a failing anchor won't just creep or sag. Usually, when a concrete connector fails, it fails completely.

Tension and shear. All anchor catalogs list ultimate values (in pounds) for an anchor's resistance to tension and shear, the two primary loads that will be applied to the fastener.

The ultimate tension load gives a measure of the anchor's pullout strength, which depends not just on the strength of the anchor mater-

ial and the strength of bond, but also on the strength of the concrete or masonry. Ultimate shear loads give a measure of an anchor's resistance to forces across the face of the concrete or masonry — a force threatening to tear the anchor, and to crush the bearing material around the anchor.

Base material. To make use of these performance values, you need to know the strength of the concrete. In new construction, you can go by the compressive strength of the mix design, provided you're confident in the abilities of your foundation sub and ready-mix supplier. For important structural connections in existing base materials, you will need to take a core sample and perform an impact test. In less critical installations, you can investigate the base material with a three-pound sledge and a masonry nail. The condition of brick and block varies widely, but with experience you can learn a lot about how well the anchor will respond in a particular substrate. A hammer blow will hardly show on the surface of 4,000-psi concrete, whereas the nail will be relatively easy to sink in concrete less than 2,000 psi. Poorer base materials will crumble or spall with each blow.

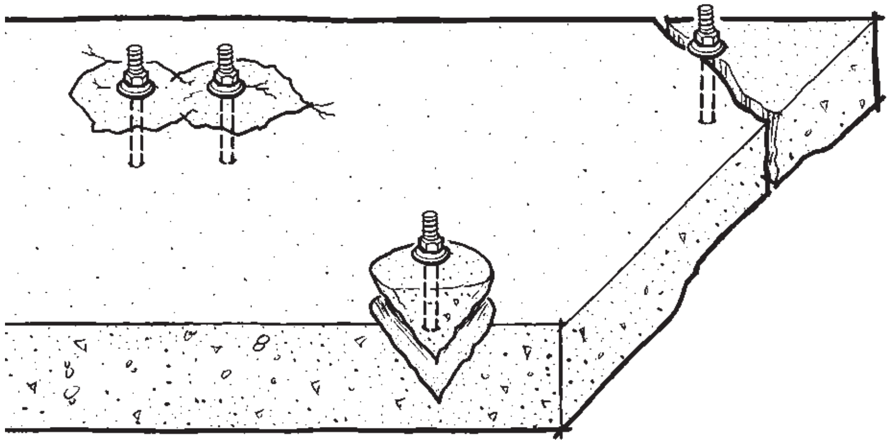
Embedment depth. Performance values for anchors are always listed for different embedment depths. This should not be confused with the length of the anchor. Anchors are almost always longer to account for the thickness of the fixture you are attaching.

Ultimate vs. allowable working loads. The ultimate load, however, does not reflect the fastener's performance in actual use. To find the *allowable working load*, you have to reduce the ultimate value by a safety factor to account for imperfect field installations and real-world concrete and mortar conditions. Industry standards call for a 4:1 reduction (in other words, 1/4 of the ultimate value) for the static loads found in most residential framing connections. The exception is powder-actuated fasteners (PAFs), where a larger reduction of 8:1 for static loads is required to account for imperfect use. For dynamic loads, such as shear wall loading or impact and vibration loads encountered in industrial applications, a reduction of 8:1 or more is common.

In engineered applications, the designer may also make other reductions. For example, when anchors are embedded in a vertical surface, tension and shear forces combine, so the anchor must be stronger. Similarly, if the load is applied at a distance from the concrete surface, it imposes a bending load on the fastener as well. In addition to requiring a stronger anchor, this bending load may affect the substrate, particularly masonry, which is more likely than concrete to spall at the surface.

Edge distance and spacing. With concrete anchors, more is not always better. Every anchor stresses the concrete around it, whether the anchor is driven or predrilled and tightened down. The size of this "stress zone" varies by size and type of anchor. If you crowd too many anchors together, these stress zones will overlap and the concrete may fail (see illustration, next page).

Common Anchor Failures



To avoid overstressing the base material, pay strict attention to anchor placement. Manufacturers specify a minimum spacing between anchors to prevent stress areas from overlapping (top left), minimum distance from edges to prevent blowing out the slab (bottom), and a minimum slab thickness to prevent cracking (top right).

The Right Anchor for the Job

Application	Anchor
Sill to foundation	
Bearing wall	Sleeve, wedge, or epoxy
Partition wall	PAF or hammer-in
Floor sleepers	PAF or hammer-in (no shims)
	Sleeve or wedge (with shims)
Strapping for siding or drywall	PAF or hammer-in
Stair stringer	
Poured concrete	PAF or hammer-in
Masonry	Sleeve or nylon
Handrail to concrete	Nylon or sleeve
Jamb in concrete or block opening	PAF or nylon
Ledger	
Poured foundation	Wedge
Masonry	Adhesive w/ screen insert
Steel column to slab	Wedge or adhesive
Rebar dowel connection	Epoxy

Anchor selection is based not only on loads, but also on ease of installation. For example, nylon anchors will often hold furring for drywall or siding to concrete, and may be a good choice if you only have a small portion of the foundation to cover. But if you have an extensive area to cover, it's usually worth the time and additional cost to send a helper across town to rent a powder-actuated tool.

Similarly, if an anchor is installed too close to the free edge of a slab or wall, it may not have enough solid material around it to support the loads. To prevent these types of failures, pay attention to the minimum edge and spacing distances for the anchor you plan to use.

The Cost of Callbacks

Performance data may help you compare the relative strengths of various fasteners, but they won't account for the installation time involved. With high labor costs, ease of installation is almost always more important than the cost of the fastener. In general, the easier an anchor is to install, the higher the purchase price.

But the cost of a concrete anchor must be weighed against its reliability. A single callback can rapidly erase any cost difference between anchors. To make a cost-effective choice, contractors need to have a general understanding of how different anchors are installed and how different anchor materials respond to long-term conditions. Changes in moisture levels can have profound effects on connections over time, particularly those made with plastic anchors. Temperature variations can cause the fastener, fixture, and base material to move at different rates, which exerts additional loads. And vibration — even low-level, periodic vibration from operating doors and windows, for example, or using fixtures — can rattle an anchor loose, particularly if the material is already failing due to environmental conditions.

Below is a rundown of how various types of anchors work and some of the key installation and material issues for each.

Friction Anchors

For light- and medium-duty applications, friction anchors tend to be the least expensive.

Concrete screws. Concrete screws are typically available in $^3/_{16}$- and $^1/_4$-inch-diameters for light-duty applications or $^3/_8$-inch-diameters for heavier-duty applications. Screw lengths range from $1^1/_4$ to 6 inches, but usually with only enough thread for embedments up to $2\frac{1}{2}$ inches. Most manufacturers recommend drilling a pilot hole $\frac{1}{4}$ inch longer than the screw to allow room for displaced concrete or mortar to collect.

Concrete screws have hardened-steel threads, which cut a thread in the sides of a predrilled hole. If you've used concrete screws, you've probably stripped out a fair number of holes. That's because the tolerance between the screw shank and the thread diameter is very tight, so the pilot hole must be of an exact diameter: Too big, and the threads won't bite deep enough; too small, and the shank either pulverizes the sides of the hole or jams. Depending on how far you were able to drive a concrete screw before it jams, you'll either bend it or strip the head.

To ensure a perfectly matched pilot hole, several concrete screw manufacturers package "tolerance-matched" bits with their concrete screws. You'll pay more for *Tapcons* (ITW Buildex), *Tappers* (Powers-Rawl), or *Scru-n-Taps* (Star Fasteners) compared with generic brands sold in home centers, but we've noticed fewer stripped holes using tolerance-matched bits. All three manufacturers also offer drivers that slip over the drill bit, so you can drill the pilot and immediately drive the screw without changing bits.

Concrete screws work well for temporary installations, such as attaching formwork to existing foundations. But they are not the best choice for applications that must be removed, then reinstalled. In theory, a concrete screw can be unscrewed and reseated. But you lose considerable holding power, even if you're lucky enough to reseat the threads. Mostly, you wind up stripping the concrete.

Because of the narrow tolerance between the hole and the threads, concrete screws require a solid base material, such as a sound poured concrete wall or slab. In brick or block, manufacturers recommend installing the screw in the mortar joint for optimum holding power. This will work best in a new brick or block wall with consistent mortar joints, but on older structures that have been repointed, the joints won't always be stable. If you're having trouble with poor base materials, it may help to drill a smaller pilot hole or use the next larger diameter screw.

PAFs. Powder-actuated fasteners (PAFs) are one of the most commonly used concrete anchors in the trade, but not the strongest. They are certainly the fastest way to fasten to concrete, provided you drive the pin into a sound base material. In weak base materials, like soft concrete or old mortar, they are likely to pull out, especially if you're trying to take a bow out of a board.

As common as they are, and as careful as manufacturers have been about training and licensing, PAFs are often misused. Operators tend to use the fastening tool like a nail gun, yet concrete cannot sustain a close network of stresses. Keep pins at least 3 inches from each other and from the free edge of concrete.

Each shot exerts a tremendous shock load, so unless you're firing into good, dense concrete or mortar, the impact of a PAF often causes the base material to crumble or spall. To avoid overstressing the base material, manufacturers recommend using the lowest load possible. This means you have to work up from the lowest power load until you find the one that just seats the pin with the proper amount of embedment. This rule may be one of the most overlooked in the field; most operators tend to go with

Concrete screws. The tolerance between the screw shank and the pilot hole is critical when using concrete screws. Several manufacturers provide "tolerance matched" carbide drill bits for their screws, but even with these, it's easy to strip the holes if the base material isn't up to specs. In poor base materials, try drilling the smallest hole possible.

whatever loads they have on hand.

Hammer-in. There are several distinct kinds of hammer-ins, although they are typically lumped into one group. Many light-duty (non-structural) hammer-ins look like rivets. After predrilling, you insert the plug and hammer home the pre-assembled pin, which spreads the sides of the plug. These fasteners are available in zinc, nylon, and Zamac (an alloy).

Other light-duty hammer-ins, such as Star Fastener's *Strikr,* look just like a PAF that you pound in with a small sledgehammer. In masonry and green or lightweight concrete, you don't need a pilot hole if you use the manufacturer's installation tool. This tool resembles a "pea shooter" — a pounding rod that slides inside a metal tube. The tube holds the pin straight, and it gives you more to hold onto as you work. In dense concrete, however, it's hard work, and even with the driving tool you don't always get a good seat for the pin. A slightly undersized pilot hole often works better.

One of the strongest hammer-ins is the crook-style pin, typified by the Rawl *Spike*. This pin has a curved shaft which compresses as it is pounded into a pilot hole, exerting force at three points on the sides of the hole.

Ramset/Redhead recently introduced two hammer-ins — the *King-Con* and *Redi-Drive* — that have holding values comparable to the Spike. The King-Con is made chiefly for attaching 1-by or 2-by furring strips or sleepers to concrete. It has a wide spiral flange that's slightly larger than the pilot hole, while the shaft is slightly smaller. This makes the King-Con very quick to pound in, but requires a tolerance-matched bit.

The Redi-Drive has a straight shank that's slightly larger than the hole, so it provides continuous holding along the entire length of the hole. As a result, Redi-Drives have one of the highest pullout values among hammer-in fasteners. But this rigorous holding power also makes Redi-Drives more difficult to pound in, requiring about twice as many hammer blows to seat as the King-Cons. Redi-Drives have been targeted for commercial electrical and hvac installations, and are sized to fit through predrilled holes in standard fixtures (the King-Con's spiral is too wide for this application).

Compression Anchors

Compression anchors depend on a screw, lag, or bolt to expand the anchor, causing it to squeeze against the sides of a pilot hole. The most common example of this is the simple plastic shield. While it's obvious that plastic shields could never be used to connect structural elements or anchor heavy mechanical fixtures, the variable loads exerted in many non-structural applications may also be too extreme. Plastic shields do not react well in the long term to changes in humidity and temperature. As the anchor dries and shrinks, play between screw and anchor rattles the anchor loose. Even in light-duty applications, such as anchoring a toilet paper holder or towel bar, intermittent vibration from using the fixture can lead to the demise of a shrunken plastic shield.

Nylon plugs have been used in Europe for over a decade. Fischerwerke of Germany is the world leader in sales of nylon plugs, and Fischer plugs are widely distributed through U.S. contractor supply houses; more recently, Driltec has introduced its Mungo anchor (see "Sources of Supply," page 66). For light- and medium-duty applications, nylon plugs are extremely versatile, offering reliable holding power in concrete and masonry. Nylon plugs are almost always a better choice than plastic shields, because the material is more durable over time, even with extreme changes in moisture and temperature. In many cases, nylon plugs are a better choice than concrete screws, especially in weak or lightweight concrete and old masonry. Nylon absorbs vibration much better, and the material draws tight to the sides of the hole, expanding into irregularities to form a mechanical key. Nylon plugs also retain most of their

Hammer-ins. Two of the latest light- and medium-duty concrete anchors include Redhead's King-Con (right) and Redi-Drive (below). King-Cons have been developed for attaching strapping and 2x-stock. Redi-Drives, which have the highest holding values among hammer-in fasteners, have been targeted to the electrical trades. Both require precise pilot holes, but can be installed with a 3-pound sledge.

Sleeve anchors. Tightening the nut of a sleeve anchor, forces the outer sleeve down, causing it to expand against the sides of the predrilled hole. Sleeve anchors have a wider bearing than wedge anchors, making them a better choice in weaker substrates.

Wedge anchors exhibit the highest holding values among mechanical anchors, but need a strong base material to prevent the concentrated compression forces from pulverizing or cracking the concrete.

Dispensing adhesives. True epoxy-based adhesives are unaffected by water, making them a good choice for damp locations, such as foundation pins in water-bearing granite.

holding power in applications that require removal and reinstallation of the fixture.

While most nylon plugs are non-structural, the Mungo *Frame Anchor* exhibits holding values comparable to small sleeve and wedge anchors for medium-duty structural applications, such as attaching ledgers or stair stringers. The long bearing range makes this anchor a good choice in hollow-wall masonry. Frame Anchors are supplied with lags with either hex-drive or flush Posi-drive heads.

Metal shields. Don't confuse modern steel drop-ins with the old-style lead or zinc shields. The newer fasteners are made for holding heavy pipes and other fixtures to concrete, primarily in overhead applications. While steel drop-ins have relatively high holding values, they must be installed with a setting tool that expands the plug inside a predrilled hole, leaving a threaded hole to accept a bolt or threaded pipe hanger.

Pay close attention to edge spacing and distance requirements; otherwise, the drop-in can crack the base material when it expands.

Sleeve and wedge anchors are the heavyweights of mechanical anchors. Both types come pre-assembled. After dropping the anchor in the hole, tightening the nut draws the bolt together, expanding the anchor until it's locked tight against the sides of the hole.

Wedge anchors have the highest holding values — sizes $^1/_2$-inch in diameter and larger can serve as shear wall anchors in sound base materials, provided you're not too close to an edge. Metal sleeve anchors exert compression over a larger area of the hole as the fastener is tightened, making them better for weak base materials.

Neither fastener, however, is a particularly good choice in hollow-wall masonry. Wedge anchors exert enough localized force at the bottom of the hole to compress the concrete (called undercutting), creating a mechanical key. But this concentrated force has a greater chance of overstressing the base material. Most sleeve and wedge anchors must be tightened to a specific torque; too tight, and the anchor can easily overexpand, pulverizing or cracking the base material.

Adhesive Anchors

Adhesive systems tend to be the most expensive concrete anchors, but they have advantages that make them ideal for some applications. They can be spaced closer to each other and to the edge of a slab than comparable mechanical anchors, so when the foundation sub leaves out or misplaces an anchor bolt, adhesive fasteners may be the only alternative. Adhesive systems also tend to be more resilient than comparable mechanical anchors, so they perform better against impact and vibration loads.

Adhesive systems are available in two forms — dispensing systems and glass capsules. Dispensing systems use a gun (similar to a caulk gun) to premix the adhesive and inject it into the hole. This system tends to be the most economical, but not the most convenient. Obviously, you have to use up an open cartridge fairly quickly, and you have to pay close

Glass capsules. The simplest, but most expensive adhesive anchors come in glass capsules. Two types are available — spin-in capsules, which require a special chuck for a hammer drill to drive in the anchor and mix the chemicals, and hammer-ins, which only require a hammer to drive in a rebar dowel or threaded anchor.

attention to the "nozzle time" — how quickly the adhesive sets up in the gun nozzle. Also, non-acrylic adhesives can be tough to inject in below-freezing temperatures, not so much because the bond reaction is affected, but because the adhesive becomes so stiff.

Glass capsules come in two types, spin-in (such as Hilti *HVA*, Powers/Rawl *Chem-Stud*, and Ramset/Redhead *Maxim*), and hammer-in (Powers/Rawl *Hammer Capsule* and Ramset/Redhead *Impact).* Spin-in systems require a specialized chuck to drive the anchor in and mix the chemicals. With a hammer-in capsule, all you need is a small sledgehammer. The chemicals mix when you pound a rebar dowel or threaded anchor into a hole containing a capsule. Typically sold in boxes of ten, capsules have a long shelf life, so you can keep them on the truck for use when needed.

Adhesive anchors are generally available in three formulations — epoxies, vinylesters/polyesters, and acrylics.

Epoxy-based adhesives cure strong and aren't effected by water, so they can be used in damp or water-filled holes. (Redhead's *Ceramic 6* is even recommended for use under water.) But the mixing and proportions must be exact, so you usually find true epoxies only in dispenser systems with high-quality (and more expensive) mixing guns.

Vinylesters and polyesters cure by a chain reaction, so they don't need thorough mixing, which is why most of the glass capsules use this formulation. The drawback is that these adhesives shrink more than other formulations when cured.

Acrylics have the fastest curing times with little shrinkage. They also perform better in cold weather (for example, Ramset/Redhead's *Epcon 7* stays workable and bonds down to 0°F).

With all adhesive systems, you need to be careful to clear the hole of dust or slurry to ensure a good bond to the base material. This involves using compressed air (a squeeze bulb will work if a compressor is not available), and a wire brush to roughen the sides of the hole.

Information Resources

Between the World Wide Web and a vast network of local contractor suppliers, the answer to your specific fastening needs is out there.

Literature. One of the best resources available is the Powers/Rawl *Fastening Systems Design Manual*. This is the concrete-fastener equivalent of USG's *Drywall Handbook* or the Simpson Strong-Tie catalogs. Once you've plowed through this one, the performance specs in other references will make a whole lot more sense.

CD-ROM. ITW Ramset/Redhead offers an interesting CD — *Concrete Fastening Solutions* — complete with performance data and animated installation instructions.

Web. Several manufacturers, including Ankr-Tite, Ramset/Redhead, Star Fasteners, and Simpson Strong-Tie, have Web sites with product listings and performance data. More useful, however, are a few sites that offer an extensive listing of distributors by state for a wide range of concrete fasteners (as well as other construction products):

Construction Net:
www.constructionnet.net
Blue Book of Construction:
www.thebluebook.com
Grainger:
www.grainger.com

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Sources of Supply

Ankr-Tite Fastening Systems
2415 E. 13th Place
Tulsa, OK 74104
800/343-1264

Hilti
P.O. Box 21148
Tulsa, OK 74121
800/879-8000

Powers/Rawl
P.O. Box 641
New Rochelle, NY 10802
914/235-6300

Star Anchors and Fasteners
P.O. Box 1
Mountainville, NY 10953
800/431-8700

Driltec
P.O. Box 1740
Ridgeland, MS 39158
800/336-1304

ITW Ramset/Redhead
1300 N. Michael Dr.
Wood Dale, IL 60191
800/354-7432

Simpson Strong-Tie
4637 Chabot Dr. Suite 200
Pleasanton, CA 94588
800/999-5099

U.S. Anchor Corp.
450 E. Copans Rd.
Pompano Beach, FL 33064
800/872-3330