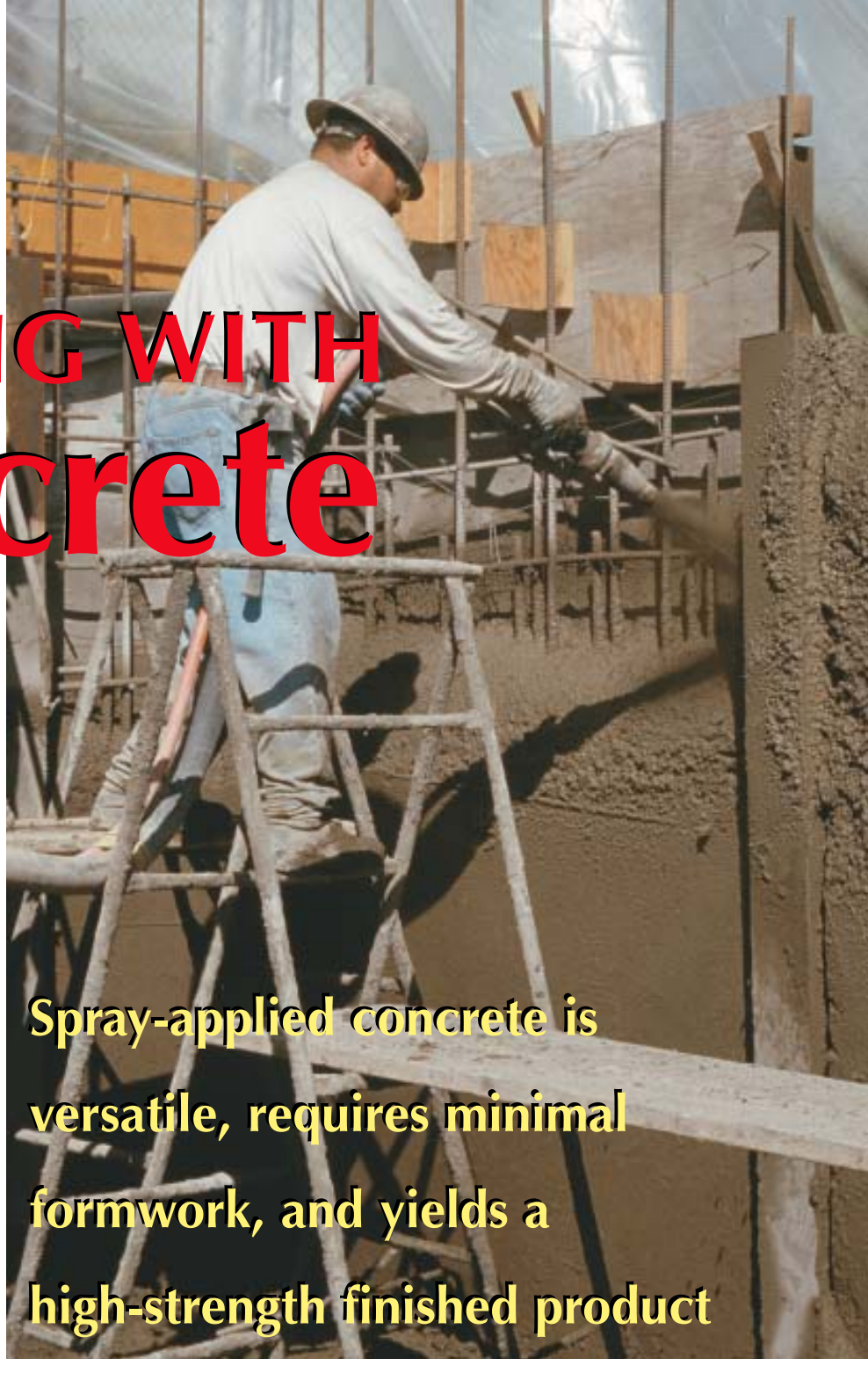
WORKING WITH Shotcrete



Spray-applied concrete is versatile, requires minimal formwork, and yields a high-strength finished product

by Bill Brown

Shotcrete, or pneumatically applied concrete, is commonplace on commercial jobs and civil engineering projects. But as a specialty concrete contractor, I've found that it can also save a lot of time and effort on residential jobs. My company started using shotcrete several years ago to build and repair foundations under existing houses, and it didn't take us long to realize that it has an almost unlimited range of other uses.

Our first nonbasement shotcrete job came up several years ago, as we were preparing to build a conventionally poured retaining wall for a new home on a bluff overlooking the Pacific Ocean. It was late in the year, and building the forms for the 18-foot-high, 150-foot-long, 18-inch-thick wall threatened to drag on into an extended spell of bad weather. We were about halfway done with forming the back face of the wall with plywood, snap ties, and walers when we realized that we could save at least a week by switching to shotcrete. With the approval of the project engineer and local building officials, we made the necessary changes and brought the project in ahead of schedule.

Since that time, I've used shotcrete for many applications that I would once have used poured concrete for. The process is so regulated and carefully controlled that the average contractor can use it with confidence for all sorts of difficult and unusual projects. The purpose of this article is to demystify the process for contractors, engineers, and building officials who don't yet have any firsthand experience with it.

Why Shotcrete?

From my perspective, there are three major benefits to working with shotcrete rather than standard cast-in-place concrete. First, it's less demanding in terms of formwork. The mortar-tight

forms used with poured concrete have to withstand serious lumber-cracking pressures of up to 900 pounds per square foot. Shotcrete forms, on the other hand, only have to withstand pressures of about 150 psf, which is basically the pressure of the shotcrete as it emerges from the nozzle. Because shotcrete is sprayed against a single-sided form rather than confined between the walls of a closed form, the pressure at the bottom of the form is no greater than the pressure at the top, regardless of the height of the wall. We find that forming a shotcrete job generally takes between 20% and 25% as long as it would to form the same job for poured concrete.

Second, shotcrete lets you place concrete in locations that are difficult or impossible to form otherwise, such as against vertical soil cuts, or even against overhead surfaces. Finally, the quality of the finished concrete is often exceptionally high. It can be difficult to push low-slump poured concrete around in closed forms, but because shotcrete is sprayed exactly where it's needed, there's no temptation to weaken the mix by adding extra water. The shotcrete on our jobs typically has a 2 1/2- to 3-inch slump and yields a finished strength of 5,000 to 6,000 psi. We've had some material test out as high as 7,500 psi.

Dry mix vs. wet mix. There are two kinds of spray-applied concrete — wet mix and dry mix. In the dry-mix process, dry aggregate and cement are driven through the hose to the nozzle, where the water is injected into the mix just before it emerges. This is generally known as the gunite process, and it's popular for building swimming pools and things like low retaining walls.

With gunite (originally a trade name), the amount of water used is controlled by the operator, which makes it difficult to accurately control the quality of the finished product. The equipment can't handle coarse aggregate, so the mix consists of just sand, cement, and water, which further limits its strength. Finally, gunite isn't air entraining. That leaves it vulnerable to damage from freezing and thawing in areas where that's a concern.

Wet mix, which is what we use, is better for engineered applications requiring high strength. (To avoid confusion, we call wet mix "shotcrete" and dry mix "gunite," although some people refer to both as shotcrete.) In the wet-mix process, the concrete itself is mixed at a batch plant and delivered to the site like standard ready-mix. At the site, it's dumped into the hopper of a powerful pump that forces it through a hose to where it's needed. A supply of compressed air, delivered through a separate hose, is mixed with the concrete at the nozzle to spray the concrete against the receiving surface.

Comparing costs. On a yard-for-yard basis, shotcrete definitely costs more than poured-in-place concrete placed with a pumper truck. This is partly a function of labor: A shotcrete crew consists of seven to ten workers and a mechanic-operator to run the machinery, while a poured-in-place crew requires only five or six people.

It also takes more time to spray shotcrete against an open form than it does to dump ordinary concrete into a closed form or slab. Under most conditions, a shotcrete crew can place about 7 or 8 yards an hour, although we've placed up to 150 yards in a day by working with two crews. But these higher labor and equipment costs are nearly offset by the time and effort saved in building forms. In most cases, we find that overall costs for shotcrete and poured-in-place are fairly comparable.

Formwork

We do all of our own forming because we want to remain in complete control of the process. One of the most frustrating aspects of contracting for me is when a subcontractor with whom I am locked in on a price runs into a problem during the course of the job and says, "It can't be done" or "We didn't figure on that." As innovators in our medium, we pride ourselves on our ability to build anything.

Figure 1. In this basement application, the lower part of the wall will be shot against the bank, which has been covered with a waterproofing membrane. The above-grade section is backed by a single-sided plywood form. To prevent the completed rebar grid from vibrating when struck by the high-pressure stream of shotcrete, the top will be wired to the plywood form and the bottom to rebar projecting from the floor slab. Number 2 wire chairs, not shown, will be wedged between the grid and the bank or form to maintain the proper spacing.

Formless application. Some shotcrete jobs require little or no formwork. When we build below-grade basement walls or earth-retaining walls, we can often use the excavated bank as a form. For a basement wall, we usually pin a drain mat directly against the soil and apply a waterproofing membrane over the drain mat before tying in the rebar and shooting the wall (see "Retrofitting Basements," 8/02).

The same general technique is used to build retaining walls. High retaining walls are often reinforced with soil nails, which are created by boring regularly spaced 6-inch-diameter holes horizontally into the face of the excavation. The depth of the boreholes is determined by the soil engineer, but they typically extend anywhere from 20 to 40 feet into undisturbed soil. Heavy strands of rebar are inserted into the holes and tied into the rebar grid in the face of the wall. The concrete crew then pumps concrete into the holes and shoots the face of the wall.

One advantage to this approach is that it eliminates the need for a huge footing because the wall is supported by the soil nails — something like a slab on friction piles that's been stood on edge. In cases where the earth cut for the wall would exceed a safe working height, this method also makes it possible to build properly engineered high walls from the top down, often in a series of 6-foot cuts.

Single-sided forms. The first step in setting up a single-sided form is determining which side of the resulting wall is to be formed and which side is to be sprayed and troweled. If we need a perfectly true inner surface in a basement, such as a wall that will be faced with thinset tile, we may set the form on the inside and shoot against it from the outside. The problem with that is that it requires a much wider excavation to provide the shotcrete crew with room to work. For above-grade applications, that's not an issue.

Compared to the forms used for poured concrete, single-sided shotcrete forms can seem pretty flimsy. One shotcrete foreman told me that a form is heavy enough if it doesn't move when shaken by hand. We use 3/4 plywood for the straight runs and gentle curves and 3/8 plywood doubled for tighter radii. The plywood is typically set up with a snap tie cut in half, and single waler brackets holding either vertical or horizontal 2x4 walers. In some cases, we'll make "lost forms," which are not stripped but simply buried in the ground and left there. These can be made from ordinary U-channel steel studs faced with drywall or an expanded metal lath with stiffening rib called SureForm.

Placing rebar. In California, just about everything we build is engineered as if it was going to support a skyscraper, so all of our projects contain engineering specs for the reinforcing steel. These specs will be all over the board with what they contain. One project will specify a single mat of #5 rebar at 12 inches on-center, while a similar installation in similar geology, across the street, by a different engineer, will call out a double mat of #7

Figure 2. Highly tensioned guide wires are strung across the faces of the forms to control depth and permit accurate screeding. The steel soldier beam supports temporary shoring during construction (left). The vertical guide wire in this partially completed basement allows the finishers to create a sharply defined outside corner (right).

Figure 3. A length of threaded rod, driven through the bentonite-coated polyethylene waterproofing membrane and into the soil beyond, serves both to anchor the rebar grid and to position a horizontal guide wire that will help define the face of the finished shotcrete. The rod has been notched with bolt cutters so it can be snapped off after the wall has been sprayed and finished. To prevent leakage, the membrane penetration will be sealed with a proprietary mastic before the shotcrete is applied.

rebar at 4 to 6 inches on-center.

No matter what the specs call for, though, the reinforcing steel must be very rigid (see Figure 1, page 2). This is an important difference from cast-in-place concrete, where the rebar can be allowed to rattle around inside the form. If the rebar moves at all when the shotcrete is gunned against it, the concrete can slump or fall away from the rebar, leaving voids.

Guide wires. Once we've tied and braced the rebar, an employee of the shotcrete sub called the wireman shows up with a portable laser, several 300-foot rolls of high-tension piano wire, and an assortment of pliers and wire cutters (Figure 2, previous page). The wireman's job is to string the wire along all flat surfaces and corners on about 2-foot centers as a guide to permit accurate placement and screeding of the shotcrete. Notched lengths of threaded rod are used to hold the guide wires in the desired plane of the finished wall (Figure 3). Once they're in place, the guide wires are tensioned with something like a trucker's knot until they're tight enough to give off a C-note when plucked. A good wireman can string the forms so that the finished surface will never be in or out by more than 1/4 inch.

Shooting the Shotcrete

In our area, all shotcrete subs are unionized, but they don't have a problem working on nonunion residential jobs. Our regular sub is a company called Dees-Hennessey, which also specializes in earth-retention shoring. The crew shows up on the site with a 16- to 20-foot flatbed truck that has a high-capacity concrete pump in tow. The truck bed contains a big 350-cfm compressor and a couple of huge reels of 2-inch pump hose (Figure 4).

The equipment is positioned so that ready-mix trucks can back up and discharge concrete directly into the hopper of the concrete pump. The concrete itself is mixed at the batch plant to the engineer's specifications. These typically call for a 7- or 8-sack mix — substantially richer than the 5- or 6-sack mix used in poured applications — and pea-gravel aggregate. We try to park the equipment as close to the work as

Figure 4. In addition to the ready-mix truck visible at rear (left), a shotcrete job requires a high-powered compressor mounted on a flatbed truck and a tow-behind concrete pump. The author's shotcrete sub brings a second concrete pump to the site as a backup. The batched concrete is discharged directly into the hopper of the pump and is then forced through a 2-inch hose to the nozzle, where compressed air is added (above).

possible, but the concrete pump has the power to move the material a long way if necessary. Our sub has successfully pumped concrete up to 600 feet horizontally and 300 feet vertically, although not both at the same time.

The nozzleman. The quality of a shotcrete job is only as good as the nozzleman, as the person at the business end of the hose is called (Figure 5). The nozzle has to be oscillated continuously to prevent a defect called "shadowing," in which the concrete builds up on the front of the strands of rebar without filling the area behind. A good nozzleman can keep an eye on the slump of the material and build its thickness in a series of 3- to 4-foot lifts without sagging or other defects (an accelerator is often added at the batch plant to allow the material to stiffen soon after it's blown on).

Doing all this well takes a lot of practice. To become certified as a nozzleman by the American Concrete Institute, a worker must accumulate at least 500 hours of work experience or training and pass both a written exam and a field performance exam.

Dealing with rebound. The nozzleman is assisted by a blowpipe operator, who is responsible for blowing away the rebound, or material that bounces off the fresh surface rather than sticking. This is essential because rebound material is mostly aggregate with little cement paste. If it's allowed to build up and is covered over, the result will be a permanent weak spot. The blowpipe is simply a length of 3/4-inch pipe connected to the compressor with a jackhammer-type hose and controlled with a gate valve. The operator — who is usually also a nozzleman or a nozzleman trainee — moves in step with the nozzleman to maintain a clean leading edge.

Something like 10% or 15% of the pumped-in material typically ends up as rebound. On a big pour, that's enough to keep several laborers busy with shovels, sometimes with the assistance of a material conveyor (Figure 6). The laborers also help the nozzleman drag the heavy concrete hose from place to place.

Test panels and inspection. The nozzleman's skill is particularly tested in areas where the reinforcing steel is tightly spaced (Figure 7, next page), which can make it difficult to fill around the rebar without leaving voids and other defects. When this "congested steel" condition is unavoidable, the engineer will usually require the shotcrete sub to make a preconstruction test panel. This 4x4-foot mockup is shot by the same nozzleman who will later do the actual work, using the specified concrete mix. This test panel is then cured for five to ten days, cored and inspected for shadowing around the steel, and crushed for a strength reading.

In our area, we're also required to have an inspector on the site whenever we're applying shotcrete with engineering specs of 3,000 psi or more. (Practically speaking, this includes every shotcrete job we do.) This "special inspector," who works for an independent engineering firm, watches over the entire process to ensure that nothing is done that could leave hidden defects in the work.

Figure 5. The shotcrete nozzleman guns a steady stream of concrete against a below-grade foundation wall while the blowpipe operator prepares to blow away unconsolidated debris, known as rebound. The area to the right has already been screeded to the level of the guide wires.

Figure 6. Up to 15% of the concrete used on a given job ends up as rebound, and several laborers may be kept busy removing this waste material. A material conveyor is an efficient way of moving rebound from a basement to ground level.

Figure 7. Heavily reinforced structural elements such as this pilaster are susceptible to shadowing and other defects if the shotcrete is applied improperly. To ensure quality, a mocked-up test panel is often shot, allowed to cure, and tested before construction begins.

Figure 8. As each successive 3- to 4-foot lift of shotcrete is built to the required depth, it's screeded to the guide wires. The lift below has already been screeded and troweled; when the current lift has been finished the same way, the nozzleman will spray another lift over the exposed rebar visible at the top of the photo.

Screeding and Finishing

After each 3- to 4-foot lift, the nozzleman moves his operation to allow the finishers to screed the slightly set-up material to the level of the guide wires (Figure 8). Once screeding is complete, the guide wires are clipped and removed. Screeding leaves the surface flat but very rough, so it's troweled to provide a more acceptable finish. For utility installations, we usually want a wood or rubber-float finish (Figure 9). Quite often we apply a steel trowel finish to our walls if they will be in an area that's exposed to view.

Other more ornamental finishes are also possible. People have attempted some light stamping, although this has to be done carefully because it can cause vibration that may lead to slumping. The concrete can also be finished with stucco. One of my favorite non-stucco finishes was on a pool structure in Atherton, where we shot from the inside of the structure, stripped the forms after curing, and bush-hammered the formed exterior face, resulting in a woven cloth-like effect. The inside of the vault was rubber floated, which was fine for the pool equipment room.

Figure 9. Shotcrete can be finished and ornamented in various ways, but a simple rubber-float finish is a common choice for utility applications.

Curing. Once the shotcrete has been screeded and troweled to the required finish, it's cured about like ordinary poured concrete. To limit cracking and prevent shrinkage and other defects, we spray the finished shotcrete with a chemical curing compound that dries to form a plastic moisture barrier. The manufacturer of the product we use specifies that it shouldn't be applied until excess bleed water has disappeared, but because there's little bleed from the low-slump shotcrete mix, we don't have to wait long to apply it to the exposed face. We coat the remaining face after we strip the forms, usually about five days later.

The only time we don't use the curing compound is when the concrete will be covered with tile or faced with stone, because the sealant film can compromise adhesion. In that case, we'll cure the concrete the old-fashioned way, by covering it with blankets and keeping them misted with water.

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