# Shotcrete Redefined

BY ROB VONARB

Qualified contractors are using shotcrete for shear wall construction, seismic rehabilitation and strengthening, foundation wall construction, and even architectural concrete.

The entire structure of Rose Hills Buddhist Columbarium in Whittier, Calif., was built using shotcrete with one-sided forms. This method proved to be more economical and time efficient than cast-in-place concrete

"Is shotcrete a logical construction method for this project?" This question is now asked before almost every seismic-renovation project is started, and also is being asked during the bidding phase of many new construction projects that used to be built exclusively with conventional concreting methods. For many years after wet-mix shotcreting equipment was introduced, use of the wet-mix process was largely restricted to undemanding projects such as slope linings, overlays, and tunnel applications. Many people believed that shotcrete could only be used for structures with #5 reinforcing bars or smaller. In structures with bars larger than #5, minimum clearance between parallel bars was limited to 6 bar diameters. When two curtains of reinforcement were used, the minimum allowable clearance was 12 bar diameters for the curtain nearest the nozzle. These antiquated restrictions on shotcrete still appear in the International Building Code (IBC) 2000, but important exceptions have been added.

## Code changes

Before 1991, the Uniform Building Code (UBC) limited the maximum size of reinforcement to #5 bars unless it could be demonstrated by preconstruction tests that adequate encasement of larger bars could be achieved. Minimum allowable clearance between reinforcing bars was 2-1/2 in. The minimum 6- and 12-bar-diameter clearances for larger bars, as mentioned above, were also included in the UBC. But in 1991, the following exception was added:

"Subject to the approval of the building official, reduced clearances may be used where it can be demonstrated by preconstruction tests that adequate encasement of the bars used in the design can be achieved."

An exception with similar wording appears in the IBC 2000. The required preconstruction tests allow qualified contractors to place shotcrete in heavily reinforced structural sections, without completely opening the door to improperly qualified contractors.

Even without these code requirements, heavily reinforced shotcrete has been used in California for some 50 years. In response to the widespread damage to schools and hospitals following the 1933 Long Beach earthquake, the state implemented higher standards for such structures. The Field Act placed final authority for design and construction of schools and hospitals under the jurisdiction of the Office of State Architect (OSA), whose requirements were generally more stringent than those in the prevailing codes. The Field Act also required strengthening of most existing structures. Because of access limitations in existing buildings, shotcrete was the most practical placement method for the often heavily reinforced augmentation of existing concrete and masonry sections.

To qualify for OSA work, contractors had to satisfactorily complete full-scale test panels. This led to the process being extensively used, primarily to strengthen school structures. Also, starting in the early 1950s, the telephone provider in Southern California chose to upgrade its structures. The provider imposed an even more rigorous standard on its structures than that for schools and hospitals, which led to even heavier reinforcement. All of this work was performed by a small group of shotcrete contractors who took great pride in producing a high-quality product. They formed the Gunite Contractors Association (GCA) and limited membership to those firms with demonstrated expertise in structural applications. To ensure a competent work force, the GCA worked closely with the laborers union to form a special union local in Los Angeles, exclusively for shotcrete workers. This local—the sole shotcrete-only local in the country—still exists and has no doubt contributed greatly to California's leadership in producing quality thick and heavily reinforced shotcrete.

## The approval process

To get the building officials approval, the engineer of record must show that the contractor is properly qualified, using criteria outlined in several American Concrete Institute (ACI) publications.[1-5] Prequalification of the shotcrete contractor is a crucial element in the approval process and should be weighted heavily to ensure quality craftsmanship. While the ability of a contractor placing cast-in-place concrete is important, the ability of a shotcrete contractor is even more critical to the success of the project.

Extensive preconstruction testing helps to assure the project owner that this efficient and economical construction option will produce high-quality results. Test panels simulate job conditions, with at least part of the panel containing the heaviest and most congested reinforcement that will be used in the structure. This permits verification that the shotcrete behind reinforcing bars is sound. Separate panels for each nozzleman and concrete mixture to be gunned allow the nozzlemen to demonstrate that each mixture has adequate plasticity to properly encase the steel. Separate test panels for each shooting position to be used—down, horizontal, and overhead—also help to demonstrate the expected quality in the structure.

## Save time and money

The utility of shotcrete provides contractors, engineers, and architects with a construction method that is typically more economical and expedient, and often produces a cosmetically superior product. Substantial cost savings in formwork, and additional savings resulting from reduced construction duration are possible. For example, below-grade foundation

Shooting a preconstruction test panel (right) confirms the shotcrete contractor's ability to properly encase reinforcing steel. Prior to shooting the second lift, a worker uses an air lance to remove rebound from the bars above the first lift (far right)

walls can typically be constructed at 70% of the cost of cast-in-place concrete with average time savings of 50%. Using shotcrete for walls doesn't necessarily require any modifications in the reinforcing steel placement, and the finished wall can match all of the structural requirements of cast-in-place concrete. Depending on the finish requirements of the project, the shotcrete contractor can apply a steel trowel finish to nearly replicate a Class A finish, or a less costly finish using a rubber float. In many cases, a rubber float finish is adequate, and increases the overall shotcrete-process savings.

Regardless of whether savings in cost or time are more important, there are growing opportunities for shotcrete applications in every aspect of concrete construction. Conventional wisdom on shotcrete use is currently being redefined.

Partially completed Hollywood & Highland project in Hollywood, Calif. This project required over 13,000 $yd^3$ of 25-in.-thick shotcrete walls. A section of sawcut preconstruction panel for the project showed complete encasement of the reinforcing steel, even with lap-spliced #11 bars

## References


1. ACI Committee 506, "Guide to Shotcrete, (ACI 506R-90)," American Concrete Institute, Farmington Hills, Mich., 1990, 41 pp.

2. ACI Committee 506, "Committee Report on Fiber Reinforced Shotcrete, (ACI 506.1R-98)," American Concrete Institute, Farmington Hills, Mich., 1998, 11 pp.

3. ACI Committee 506, "Specification

## Gunning heavily reinforced shotcrete

Although shotcreting equipment has improved in recent years, the greatest strides have been made in shotcreting techniques over the past 50 years as contractors learned what works and what doesn't. These techniques permitted expansion of shotcrete applications to seismic rehabilitation projects and heavily reinforced new construction.

Reinforcing bars as large as #14 with bar clearances as small as 3 in. (100 mm) have been satisfactorily encased, as have multiple layers of #6 bars spaced at 4 in. on center. Shotcreting sections several feet thick and containing multiple layers of reinforcing with individual bars as large as #14 is now proven to be obtainable through proper Shotcreting methods.

As job requirements have expanded, contractors have developed well-established procedures to produce the highest quality work. These procedures require skilled nozzlemen backed by a competent crew and experienced management. Shooting methods must minimize rebound entrapment, and a crew member must effectively remove any rebound that does accumulate. The nozzleman also has to avoid creating shadow voids behind the bars.

Steel bars in the shotcrete stream create a shadow area behind the bar where the material steam doesn't hit the surface being shot. Voids can develop in this area. Properly filling the shadow area requires a plastic concrete (not too stiff) and enough impact velocity to make the concrete flow easily around the bar. The nozzleman must ensure that the concrete has adequate plasticity—usually a slump between 1-1/2 to 3 in. (38 to 75 mm)—and the proper impact velocity. To increase impact velocity, he can move the nozzle closer to the work (typically 1-1/2 to 3 ft is the right distance) or add more air at the nozzle. When encasing bars larger than a #5, the nozzleman should direct the concrete stream at an angle from both sides to force the material behind the bar. He also may reduce the air volume and direct the nozzle stream so it hits the area directly behind the bar, or bring the nozzle closer to the work.

Shotcrete applications with heavy structural reinforcement also require extra attention by the designer, detailer, and rebar installer. They should size and configure the bars to provide the greatest possible access for nozzling, and the least opportunity for entrapping rebound. Multiple layers of bars should be placed so the configuration allows complete encapsulation of the most distant layer. Designers should generally avoid standard lap splices, either by using welded or mechanical splicing devices or noncontact lap splices. In high-seismic-risk areas, congestion caused by closely spaced column ties and beam stirrups can be reduced using readily available clamp-type mechanical splices approved by code authorities.

In recognition of its use in structural applications, the expectations for shotcrete are ever increasing, but practical limitations should be recognized. Individual placements must allow for nozzling to distant locations, and allowing exhaust of both air and rebound. Sufficient space is required for the air-lance operator—who keeps the area ahead of the shotcrete free of dust and rebound—to always work alongside the nozzleman. When designing and detailing heavily reinforced shotcrete projects, it's helpful to consult with a contractor experienced in structural applications.

### References

1. Warner, J., "Understanding Shotcrete—Structural Applications," *Concrete International*, V. 17, No. 10, pp. 55-61.

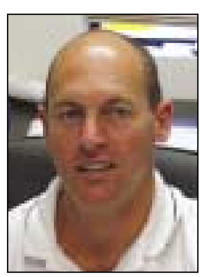
2. ACI Committee E-703, *Shotcrete for the Craftsman*, CCS-4, American Concrete Institute, Farmington Hills, Mich., 2000.

for Shotcrete (ACI 506.2R-95)," American Concrete Institute, Farmington Hills, Mich., 1995, 8 pp.

4. ACI Committee 506, "Guide to Certification of Shotcrete Nozzlemen (ACI 506.3R-91)," American Concrete Institute, Farmington Hills, Mich., 1991, 13 pp.

5. ACI Committee 506, "Guide for the Evaluation of Shotcrete, (ACI 506.4R-94)," American Concrete Institute, Farmington Hills, Mich., 1994, 12 pp.

Selected for reader interest by the editors after independent expert evaluation and recommendations.



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