Shotcrete Panels for Evaluation and Testing

By Chris Zynda

Shotcrete panels come in a variety of sizes and shapes, and with differing purposes. I will discuss the three most common types:

- Preconstruction;
- Mockup; and
- Production.

Preconstruction Test Panels

Preconstruction test panels are used to qualify the shotcrete nozzleman, crew, equipment, and material. It takes a complete, experienced team for a successful concrete project using shotcrete placement. The preconstruction panel should represent the most difficult-to-shoot part of the proposed project. This will often be the sections with the most congested reinforcing, large or irregular shaped block-outs or embeds, or a complicated geometry. I suggest doing a shop drawing for all preconstruction test panels. The shop drawing would include plan size and depth of the panel along with the layout of all the reinforcing and embeds to be included (refer to Fig. 1).

The test panel shown in Fig. 2 was designed for qualifying two nozzlemen, one on the left and one on the right. The reinforcement layout has three curtains of reinforcing with vertical No. 11 (No. 36M) bars with staggered couplers; the boundary elements have No. 5 (No. 16M) stirrups spaced at 6 in. (150 mm). The test panel section was 24 in. (600 mm) thick. The minimum crew to prepare this representative panel required a nozzleman, an air lance tender, a hose tender, and a concrete pump operator. Note in the picture, the nozzleman (on the right) is shooting the face of the panel with an air lance tender (on the left). With this heavily congested section and with large reinforcing bars, an experienced, qualified contractor is a must for a quality job.

Note in Fig. 3, the plywood at the top of panel was placed to represent the beam that will be shot against in the structural section. You should also note there is no sag of the shotcrete below the beam. The reinforcing bars sticking out represent the dowels that will be coming out of the existing building after the epoxy-set dowels are installed. Typical preconstruction panels will have three cores taken for evaluation of encasement and consolidation, while three additional cores are taken for evaluation of compressive strength.

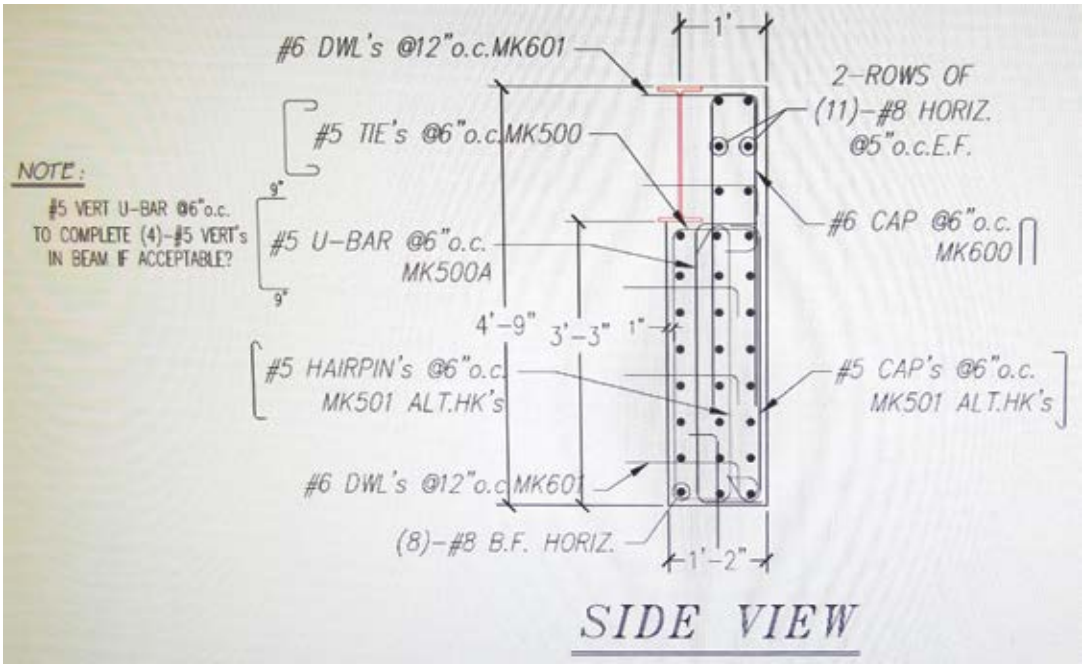

Fig. 1: Section drawings of a heavily reinforced wall

Fig. 2: Crew shooting preconstruction test panel

Fig. 3: Preconstruction test panels have been stripped, cored, and inspected

Core grading is a term that has been used for years for the evaluation of the concrete cores taken from preconstruction shotcrete test panels. This method has been linked to photos for acceptable and non-acceptable work taken from a now severely outdated version of ACI 506.2, "Specification for Shotcrete," published over 20 years ago in 1995. The current version of ACI 506.2 was printed in 2013 and no longer includes core grading as an evaluation method due to its lack of consistency and the inability to relate a "grade" to actual structural performance. This antiquated "core grading" method is very subjective and interpretation can vary widely from one person to another. I have been in concrete testing labs that use a paper clip to measure voids. We need to remember shotcrete is concrete, and no concrete is perfect.

The team approach is the best way to approach cores when evaluating the quality of in-place shotcrete in the pre-production test panel. By team, I mean the contractor and the engineer. Here are the steps I use to best evaluate the panels:

- Start with a good mixture design and a qualified shotcrete team;
- Submit shop drawings for all anticipated test panels;
- Meet with the structural engineer responsible for evaluating the project and explain the shotcrete process (this is a must and I have been doing this for over 40 years)—it will be the best conversation you will have with the structural engineer, and he should have a much better appreciation for all the factors required for a successful shotcrete project. When the cores are ready for inspection, lay them out so you can get an overview of their sample locations in the test panel; and
- Review the shop drawing—look at the consolidation of the concrete around the reinforcing where small voids or rock pockets may be, and report the percentage of embedment around bars.

Please remember when larger 6 in. (150 mm) cores are taken through the full depth of the test panel, the surface area is much greater than

Fig. 4: Cores taken from thick wall preconstruction panels

Fig. 5: Core drilling with a large barrel in a thick wall condition

anticipated from the outdated ACI 506.2-95 grading system. The cores shown in Fig. 4 are from 12 in. (300 mm) and 24 in. (600 mm) thick test panels representing walls on the proposed project. All cores are 6 in. (150 mm) in diameter and drilled through the full depth of the panel. Figure 5 shows the core drill setup on the mockup panel for extracting the needed cores. These cores

may vary in surface area from 50 in.^{2} (3200 mm^2) to over 300 in.^{2} (19,000 mm^2). I suggest a minimum 6 in. (150 mm) diameter core for best evaluation of the shotcrete in congested test panels. This size core will help prevent the core from breaking during the coring operation and will also have more surface area for evaluation.

Fig. 6: Cores taken from a 24 in. (600 mm) wall that went to the testing lab for inspection

Fig. 7: Irregularities in one of the cores

Fig. 8: Lightweight shotcrete mockup panel

In Fig. 6, all the cores taken from the test panels were good except for the core shown in Fig. 7, which had a few voids adjacent to the reinforcing bars. All cores were evaluated by the structural Engineer of Record for the project, and based on the results, approved the shotcrete team for this project. When the cores exhibit some voids, closer inspection is required, and the larger cores with more surface area and embedded reinforcement can help give the engineer a better idea of how the shotcrete placed can perform in their structural sections. Core evaluation can be very subjective, as stated previously, and it is extremely helpful to have the engineer doing the evaluation be familiarized with the shotcrete process. My practice, which I've used successfully for years, is to submit shop drawings, check for workable mixture designs, use the proper equipment (it takes horsepower to shoot heavy bar), use a qualified crew, and both communicate and involve the special inspector, testing lab, and engineer on the project. I have looked at cores for over 40 years and I have seen some that may look marginal to the inexperienced eye, but when presented to the knowledgeable Engineer of Record, are approved for the proposed project. The team approach with the qualified shotcrete contractor, the testing lab, and informed Engineer of Record really works.

Mockup Panels

The second type of panel common in shotcrete construction is the mockup panel. These panels are used to show the finish of the final exposed shotcrete surface for review and approval by the owner, engineer, or architect. Mockup panels can vary in size and shape. Often, multiple panels are shot to show the variety of finishes possible for the final project appearance. The mockup panels will be shot with either the wet- or dry-mix process according to the process to be used on the project. Sometimes both processes are used on the same project. Shotcrete finishing can be a very creative vehicle for a talented contractor to express their artistic side. The finish can vary from a plain float finish on a highway wall to a creative carved rock design with a variety of coloring to give the appearance of natural, weathered rock. Figure 8 shows a mockup panel shot with lightweight concrete. The panel is 4 x 4 ft (1.2 x 1.2 m) and 24 in. (600 mm) deep. This is the same thickness as the walls on the project. This mockup used a color additive to help match the existing building and also included a heavy sandblast finish. This is the final finish for all the exterior walls of the project.

Production Panels

After all the preconstruction and mockup test panels are complete and accepted, and shotcrete

Fig. 9: Heavy reinforcing layout for a parking garage wall

Fig. 10: Completed parking garage wall

is finally approved as the method to place concrete on the project, it's time to build the job. Figure 9 shows why it is so important to have all submittals complete. This project is an advanced shotcrete project. To properly shotcrete this type of project with thick walls, heavy reinforcing bar sizes, and tight spacing requires using a qualified shotcrete contractor with a proper concrete mixture design, well-maintained and smoothly operating equipment, and a highly trained crew. In Fig. 10, you'll see the completed wall depicted in Fig. 9. Note the steel trowel finish with chamfered corners that resulted from excellent shotcrete finishing; there was no forming or sacking required.

Production panels are the equivalent of concrete cylinders used to evaluate compressive strength of the concrete material. Because shotcrete cannot be shot into a closed cylinder form, the shotcrete is shot into an open-faced form. Cores taken from the panel are then tested at the appropriate age to establish the strength of the shotcreted concrete. These panels do not contain any reinforcing. ASTM C1140, "Standard Practice for Preparing and Testing Specimens from Shotcrete Test Panels," provides testing requirements for production test panels. Figure 11 shows a typical production panel. Care must be taken in the handling and storing of production panels. Don't move the panels and disturb the concrete before they gain adequate strength. Also, don't expose the panels to environments that are significantly different than the exposed project's sections (much hotter, colder, or drier).

There are many different size requirements for production panels. This includes both plan dimensions and thickness. For example, a 12 x 12 in. (300 x 300 mm) panel 3 in. (75 mm) deep may cause problems down the road. The panel may not have enough room for removing all the cores required. ASTM testing requires cores not be taken closer than the depth of the panel plus 1 in. (25 mm). So in a 12 x 12 in. (300 x 300 mm) by 3 in. (75 mm) deep panel, the outer 4 in. (100 mm) of the panel can't be cored, and leaves only a 4 in. (100 mm) square area in the center of the panel. If taking a 3 in. (75 mm) diameter core (the recommended minimum core diameter), you could only get one core out of each panel. Also, the 3 in. (75 mm) thickness doesn't allow any additional length to square up the ends of the core for testing. I suggest a minimum shotcrete production panel be 24 x 24 in. (600 x 600 mm) by 5.5 in. (140 mm) deep. This is 2 in. (50 mm) deeper than the ASTM C1140 minimum panel size of 24 x 24 in. (600 x 600 mm) by 3.5 in. (90 mm). The added plan dimensions leave enough room to stay well off the edge and other cores for a non-disturbed sample, and the added length allows the lab to square up the end before

Fig. 11: Typical daily wet-mix shotcrete production panel

testing. Remember, the production panel is a sample of the concrete material as shot in-place. If panel sizes are not thought out in advance, you may not be able to get enough cores for the testing at the desired ages. If the panels are damaged in handling or storage, low strength results could result despite the fact that the concrete in-place is perfectly good. Thus, proper sizing, preparation, and handling of production panels are essential to make sure the cores are truly representative of the work.

In summary, with all three test panels, planning ahead, educating the team members, good communication, quality concrete mixtures, and shotcrete placement by a qualified and experienced shotcrete contractor with proper equipment and a well-trained crew will make your job run much more smoothly.

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