Guide to Shotcrete

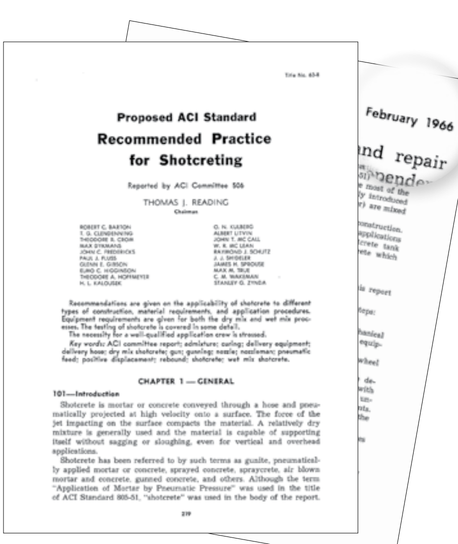
By Lars Balck

In 1910, naturalist Carl Akeley introduced a machine he invented to build mortar models of animals at the cement show in New York. Shortly after, the Cement Gun Product Company was formed and the term "gunite"—what we now call dry-mix shotcrete—was coined. The cement gun was a breakthrough for concrete construction. Mortar could now be conveyed long distances and produce high-strength concrete (shotcrete).

By 1916, however, manufacturing problems, the failure of a test application on the Panama Canal, and bickering among the original partners put the Cement Gun Product Company on the verge of bankruptcy. Samuel Taylor, a munitions and mining equipment manufacturer, bought the Cement Gun Company later the same year. He recognized both the potential of the cement gun and knew that the poor reputation gunite had developed impeded its success. To turn things around, Taylor consolidated control of the company and became the sole manufacturer. He then put together an experienced team and organized a contracting company to specialize in the placement of gunite. Engineering articles in the *Cement Gun Company Bulletin* were produced and reprinted in a number of engineering periodicals. These articles documented many of the merits of using gunite, including producing compressive strengths as high as 10,000 psi (69 MPa). Those strengths were extremely impressive for that time. Mixture proportions of 1-2-3 concrete (one shovel of cement, two shovels of sand, and three of large aggregate) were customary for site-mixed concrete and generally only achieved strengths of 3000 psi (21 MPa).

Between 1916 and 1920, Taylor improved gunite's reputation and reversed the cement gun sales decline. Everyone wanted a cement gun, and many were sent overseas. Of course success also attracted imitators. By 1950, with no standards for equipment, a variety of manufacturers around the world produced inferior equipment that impeded the proper application of gunite. On top of that, inexperienced contractors with no idea of the details required for good gunite field application produced poor-quality gunite on many projects. Once again, gunite developed a bad reputation.

Although the American Concrete Institute (ACI) was organized in 1913, the Institute didn't establish a shotcrete technical committee until 1960. The term "shotcrete" was adopted by ACI because the original "gunite" was a registered tradename. The new committee was charged with revising ACI Standard 805-51, "Recommended Practice for the Application of Mortar by Pneumatic Pressure." In 6 years, the committee made up of experienced shotcrete contractors, owners (including the U.S. Army Corps of Engineers), and testing laboratories published the ACI Standard, "Recommended Practice for Shotcreting (ACI 506-66)." This was essentially the first version of the document we now call the "Guide to Shotcrete." The purpose of the Recommended Practice was to educate engineers, owners, and contractors about shotcrete and to provide practice standards to improve the quality of shotcrete projects. Much of the content in the early ACI 506-66 document is still contained in the present Guide. Updated versions were published in 1985, 1990, 1995, and 2005.


Proposed ACI Standard

Recommended Practice for Shotcreting

Reported by ACI Committee 506

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Chairman

Recommendations are given on the applicability of shotcrete to different types of construction, material requirements, and application procedures. Equipment requirements are given for both the dry mix and wet mix processes. The testing of shotcrete is covered in some detail.

The necessity for a well-qualified application crew is stressed.

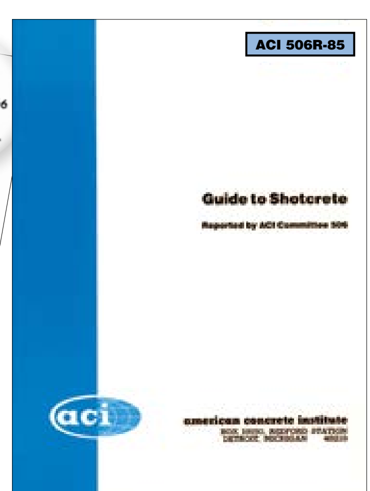
Key words: ACI committee report; admixture; curing; delivery equipment; delivery hose; dry mix shotcrete; gun; gunning; nozzle; nozzleman; pneumatic feed; positive displacement; rebound; shotcrete; wet mix shotcrete.

CHAPTER 1 — GENERAL

101—Introduction

Shotcrete is mortar or concrete conveyed through a hose and pneumatically projected at high velocity onto a surface. The force of the jet impacting on the surface compacts the material. A relatively dry mixture is generally used and the material is capable of supporting itself without sagging or sloughing, even for vertical and overhead applications.

Shotcrete has been referred to by such terms as gunite, pneumatically applied mortar or concrete, sprayed concrete, spraycrete, air blown mortar and concrete, gunned concrete, and others. Although the term "Application of Mortar by Pneumatic Pressure" was used in the title of ACI Standard 805-51, "shotcrete" was used in the body of the report.



ACI 506 continued to develop an assortment of documents to provide the engineering and construction industry comprehensive technical information on shotcrete. Currently, the 506 committee's catalog of documents includes:

- ACI 506.1R-08, "Guide to Fiber-Reinforced Shotcrete";
- ACI 506.2-13, "Specification for Shotcrete";
- ACI 506.4R-04, "Guide for the Evaluation of Shotcrete"; and
- ACI 506.5R-09, "Guide to Specifying Underground Shotcrete."

The latest version of the specification document, ACI 506.2, "Specification for Shotcrete," was published in 2013. Because ACI's format for specification documents requires concise, mandatory language without any explanatory commentary, it was decided to reorganize the next revision of the Guide to serve as a commentary for the new specification. ACI 506.2-13, "Specification for Shotcrete," is organized in standard three-part format (1.0 General, 2.0 Materials, and 3.0 Execution). The new Guide follows the same format with the addition of extra sections on equipment and crew responsibilities, which were part of the old Guide. A new section on sustainability has also been added to the new Guide.

The front end of the Guide was rearranged to accommodate sections on History, Application, New Developments, and Research. These sections form the Preface in the front to the Guide.

Here are some of the key changes in the new Guide:

Scope—ACI 506.2-13 directs the engineer to specify whether the shotcrete is structural or nonstructural. The new Guide defines structural shotcrete as shotcrete with a compressive strength of 4000 psi (28 MPa) or greater.

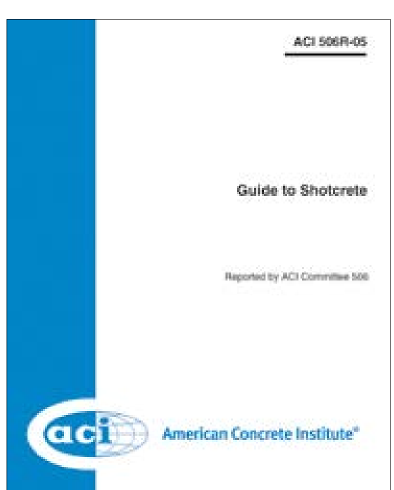
After considerable discussion, it was decided to not address polymer shotcrete due to the numerous field problems and dwindling use. The Guide does not recommend use of polymer shotcrete.

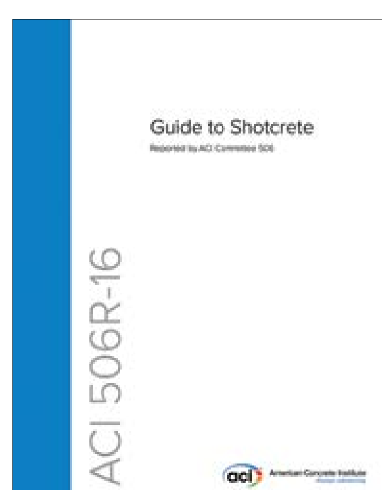
Submittals—This is a new section in the Guide. The purpose is to provide a handy cross-reference for the contractor when preparing project submittals. It should also help the engineer when reviewing submittals.

Preconstruction testing by contractor—Another new section. Increasingly, shotcrete is replacing "form-and-pour" concrete. Many engineers, however, are unfamiliar with shotcrete, so preconstruction testing by the contractor is recommended. This section gives guidance to both the engineer and contractor as to when preconstruction testing best serves the purpose and scope of the project. Preconstruction testing is typically needed to demonstrate that the contractor can properly encase complex reinforcing steel layouts on the project. In some cases, use of special concrete mixtures will necessitate preconstruction testing. Mockup panels are helpful for demonstrating a particular shotcrete surface finish early in the project. Agreement by the A/E on a mockup panel can prevent a lot of future conflict. On a side note, this section started out as a separate document but the committee eventually decided to include it in the Guide instead of referring to a separate document.

Testing during construction—In the previous version of the Guide there was just a brief section on testing. Quality assurance and quality control (QA/QC) guidance has been expanded. However, implementing a QA/QC program requires a holistic approach so the size and character of the project should determine the amount of effort given to QA/QC. The Guide provides some guidance for making this determination.

Shotcrete samples for compressive testing, unlike concrete cylinder samples, are cores taken from a shot panel. Compressive strength testing of samples of the concrete mixture taken from the back of a concrete truck only verifies concrete mixture capability. Because shotcrete placement uses high-velocity impact for consolidation and it has some change in mixture proportions as a





result of rebound, it does not represent in-place shotcrete strength. The only way to know the shotcrete strength is to take a core from a shot sample panel. Typically, the compressive strength of shotcrete cores exceeds the compressive strength of molded cylinder samples of the shotcrete mixture as delivered in the truck. Because there are different shotcrete panels used for shotcrete sampling, the new guide describes both the difference and purpose of three different shotcrete panels:

1. Material panels;
2. Nozzleman/project qualification panels; and
3. Nozzleman certification panels.

Admixtures—Advances in chemistry have improved admixtures and made dramatic impact on plastic concrete properties. In the past, shotcrete had to have a 2 to 3 in. (50 to 75 mm) slump. Today with admixtures, we are able to pump high-slump concrete through a small-diameter line long distances, and yet hang or stack the shotcrete as needed. The increased use of admixtures is one reason shotcrete contractors are competing and winning projects based on cost from traditional form-and-pour concrete contractors. Also, throughout the Guide, the committee recommends testing if a contractor is trying anything new.

Shotcrete properties—Shotcrete properties have remained the same with the default compressive strength for structural shotcrete in ACI 506.2-13 as 4000 psi (28 MPa).

Air content—Air content in shotcrete has been a source of friction between contractors and inspectors/engineers. Inspectors familiar with concrete become alarmed if the air content in the shotcrete mixture is greater than 6%. It has been repeatedly demonstrated that even with air content in the delivered concrete as great as 10%, the resultant in-place air content will be only 3 to 5%.

Most concrete specifications call for 5 to 6% air content for concrete to provide resistance to frequent freezing-and-thawing cycling. Dry-mix shotcrete, however, has for years demonstrated excellent freezing-and-thawing resistance with only 2 to 3% in-place air content. Likewise, wet-mix shotcrete when shot with 5 to 6% entrained air has also demonstrated excellent freezing-and-thawing resistance, although the in-place air content of the as-shot shotcrete is only 3 to 5%. In practice, we find about half of the entrained air in concrete is lost during wet-mix shotcrete placement. Shotcrete, however, due to its low water-cementitious materials ratio (*w/cm*) and the high level of compaction that occurs during placement has proven to be resistant to repeated freezing-and-thawing cycles.

Boiled water absorption (BWA)—The BWA test can also cause controversy so clarification has been added. The BWA test and volume of permeable voids test is widely used in Canada. However, testing labs in the continental United States don't have much experience with BWA testing, so erratic results have been reported and often lead to questions about the ability of the testing laboratory to properly conduct the test. A baseline BWA for the concrete mixture (not shot) should be conducted before testing shotcrete cores.

Bond strength—The bond strength of shotcrete continues to be one of shotcrete's main attributes. Because shotcrete is physically driven into the receiving surface by the high-velocity impact of the fresh concrete particles, excellent bond is achieved. Studies focusing on the bond qualities of shotcrete have proven that high-velocity placement to a sound substrate surface with adequate roughness provides durable bond.

Multiple layers—This section has been added to help inform engineers who often confuse placement of multiple layers of shotcrete with the cold joints experienced with form-and-pour concrete. Shotcrete provides excellent bond between layers due to the consolidation and densification by high-velocity impact of fresh concrete onto a properly prepared concrete substrate. Studies of bond between multiple layers of shotcrete have proven shotcrete achieves excellent bond between layers, and provides a structural section that acts as if placed monolithically.

Finishing—The Guide has expanded the section on finishes. The preferred finish is still a "gun" or "natural as-shot" finish. However, to compete with form-and-pour concrete, some owners want a smooth trowel finish which, for shotcrete, requires a two- or three-step procedure.

Tolerances—The tolerance section has been expanded. Because shotcrete permits a wider variety of applications and surface finishes than form-and-poured concrete, ACI 117, "Specification for Tolerances for Concrete Construction and Materials," specifically excludes shotcrete. ACI 117 provides excellent guidance for reinforcement placement and cover. The Guide gives the shotcrete project specifier criteria for specifying tolerances.

Repair—A section on shotcrete repair was added to provide commentary to the ACI 506.2-13 repair section.

Sustainability—In recent years, ACI has requested that new documents address sustainability. Shotcrete shares not only concrete's durability, but because of its unique characteristics, also enhances concrete's sustainability. Shotcrete promotes sustainability in many ways, including but not limited to:

- A repair material that extends a structure's life;
- Formwork reduction, which saves resources;
- Reduction of equipment needs on a project;
- Reduction of the time for construction; and
- Promotes creativity due to the ease of construction of curved sections.

Safety—Early in preparation of the Guide, a chapter on safety was compiled. Traditionally, however, ACI has not produced safety documents. As we were developing the Guide, the American Shotcrete Association (ASA) put together a safety document far more encompassing than what was planned for the guide so the safety chapter was discarded.

Summary

Shotcrete has come a long way. The new ACI 506R-16, "Guide to Shotcrete," builds on the original 1966 ACI Standard ACI 506-66, "Recommended Practice for Shotcreting," and has been reorganized to serve as commentary to ACI 506.2-13, "Specification for Shotcrete." A section, "Preconstruction testing by contractor," was added to provide guidance of when to include and what to include preconstruction testing. Also, "Testing during construction," which is QA/QC guidance, was expanded. The QA/QC section defines the different types of shotcrete panels for testing or evaluation. The section on admixtures has been updated. The new Guide continues to emphasize the superior bond strength shotcrete achieves and explains why multilayered shotcrete should not be considered multiple cold joints. Lastly, shotcrete enhances the sustainability properties of concrete.

The new Guide, like the first guide, is a consensus document compiled by volunteers with the goal of improving the quality of shotcrete projects. The volunteers, to be sure, have differences of opinion most often driven by different experiences in different regions. Thank you to all the Guide volunteers who devoted many, many hours of their time.

References

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***Lars Balck** is a concrete consultant and ASA/ACI Nozzleman Examiner. He recently retired from CROM, LLC, as a Senior Vice President. He has been involved in the design and construction of prestressed concrete tanks built with shotcrete for over 40 years. He received his bachelor's degree in civil engineering from the University of Florida and served with the U.S. Army as First Lieutenant in Vietnam as a Combat Engineer. Balck is a Past President of ASA. He is Chair of ACI Subcommittee 506-C, Shotcreting-Guide; a past Chair and current member of ACI Committee 506, Shotcreting; and member of ACI Committees 376, Concrete Structures for Refrigerated Liquefied Gas Containment; 563, Specifications for Repair of Structural Concrete in Buildings; and C660, Shotcrete Nozzleman Certification.*