# Shotcrete Guides and Specifications

*by D. R. Morgan*

Most architects, design engineers and design-build contractors are familiar with preparing and producing specifications for various types of concrete construction. There are projects where the use of shotcrete, rather than cast concrete, may be more technically and economically advantageous, but the designer is reluctant to specify shotcrete because of a lack of familiarity in preparing shotcrete specifications. This article provides owners and designers considering the use of shotcrete with information on guidelines and specifications for shotcrete in a variety of different applications. This information should assist designers in preparing project-specific specifications.

## Guides and Standard Specifications

In the Premier Issue of the American Shotcrete Association (ASA) Magazine in February of 1999,[1] a Shotcrete Bibliography was published by the author that included a listing of Shotcrete Guides and Standards. The shotcrete industry is proving to be dynamic and growing, and since that time, additional guides and standards have been published by various agencies around the world. An updated "Shotcrete Bibliography of Selected Guides and Standards" is provided at the end of this article.

Various national, federal, and state agencies, such as the U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation, many State Departments of Transportation, the American Institute of Architects (Masterspec: Section 03361—Shotcrete), and other agencies have also published their own shotcrete specifications. It is, however, this author's experience that these documents should be read with a critical eye, as shotcrete technology is advancing at a rapid rate and some of the documents do not reflect the current state of the art. They should thus be used with caution if one is contemplating using them as *templates* for preparation of new shotcrete specifications.

*Figure 1. An earth-formed, reinforced shotcrete wildlife underpass being constructed on the Island Highway, Vancouver Island, British Columbia, Canada, as a value-engineering alternative to a corrugated metal structure.*

## American Concrete Institute

Perhaps the most widely used specification for shotcrete in North America (and many other parts of the world) is ACI 506.2-95, "Specification for Shotcrete." This document, written by ACI Committee 506, Shotcreting, is updated about every 5 years, and as such represents reasonably current technology. The last edition was published in 1995, and a new edition is currently being balloted by the committee. The Specification is written in the three-part section format of the Construction Specifications Institute, adopted by ACI, and the language is generally imperative and terse. The Specification contains a checklist to assist the designer in properly choosing and specifying necessary requirements for the project specification.

ACI 506.2-95 is a general document. As such, it provides a useful basis for the preparation of detailed specifications for a variety of different shotcrete constructions, varying from new construction, to infrastructure rehabilitation, to ground support. Being so terse, however, it provides only limited guidance to designers wanting to write detailed project specifications. More detailed guidance is provided in ACI 506R-90, "Guide to Shotcrete." One should be cautioned, however, that this document is now 10 years old and thus, not current. A new version of this document, which contains substantial changes, is currently being balloted by ACI Committee 506, and should be published soon.

## Nozzleman Certification

One of the most controversial areas in the shotcrete industry has been the issue of "certification of shotcrete nozzleman." Some designers have erroneously written into their specifications a statement that, "Only ACI Certified Shotcrete Nozzleman shall be allowed to apply shotcrete." The problem is that while there is a publication, ACI 506.3R-91, "Guide to Certification of Shotcrete Nozzlemen," ACI has not had a Shotcrete Nozzleman Certification program in place. Various private testing laboratories, and more recently, the American Shotcrete Association[2] have certified Shotcrete Nozzlemen, using ACI 506.3-91 as the basis for the certification, but these nozzlemen are not "ACI Certified Shotcrete Nozzlemen."

Fortunately, this is about to change. ACI Committee C 660, Shotcrete Nozzleman Certification,

*Figure 2. Shotcrete nozzleman shooting a test panel in an ASA-sponsored Nozzleman Certification Program.*

is in the final stages of preparation of a Shotcrete Nozzleman Certification program. This program will hopefully be available by 2001. The ASA intends to act as a Sponsoring Group for the ACI Shotcrete Nozzleman Certification program, offering Public Certifications on a regular basis at venues such as the World of Concrete and elsewhere, as well as Private Certifications to organizations requesting that their nozzlemen be certified. It will then be possible for designers to write into their specifications a statement that only ACI Certified Shotcrete Nozzlemen will be allowed to apply shotcrete on the job.

ACI has just published ACI CCS-4, "Shotcrete for the Craftsman." This publication will form the basis for examination of nozzlemen in the ACI C 660 Shotcrete Nozzlemen Certification program. It is also the basic text used in Shotcrete Nozzleman Training Schools being offered by the ASA for nozzlemen planning on taking the ACI Shotcrete Nozzleman Certification examination, or for architects, engineers, designers, inspectors, contractors, or others wanting to become more knowledgeable about shotcrete technology.

## AASHTO-AGC-ARTBA

The American Association of State Highway and Transportation Officials (AASHTO), in conjunction with the Association of General Contractors of America (AGC) and American Road and Transportation Builders Association (ARTBA), formed a task force to look into the use of shotcrete for repair of highway bridges. They concluded that while ACI 506.2 was a useful general specification document, it was not sufficiently targeted towards their specific needs. Thus, they reviewed various specifications for infrastructure repair available elsewhere in the world. They elected to use a document prepared for the Transportation Association of Canada, entitled "Recommended Practice for Shotcrete Repair of Highway Bridges," under the auspices of the Canadian Strategic Highway Research Program (C-SHRP) as the basis for a new guide specification. This document is now available as the AASHTO-AGC-ARTBA Task Force 37 Report, "Guide Specification for Shotcrete Repair of Highway Bridges."

This document is written in a two-part format for each of the wet-mix and dry-mix shotcrete processes: a guide specification, followed by a commentary section, designed to aid the specifier in making selections and choices in preparing a project-specific document. This Task Force 37 Report now forms the basis for preparation of shotcrete bridge repair specifications for many U.S. State Departments of Transportation. It is also readily adaptable to shotcrete repair of other infrastructure.

Task Force 37 recognized that having a good shotcrete specification was in itself not sufficient to insure a successful bridge repair. A vital part of the process is the monitoring of the repair process and enforcement of the specification by knowledgeable inspectors. They consequently developed an "Inspector's Guide for Shotcrete Repair of Bridges." This document, published in December 1999, provides useful guidance to all parties involved in the shotcrete repair process. *(See "Shotcrete Corner" in this issue for more information, p. 4).*

## EFNARC

In 1993 the European Federation of Producers and Applicators of Specialist Products for Structures (EFNARC) published a "European Specification for Sprayed Concrete." This document is a general specification-type document, intended primarily for use in shotcrete repairs, but also with some provisions for the use of shotcrete in underground support. It also contains test methods for parameters such as flexural strength, residual strength, and energy absorption of fiber-reinforced shotcretes, as well as other tests where suitable European standards were not available.

While the EFNARC "Specification for Sprayed Concrete" is useful, and has rapidly found widespread adoption in Europe and elsewhere, it was found that it was somewhat lacking in providing in-depth guidance to persons writing project specifications. As a consequence, in 1999, EFNARC published "European Specifications for Sprayed Concrete: Guidelines for Specifiers and Contractors." This more detailed document provides a Commentary on the original 1996 Specification, and provides useful guidance to persons writing shotcrete specifications and contractors using shotcrete for new construction, repairs, and underground support.

The EFNARC 1996 Specification document and 1999 Guide document mainly reference European standards and test methods. As such, these documents are not used much in North America, where the equivalent ACI documents mainly reference ASTM standards and test methods.

## Shotcrete for Underground Support

There are currently no ACI specifications or guides specifically directed towards the use of shotcrete for underground support. ACI Committee 506 has recognized this deficiency and a Shotcrete for Underground Support subcommittee has been working for about 5 years on producing a "Guide Specification with Commentary on Shotcrete for Underground Support." This document is nearing completion and will hopefully be available within 1 to 2 years.

In 1993, the International Tunneling Association published the document, "Shotcrete for Rock Support, Guidelines and Recommendations — A Compilation." While useful, this document is no longer up to date, given the rapid advances in shotcrete for underground support that have taken place in the past decade. The most current, and perhaps most comprehensive, national document on shotcrete for underground support is the "Austrian Concrete Society Sprayed Concrete Guideline: Application and Testing," published in March 1999. This document is specifically directed to the use of shotcrete for underground support and contains considerable detail regarding items of interest with respect to the underground shotcrete construction process, such as environmental considerations, use of accelerators, early age compressive strength development, structural requirements, including use of mesh and/or fiber-reinforced shotcretes, testing of fiber-reinforced shotcrete, and construction methods.

The document references Austrian, DIN, and ASTM standard test methods. *(For more details regarding this document, see the article by Wolfgang Kusterle[3] on page 22 of this issue.)*

*Figure 3. Repair of a highway bridge with dry-mix shotcrete.*

## Fiber-Reinforced Shotcrete

Another somewhat controversial area in shotcrete technology is in the specification and testing of steel and/or synthetic fiber-reinforced shotcrete (FRS). FRS is used mainly for ground support (for example, slope stabilization and underground support in tunnels and mines) but is also used in new construction (for example, creek channelization, erosion control, containment beams, etc.) and infrastructure rehabilitation (for example, dam and bridge repair, seismic retrofit, etc.).[4]

In North America, ASTM C 1018, "Standard Test Method for Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using Beam with Third Point Loading)," has been the most widely specified and used test method. The method has its limitations, however, as discussed by Morgan, Chen, and Beaupré,[5] Bernard,[6] and others. In particular, concern has been raised about the suitability of specifying and using the Toughness Index ($I_5$, $I_{10}$, $I_{20}$, etc.) method given in the standard. The standard is currently under review in the ASTM committee and there is a proposal to dispense with the Toughness Index approach to calculating and specifying flexural toughness requirements, and instead simply specify residual (postcrack) flexural strengths at predetermined deflections selected by the design engineer. This is in essence the approach taken in the EFNARC standard and in the Toughness Performance Level (TPL) method developed by Morgan, Chen, and Beaupré.[5] The TPL method of specifying and interpreting the data is now used in Canada and other parts of the Americas, and has also been incorporated into the new Austrian Sprayed Concrete Guideline.[3]

Bernard[6] has pointed out the limitations of testing fiber shotcrete in beams, as opposed to panels, including the considerably higher coefficient of variation inherent in beam testing, compared to panel testing. He conducted comparative evaluations of a wide range of different beam and panel tests for FRS.[7] He carried out a comprehensive evaluation of the rectangular, fully edge-supported

*Figure 4. Application of wet-mix shotcrete in a tunnel using a remote-control application boom (provided by MBT Shotcrete and Underground Group).*

*Figure 5. Shooting of a round panel with fiber-reinforced shotcrete for testing using the proposed new ASTM centrally loaded round determinate panel test.*

EFNARC 600 x 600 x 100 mm rectangular panel and the new 800 mm dia. x 100 mm round determinate panel, with three-point bearing, developed by him. He concluded that of all the test methods evaluated, the latter round determinate panel test provided the lowest coefficient of variation, making it the most suitable for use in quality control in project specifications. Also, the test is relatively simply and economical to conduct, compared to the ASTM C 1018 beam test, which now requires the use of a very expensive closed-loop servo-controlled testing machine (few of which are available at commercial testing laboratories).

The ASTM C.09.42 Fiber Concrete Committee has recognized these concerns, and a new "Standard Test Method for Flexural Toughness of Fiber Reinforced Concrete (using Centrally Loaded Round Determinate Panel)" is currently under development by the ASTM Committee. Certain organizations are already using this draft test method and performance data for FRS made with various types of steel or synthetic fibers can be found in publications by Morgan et al.[8] and Bernard.[7]

## SUMMARY

In summary, the state of the art of shotcrete technology is advancing rapidly. Potential designers, specifiers and constructors of shotcrete structures need to have objective and current design guides, specifications, and standards to enable them to keep pace with this growing technology. The shotcrete industry has recognized these challenges and is responding with active participation in organizations such as ACI, ASTM, AASHTO, EFNARC, and other associations who prepare such documents. In addition, the efforts of organizations such as the ASA, and the International Center of Geotechnics and Underground Construction in Switzerland are providing shotcrete training and certification programs to produce the skilled craftsmen who are such a vital part of the shotcrete construction process. The joint efforts of all these individuals and organizations are providing the information needed by owners, architects, and engineers to design and build confidently with shotcrete. This augurs well for the future of this dynamic industry.

## REFERENCES


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