Shotcrete Incorporated into ACI 318-19 Building Code

A supplement to the commentary to ACI 318-19

by Charles Hanskat, Terence C. Holland, and Bruce A. Suprenant

Since the shotcrete process originated well over 100 years ago, improvements in materials, equipment, and placement techniques have enabled it to become a well-proven method for structural concrete placement. The efficiency and flexibility of shotcrete have been used to great advantage in sizable structural projects, as the high-velocity impact inherent in the process provides the compaction needed to turn low-slump concrete into freestanding vertical and overhead placements with minimal formwork.

Shotcrete has been incorporated into the International Building Code (IBC) for many years, but there was no assigned responsibility for reviewing and updating the provisions. Further, shotcrete was not expressly covered in the ACI 318 Code. To address these shortcomings, during the 2019 code cycle, Jack Moehle, Chair of ACI Committee 318, Structural Concrete Building Code, requested that ACI 318 subcommittees work to incorporate shotcrete provisions into the ACI 318 Code. Thus, ACI Subcommittees 318-A, General, Concrete, and Construction, and 318-B, Anchorage and Reinforcement, started a 5-year journey, ending in the successful inclusion of shotcrete into ACI 318-19.[1] Here is that story.

IBC Shotcrete Provisions

Conversations between ACI and International Code Council (ICC) staff indicated that it would be possible to delete the shotcrete provisions from the IBC upon satisfactory incorporation of shotcrete into the ACI 318 Code. Thus, the first task for the subcommittee members was to study the shotcrete provisions in the IBC. The topics covered in 2015 IBC Section 1908 Shotcrete are shown in Table 1.[2] A table prepared for the subcommittees to summarize the shotcrete provisions in the 2000, 2003, 2006, 2009, 2012, and 2015 editions of the IBC showed that very little change had occurred since 2000. Further, it was evident that the 2000 IBC provisions[3] were primarily based on an extremely dated document, "Guide to Shotcrete (ACI 506R-90)."[4]

ACI Shotcrete Information

The next task for subcommittee members was to review relevant, current information in the following ACI documents:

- "Guide to Shotcrete (ACI 506R-16)"[5];
- "Guide to Fiber-Reinforced Shotcrete (ACI 506.1R-08)"[6];
- "Specifications for Shotcrete (ACI 506.2-13 (Reapproved 2018))"[7];
- "Guide for the Evaluation of Shotcrete (ACI 506.4R-94 (Reapproved 2004))"[8];
- "Guide for Specifying Underground Shotcrete (ACI 506.5R-09 (Reapproved 2016))"[9]; and
- "Visual Shotcrete Core Quality Evaluation TechNote (ACI 506.6T-17)."[10]

It should be noted that the latest edition of "Guide for the Evaluation of Shotcrete (ACI 506.4R-19)"[11] was approved too late to be considered in developing the shotcrete provisions for ACI 318-19.

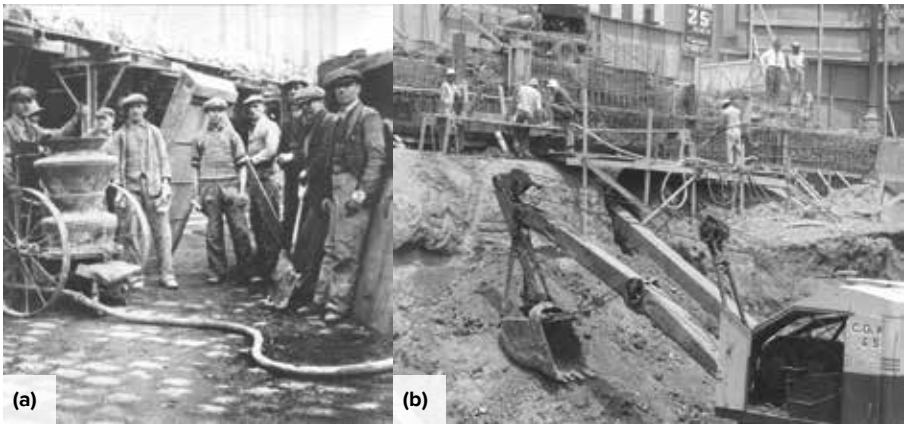
Table 1:
Provisions in 2015 IBC Section 1908 Shotcrete[2]

Provision	Title
1908.1	General
1908.2	Proportions and materials
1908.3	Aggregate
1908.4	Reinforcement
1908.4.1	Size
1908.4.2	Clearance
1908.4.3	Splices
1908.4.4	Spirally tied columns
1908.5	Preconstruction tests
1908.6	Rebound
1908.7	Joints
1908.8	Damage
1908.9	Curing
1908.9.1	Initial curing
1908.9.2	Final curing
1908.9.3	Natural curing
1908.10	Strength tests
1908.10.1	Sampling
1908.10.2	Panel criteria
1908.10.3	Acceptance criteria

IBC versus ACI Code—Applying ASTM Standards

The 2015 IBC provisions in Section 1908 Shotcrete were created well before ASTM developed testing standards for shotcrete, so no ASTM standards on shotcrete were referenced. Therefore, the IBC provisions considered for inclusion in ACI 318 had to be modified to reflect ACI Code usage of ASTM standards. The following ASTM standards for shotcrete were used and cited in ACI 318-19:

- C1385/C1385M-10(2017), "Standard Practice for Sampling Materials for Shotcrete";
- C1140/C1140M-11, "Standard Practice for Preparing and Testing Specimens from Shotcrete Test Panels";
- C1141/C1141M-15, "Standard Specification for Admixtures for Shotcrete";
- C1436-13, "Standard Specification for Materials for Shotcrete";
- C1480/C1480M-07(2012), "Standard Specification for Packaged, Pre-Blended, Dry, Combined Materials for Use in Wet or Dry Shotcrete Application"; and
- C1604/C1604M-05(2012), "Standard Test Method for Obtaining and Testing Drilled Cores of Shotcrete."



Shotcrete has been widely used for over a century: (a) a crew poses with their equipment in the 1920s; and (b) a crew places a foundation wall in the 1940s

Shotcrete is ideal for placing complex structures: (a) the curved enclosure wall of Stanford University's Bing Concert Hall comprises shotcrete with a sand float finish; (b) a certified nozzle operator and a blowpipe operator construct mockup panels for the enclosure wall; and (c) crews placed the 12 in. (300 mm) thick enclosure wall in multiple lifts, using a removable screed rail to control the thickness *(photos courtesy of Joseph J. Albanese, Inc.)*

Incorporating Shotcrete in ACI 318-19

ACI 318-14[12] did not include the word "shotcrete," and it was silent as to whether the provisions applied to shotcrete. If shotcrete had been incorporated into the ACI Code prior to the 2014 edition, it would have been appropriate to develop a new chapter on shotcrete that included all relevant provisions on materials, placement, and acceptance. However, that was not a feasible option within the member-based code organization implemented in the 2014 edition of the Code.

Thus, the incorporation of shotcrete into the Code required the application of two principles in the context of the complete 318 Code:

- Shotcrete is cast-in-place concrete; and
- Shotcrete is a construction placement method.

In effect, the subcommittees' primary objective was to implement shotcrete as a cast-in-place method, and this required them to consider and implement the following rules:

- Respect the intent of the IBC shotcrete provisions;
- Update the IBC shotcrete provisions to reflect current ACI information;
- Use ASTM standards in the development of the Code language; and
- Integrate shotcrete provisions to be compatible with existing Code language.

This required shotcrete provisions to be incorporated into ACI 318 where it was appropriate to modify the provisions in the 2014 edition. Thus, shotcrete provisions are distributed throughout the relevant sections of the ACI Code. As a result, ACI 318-19 contains 135 instances of the word "shotcrete."

ACI 318-19: The Result

Drafts of the shotcrete provisions were vetted by Marc Jolin, Chair of ACI Committee 506, Shotcrete, and Charles Hanskat, Executive Director of the American Shotcrete Association (ASA), along with members of ACI Subcommittee 318-A. After numerous 318 subcommittee and 318 main committee ballots, and review by the ACI Technical Activities Committee (TAC) and the public, the shotcrete provisions were incorporated into ACI 318-19. Table 2 shows the covered shotcrete topics and their locations within ACI 318-19.

Extended Commentary

The following sections provide extended commentary on ACI 318-19 provisions addressing air content in shotcrete and certification requirements for nozzle operators. In addition, an erratum on acceptance testing requirements for shotcrete is discussed.

Air content of shotcrete

Both wet-mix and dry-mix shotcrete can be air entrained for enhanced resistance to cyclic freezing and thawing. Provisions for air entrainment are provided in Table 3 for shotcrete exposed to cycles of freezing and thawing. The higher air content of wet-mix shotcrete sampled at the point of delivery accounts for expected air losses during shooting.

Dry-mix shotcrete without air entrainment has performed well in freezing-and-thawing environments with no exposure to saltwater or deicing salts.[5,13] For exposure to saltwater or deicing salts, air-entraining admixtures, in either a wet or dry form, can be added to dry-mix shotcrete to provide the required air content for durability in these exposures.[14]

In wet-mix shotcrete, air entraining is introduced into the concrete mixture before pumping and placing the concrete. The air content can be tested at the point of delivery using normal ASTM testing standards. In dry-mix shotcrete, the dry concrete materials are wetted at the nozzle so there is no opportunity to test for air content until the mixture is placed. Thus, ACI 318 does not include a specific testing method for evaluating the air content of dry-mix shotcrete and requires the licensed design professional to specify a method to be used.

Field measurements of air content of dry-mix shotcrete have been obtained by shooting the material directly into a bowl of an air meter.[14] Samples for air content testing can also be taken from material shot into test panels, into a wheelbarrow, or onto the ground. These samples can then be used for testing in accordance with ASTM C231/C231M, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method."[15]

Certification

ACI 318-14 incorporated certification requirements for concrete field and strength testing technicians and adhesive anchor installers. Similarly, certification requirements are included in ACI 318-19 for shotcrete nozzle operators: "A certified shotcrete nozzle operator shall place all shotcrete" (Provision 26.5.2.1 (o)). The Commentary Provision R26.5.2.1(o) provides the following information:

"Nozzle operators become certified through testing and training programs

Table 2:
Shotcrete provisions and relevant ACI 318-19 sections[1]

Topic covered	Section
Terminology	2.3*
Freezing and thawing	19.3.3.3 through 19.3.3.6
Reinforcement	25.2.7 through 25.2.10, 25.5.1.6, and 25.5.1.7
When shotcrete is required or permitted	26.3.1, 26.3.2
Materials	26.4.1.2, 26.4.1.4, and 26.4.1.6
Proportioning mixtures	26.4.3
Documentation of mixtures	26.4.4.1
Placement and consolidation	26.5.2.1
Curing	26.5.3
Joints	26.5.6
Evaluation and acceptance	26.12

*The terms shotcrete mockup panel, shotcrete test panel, shotcrete, and wet- and dry-mix shotcrete were added to Section 2.3—Terminology

Table 3:
Total air content for shotcrete (based on Table 19.3.3 in ACI 318-19[1])

Mixture type	Sampling location	Target air content, %		
		F1	F2	F3
Wet-mix shotcrete	Before placement	5.0	6.0	6.0
Dry-mix shotcrete	In-place	N/A*	N/A*	4.5

*Entrained air is not required in dry-mix shotcrete for these exposures

ACI Subcommittee 318-B Updates Reinforcement for Shotcrete

ACI Subcommittee 318-B members David Darwin, the University of Kansas, and Neal Anderson, Simpson Gumpertz and Heger, were responsible for getting the shotcrete reinforcement details into ACI 318-19. The minimum spacing for reinforcement for shotcrete is provided in Provisions 25.2.7 through 25.2.10. Noncontact lap splices for shotcrete are covered in Provision 25.5.1.6 and contact lap splices for shotcrete are covered in Provision 25.5.1.7. These reinforcement provisions provide for the use of shotcrete mockup panels to demonstrate clear spacing and lap splices other than those permitted by the Code.

that include written and performance examinations. Each shotcrete nozzle operator should be certified in accordance with the applicable ACI certification program for dry-mix or wet-mix shotcrete (both are covered by CPP 660.1-15)."

An erratum on strength acceptance

After publication of ACI 318-19, Jim Klinger, Conco Companies, an incoming member of ACI Subcommittee 318-A, spotted an inconsistency in Section 26—Evaluation and acceptance of hardened concrete. In their attempt to match the acceptance criteria for standard-cured specimens, the subcommittee members provided two criteria for shotcrete. Klinger observed that these two criteria were not consistent. The error was discussed during the ACI Subcommittee 318-A meeting in Cincinnati, OH, and it was agreed to modify the wording as shown below. Strikethrough font indicates text deleted from the Code; underlined text has been added. An erratum to ACI 318-19 Provision 26.12.4.1 will be issued to make this change:

26.12.4.1 Compliance requirements:

(a) Specimens for acceptance tests shall be in accordance with (1) and (2):

(1) Test panels shall be prepared in the same orientation and by the same nozzle operator placing shotcrete.

(2) Cores shall be obtained, conditioned, and tested in accordance with ASTM C1604.

(b) Strength of a shotcrete mixture shall be acceptable if ~~(1) and (2) are satisfied:~~

~~(1) Every arithmetic average of the strengths from three consecutive test panels equals or exceeds f'_c.~~

~~(2) The~~ average compressive strength of three cores from a single test panel is not less than $\mathbf{0.85}\,f_c'$, with no core having a strength less than $\mathbf{0.75}\,f_c'$.

(c) If ~~either of~~ the requirements ~~of~~ 26.12.4.1(b) ~~are~~ is not satisfied, steps shall be taken to increase the average of subsequent strength results.

(d) Requirements for investigating low strength-test results shall apply if the requirements ~~of 26.12.6.1(b)(2)~~ 26.12.4.1(b) ~~(2) are~~ is not met.

Looking to the Future

Shotcrete placement has been successfully used in structural concrete work for decades. Up-to-date requirements reflecting current shotcrete technology have been incorporated into ACI 318-19. It is the expectation of the committee that these requirements, like all other requirements in the Code, will be reviewed and updated on a continuing basis as the industry advances. The committee looks forward to receiving feedback from the shotcrete community as the provisions are implemented in practice.

References

1. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19)," American Concrete Institute, Farmington Hills, MI, 2019, 623 pp.
2. "2015 International Building Code," first edition, International Code Council, Falls Church, VA, 2014, 690 pp.
3. "2000 International Building Code," International Code Council, Falls Church, VA, 2000, 300 pp.
4. ACI Committee 506, "Guide to Shotcrete (ACI 506R-90)," American Concrete Institute, Farmington Hills, MI, 1990, 81 pp.
5. ACI Committee 506, "Guide to Shotcrete (ACI 506R-16)," American Concrete Institute, Farmington Hills, MI, 2016, 52 pp.
6. ACI Committee 506, "Guide to Fiber-Reinforced Shotcrete (ACI 506.1R-08)," American Concrete Institute, Farmington Hills, MI, 2008, 14 pp.
7. ACI Committee 506, "Specifications for Shotcrete (ACI 506.2-13 (Reapproved 2018))," American Concrete Institute, Farmington Hills, MI, 2013, 12 pp.
8. ACI Committee 506, "Guide for the Evaluation of Shotcrete (ACI 506.4R-94 (Reapproved 2004))," American Concrete Institute, Farmington Hills, MI, 1994, 12 pp.
9. ACI Committee 506, "Guide for Specifying Underground Shotcrete (ACI 506.5R-09 (Reapproved 2016))," American Concrete Institute, Farmington Hills, MI, 2009, 52 pp.
10. ACI Committee 506, "Visual Shotcrete Core Quality Evaluation TechNote (ACI 506.6T-17)," American Concrete Institute, Farmington Hills, MI, 2017, 4 pp.
11. ACI Committee 506, "Guide for the Evaluation of Shotcrete (ACI 506.4R-19)," American Concrete Institute, Farmington Hills, MI, 2019, 18 pp.
12. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)," American Concrete Institute, Farmington Hills, MI, 2014, 519 pp.
13. Seegebrecht, G.W.; Litvan, A.; and Gebler, S.H., "Durability of Dry-Mix Shotcrete," *Concrete International*, V. 11, No. 10, Oct. 1989, pp. 47-50.
14. Bertrand, J., and Vezina, D., "The Development of Air-Entrained Durable Shotcrete for Structural Repairs," *Proceedings of Shotcrete for Underground Support VII*, Telfs, Austria, June 11-15, 1994, pp. 58-65.
15. Zhang, L., "Testing Air Content of Dry-Mix Shotcrete," *Shotcrete*, V. 17, No. 2, Spring 2015, pp. 22-24.

Note: Additional information on the ASTM standards and IBC codes discussed in this article can be found at **www.astm.org** and **www.iccsafe.org**, respectively.

Selected for reader interest by the editors.

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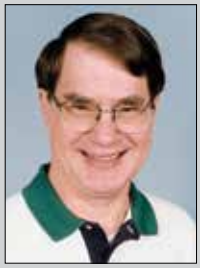

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