shotcrete MAGAZINE

A quarterly publication of the American Shotcrete Association

VOLUME 21, NUMBER 2 • SPRING 2019

www.shotcrete.org

Repair/Retrofit/Repurpose

american shotcrete association asa

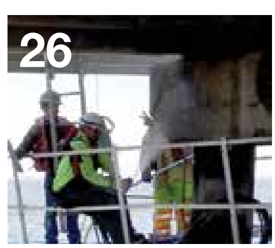
38800 Country Club Drive, Farmington Hills, MI 48331 ELECTRONIC SERVICE REQUESTED

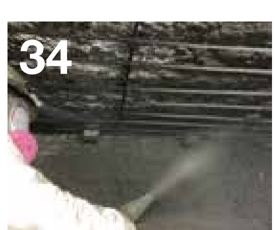
american shotcrete association | asa

shotcrete MAGAZINE

Volume 21, Number 2 • Spring 2019

FEATURES





ALSO FEATURING

DEPARTMENTS

On the cover: Repair location on bent cap of the Wright Memorial Bridge. Read the article on page 26.

Shotcrete is a quarterly publication of the American Shotcrete Association. For information about this publication or about membership in the American Shotcrete Association, please contact ASA Headquarters at:

American Shotcrete Association
38800 Country Club Dr.
Farmington Hills, MI 48331
Phone: 248.848.3780
Fax: 248.848.3740
E-mail: info@shotcrete.org
Website: **www.shotcrete.org**

To unsubscribe, please go to **www.shotcrete.org/pages/products-services/e-remove.asp**

american shotcrete association | asa

Editor's Note: Shotcrete is a placement method for concrete. However, for the sake of readability, the word "shotcrete" is often used either to identify the shotcrete process (method of placement) or the shotcrete mixture (product materials).

Executive Director
Charles S. Hanskat

Assistant Director
Alice L. McComas

Editor-in-Chief
Charles S. Hanskat

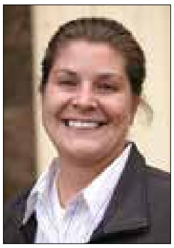
Managing Editor
Lacey J. Stachel

Editing
Barry M. Bergin (Manager), Carl R. Bischof, Kaitlyn J. Dobberteen, Tiesha Elam, Kelli R. Slayden

Graphic Design
Susan K. Esper, Ryan M. Jay, Gail L. Tatum

Toward Another Year of Progress

By Cathy Burkert



As I step into the honorable role as ASA's next President, I am deeply honored, and I thank each and every one of you who have supported, guided, and expressed their confidence in me. I am truly grateful for this opportunity—to represent our incredible organization as your next President. To have the privilege to serve this organization, comprised of professionals who are dedicated to the shotcrete industry, is truly what makes this honor so meaningful to me.

I would like to thank all the past presidents for their incredible work in building the foundation, so ASA can continue to grow and achieve its goals to provide knowledge resources, qualification, certification, education, and leadership to increase acceptance, quality, and safe practices of the shotcrete process.

I look forward to working with the new Executive Committee including Ryan Poole, Consultant, as Vice President; Lars Balck, Consultant, as Secretary; and Axel Nitschke, WSP USA, as Treasurer, as well as the Board of Directors, including newly elected Directors Frank Townsend, Superior Gunite; Mike Reeves, Gunite Specialists, Inc.; and Jason Myers, Dees-Hennessey Inc.; and returning Directors Jonathan Dongell, Pebble Technologies; Oscar Duckworth, Valley Concrete Services; William Geers, Bekaert-Maccaferri Underground Solutions; Mason Guarino, South Shore Gunite Pools & Spas, Inc.; Marcus von der Hofen, Coastal Gunite Construction Company; and Ryan Oakes, Revolution Gunite.

ASA keeps us up to date, informed, and allows us to have one of the most powerful collective voices in the shotcrete community. We achieve all of this through the work of our dedicated army of volunteers, and with the help of Charles Hanskat, ASA Executive Director and Technical Director, and Alice McComas, ASA Assistant Director. ASA has over 800 members and we're grateful to have so many active members who have stepped up to fill a vast array of committee and representative positions including the committee Chairs: Marcus von der Hofen, Coastal Gunite Construction Company, Contractor Qualification Committee; Oscar Duckworth, Valley Concrete Services, Education Committee; Tait Pirkle, Eastco Shotcrete LLC, Marketing Committee; Jason Myers, Dees-Hennessey Inc., Membership Committee; Mason Guarino, South Shore Gunite Pools & Spas, Inc., Pool and Recreational Committee; Andrea Scott, Hydro-Arch, Safety Committee; Lihe "John" Zhang, LZhang Consulting & Testing Ltd., Technical Committee; and Axel Nitschke, WSP USA, Underground Committee.

The shotcrete industry has experienced significant growth and through efforts of ASA has made significant gains in acceptance and recognition as a method of placing quality concrete among designers, engineers, owners, and contractors. It is exciting to see the number of candidates pursuing ACI Shotcrete Nozzleman Certifications. Nozzleman Certification consists of a general knowledge written examination and a performance examination that includes shooting a small test panel containing reinforcing steel. This program establishes a basic skill level for shotcrete placement. However, as vital as the Nozzleman Certification

The shotcrete industry has experienced significant growth and through efforts of ASA, has made significant gains in acceptance and recognition as a method of placing quality concrete...

knowledge is to proper shotcrete placement, many specifiers have mistakenly relied upon Nozzleman Certification as an all-encompassing credential that equates to the nozzleman's competency to shoot ALL types of shotcrete applications. The versatility of shotcrete placement allows it to be an ideal choice for many applications from a simple architectural overlay to structural repair and seismic retrofits. However, successful performance in one application does not necessarily equate to successful execution in another.

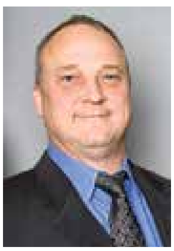
The ASA Contractor Qualification Program (CQP) was developed to evaluate the shotcrete contractor and not just the person holding the nozzle. This program allows ASA to assist the specifier by evaluating a contractor's shotcrete knowledge, experience, shotcrete equipment, current level of expertise of the management staff and field crews, and support of the nozzlemen. I have heard many horror stories related to a person getting certified as a nozzleman, sometimes only in the vertical position, then thinking they can easily start a shotcrete company. So, they rent a pump, buy some shotcrete material, and take a job foolishly inexpensive—only to try to "fake it until they make it." Unfortunately, they either do such a poor job to the point the owner scorns shotcrete all together, or even worse—they hurt someone.

The CQP has already hosted nearly 50 attendees at its Shotcrete Contractor Education seminars around the country, resulting in numerous companies applying for qualification and growing interest. It is good to know that other quality shotcrete contractors are supporting the program and understand its necessity. ASA speakers discuss the benefits of the program during ASA's complimentary on-site seminars, encouraging designers, engineers, and owners to specify it.

I am excited that this will be another year of significant growth and progress for ASA as it continues to develop programs and services to benefit its members and the industry. Because I am grateful for all that I have received from ASA, I want to serve our organization and do what I can to ensure these same opportunities are available now and for generations to come. Thank you for the privilege to serve as your President in the 21st year of ASA. I welcome your thoughts, suggestions, and opinions. I will do my best for you and our profession, as well as the legacy and future of ASA.

Contractor Qualification Committee

By Marcus von der Hofen



Kicking off Spring 2019, ASA's online application for the Contractor Qualification Program (CQP) is now available. Many years ago, ASA laid the groundwork for the Nozzleman Certification Program, which—through cooperation between ASA and ACI—became the ACI Shotcrete Nozzleman Certification Program. Though definitely a valuable resource to the industry, it does not establish the complexity of work a nozzleman could successfully accomplish on a specific project. A successful project requires more than one nozzleman. A cohesive crew, properly maintained equipment, and experienced leadership to mobilize and assign resources, identify and order materials, and coordinate activities, are just a few of the many factors that—along with certified nozzlemen—achieve success on a project.

A design engineer or specifier should always require an experienced and qualified contractor for support, which includes experienced crew members with the proper equipment and material selection for the specific project. The CQP reviews the entire shotcrete team, including the contractor management, ACI Certified Nozzleman, experienced crew, proper equipment, and verified projects, to validate the shotcrete contractor's knowledge and ability to consistently place quality shotcrete.

The ASA process starts with education, providing a full-day contractor education seminar. This precursor to the qualification process stands alone in today's shotcrete industry as the first of its kind. The 7-hour course covers the components of the shotcrete process, in a small setting with instructors who have decades of experience in the industry. The participants have the opportunity to interact with the speakers and gain a great deal of knowledge about shotcrete, its history, and much more. The fact is many participants are individuals such as specifiers, general contractors, and others who are looking to strengthen their overall shotcrete knowledge. I personally think it would be a great course for owners, specifiers, and construction managers alike.

The seminar reference materials provided are valuable tools in the industry and their content and application are covered in the course. At the end of the course, participants can optionally take a shotcrete general knowledge exam. (Passing the exam by a qualified individual is a requirement for applying for Contractor Qualification). The written test, similar to the ACI

DESCRIPTIONS OF PROJECTS UNDER THE BASIC VS ADVANCED CATEGORIES

BASIC PROJECTS:

- Sections 6 in. (152 mm) or less in thickness;
- One curtain of reinforcing with No. 5 or smaller bars and noncontact lap splices with 2.5 in. (64 mm) separation;
- Shallow depth of 3 to 8 ft (1 to 2 m) with slopes;
- No problems with subgrade soils or groundwater;
- No overhead work; and
- Volume of shotcrete 30 yd^3 (23 m^3) or less.

Examples of this type of project include:

- Small swimming pools and ponds;
- V-ditches and channels;
- Temporary shoring;
- Slope paving/stabilization;
- Architectural overlays; and
- Small, limited repair, and patching.

ADVANCED PROJECTS:

- Structures that require preconstruction test panels per the applicable Building Code;
- Projects with reinforcing bars greater than No. 5 bars;
- Sections that require two curtains of reinforcing or contact lap splices;
- Projects with overhead shooting;
- Sections greater than 6 in. in thickness;
- Sections that require water stops or movement joints;
- Projects that require scaffolding, man-lifts, or use of safety harnesses;
- Vertical height over 8 ft;
- Pumping distance greater than 200 ft (60 m) horizontally or 25 ft (8 m) vertically; and
- Difficult access or environmental conditions

Examples of this type of project include:

- Structural concrete projects;
- Seismic retrofitting;
- Commercial or complex residential swimming pools;
- Structural repair and overlays;
- Permanent shoring and retaining walls;
- Liquid-storage tanks;
- Domes and other free-form concrete structural shells; and
- Skateparks.

Certified Nozzleman exam, shows the ability of the participant to answer real-life shotcrete questions. Feedback from participants confirms this course has added to their personal knowledge regardless of their experience in the industry. It's really the only course of its kind available in the industry.

The final component of contractor qualification is the application process. ASA administers the Shotcrete Contractor Qualification as a review service for shotcrete contractors. The Contractor Qualification Committee (CQC) reviews the Contractor Qualification Application for contractor's seeking qualification. The contractor must specify the level of qualification (Basic or Advanced) they are pursuing. The CQC reviews and verifies the information submitted in the application. Upon completion of the review, the CQC provides the contractor with a certificate of qualification in either the Basic or Advanced categories.

As more shotcrete contractors become qualified, specifiers should require an ASA Shotcrete Contractor Qualification for their specific projects, selecting the appropriate level of qualification based on the difficulty of the project. Qualified Contractors will be posted on the ASA website and promoted in *Shotcrete* magazine and at the various venues where ASA is represented. Contractor Qualification is good for 5 years. Upon or before expiration, the ASA Qualified Contactor will submit a renewal application. This helps ensure the ASA Qualified Contractor's current shotcrete team and equipment are still qualified to do either Basic or Advanced shotcrete work.

This CQP has been a long time in the making with uncounted volunteer hours. As with the ACI Nozzleman Certification, ASA will strive to make this program a key component for advancement of the shotcrete industry. The primary role of the CQC will be the continuous review, maintenance, and advocacy of this program. For more information about this program and others offered by ASA, visit **www.shotcrete.org**.

CONTRACTOR QUALIFICATION COMMITTEE

Marcus H. von der Hofen, Chair | Coastal Gunite Construction Company

Ryan Oakes, Vice Chair | Revolution Gunite

Cathy Burkert, Secretary | American Concrete Restorations, Inc.

Lars Balck | Consultant

Michael Cotter | Consultant

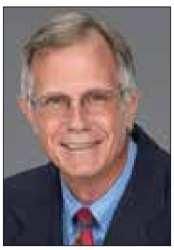
Jason Myers | Dees-Hennessy Inc.

Axel Nitschke | WSP USA

Mike Reeves | Gunite Specialists, Inc.

Our Mission

By Charles Hanskat, PE, FACI, FASCE, ASA Executive Director



ASA's Vision is "Structures built or repaired with the shotcrete process are accepted as equal or superior to cast concrete." And we move our vision forward guided by our Mission "ASA provides knowledge resources, qualification, certification, education, and leadership to increase the acceptance, quality, and safe practices of the shotcrete process."

So where do we stand in our activities providing knowledge resources, qualification, certification, education, and leadership to support our Mission?

KNOWLEDGE RESOURCES

From our inception over 20 years ago, we have worked hard to provide a wealth of knowledge resources through our website. The website is a primary resource and includes the Why Shotcrete? Informational pages, our Buyer's Guide, past issues of *Shotcrete* magazine, a searchable archive of past Shotcrete articles, an up-to-date Calendar of shotcrete-related events, Board-approved Position Papers, and a Shotcrete Resources page with a wide variety of helpful shotcrete information. All of these resources are freely available for full public access to those looking to learn more about shotcrete. We also provide an online bookstore to provide our publications as well as shotcrete related ACI documents. In addition, we answer many technical inquiries from owners, engineers, contractors, and members.

CERTIFICATION

We were the driving force nearly 20 years ago in developing and spreading the acceptance of the ACI Shotcrete Nozzleman certification program. Last year alone ASA conducted 88 sessions with a total of over 600 resulting certifications (new full certifications, nozzleman-in-training, and recertifications). We emphasize in all our educational activities that nozzlemen should always be ACI-certified in the process and orientation needed on a specific project. Our shotcrete nozzleman education program is the most comprehensive full-day seminar available to teach nozzlemen the basics of shotcrete. Specifiers now routinely include ACI Shotcrete Nozzleman certification in their contract documents.

EDUCATION

We started our free on-site seminars many years ago. Our 1-hour seminars include "Introduction to Shotcrete" and "Shotcrete for Underground Applications." We've seen a substantial increase in demand for these 1-hour seminars over the last year as an increasing number of specifiers want to learn more about the shotcrete process and quality shotcrete placement. The ACI Chapters Department also promotes our "Introduction to Shotcrete" seminar as a resource for ACI local chapter meetings and many chapters requested a seminar for their lunch or dinner meetings.

Two years ago, we introduced the ASA Shotcrete Inspector full-day education program. This program provides inspectors, who generally know concrete, the basics of shotcrete material, equipment, placement, protection, curing, and testing. With this extended knowledge they can more readily know the details required for quality shotcrete placement on their projects. We have reached seven state Department of Transportation offices and hope to add many more in the future. The seminar also helps support the upcoming ACI Shotcrete Inspector certification program that is expected to be launched later this year.

Last year we added our Shotcrete Contractor education program. We developed this full-day seminar as a prerequisite for our Contractor Qualification program. Like the shotcrete inspector education this seminar gives the contractor's perspective on the fundamentals of shotcrete material, equipment, site planning, crew composition, placement, protection, curing, and testing. Those contractors pursuing ASA Contractor Qualification must pass a written exam after attending the seminar.

Also last year we initiated an annual Shotcrete Convention and Technology Conference. Our first convention celebrated our 20th Anniversary and was originally expected to be a one-time event. However, once our members found the networking and educational opportunities in attending a conference dedicated to the shotcrete industry so rewarding, a second convention was held this year. Happy to report that after another successful event this year it was decided to make this an annual event in the future.

Finally, ASA members have also made numerous presentations at various tradeshows, technical conferences, and conventions. Though I have been involved in many of the educational sessions we conducted, I'd also like to recognize ASA members, including Frank Townsend, Marcus von der Hofen, Axel Nitschke, Bill Drakeley, John Zhang, Lars Black, Oscar Duckworth, and Bill Allen. Last year well over 1000 attendees attended a seminar or session conducted by ASA members. This year through May we've already passed the 1000 attendee mark and look to add significantly to our total outreach by the end of the year.

QUALIFICATION

As described in greater detail in the Winter 2018 issue of *Shotcrete*, our Contractor Qualification program is fully developed and has been rolled out for applications. Thus far, we have three shotcrete contractors who have qualified for the Advanced Shotcrete Contractor Qualification. In addition, there are several additional applications in progress. The intent of the program is to help establish a shotcrete contractor's qualifications through review of the contractor's work, company composition, field crew resources, equipment, and successful performance on their past work. Though the program is in its infancy we trust it will be a resource for specifiers to help identify shotcrete contractors who have demonstrated they have the knowledge, experience, and staff to consistently place high-quality, durable shotcrete on their projects.

LEADERSHIP

Through ASA staff and member involvement, we have made major gains in the visibility and acceptance of shotcrete in a wide variety of concrete applications. Underground, pool, and repair applications have traditionally been excellent applications for shotcrete. However, in recent years we've seen a distinct ramp up in other areas such as heavy foundation walls, architectural treatment of structural concrete, historic restoration, skate parks, rock carving, and increasingly complicated water features.

ASA staff and members have been actively promoting shotcrete in a wide variety of codes, specifications, standards, and reports. Technical committee work usually takes years in development of new or revised documents. Thus, progress may seem slow but through perseverance and establishing credibility by demonstrating comprehensive shotcrete knowledge our ASA members have helped shotcrete reach new levels of acceptance.

Our efforts are showing great results. ASA staff worked with ACI Committee 318 to help get shotcrete directly included in the ACI 318-19, "Building Code Requirements for Structural Concrete". We are working with ACI Committee 301 to get shotcrete directly addressed in the "Specifications for Structural Concrete". ASA members are active participants on ACI Committee 506, Shotcreting, and all its subcommittees, as well as other ACI committees that deal with shotcrete. Our members are active in ASTM to get the shotcrete-related standards to properly address shotcrete as we routinely place today. We also have active participation in ICRI, AREMA, TRB, and AASHTO committees that potentially deal with shotcrete materials or applications.

We also recognize leadership through our Awards program. Every year we identify the projects that are the cream of the crop. Our award winners are leaders in the industry. They show by their creativity and hard work, how and why shotcrete placement is the method of choice for strength, quality, and durability in a wide variety of applications.

Finally, our Leadership for the shotcrete industry is exemplified by our volunteers. Our officers, Board, and committee members. These are the folks that give their time and expertise to move us forward as an Association. These are the folks who may sacrifice their individual gain for the good of ASA and the industry, understanding that what improves the quality and breath of acceptance in the industry ultimately improves their business. These are the folks who say, "Yes I'll help" and then do! Can you be one of our active volunteers? Definitely. Our committees are all listed at **shotcrete.org/pages/membership/committees.htm**. Voting membership is open to all individual and corporate members subject to approval by the committee chair. Just send us an email request to info@shotcrete.org and we can submit your name for consideration to the committee chair. My hat is off to all those who have volunteered their time to make us the great Association we are today! And hopefully with your involvement you too can help make us an even more awesome Association in the future.

Hudson River Park Repairs

By Tait Pirkle and Marcus Jeffreys

Hudson River Park (HRP) is a waterside park located along the Hudson River that is operated by Hudson River Park Trust. The trust was formed jointly by New York City and the state of New York. The 550 acre (223 ha) park spans 4.5 miles (7.2 km), from 59th Street to Battery Park. Notable piers in HRP include Pier 57 (Super Pier), Piers 59-62 (Chelsea Pier), and Pier 86 (Intrepid). Pier 40 at HRP is approximately 14 acres (6 ha) and is shaped like "a square donut." The center of the pier is a 400 x 400 ft (120 x 120 m) sports facility for soccer, baseball, lacrosse, and other sports. Surrounding the sports field is a 1700-car parking facility that is open to the public. There is another sports field and a trapeze located on the second level of the pier.

Fig. 1: A Type 3 repair after deteriorated concrete was removed

PIER 40 PHASE 2

Pier 40 extends 810 ft (247 m) into the Hudson River and was built on 3500 concrete-reinforced steel H-piles. Due to the large size of the pier, the work was broken into multiple phases. Trevcon Construction Co., Inc. was awarded Phase 2, which included piling and underdeck repairs. Eastco Shotcrete LLC, a subsidiary of Trevcon, was contracted to perform the underdeck work, which included beam, pile cap, underdeck, and crack injection repairs. Eastco Shotcrete performed 132 total repairs over the entire project. Most of the repairs were Type 2 (underdeck), Type 3 (beams), and Type 4 (pile caps).

The underdeck repairs required deteriorated concrete to be removed back to sound concrete. Any corroded reinforcement was removed and replaced with epoxy-coated reinforcement with the proper lap splice. Welded-wire reinforcement (2 x 2 in. [50 x 50 mm]) was installed using J-bolts and tie wire. After inspector approval, shotcrete was applied to the repair area with a minimum of a 2 in. cover over the reinforcement. The Type 2 repairs were difficult to reach from the stage floats and crews could typically access them for an hour or two each day due to the tides. Access normally occurred right after or right before high tide.

The Type 3 repairs, or beam repairs, called for the bottom and bottom corners of each beam to be repaired. The deteriorated beams were chipped back to sound concrete with a requirement to remove 1 in. (25 mm) around the reinforcement. The reinforcement was cleaned by abrasive blasting. All reinforcing stirrups that were deteriorated 25% or more were replaced using EZ-lock epoxy-coated couplers. A total of

Fig. 2: A Type 3 repair with preparation completed. The repair is awaiting the application of shotcrete

Fig. 3: An ACI Certified Nozzleman applying shotcrete to a Type 3 repair

approximately 200 couplers were installed on the job. A natural gun finish was applied to the final surface. Any overspray was cut back to the saw-cut line around the repaired area.

The Type 4 repair, or pile cap repairs, also required deteriorated concrete to be removed back to sound concrete. New reinforcement was required to be installed to form a new reinforcement cage. Epoxy-coated No. 5 bar was epoxy embedded 6 in. (150 mm) on center into the existing concrete. A bottom "U-bar" was installed with a 1 in. overlap of the vertical bars. Welded-wire reinforcement was installed and shotcrete was applied using a natural gun finish.

Eastco Access

To access the work, Eastco worked off stage floats. We used three different stage floats. The first type of stage float was a simple "bobber"—polystyrene roughly 6 in. thick was covered by 1/2 in. (13 mm) plywood and bolted together to create a lightweight, easily maneuverable float that could be operated by one person. The second stage float used was a 20 x 5 ft (6 x 2 m) stage float positioned at the base of a ladder so the crew could safely climb down the ladder to access the work. It was also used to access tough-to-reach work areas, as it was smaller than the working stage float. The third and final type of stage float was a 20 x 4 ft (6 x 1 m) float banded together to create a 20 x 8 ft stage float. This provided the crew plenty of work space and helped to accommodate the aggressive wake conditions of the Hudson River.

A common issue with marine construction is the necessity to work by the tides. The underdeck repairs could only

Fig. 4: A completed Type 4 repair

Fig. 5: Pier 40 as the tide shifts from low tide to high tide

be accessed 2 hours before low tide and 2 hours after low tide. This created a narrow window for the crew to be underneath the pier. These constraints necessitated that the crew operate at a high level of efficiency in that limited work time window to remain on schedule.

The inherent nature of the Hudson River contributed another powerful inhibiting factor to accessing the work. Eastco's work was located on the southwest corner of Pier 40, at the farthest point out of the pier. This left the crew exposed to not only the strong current of the Hudson but also to the wake of other vessels passing Pier 40. During ferry rush hour (8:00 to 10:00 a.m. and 5:00 p.m. to 7:00 p.m.), the wake was very strong and created hazardous conditions for our crew. Storms in the vicinity would also intensify the wake effects. To mitigate the hazardous wake and current of the Hudson, Eastco made the decision to work nights. This, for the most part, eliminated any wake from other vessels. The elimination of the wake and overall hazardous conditions was important on this project because most of the demolition and preparation were performed during the winter. The water temperature and ambient temperature on most nights were well below freezing and falling in the water could lead to hypothermia. The crew was required to wear dry diving suits to slow the development of hypothermia if an employee were to fall in the water. All jobsite actions were planned and implemented with the safety of the employees as the top priority.

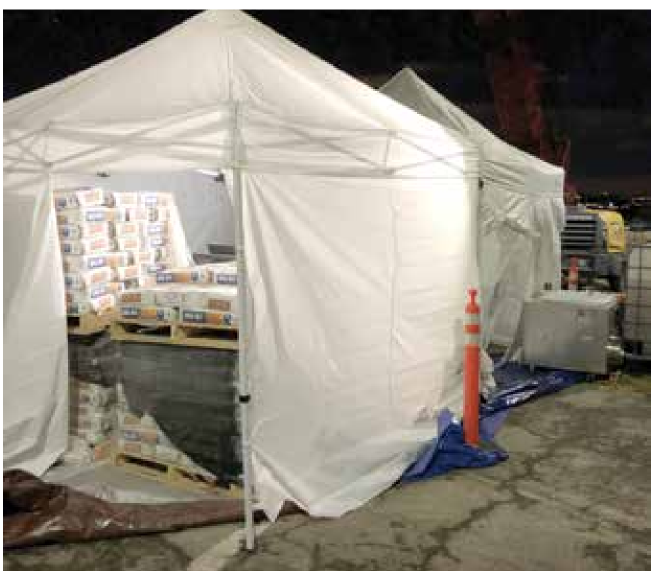


Fig. 6: A part of Eastco's laydown on the apron of Pier 40

Fig. 7: Eastco's barge used to access Pier 40

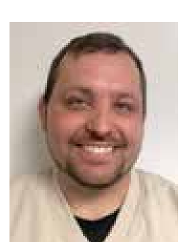
EASTCO EQUIPMENT LAYDOWN

For most of the job, Eastco had an air compressor, a dry-mix gun, water tanks, air lines, shotcrete hose, generators, and other equipment staged on the apron of the pier. With 3 weeks left to finish the job, Eastco was requested to remove all the equipment from the apron and return to the site with all the equipment staged on a barge. Within 2 days of receiving this request, a 30 x 80 ft (9 x 24 m) barge was loaded down with all the equipment and material needed to finish the job. A major issue that arose from using the barge was having all the material needed to finish the project onboard. This eliminated having to tug the barge back to Trevcon's yard to have it restocked with material. Each movement of the barge is extremely expensive and would have greatly increased the job costs.

SUCCESS OF PIER 40

Throughout the 4-month project, Eastco faced ups and downs, but overall the project was successful. Consisting of approximately 1200 ft^2 (110 m^2) of placed concrete, this project demonstrated the versatility, effectiveness, and efficiency shotcrete has over form-and-pour concrete. At no point in the project were forms required or used. This fact alone greatly reduced the costs for the owner. Hopefully, the hard, efficient work from Trevcon, Eastco, and Eastco's crew made a lasting impression on the Hudson River Park Trust and it will continue to see the benefits of marine facility shotcrete.

Tait Pirkle *is a Project Manager for Eastco Shotcrete, a New Jersey-based shotcrete contractor which specializes in marine and other rehabilitation projects. Working part-time in the field until his 2015 graduation from the University of Alabama, Tuscaloosa, AL, he now manages special projects for Eastco. He serves as Chair of the ASA Marketing Committee and is a member of the American Concrete Institute (ACI) and the International Concrete Repair Institute (ICRI).*



Marcus Jeffreys*, an ACI Certified Nozzleman in both wet- and dry-mix processes, has been in the industry since 2007. He became a certified nozzleman in 2010. He began working for Eastco Shotcrete in 2015, where he is a Field Supervisor and specializes in marine and other concrete rehabilitation projects.*

ICRI: 30 Years and Getting Stronger

The lack of standards and undertrained professionals are two factors that were key to the formation of the International Concrete Repair Institute, or as it is better known, ICRI. As professionals networked during the World of Concrete seminar in February 1988, the conversations took on a theme—frustration. The attendees expressed frustrations about the lack of standards and guidelines for concrete repair and concerns over the rush of contractors entering the industry without proper knowledge of surface preparation, equipment, materials, and techniques. In direct response to these concerns, the International Association of Concrete Repair Specialists (IACRS) was formed in May 1988, later changing its name to the International Concrete Repair Institute (ICRI). ICRI was founded with the vision to be the center for repair leadership supporting the profession by building on science and craftmanship, making the built world safer and longer lasting.

ICRI EVOLUTION

In the past 30 years, ICRI has evolved from a small organization to 2600 members around the world, including 38 chapters. Its global membership includes contractors, architects, engineers, manufacturers, distributors, owners, and other professionals with a common goal—prolonging the useful life of concrete through quality repair, restoration, and protection. ICRI is the only organization in the concrete industry devoted solely to repair and restoration practices and is a recognized authority in the field.

Fig. 1: ICRI has 38 chapters, including two student chapters, in metropolitan areas around the world

Fig. 2: ICRI conducts two conventions each year, in the spring and again in the fall, with an average attendance of 300 contractors, engineers, architects, consultants, manufacturers, students, and more

Fig. 3: Eighteen technical presentations are presented at both ICRI annual conventions

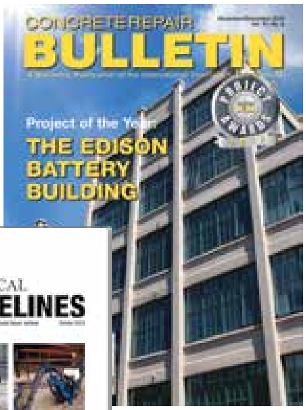


Fig. 4: ICRI's *Concrete Repair Bulletin* features technical articles on the repair, protection, and restoration of concrete structures and surfaces

Fig. 5: Included in the publications are the Concrete Surface Profile Chips and the Technical Guidelines, which are free to ICRI members

ICRI PROFESSIONAL DEVELOPMENT

ICRI provides many methods of helping industry professionals improve their companies and their careers. Over the years, members repeatedly report that networking is the number one benefit of ICRI membership. Conventions are held in the spring and fall each year with technical sessions, social events, and plenty of networking opportunities. Open to all levels of concrete professionals, these conventions are a great opportunity for concrete professionals to expand their network by meeting others in the concrete repair industry and increasing their understanding of concrete repair, protection, and restoration.

The *Concrete Repair Bulletin* (*CRB*), ICRI's bimonthly magazine, features technical articles focused exclusively on the concrete restoration and repair industry.

"ICRI educates and provides information and direction toward the future of the concrete repair industry," said longtime member Scott B. Harrison, Construction Insight, Inc. "After over 24 years of participation, ICRI continues to make a professional and personal impact in my life."

THE ICRI TECHNICAL STANDARD

ICRI serves as a clearinghouse of information on the concrete restoration and repair industry. The organization regularly publishes technical guidelines that provide best practice guidance for specifying and assessing, designing, planning, and executing concrete repair and masonry repair projects used across the industry. These guidelines include the popular "Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, Polymer Overlays, and Concrete Repair" and Concrete Surface Profile (CSP) Chips. All of ICRI's technical guidelines are developed by members and volunteers of ICRI, which include some of the brightest individuals in the industry.

ICRI 320.1R, "Guide for Selecting Application Methods for the Repair of Concrete Surfaces" has recently been updated, approved, and targeted for release this summer. Revisions here include defining the difference between low velocity work and shotcrete for the repair industry.

CERTIFICATION

Concrete Surface Repair Technician Certification Program

Alongside the educational presentations, publications, and conventions, ICRI provides two certification programs specifically crafted for concrete repair professionals. The first is the Concrete Surface Repair Technician (CSRT) Certification Program, open to professionals who are looking to become qualified as a concrete surface repair inspector. The program was developed based on industry demand and code language. ACI 562-16, "Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures" outlines repair inspector qualifications for the inspection of concrete repairs and designates an individual who has been certified as an ICRI Concrete Surface Repair Technician as a qualified inspector.

Concrete Slab Moisture Testing Technician Certification Program

The second certification program provided by ICRI is the Concrete Slab Moisture Testing Technician (CSMT) Certification Program. The purpose of this program is to help improve the performance of concrete slab moisture testing to result in more consistent, accurate, and reliable results that will help flooring manufacturers, architects, engineers, and contractors make better decisions as to when a concrete floor is ready for a floor covering installation.

ICRI COMPENSATION AND BENEFITS STUDY

In 2018, ICRI conducted a compensation and benefits study for the concrete repair industry. The results of the study help keep companies competitive in hiring new employees and fairly compensating existing employees. Information in the report includes:

- detailed wage information per specific job titles;
- staff profiles;
- overtime reports;
- insurance benefits;
- retirement plans;
- holiday, vacation, and sick/personal leave;
- transportation/commuting benefits; and
- additional financial benefits.

ICRI AND THE FUTURE

ICRI members are very proud of the organization they represent and know their membership brings with it a special camaraderie with the colleagues and a high level of responsibility to serve the industry. The past 30 years have been full of exponential growth and development both for the organization and the industry. As the concrete repair field evolves and changes, ICRI will continue to be at the forefront, providing industry setting standards and professional development.


LARGE JOB OR SMALL, WHATEVER THE APPLICATION AND MIX, WE HAVE THE RIGHT STYLE AND SIZE STATIONARY PUMP FOR MAXIMUM EFFICIENCY AND PROFITABILITY
INFO@OLINPUMP.COM
714 897 1230 X2
OLINPUMP®
CONCRETE - SHOTCRETE - GROUT
CATALINA PACIFIC
CAT
asa
PDCA
WWW.PILEDRIVERS.ORG
DEEP FOUNDATIONS INSTITUTE
DFI
CPMA

Compatible Shotcrete Specifications and Repair Materials

By William Clements and Kevin Robertson

Concrete repair projects can often be completed using a variety of different repair materials and methods, though in some cases, the specific performance requirements of a project may dictate use of a specific material or method. Shotcrete is often used as a repair method to replace other methods such as form-and-pour to reduce labor costs and accelerate the construction schedule. Shotcrete is the best method when access to the repair area is limited in location and availability (Fig. 1). In selecting a repair method, a repair material must then be selected that is compatible with the concrete substrate, durable in the expected exposure conditions, and meets the structural requirements detailed by the design professional responsible for the repair. Ideally, these important criteria would be evaluated by the design professional and incorporated into the project specification to address the specific requirements of the project based on the expected service life of the repair. However, some design professionals, in developing their project specifications, are not well informed about the specific details for quality shotcrete placement and may miss or overlook important repair criteria.

Fig. 1: Remote dam repair using dry-mix shotcrete and a cofferdam[1]

The service life of any repair depends on the repair material's successful bond to the substrate, resistance to the exposure conditions, and crack resistance while in service. Even if the repair material exhibits excellent durability properties, if cracks develop either in the repair material or around the perimeter of the repair area, they allow easier ingress of corrosive agents such as water and chlorides to the embedded reinforcing steel. Thus, when considering these factors, the repair material must be as compatible as possible with the substrate to reduce the potential for cracking.[2]

Specifications

As with most specifications in the construction industry, concrete repair specifications typically use either a prescriptive specification or a performance specification. Prescriptive specifications either reference the actual repair product(s) by name or the constituents or characteristics of the repair material. In contrast, a performance specification outlines the performance requirements of the repair material after placement in accordance with applicable standards. In general, there is currently a trend towards performance specifications, but in North America, both ACI 318[3] and CSA A23.1/A23.2[4] still use a hybrid method of both prescription and performance when classifying concrete.[5] There are cases where contractors prefer to submit an "or equal" alternative to prescribed products based on past experience. The contractor may propose the shotcrete method in lieu of form-and-pour. It can be simpler for a contractor to submit shotcrete placement for a performance specification, as the contractor and manufacturer simply need to display compliance with the project specification through the appropriate submittals to obtain approval. This process does become much more difficult however, when the project specification presents a product or certain performance criteria that do not match the typical test methods applicable to shotcrete. ACI 506.2-13, "Specification for Shotcrete"[6] includes mandatory provisions for the commonly tested performance characteristics such as compressive strength and flexural strength, noting that any hardened test samples must be produced from sprayed test panels. Unfortunately,

Table 1: Test Methods for Repair Mortars Compared to the Corresponding Method for Shotcrete

Property	Repair mortar test method	Repair mortar specimen type	Shotcrete test method	Shotcrete specimen type
Compressive strength	ASTM C109/ C109M[8]	Cast cube (2 x 2 in.)	ASTM C1604/ C1604M[7]	Core (3 in. Ø)
Flexural strength	ASTM C348[9]	Cast beam (1.5 x 1.5 x 6.5 in.)	ASTM C78/C78M[10]	Sawed beam (6 x 6 x 21 in.)
Splitting tensile strength	ASTM C496/ C496M[11]	Cast cylinder (4 x 8 in.)	ASTM C496/C496M[11] (modified)	Core (3 in. Ø)
Slant shear bond strength	ASTM C882/ C882M[12]	Cast cylinder (3 x 6 in., -30-degree incline)	ASTM C1583/C1583M[13] (Pulloff bond strength)	Tensile bond of core (3 in. Ø)

Note: 1 in. = 25 mm

it is common to see specifications or even technical data sheets from manufacturers of shotcrete materials showing results for test methods applicable to repair mortars and not for shotcrete. For example, the compressive strength of shotcrete should always be evaluated in accordance with ASTM C1604/C1604M,[7] but it is typical for manufacturers to present data in accordance with ASTM C109/C109M.[8] ASTM C109/C109M involves manually consolidating shotcrete mortar into cube molds, as opposed to being shot, and is not representative of the in-place shotcrete that is compacted by high-velocity impact. An example of commonly specified test methods in a shotcrete repair specification compared to the corresponding applicable test method for shotcrete is presented in Table 1.

A common misconception when it comes to current shotcrete specifications for repair projects is where "low-velocity mortar spray" or "low-pressure mortar spray" is somehow considered equal to high-velocity dry-mix or wet-mix shotcrete. As noted in Table 1, the adapted ASTM test methods for compressive strength, flexural strength, and other test methods differentiate shotcrete from mortar. Low-velocity spraying involves pumping at a lower pressure and air flow than conventional wet-mix shotcrete, resulting in a much lower velocity placement. The main difference between both methods is the velocity at which the material is shot into place. Shotcrete has been characterized to travel at speeds of 45 to 78 mph (72 to 125 km/h), which produces a high impact force and fully consolidates the concrete in-place. Conversely, low-velocity mortar spray was developed and is essentially a method to replace hand-troweling of a repair material.[14] Low-velocity mortar spraying simply lacks the velocity required to fully encapsulate reinforcing steel and even wire mesh in most cases. In some of North America's construction markets, the shotcrete method has been given a bad reputation because the specifications have been written around low-velocity mortar spraying that was considered to be "as equal" to shotcrete. Both methods have their place in the repair industry depending on the type of repairs to be completed. When designing repairs that use wire mesh or reinforcing steel, high-velocity shotcrete must be used to have the ability to properly encapsulate the embedded reinforcing steel and not create voids behind the steel.

The shotcrete process selected can impact the mixture design of the concrete materials being shot. Wet-mix shotcrete materials must be pumped through the delivery pipe and hose prior to spraying. Wet-mix shotcrete commonly contains an air-entraining admixture to either provide durability in freezing-and-thawing environments, or to improve the pumpability of the material using the "high initial air content concept".[15] Using a high initial air content ranging from 10 to 20%, the "high initial air content concept" has been proven to increase the slump and pumpability of shotcrete during pumping, and due to high velocity impact of the shotcrete produce an in-place air content of 3 to 5% in place after shooting. In the case of dry-mix shotcrete where water is added at the nozzle, it is impossible to ascertain the air content because the concrete materials are not mixed to form the cement paste until water is added at the nozzle. Therefore, any test results presented for the mechanical and durability properties of a shotcrete repair material, whether wet-mix or dry-mix, should be from as-shot samples.

ADAPTING TEST METHODS TO THE SHOTCRETE PROCESS

The International Concrete Repair Institute (ICRI) technical data sheet protocol established in ICRI Guideline No. 320.3R,[16] provides a thorough list of both mechanical and durability parameters that should be provided on the technical data sheet of any repair material. Although the guideline details which ASTM standard test method should be followed for mortars and which methods should be followed for concrete, some adaptations are required when applying the protocol to a shotcrete material. Considering most of the test methods described in ICRI Guideline No. 320.3R and noted in Table 1 reoccur in concrete repair specifications from the industry, KING enlisted Laval University to execute a testing program for the required parameters using a silica fume-enhanced dry-mix shotcrete (KING MS-D1). All of the samples tested were obtained from coring or sawing conventional test panels (Fig. 2), spraying shotcrete onto previously cast concrete sections, or by

Table 2: Adapted Test Methods for Shotcrete using ICRI Guideline No. 320.3R

Property	Test method	Sample type	Result (28 days)
Flexural strength	ASTM C78/C78M	Sawed beam (6 x 6 x 21 in.)	1088 psi (7.5 MPa)
Splitting tensile strength	ASTM C496/C496M	Core (3 in. Ø)	645 psi (4.45 MPa)
Direct tensile strength	CRD-C 164[17]	Core (3 in. Ø)	500 psi (3.45 MPa)
Modulus of elasticity	ASTM C469/C469M[18]	Core (3 in. Ø)	4.2 x 10^6 psi (29.0 GPa)
Pulloff bond strength	ASTM C1583/C1583M	Tensile bond of core (3 in. Ø)	420 psi (2.9 MPa)
Slant shear bond strength	ASTM C882/C882M	Core (3 in. Ø-30-degree incline)	3335 psi (23.0 MPa)
Length change	ASTM C157/C157M[19]	Sawed beam (3 x 3 x 11.25 in.)	50% RH: -0.0494% 100% RH: +0.0122%
Coefficient of thermal expansion	CRD-C 39[20]	Core (3 in. Ø)	6.5 x 10^{-6}/°F (11.7 x 10^{-6}/°C)
Freezing-and-thawing	ASTM C666/C666M[21]	Sawed beam (3 x 3 x 11.25 in.)	100% durability factor
Salt scaling	ASTM C672/C672M[22]	Sawed slab (72 in.^{2} surface)	0.04 lb/ft^2 (0.2 kg/m^2)
Chloride ion penetrability	ASTM C1202[23]	Core (4 in. Ø)	500 Coulombs

Note: 1 in. = 25 mm; 1 MPa = 145 psi

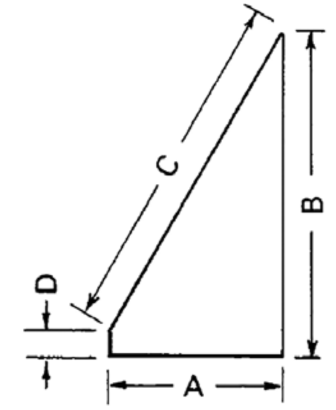
spraying oversized test samples for durability testing and then sawing the edges around the perimeter of the samples to remove sections of rebound and overspray.

The Slant Shear Bond Strength test (ASTM C882/C882M) was originally developed to test the bond strength of epoxy between two cast mortar sections. The concrete repair industry has since adopted a modified version of the test, wherein the concrete repair material is placed onto the hardened mortar dummy (Fig. 3) and then the composite cylinder is tested in compression.

The resulting load on the cylinder is divided by the area of the ellipse, resulting in a shear bond strength along the 30-degree plane of the bonding surface. To modify the test method to the shotcrete process, a concrete section was cast using the appropriate angle (Fig. 4), and then shotcrete was sprayed onto the concrete section. Cores were taken perpendicular to top surface of the composite sample to model the shotcrete being cast onto the mortar dummy as per the standard (Fig. 5).

Following the completion of the test program, it is apparent that most test methods for concrete materials can be adapted to the shotcrete process, although in some cases execution is more complicated. Table 2 presents the results of the testing program. When compared to typical requirements for concrete, it can be seen that dry-mix shotcrete is an excellent concrete repair material. Notably, the bond strength exhibited by the ASTM C882/C882M test samples were very high, and two of the five cores tested at 28 days

Fig. 2: Conventional square shotcrete test panels used for obtaining cores



	in.	mm
A—Diameter	3.000	[75±2]
B—Height	5.598	[140±2]
C—Slant height	6.000	[150±2]
D—Base height	0.402	[10±2]

Dimensions

Fig. 3: Schematic of slant shear dummy section (ASTM C882/C882M)

failed with multiple vertical cracks as opposed to failing along the bond line.

DEVELOPING COMPATIBLE DRY-MIX SHOTCRETE

Almost all reinforced concrete structures will require some maintenance during their expected service life. The type and extent of repairs needed are a function of the structure's age, exposure conditions, original design, construction methods, and building materials used. Where possible, it is best to replace any concrete that is removed from the structure with a repair material that has physical properties similar to the substrate, such as compressive strength, modulus of elasticity, and coefficient of thermal expansion. This helps reduce potential debonding by ensuring that any physical movement, either due to loading or temperature changes in the substrate, are mirrored in the repair material. These properties do not, however, predict the inevitable volume change that a concrete repair material will undergo once in place. This volume change is a complex combination of chemical/autogenous shrinkage of the cement paste, drying shrinkage from moisture loss, and tensile creep (relaxation). Once the tensile forces of shrinkage exceed the tensile strength of the material, internal cracking can occur. If the tensile shrinkage forces exceed the bond strength of the repair material to the substrate, cracking can occur at the perimeter of the repair.

Even though shotcrete is very similar once shot to form-and-pour concrete, the shotcrete mixture design must be tailored to the process to facilitate pumping, optimize build-up while spraying, and to reduce rebound. The use of silica fume in shotcrete can greatly reduce rebound, increase build-up thickness, increase compressive strength, and reduce permeability.[24] Conversely, silica fume, with its high water demand, requires swift and proper wet curing techniques after shooting that if not followed will increase drying shrinkage and can increase the risk of cracking. To reduce the potential for shrinkage and improve compatibility, it may be beneficial to remove silica fume from the dry-mix shotcrete formulation, but the loss of productivity and efficiency due to increased rebound in the field would generally not be acceptable. Some potential techniques for reducing the shrinkage potential in shotcrete materials include the use of coarse aggregate, reducing the cementitious content, replacing portland cement with fly ash, and using polymer. To evaluate the effectiveness of these approaches to resist shrinkage potential requires a test method that captures all of the parameters noted previously as the shotcrete undergoes volume change.

Currently, the best test method for predicting the risk of cracking in a repair material is the AASHTO T 344[25] standard test method (ring test), which has recently been adapted to the shotcrete process at Laval University.[26] The method involves spraying shotcrete into a steel ring mold, which is mounted in an inclined overhead position to allow rebound to escape the mold (Fig. 6).

Following moist curing, the shotcrete ring is placed in a controlled environment at 50% (±5%) relative humidity and a temperature of 70 ± 2°F (21 ± 1°C). The stress developed

Fig. 4: Inclined precast mold for slant shear bond strength testing (ASTM C882/C882M)

Fig. 5: Composite core for slant shear bond strength testing (ASTM C882/C882M)

Fig. 6: Shotcrete being sprayed into inclined AASHTO T 344 rings

in the shotcrete ring is monitored using a data acquisition system, wherein cracking potential is then calculated as a function of the average stress developed and the age at which cracking occurs. Using a wet curing period of 3 days followed by drying, several mixture designs along with a proprietary mixture design developed by KING (HC-D1) were compared using the ring test to evaluate cracking potential.[27] The formula used and the age of cracking for each mixture design is presented in Table 3.

Conclusions

The shotcrete process can be used to achieve compatible concrete repairs offering a long service life. The combination of specifying the correct physical properties (test methods) and using the right shotcrete material helps achieve success in the field. The mechanical and durability properties of shotcrete should always be determined using samples that are shot and not cast, by adapting any applicable standards to the shotcrete process. The development of a highly

Table 3: Age of Cracking for Different Dry-Mix Shotcrete Formulas

Mix no.	Cement content (%)	Coarse aggregate (%)	Silica fume (%)	Fly ash (%)	Polymer (%)	Age of cracking AASHTO T 344 (days)
1	21	15	0	0	0	25
2	18.9	15	2.1	0	0	9
3	19.4	15	1.6	0	0	6.5
4	14.4	15	1.6	5	0	6
5	19.4	15	1.6	0	2.0	7
6 (HC-D1)	*	*	*	*	*	40

**Proprietary mixture design*
Note: The remainder of the formula consisted of sand

compatible dry-mix shotcrete with a very low cracking potential shows promise and testing of the other key properties as described in this article are currently underway.

References

1. Côté, R.; Ferland, H.; and Robertson, K., "McCormick Dam & Power Station: Submerged Concrete Repairs," *Shotcrete*, V. 17, No. 1, Winter 2015, pp. 36-39.

2. McDonald, J.E.; Vaysburd, A.M.; Emmons, P.H.; Poston, R.W.; and Kesner, K.E., "Selecting Durable Repair Materials: Performance Criteria–Summary," *Concrete International*, V. 24, No. 1, Jan. 2002, pp. 37-44.

3. 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.

4. CSA A23.1/A23.2, "Concrete Materials and Methods of Concrete Construction/Test Methods and Standard Practices for Concrete," CSA Group, Mississauga, ON, Canada, 693 pp.

5. Tanesi, J.; Da Silva, M.G.; Gomes, V.; and Camarini, G., "From prescription to performance: international trends on concrete specifications and the Brazilian perspective," *IBRACON Structural and Materials Journal*, V. 3, No. 4, Dec. 2010, pp. 420-431.

6. ACI Committee 506, "Specification for Shotcrete (ACI 506.2-13)," American Concrete Institute Farmington Hills, MI, 2014, 12 pp.

7. ASTM C1604/C1604M, "Standard Test Method for Obtaining and Testing Drilled Cores of Shotcrete," ASTM International, West Conshohocken, PA, 5 pp.

8. ASTM C109/C109M, "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)," ASTM International, West Conshohocken, PA, 10 pp.

9. ASTM C348, "Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars," ASTM International, West Conshohocken, PA, 6 pp.

10. ASTM C78/C78M, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading," ASTM International, West Conshohocken, PA, 5 pp.

11. ASTM C496/C496M, "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," ASTM International, West Conshohocken, PA, 5 pp.

12. ASTM C882/C882M, "Standard Test Method for Bond Strength of Epoxy-Resin Systems Used With Concrete By Slant Shear," ASTM International, West Conshohocken, PA, 4 pp.

13. ASTM C1583/C1583M, "Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)," ASTM International, West Conshohocken, PA, 4 pp.

14. Hanskat, C., "Pneumatically Applied Concrete: A Confusion of Terminology," *Shotcrete*, V. 18, No. 4, Fall 2016, pp. 22-25.

15. Jolin, M., and Ginouse, N., "Recent Research in Wet-Mix Shotcrete at Laval University," 3 Congresso Brasileiro de Tuneis E Estruturas Subterraneas, 2012, São Paulo, Brazil, p. 19.

16. ICRI 320.3R,"Guideline for Inorganic Repair Material Data Sheet Protocol," International Concrete Repair Institute, Inc., St. Paul, MN, 9 pp.

17. CRD-C 164-92, "Standard Test Method for Direct Tensile Strength of Cylindrical Concrete or Mortar Specimens," US Army Corps of Engineers, Washington, DC, 4 pp.

18. ASTM C469/C469M, "Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression," ASTM International, West Conshohocken, PA, 5 pp.

19. ASTM C157/C157M, "Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete," ASTM International, West Conshohocken, PA, 8 pp.

20. CRD-C 39-81, "Test Method for Coefficient of Linear Thermal Expansion of Concrete," US Army Corps of Engineers, Washington, DC, 2 pp.

21. ASTM C666/C666M, "Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing," ASTM International, West Conshohocken, PA, 7 pp.

22. ASTM C672/C672M, "Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals," ASTM International, West Conshohocken, PA, 3 pp.

23. ASTM C1202, "Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration," ASTM International, West Conshohocken, PA, 8 pp.

24. Wolseifer, J., and Morgan, D.R., "Silica Fume in Shotcrete," *Concrete International*, V. 15, No. 4, Apr. 1993, pp. 34-39.

25. AASHTO T 344, "Standard Method of Test for Estimating the Cracking Tendency of Concrete," American Association of State and Highway Transportation Officials, Washington, DC, 6 pp.

26. Girard, S.; Jolin, M.; Bissonnette, B.; and Lemay, J-D, "Measuring the Cracking Potential of Shotcrete," *Concrete International*, V. 39, No. 8, Aug. 2018, pp. 44-48.

27. Menu, B.; Pépin Beaudet, A.; Jolin, M.; Bissonnette, B.; and Molez, L., "Évaluation quantitative de la sensibilite a la fissuration du beton projeté au moyen de l'essai de retrait restreint annulaire," 19e Edition des Journées scientifiques du Regroupement Francophone pour la Recherche et la Formation sur le Béton (RF)^{2}B, July 2018, Anglet, France, 10 pp.

***William Clements** is Engineering Services Manager for King Packaged Materials Company, where he is responsible for all mixture design development, quality control, and technical support. He received his bachelor's and master's degrees in civil engineering from the University of Windsor, Windsor, ON, Canada. He is a member of the American Concrete Institute (ACI); a member of ACI Committee 239, Ultra-High-Performance Concrete; and ACI Subcommittees 239-D, Materials & Methods of Construction with UHPC, and 546-D, Packaged Repair Materials.*

***Kevin Robertson** is the Business Development Manager, U.S. Markets for King Packaged Materials Company. For the past 12 years, he has played a key role in the growth of KING's concrete rehabilitation, civil, and tunneling business in Eastern Ontario, Quebec, and U.S. Markets. His areas of expertise include shotcrete materials, application, and equipment for all shotcrete applications. Robertson is a member of the American Shotcrete Association (ASA), the American Concrete Institute (ACI), and is on the Board of Directors of the International Concrete Repair Institute (ICRI) as the Region 4 Representative. He is a member of ICRI Committee 320, Concrete Repair Materials and Methods.*

Concrete Repairs of the Wright Memorial Bridge

By Michael LaPrade

The Wright Memorial Bridge has served as the gateway to the sunny beaches of the iconic Outer Banks of North Carolina for millions of vacationers since 1930. The bridge crosses roughly 3 miles (5 km) across the Albemarle Sound between the towns of Currituck and Kitty Hawk. The first bridge, completed in 1930, was an entirely wooden toll bridge, which replaced a ferry. As the Outer Banks gained in popularity and traffic flows increased, it became abundantly clear that an update was in order. In 1966, the "new" Wright Memorial Bridge was built and opened to traffic. This upgraded bridge allowed beachgoers to travel at speeds of 55 mph (89 km/h). A second bridge to serve westbound travelers was completed in 1995, resulting in two lanes of traffic in both directions. The older, now eastbound, bridge was determined to be in need of repairs by the North Carolina Department of Transportation (NCDOT). Flatiron Constructors Inc. won the bid for the project and brought in Coastal Gunite Construction to provide the substructure concrete repairs and the installation of cathodic protection on the bent caps.

Selecting Shotcrete for the Repair Method

Spalled concrete and damaged reinforcing steel were prevalent throughout the entire structure. Indeed, the need for repairs was far more extensive than originally determined. Coastal Gunite and the NCDOT agreed that shotcrete was a superior method of repair for all the damaged concrete including the prestressed girders that were originally specified to be repaired using form-and-pour methods. This change allowed for a more efficient and cost-effective high-quality repair.

US Concrete Products, operating out of Timonium, MD, provided a dry-process shotcrete mixture that was specifically designed to work with cathodic protection systems. A reduction in fly ash in its standard prebagged dry-mix shotcrete product allowed for increased permeability while maintaining an acceptable design strength. This mixture was used to repair the concrete of the bent caps prior to surface metalizing operations. The metalizing operations had a strict 10-day waiting period after a cap was shot, before molten

Fig. 1: The Wright Memorial Bridge

Fig. 2: Repair location on bent cap

Fig. 4: Coastal Gunite Construction Company and Inspector testing for continuity

Fig. 3: Nozzlemen shooting back damaged bent cap

Fig. 5: Preparing to apply zinc anode

zinc could be applied. This timetable, paired with numerous other subcontractor operations, created an environment that required detailed coordination and planning.

CATHODIC PROTECTION

The cathodic protection for the bent caps was installed in three phases after completion of the underlying concrete repairs. First, electrical continuity had to be established to each reinforcing bar in the bent cap. Using a reinforcing bar finder, every reinforcing bar was located, and a hole drilled through the concrete to it. An electrical multimeter was then used to determine if each bar was electrically continuous with the others in the cap. If not, the bars were connected by resistance welding steel wire between the individual members until continuity could be established throughout the cap reinforcement. To establish an electrical connection between the existing reinforcing steel and the zinc coating to be installed in the metalizing, threaded rods were tapped into selected reinforcing bars on each side of the cap and fitted with a metalized plate. These locations will also be used to test for electrical continuity and to observe the condition of the reinforcing steel in the future. The second phase consisted of applying a 16 to 18 mil (0.4 to 0.5 mm) coating of zinc using thermal spray equipment to project

Fig. 6: Finished application of zinc anode and testing plate

atomized zinc onto the surface where it cools in a uniform coating. The third and final phase was to apply a zinc silicate topcoat, applied with paint spraying equipment.

PROVIDING ACCESS TO THE PROJECT

Access to the underdeck, bent caps, and girders was achieved using a couple of Anderson Hydra-Platform trailer-mounted under-bridge access machines and working from the water as well. Coordinating with other contractors to perform the work on top of the bridge required Coastal Gunite to work from the water; equipment was staged on two 10 x 20 ft (3 x 6 m) barges that were married together. Rough water conditions were common, limiting the use of the barges as stable work platforms, so a swing stage was suspended from the parapet walls of the bridge to provide a suitable work access to the bent caps. Multiple scaffold hangers were installed when bridge deck access was limited so that the scaffolding sets themselves could be moved around from the water level. This system allowed the contractors on site to work efficiently and decrease the total duration of the project and limit inconvenience to travelers.

WEATHER CHALLENGES

Several severe weather events impacted the project. In the winter of 2018, record low temperatures caused the Albemarle Sound to completely freeze over, something no locals could recall happening before. This made work from the water impossible and stalled all but the concrete removal operations. The job was also plagued by two different tropical storms.

Hurricane Florence hit the Carolina coast in mid-September and caused storm surges and high winds at the Wright

Fig. 7: Anderson Hydra-Platform Bridge Access Machines in use

Memorial Bridge. Advanced warning systems allowed Coastal Gunite to properly secure and evacuate all personnel, equipment, and materials well in advance of the storm. Although Hurricane Florence had devastating impacts in North Carolina further south, the project was able to resume afterwards relatively unscathed. Hurricane Michael, which after crossing over land from the gulf coast, hit the project unexpectedly hard from the west resulting in far more equipment damage, cleanup, and delays. Scaffolding still staged under the bridge was especially hard hit despite it being secured before the storm.

Conclusions

Vacationers on the Outer Banks this season will enjoy safe access to the beaches unencumbered over a bridge which, thanks to the recent repairs, should enjoy a much longer service life. Due to the limited access and required coordination with other contractors, the flexible and nimble repairs that shotcrete enabled facilitated the swift execution of the project. The use of shotcrete in combination with thermal zinc spray cathodic protection systems provide a product that will sustain the bridge far into the future.

Michael LaPrade *is a Project Manager for Coastal Gunite Construction Company and a graduate of the Virginia Military Institute. He has managed concrete rehabilitation jobs from Maryland to North Carolina. He is currently overseeing bridge rehabilitation on the coasts of North Carolina.*

Fig. 8: Barge system for metalizing operations

Fig. 9: Swing stage scaffolding

Swimming Pool Renovation with Shotcrete

By Bill Drakeley

The major renovation of a pool structure is never an easy undertaking. Determining the quality of the in-place concrete is an art in and of itself. Concrete quality, surface textures, finish coats, and polyvinyl chloride (PVC) and hydraulic considerations make renovating an existing pool quite challenging. The question of when and where to use proper concrete applications on the pool adds to the fact that pool renovation is not for the faint of heart. Now, admittedly, the pool industry propagates, breeds, and promotes self-proclaimed contractors who are experts without any expertise or quality experience for that matter. Countless times, we see concrete pool renovations where a "licensed" (I use this term lightly) contractor will place new concrete walls or sections to areas of an older pool where original concrete was removed. This replacement of material is set without proper substrate preparation, required bond characteristics, proper reinforcement placement, or an understanding of cold joints. A year or two later, the owner is left with a crack from debonding at the interface between the existing and new material. This crack permeates through the pool plaster cementitious finish, often showing leaching or efflorescence, and the client becomes irate with the repair contractor after spending a good sum of money only to experience the same cracking issues they probably had before.

UNDERSTANDING THE SHOTCRETE PROCESS

Understanding the use of shotcrete placement and its benefits will enhance the quality and durability of pool structural renovation. Even contractors who don't necessarily grasp the fine details of marrying two concrete installations together can benefit from using shotcrete placement and its inherent monolithic properties.

THE CONNECTICUT PROJECT

Shotcrete was the only answer to a renovation proposition we received from a client in an affluent Connecticut neighborhood, bordering the State Capitol. The streets are

Fig. 1: Close-up of raised bond beam with supplemental reinforcing and roughened substrate

populated with historic homes featuring grand architecture and design that have stood the test of time. With a homestead steeped in history, our client's back yard featured a pool that was at one time considered a jewel in the neighborhood. The structure was an outdated kidney shape with a leaking tile line and structural cracking. The renovation approach with the homeowner was to review the condition of the pool; test the hydraulic lines; assess turnover and functionality of the water in transit to determine water, electrical, and fuel consumptions; and compare this to a new sustainable and energy-efficient watershape. We also proposed removal of all the finished masonry materials to examine the core concrete structure. The goal was to have the information and data necessary to make a recommendation to the owners regarding one simple question: "Is the pool concrete structure worth building and renovating or is it too deteriorated to put money into?" With the understanding that the renovation of an existing structure in aggregate can cost as much as six figures, the answer to this question was extremely important. Our company completed the analysis of the pool systems and found that the pool concrete was deteriorated, but almost 70% of the structure was intact. Our crews and staff determined that the hydraulics, filtration, lighting, and decking were not worth saving and were to be removed and replaced. With this information gathered, the conversation with the owner was straight forward and direct. In the end, it came down to two parts:

- Can this pool be revived to today's standards? and
- What is the cost difference between this total renovation and a new pool?

As an experienced pool contractor, one must anticipate these questions and have quality arguments for both.

THE DECISION TO RENOVATE

As a conservationist myself, I was delighted to report that the freeform pool, originally constructed in the early 1960s with dry-mix shotcrete, could be renovated with wet-mix shotcrete. The owner agreed to this approach and we began the demolition and removal phase.

DEMOLITION PHASE

The demolition phase started by pumping water out of the pool in preparation for sandblasting the entire shell. During the demolition, all materials were removed from the concrete walls, including the tile line. We core drilled the original main drains and removed all PVC and metal fittings, sumps, and suction lines. Subgrade soil was evaluated for suitability, and the concrete shell was hammer sounded to identify potential delaminations or near surface voids. We then chipped out and removed porous or deteriorated concrete, cleaned or replaced any significantly rusted reinforcing steel within the concrete shell, and removed the decking and substrate around the pool area.

EXCAVATION PHASE

Once demolition was complete, we began the excavation phase. First, soils were removed from around the pool shell for trenching and new piping. This also helped to expose areas with previously undetected deterioration on the exterior of the pool shell. The dewatering well for groundwater control that had been buried for some time was located. Drainage trenching was dug for the entire pool and deck area to help alleviate frost and soil movement. The clay/silty soils surrounding the pool were not conducive to drainage and posed an issue that would have put additional lateral pressure against the pool shell and walls during the winter.

The original project estimate included an average of 1 ft^3 (0.03 m^3) of concrete removal in the pool bond beam. This was estimated due to the fact that the pool held water up to the bottom of the tile line. Interior concrete degradation followed this line around the perimeter. However, once exposed, the back of the pool walls (installed at an angle more than 11 degrees from vertical) was essentially deteriorating from the backside. The moist soils and more than 50 years of frost pressures had penetrated the back of the bond beam, exposed and corroded the No. 3 reinforcing steel, and deteriorated the concrete. This deterioration was shown to the owner and we explained that this was not expected based on our original findings. However, the majority of the shell was still a fit for renovation and we agreed to proceed with our current plan. We continued to chip and remove concrete on the backside of the pool shell, leaving a distance of 6 in. (150 mm) in thickness into the old bond beam and extending down to the walls between 2 and 4 ft (0.6 and 1.2 m).

For the pool hydraulic system, new fittings, skimmers, main drains, PVC piping, and an updated filter system were installed to improve hydraulic flow. We continued by leveling off the pool area, then setting grades and pitch. A new granite coping was installed directly to the new bond beam, and the surrounding area included matching granite decking sitting on the new sub-base and connected to the new pool coping. Drainage was installed for the decking, and new anchors for oversized shade umbrellas were set in the decking. Our tile installer then prepped the bond beam area,

Fig. 2: Kidney-shaped pool during restoration

steps, and bench; then installed a new 3/4 in. (19 mm) Italian glass tile in a custom blend.

Once existing concrete was exposed, we inserted steel pins and tied No. 4 bars to supplement reinforcing in the existing concrete. We also added new steps and deep end benches to help ease access for the client and their new grandchildren. Knowing the old pool elevations, we took advantage of the existing riser heights on the adjacent back porch steps and raised the depths and bond beam elevations of the pool which helped with concrete coverage and pool water depths. This added approximately 8 in. (200 mm) to the top of the pool walls.

The pool bond beam was roughened to create an excellent surface for the paste-rich, high-impact shotcrete materials to create an excellent bond. Once the reinforcing steel and substrate were prepped and the concrete in a saturated surface dry (SSD) condition, wet-mix shotcrete was placed. The concrete mixture design specification was 6000 psi (41 MPa) compressive strength at 28 days (refer to ASA Position Statement #1 at **www.shotcrete.org/media/pdf/ASAPositionPaper_PoolRec_1.pdf**). The shotcrete delivery system used a 375 ft^3/min (11 m^3/min) compressor with 2 in. (50 mm) hoses and a 2 in. rubber nozzle tip. The distance to the receiving surface was 2 to 4 ft at most. The shooting process consisted of the pool's interior steps, step-out bench, bond beam, and the exterior walls, bringing the wall thickness to 12 to 14 in. (300 to 350 mm) as needed. Shotcrete placement facilitated a monolithic section, which was achieved with no bonding agents, expansion joints, and cold joints (refer to ASA Position Statement #5 at **www.shotcrete.org/media/pdf/ASAPositionPaper_PoolRec_5.pdf**). We took advantage of access to groundwater and wet cured the new concrete for 14 days by constantly pumping groundwater onto the new concrete surfaces.

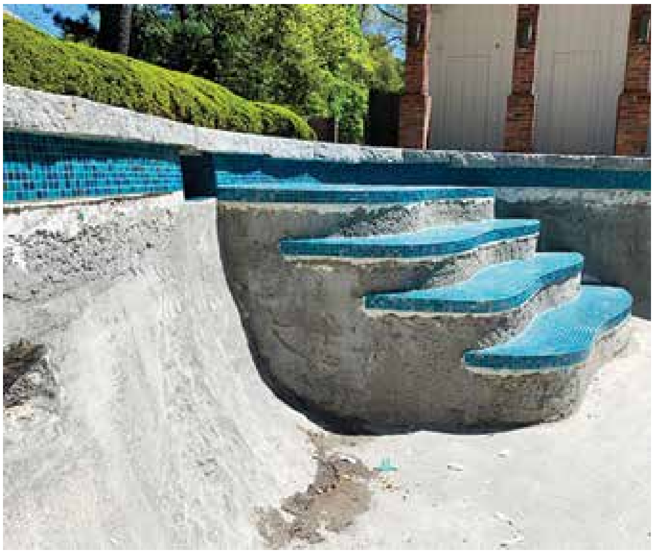


Fig. 3: Interlocking three-dimensional bond plane between new shotcrete and existing shotcrete

EXAMINING THE RESULTS

It was important for both us and the client to examine the results from the first winter freezing pressures against the pool shell. We removed the pool cover to inspect the connection and bond plane between the old pool concrete and the new shotcreted sections. The connection was intact and withstood all the pressures from the tough northeast winter weather. This was a key point not only of the pool shell's future durability, but also to highlight what we teach each year in industry classes and seminars. Watershape education needs to be precise and thorough, paying close attention to the details, and clients need to have confidence in their contractor. As a point person for our company, anything that I claim or promote to the client needs to be proven. This answers any questions and assures all parties involved that the investment was worth the time and money spent.

As our crews prep the concrete shell for future plaster and tile, we need to remain cognizant of the existing surfaces. Much like the existing concrete gets prepped for shotcrete placement, the existing concrete surface scheduled to receive plaster or tile needs to be significantly roughened for a good bond. Pressure washing, chemical cleaning,

Fig. 4: Installation of waterproofing coat

Fig. 5: Finished pool after renovation

and roughening of the existing substrate significantly increases the surface area and thus enhances the grab or bond of new hand-applied coatings. In this case, we will install a surface waterproofing agent to the entire shell as a redundant system. I am a huge proponent of not using these additives on top of high-quality concrete produced by the shotcrete process, particularly on new pools with surface texture consistency. Our current shell now has two different surface textures: the new wet-mix shotcrete with 3/8 in. (9 mm) aggregate, and the existing pool surface of dry-mix shotcrete with 1/4 in. (6 mm) aggregate. Applying a cementitious waterproofing membrane (like Basecrete) was done to bridge the textures and allow the final plaster coat to adhere and cure consistently over 100% of the pool interior. We are not using this technique for watertightness, but rather for aesthetics and plaster uniformity only.

Conclusions

The pool will be plastered and started up in the coming weeks, and our clients will most likely be enjoying their new space at the time of publication. As it stands now, the pool lacks a seam between the two concrete installations and acts together monolithically, providing complete

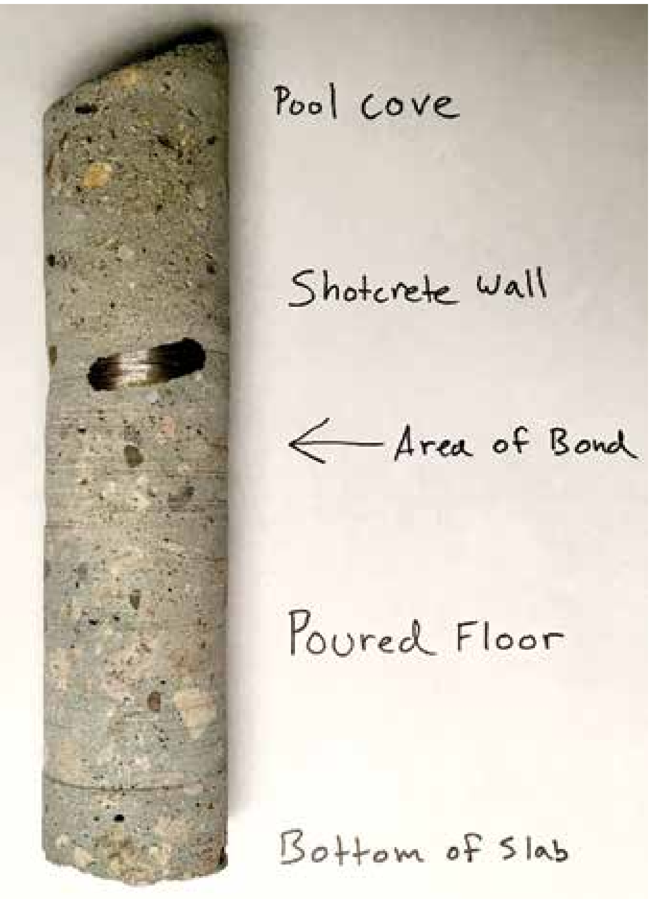


Fig. 6: Core demonstrating excellent bond of shotcrete to a poured floor

watertightness prior to any surface application (refer to ASA Position Statement #4 at **www.shotcrete.org/media/pdf/ASAPositionPaper_PoolRec_4.pdf**). Chronicling phases of implementation as they happen always seems to keep us on our feet, and hopefully does the same for those of you reading this. Stay tuned for the final result as we restore this pool's former title of neighborhood jewel.

Bill Drakeley *is Principal and Owner of Drakeley Industries and Drakeley Pool Company. Drakeley holds the distinction of being the first and only member of American Concrete Institute (ACI) Committee 506, Shotcreting, from the pool industry. He is also an approved Examiner for the ACI Certified Nozzleman program on behalf of ASA, 2016 President of ASA, an ASA Technical Adviser, a Genesis 3 Platinum member, and a member of the Society of Watershape Designers as well as Chairman of its Advisory Board. Drakeley teaches courses on shotcrete applications at the Genesis 3 Construction School, World of Concrete, and numerous other trade shows. He is a contributor to* Shotcrete *magazine and other industry publications. Drakeley is a member of the ASA Pool & Recreational Shotcrete and Underground Committees.*

Tourism Versus Shotcrete

By Jason Myers

Fisherman's Wharf is one of the major tourist attractions in San Francisco, CA, and doing a shotcrete project underneath the hub of San Francisco's tourism is a unique challenge. Pier 31.5 sits between the tourism Mecca of Pier 39, the new cruise terminal at Pier 27, and the embarkation point for Alcatraz at Pier 33. When the rehabilitation of Pier 31.5 is complete, the next phase of the project will start making a new embarkation point for Alcatraz along with a civic plaza and historical area. Pier 31.5 was constructed in 1918 and has had many modifications and repairs over its decades of use. It was determined in 2015 that a major rehabilitation and repurposing was required of the Pier and of the entire Wharf area. During the investigation stage, it was found that major concrete repairs were required to the substructure and Dees-Hennessy Inc. (DHI) was chosen to perform the shotcrete portion of the project.

Scope of the Shotcrete Placement

The present portion of the scope is over 6000 ft^2 (560 m^2) of shotcrete installation for overhead shotcrete on slabs, beams, and repairs, totaling a volume of around 200 yd^3 (150 m^3). Access for the project is from two access portals in the existing deck and all the work is performed off a temporary platform that was constructed under the existing deck. The upper portion of the deck under repair was still being used, limiting access to the upper deck portions of the work. Shotcrete was the perfect process to place the concrete because of the thinner repair sections and the complications from access issues. Shotcrete required minimal formwork around the beam replacements and some of the repair areas, allowing work to continue in multiple areas within a limited work time window.

Project Challenges

One of the scheduling challenges of the project was the coordination of the schedule with the tides and the availability of sections to be repaired. The temporary deck that was constructed is under water during large high tides so shotcrete placement could only be scheduled during a low tide and with a small high tide variation. Also, because of the large amount of daytime tourism, all work was scheduled during night shifts. Shotcrete provided a solution with the limited

Fig. 1: Beam side prepared for shotcreting with minimal formwork

Fig. 2: Underside of pier ready for shotcrete

Fig. 3: Shotcreting in limited space under pier

amount of equipment and quick setup required. Shotcrete also provided the flexibility to work in different areas as they became available around tide and access issues.

A hurtle for the project was the requirement to use a corrosion inhibitor in the shotcrete mixture. DHI completed the first portion of the project with one concrete supplier but their corrosion inhibitor also acted as a severe set accelerator. In fact, once it was added to the concrete truck in the field, even just a short load truck only had about 30 minutes before the concrete started to set. Shotcrete was helpful through this because of the speed with which we were able to place shotcrete from one location to the next. The General Contractor had a couple deck infills and we were able to more than double their production with more movement in our work than theirs.

The second portion of the project used a different concrete supplier and their corrosion inhibitor reduced the slump. We had to increase the slump at the concrete plant to hit the delivered concrete at the proper slump for our shotcrete placement. The lesson from this is to understand all the impacts admixtures have on the fresh shotcrete material properties. If an admixture is used in a concrete mixture to solve issue A, then you have to be aware that you may be causing issue B. Admixtures allow us to do a lot of creative things with concrete but there are limitations and consequences to using them. The bottom line is: it's essential to fully investigate and understand the impacts from using admixtures in our shotcrete mixtures *before* you get into production on a project.

Conclusions

Pier 31.5 has had many different uses over its decades of use in a very corrosive and aggressive environment.

Fig. 4: Shooting on underside of pier

Shotcrete is one of the tools that provided a high-quality, durable concrete repair and added significantly to its useful life and serviceability. In the near future, tourists will continue to flock to this area and never realize the role that shotcrete played in the repair work that is directly under their feet.

__Jason Myers__ received his bachelor's degree in civil engineering from California Polytechnic State University, San Luis Obispo, CA, and his MBA with an emphasis in project management from Golden Gate University, San Francisco, CA. Myers started his professional career working for an earth retention subcontractor where he learned the importance of budgeting, scheduling, and client relationships. Also during this time, he was introduced to the use of shotcrete and its applications. After working for a general contractor for a couple of years, he realized that he enjoyed the tighter knit of working for a subcontractor and the ability to construct multiple projects on a tighter timeframe. Myers also enjoys the process of handling most of the procedures that go into constructing a project rather than seeing only a small portion of the process. Myers joined Dees Hennessey in 2004 and has been a part owner of the company since 2007. He currently serves as the Vice President of Operations as well as the Safety Director. Myers is Chair of the ASA Membership Committee and a member of the ASA Board of Directors.

Déjà vu, West Aliquippa, PA

Shotcrete repairs to the Henry Mancini Bridge

By Ted W. Sofis

Forty-four years ago, after graduating from college, I first crossed the Henry Mancini Bridge into West Aliquippa, PA, while I was on my way to work at the massive J&L Aliquippa Works, one of the largest steel mills in the United States. The Aliquippa Works was 7 miles (11 km) long and I began working there gunning the steel teeming ladles. After a ladle had emptied its molten steel, the ladle would be laid on its side, where we would then shoot a layer of refractory over the still-glowing red firebrick lining. Using the dry-mix process shotcrete method to install gunned refractory would extend the life of the ladle brick from 15 heats to over 60 heats. The steel teeming ladles emptied steel into molds and were gunned every 30 minutes to an hour. This gunning work was done around the clock, 7 days a week, and 365 days a year. For the next 2 years, I crossed this bridge every day that I worked at J&L Aliquippa Works. In the 1980s, the U.S. steel industry went into a deep downturn and in 1984 the Aliquippa Works was closed.

Fig. 1: Photo of West Aliquippa with the former J&L Aliquippa Works in the background
(photo courtesy of Robert S. Dorsett)

BACKGROUND

Although the steel mill is gone, the homes in the small community of West Aliquippa still stand. The bridge is named after the native son and famous composer Henry Mancini and it crosses over the railroad tracks connecting the small community to the Route 51 Highway. Technically part of the much larger town of Aliquippa, PA, West Aliquippa is a few miles away and somewhat isolated.

Crossing the bridge for the first time in many years certainly brought back memories. On arrival in West Aliquippa I drove through the streets and circled back under the bridge to look at the condition of the structure. Several of the piers showed exposed reinforcing bars and there was deterioration of the concrete on almost every pier. The reinforcing bars were too close to the surface in many locations. Wherever there were issues with downspouts, scuppers, or expansion dams, the concrete showed deterioration. In those locations, the drainage issues caused

Fig. 2: All but one of the bridge piers had deterioration where repairs were necessary

Fig. 3: When reinforcing bars close to the concrete surface corroded, the expansion of the rust spalled concrete off the rusted bars

Fig. 4: Dry-process shotcrete placement on a bridge pier

the reinforcing steel to rust and spall the surface concrete off the bars.

REHABILITATION

The following year with the scheduled rehabilitation of the bridge, we began the dry-mix shotcrete repairs on the bridge piers and abutments. For me it provided a bit of irony to work on a project where I first started gunning shotcrete over 40 years ago.

The general contractor, Swank Construction, began the project in Spring 2016. Because of structural concerns, the repair work was limited to one side of each pier. All the surface preparation, chipping, sandblasting, and the placement of anchors and mesh were completed and the shotcrete repair concrete was shot in place. The repaired areas were then cured for a period of time to achieve adequate strength before removal work could begin on the other side of the pier. There was concern that Pier 2 might need to be replaced. However, after extensive examination by the engineers, it was determined that shotcrete repairs were acceptable, but that only one-quarter of the pier could be done at a time. This meant that after all the other work was completed, the Pier 2 repair work had to be performed

Fig. 5: Because of concerns about the condition of this pier the repairs were performed in four phases

in four separate phases, allowing for adequate curing time in between each repair.

With repairs of this type, it's important to properly prepare the surface. This means removing all the unsound concrete, exposing and chipping around the bar, sandblasting

Fig. 6: Equipment setup for gunning prepackaged material

Fig. 7: Material hopper, predampener, and continuous-feed rotary gun setup for gunning prepackaged shotcrete repair mortar

Fig. 8: Gunning of prepackaged material on bridge pier. We were required to repair one side of the piers at a time

the reinforcing steel, to remove the rust and scale, and coating the reinforcement prior to installing the mesh. The repair mortar used on the project was Quikrete's Shotcrete MS, a prepackaged microsilica-enhanced repair mortar with Cortec MCI added in as a corrosion inhibitor. The use of prepackaged repair mortars eliminates the need for on-site mixing and provides the installer an extra level of quality control that engineers and Department of Transportation material personnel prefer. Production panels were shot and cores taken and tested for confirming as-shot compressive strength. The installation was performed by an experienced shotcrete crew and shot with ACI-certified nozzlemen.

Conclusions

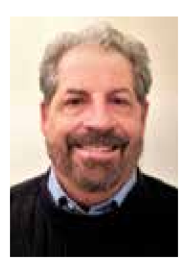
In prior years, many of these repairs were done with the form-and-pour method. The use of shotcrete eliminates the need for forming and provides a much more cost-effective method of repair. Over the past 21 years, ASA has provided state-of-the-art information on the increased technology in shotcrete placement to owners, specifiers, and engineers that has resulted in a greater acceptance of shotcrete as a repair method for structural concrete.

With the completion of the shotcrete repairs, I realized that I had gone full circle… working at the same location where I first began as a nozzleman, shooting every day over four decades ago. It was a terrific place to get experience and an unusual turn of events to bring me back to the little community of West Aliquippa.

General Contractor
Swank Construction Company, LLC

Shotcrete Contractor
Sofis Company, Inc.*

**ASA Corporate Member with ACI-Certified Nozzlemen*



Ted Sofis *and his brother, William J. Sofis Jr., are the Principal Owners of Sofis Company, Inc. After he received his BA in 1975 from Muskingum College, New Concord, OH, Ted began working full time as a shotcrete nozzleman and operator servicing the steel industry. He began managing Sofis Company, Inc., in 1984 and has over 40 years of experience in the shotcrete industry. He is a member of various ASA committees and an ACI Shotcrete Nozzleman Examiner for shotcrete certification. Over the years, Sofis Company, Inc., has been involved in bridge, dam, and slope projects using shotcrete and refractory installations in power plants and steel mills. Sofis Company, Inc., is a member of the Pittsburgh Section of the American Society of Highway Engineers (ASHE) and ASA.*

Title No. 115-S132

Bond Strength of Reinforcing Bars with Varying Encapsulation Qualities

by Pasquale Basso Trujillo, Marc Jolin, Bruno Massicotte, and Benoît Bissonnette

The encapsulation quality of reinforcing bars represents a common concern among structural engineers when shotcrete structures are designed. Because little scientific information is available regarding the potential bond strength reduction of bars with adjacent defects along their length, ASTM A944-10 "beam-end" specimens with different encasement qualities were tested. To limit the size variability of voids when spraying, voids were created using silicone inserts, which also made it possible to control their exact size and position. Artificial voids were encased with a placed shotcrete mixture and transversal lengths of up to 30% of the bars' perimeter were investigated. A low water-binder ratio (w/b) was employed to guarantee an insignificant bleeding capacity of the mixture as is commonly observed in shotcrete. The results support previous investigations by showing that transversal void lengths beyond 20% induce a considerable change in the slope of the stress-slip curve and an important reduction of the ultimate bond stress.

Keywords: artificial voids; beam end; bond strength; encapsulation; hypothesis testing; shotcrete; sprayed concrete; voids.

INTRODUCTION

Ever since the 1933 Long Beach earthquake in California, the use of shotcrete as a way to retrofit structural elements has rapidly increased in North America.[1] Its use has grown so quickly that nowadays, it is not unusual to see tunnel linings,[2] domes,[3] shear walls,[4] or even columns[5] and girders[2] being entirely built with shotcrete. The main reasons for this include the small amount (if any) of formwork needed and the ability to build structural elements of almost any shape, which often results in considerable time and cost savings. However, using the current design criteria may not be completely adequate for reinforced shotcrete elements because of the different placement processes between shotcrete and cast-in-place concrete. In particular, a recurring concern among structural engineers has been the possibility to encounter voids or entrapped aggregates (usually referred to as sand pockets) behind reinforcing bars. In wet-mix shotcrete, such defects are generally caused by the use of excessive set-accelerating admixtures and in dry-mix shotcrete by the inadequate selection of the water content by the nozzlemen. However, imperfections can be caused with the use of both processes if inadequate placement techniques are used. In reality, the concern regarding the encapsulation quality of reinforcement is widespread and covers many aspects from the design of structures to the evaluation of cores taken from preconstruction panels. Up until now, this issue has been addressed only for evaluation of shotcrete quality and not design. The approach has been to quantitatively characterize the size of the voids observed in cores[6] and then determine if the individual/crew is sufficiently experienced to place good-quality shotcrete. Unfortunately, the limits determining what is "acceptable" and "unacceptable" have been chosen empirically. An alternative and perhaps a more advantageous way to deal with both the evaluation and the design might be to establish a void size threshold (based on the bond strength performance of bars) beyond which design criteria applicable specifically for shotcrete should be adopted. Accordingly, the evaluation of cores could be relaxed knowing that preventive measures were taken during the "design phase" to overcome the structural effect of such imperfections. The development length of reinforcing bars required to be computed by North American design codes[7,8] may represent a suitable parameter to be adapted in such situations. However, a considerable amount of scientific information regarding the effect of different void sizes on the bond strength of a bar is lacking and would be needed for this purpose.

Early results within this research project using "pullout" specimens[9] have shown that the height of the voids behind reinforcing bars contributes little to the reduction of the bond strength and that a void's transversal length in contact with the bar (referred to as the unbonded perimeter) exceeding approximately 20% of the bar's perimeter represent the onset of a significant bond reduction and a change of failure mode from splitting to pullout. In that investigation, artificial voids created with silicone inserts and encased with a placed shotcrete mixture were used to overcome the difficulty to obtain specific void sizes and limit their size variability when spraying. A statistical comparison between the results obtained with such type of specimens and equivalent ones made with dry-mix shotcrete showed that the ultimate loads were statistically equivalent between them and that, although the shape of their load-slip curve differed, artificial voids represented a valuable method to ultimately set rational evaluation and design criteria.[9]

In this research, the ASTM A944-10[10] "beam-end" specimens were used to study the impact of defects on the bond behavior of reinforcing bars. This type of specimen is advantageous because it accurately recreates the stress distribution around tensioned bars of most structural elements.[11] However, because spraying specimens in the laboratory to obtain imperfect encapsulation qualities has proven to be a difficult task, the specimens were cast-in-place using a self-consolidating concrete (SCC) mixture poured by gravity

ACI Structural Journal, V. 115, No. 6, November 2018.
MS No. S-2017-412.R1, doi: 10.14359/51702415, was received November 1, 2017, and reviewed under Institute publication policies. Pertinent discussion including author's closure, if any, will be published ten months from this journal's date if the discussion is received within four months of the paper's print publication.

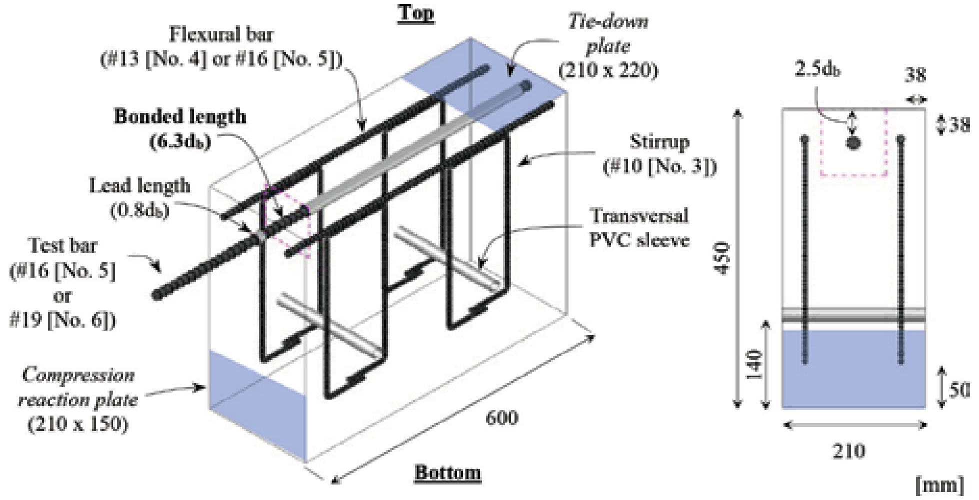


Fig. 1—ASTM A944-10 "beam-end" specimen. (Note: 25.4 mm = 1 in.)

into the molds. As in the past investigation,[9] the voids were recreated using artificial voids. This was done to obtain the most representative mechanical properties possible of typical shotcrete whilst minimizing the bleeding capacity of the mixture and to obtain a "reliably imperfect" bar-concrete interface with known void sizes.

RESEARCH SIGNIFICANCE

This experimental investigation intends to broaden knowledge regarding the bond strength reduction caused by the possible presence of voids specifically behind reinforcing bars created with improperly placed shotcrete. Ultimately, the information will serve to develop reliable guidelines for the design of shotcrete structures (in particular for the computation of the development length of bars in tension specified by North American design codes[7,8]) and for the evaluation of concrete cores as the values in existing tools were chosen subjectively and not based on the actual bond behavior of specimens tested in the laboratory.

EXPERIMENTAL INVESTIGATION

Test specimens

"Beam-end" specimens were built in accordance with the ASTM A944-10 standard[10] and consisted of 210 x 600 x 450 mm (8.3 x 23.6 x 17.7 in.) prisms with a single test bar passing through a polyvinyl chloride (PVC) sleeve at the loaded end (called the lead length) and a second sleeve at the unloaded end as seen in Fig. 1. The bonded length of the test bar was therefore controlled by these bond breaking sleeves. Test bars of 15.9 and 19.1 mm (5/8 and 6/8 in.) nominal diameter d_b were tested and placed with their longitudinal ribs facing the sides of the forms. The lead length and the bonded length were set as $0.8d_b$ and $6.3d_b$, respectively, for all specimens. The flexural bars were 12.7 and 15.9 mm (4/8 and 5/8 in.) in nominal diameter for each of the test bars, respectively. The flexural bars (9.5 or 12.7 mm [3/8 or 4/8 in.], depending on the test bar size) and the stirrups (9.5 mm [3/8 in.] for all specimens) are required by the standard to assure proper behavior in flexure and in shear. Additional PVC sleeves were placed transversally (with respect to the test bar) in between the stirrups so they could be used to move the specimens after being stripped. The concrete cover of the test bars was set to $2.5d_b$ for all specimens, which represents the cover beyond which the bond strength does not increase if a pullout failure occurs (as this type of failure become more predominant over a splitting failure as the concrete cover increases).[12,13] Specimens were cast in detachable wooden panels held together by steel threaded rods. After the test bar and its front and back sleeves were secured in place, the forms were carefully oiled. Subsequently, the flexural bars and the stirrups (attached together using cable ties) were placed inside the forms and lastly, the transversal PVC sleeves were installed. This sequence guaranteed a wider space between the form and the test bar to avoid staining the bars with the form release agent. Prior to casting, all of the joints and holes in the formwork holding the bars and PVC sleeves in place were caulked with silicone. Twenty-four hours after, the specimens were stripped and were cured for 1 week using wet burlap.

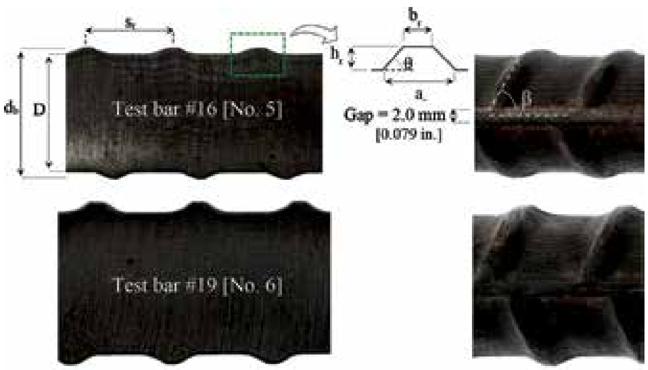


Fig. 2—Longitudinal cut with geometry nomenclature of No. 16 (No. 5) and No. 19 (No. 6) bars.

Reinforcing bars

The reinforcing bars came from the same heat of steel and complied with the ASTM A615/A615M-16 standard.[14] Their mechanical properties were averaged from three specimens and tested in accordance with ASTM A370-17.[15] Additional specimens were cut longitudinally at 45 and 90 degrees with respect to the longitudinal ribs' plan to measure their geometrical properties, as shown in Fig. 2. The measurements were performed over 10 ribs using high-resolution

Table 1—Geometrical and mechanical properties of reinforcing bars

Type	Parameter	Test bar No. 16 (No. 5)	Test bar No. 19 (No. 6)
Mechanical	Young's modulus, GPa (ksi)	197 (28570)	208 (30170)
	Yield strength at 0.2%, MPa (ksi)	733 (106.3)	475 (68.9)
	Ultimate strength, MPa (ksi)	962 (139.5)	742 (107.6)
	Elongation at rupture, %	10.5	12.7
Geometrical	Nominal diameter d_b, mm (in.)	15.9 (0.63)	19.1 (0.75)
	Core diameter D, mm (in.)	14.8 (0.58)	17.7 (0.70)
	Ribs' height h_r, mm (in.)	0.9 (0.035)	1.3 (0.051)
	Ribs' top width b_r, mm (in.)	1.0 (0.039)	1.2 (0.047)
	Ribs' base width a_r, mm (in.)	4.9 (0.193)	5.6 (0.220)
	Ribs' spacing s_r, mm (in.)	10.8 (0.425)	12.6 (0.496)
	Ribs' face angle θ, degrees	25	30
	Ribs' inclination β, degrees	67	68
	Σ gaps*, mm (in.)	4.0 (0.16)	4.0 (0.16)
	Relative rib area* R_r, adim	0.080	0.100

*Based on Fei et al.[33]

photographs and a CAD software for each longitudinal cut. Table 1 summarizes the mean mechanical and geometrical values from the three and 20 measurements of each bar size, respectively.

Artificial voids

To create the artificial voids, fresh silicone was inserted into hollow plastic tubes and extracted once the silicone had hardened. The resulting tubes were subsequently cut longitudinally into two halves and one piece was then glued over the entire bonded length of the test bars using the same material. To ensure no silicone was deposited elsewhere over the surface of the bars, the position of the voids was defined with masking tape, which was removed once the artificial voids were securely glued in place. Voids of nominal transverse lengths of 10, 20, and 30% of the test bars' perimeter were created and are referred to as unbonded perimeters (u.p.) henceforth. A "top" and "bottom" void configuration, as seen in Fig. 3(a) and (b), respectively, were also studied because, depending on the location of a bar and the direction of the shotcrete flow, voids could be created facing either the exterior or the interior of a reinforced shotcrete element.

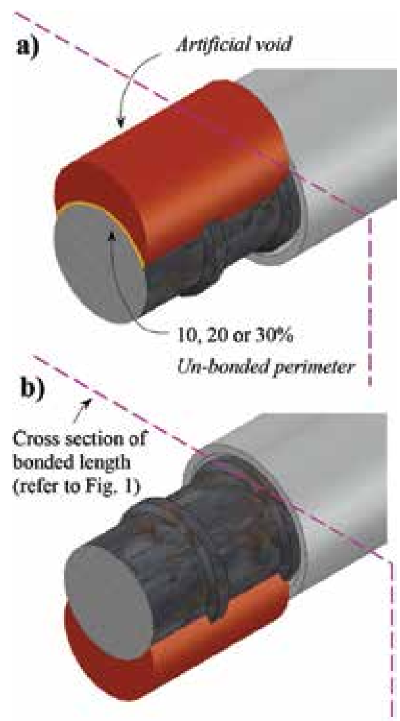


Fig. 3—(a) Top; and (b) bottom position of artificial voids.

Mixture design

Specimens were cast using a prebagged mixture intended for wet-mix shotcrete (maximum aggregate size of 10 mm [0.4 in.]), which was poured into the forms. A constant water-binder ratio (w/b) of 0.45 was used in combination with a polycarboxylate-based water reducer complying with Types A and F categories of the ASTM C494/C494M-16[16] standard. This produced an SCC mixture with which it was possible to properly encase the artificial voids by providing only a minimal amount of external consolidation; only the corners of the forms were carefully tapped a few times. All the forms were filled in two lifts and the first layer was placed in all specimens before the second layer. Because a considerable amount of concrete was placed below the test bars and a possible bond performance deterioration (additional to the presence of the voids) caused by excessive water accumulation under the test bars was a concern, a family of specimens having a 0.55 w/b mixture was also tested. In that case, no water reducer was added and the consolidation was done in accordance with ASTM C192/C192M-16a.[17] The proportions of both mixtures are shown in Table 2.

Properties of concrete

Cylinders (100 x 200 mm [4 x 8 in.]) were prepared to test the compressive strength f_c,[18] the splitting tensile strength f_s,[19] and the Young's modulus E_c[20] of all the concrete

Table 2—Mixture composition of both types of concrete

Component	w/b = 0.45	w/b = 0.55
Ordinary portland cement, kg/m^3 (lb/yd^3)	393.1 (663)	376.7 (635)
Silica fume, kg/m^3 (lb/yd^3)	34.3 (58)	32.9 (55)
Coarse aggregate 2.5 to 10 mm, kg/m^3 (lb/yd^3)	708.6 (1194)	680.7 (1147)
Sand 0.08 to 5 mm, kg/m^3 (lb/yd^3)	1016.6 (1714)	976.5 (1646)
Water, kg/m^3 (lb/yd^3)	191.2 (322)	224.8 (379)
Air, %	3.4*	2.1*
Water reducer, mL/100 kg of binder (fl. oz./100 lb)	750 (11)	—

*Based on ASTM C231/C231M-14.

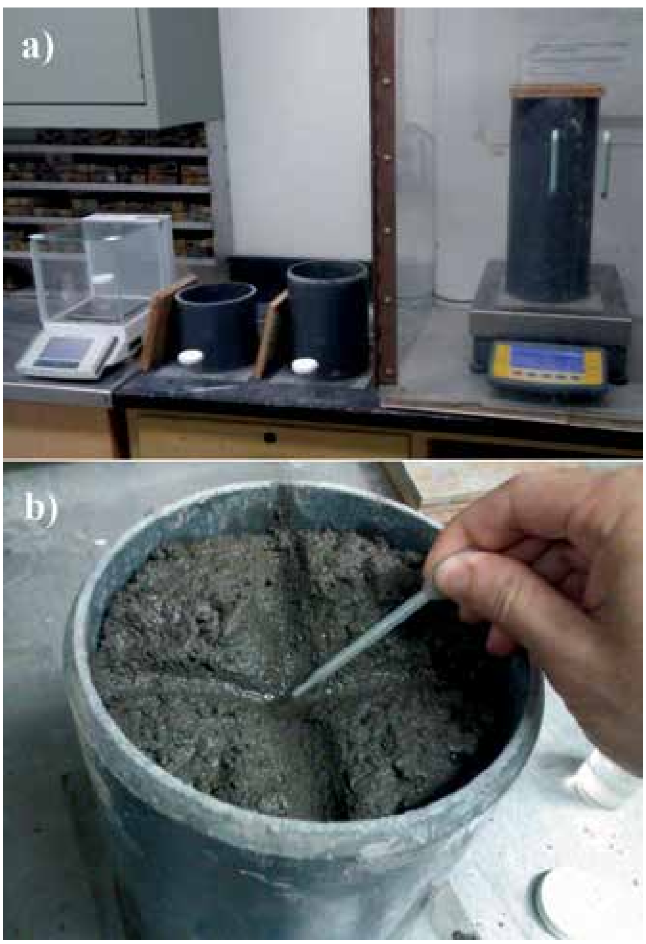


Fig. 4—(a) Equipment needed for bleed test; and (b) bleed water collected from container.

mixtures. The cylinders were cured in the same way (for 1 week using wet burlap) and were tested at the same age as the "beam-end" specimens. Moreover, the slump[21] and the slump flow along with the visual stability index (VSI)[22] were documented for the 0.55 and the 0.45 w/b mixtures, respectively; the air content was also measured for both of them.[23] All tests were performed using the concrete from the second lift, with which the test bar was encased. The bleeding properties of both types of concrete mixtures—that is, their average bleeding rate R and their bleeding capacity ΔH—were quantified following the method proposed by Josserand and de Larrard.[24] The procedure requires three cylindrical containers of different heights (as those shown in Fig. 4(a)) to be filled and to collect the bleed water from the intersection of two orthogonal tracks made on the surface of the concrete (and inclined towards the center) at a regular time interval using a pipet as shown in Fig. 4(b). The bleed water is used to calculate ΔH, which in turn, serves to calculate R (whose values are independent of the container's height) and determine its maximal value R_{max}. During the entire test, the tallest container rests on a 0.1 g (0.04 oz) accurate scale so its weight loss rate can be measured and later considered as the average bleed water evaporation of all the containers. In this investigation, the containers were 150, 210, and 430 mm (5.9, 8.3, and 16.9 in.) tall and had an inner diameter of 150 mm (5.9 in.). Moreover, the concrete was consolidated in the same manner as was done to cast the "beam-end" specimens. This method is advantageous over similar methods such as the ASTM C232/C232M-14[25] standard because the containers do not need to be tilted to collect the bleed water. However, it still provides the opportunity to calculate the bleeding in the same way as the standard does. All the concrete test results are summarized in Table 3.

Testing procedure

The "beam-end" specimens were tested using a 311 MTS frame and the setup shown in Fig. 5. The tests were performed at 0.5 mm/min displacement control and the slip of the reinforcing bars was recorded at the loaded end and at the unloaded end of the test bar using two linear position sensors with return spring on each side. The "beam-end" specimen was lifted using the holes provided by the transversal PVC sleeves and then laid on a steel box anchored to the base of the test frame. After the specimen was pushed with the alignment plate so as to align the test bar with the actuator's longitudinal axis, the specimen was gradually tightened with the compression reaction plate and the tiedown plate. Finally, the pulling device, which consisted of two square shafts pin-holding a thick cylinder with a hole in its middle, was inserted around the test bar. A conical wedge was then placed around the test bar so that the cylinder from the pulling device would bear against it while the bar was tensioned. A detailed description of the testing apparatus and procedure to test ASTM A944-10 "beam-end" specimens is given by Basso Trujillo et al.[26] The properties of the hardened concrete were measured right after the "beam-end" specimens were tested and are presented in Table 3.

Test parameters

Specimens were grouped in families using labels which indicate the size of the test bar (No. 16 [No. 5] or No. 19 [No. 6]), the w/b of the mixture (0.45 or 0.55) and the orientation of the artificial voids (T or B for top and bottom, respectively, and based on Fig. 1 and 3) if they were used. Three replicas were built for each configuration. The 10% u.p. was not tested for the "Bottom" configuration, as early results showed that the bond strength was not significantly reduced in comparison with perfectly encapsulated bars (u.p. = 0%). Considering all of the u.p.'s for each family (13) and the replicas for each one of them (3), a total of 13 x

Table 3—Test results of concrete mixtures

Family	u.p., %				w/b	f_c, MPa (psi)	f_s, MPa (psi)	E_c, GPa (ksi)	Air,%	Slump flow, mm (in.) / Slump, mm (in.)	VSI	R_{max}, µm/min (mils/min)	Test*, days
#16-0.45	0	—	—	—	0.45	57.7 (8370)	3.9 (570)	33.3† (4830)	3.4	550 (21.7)	0 ~ 1	2.2‡ (0.1)	24 ± 2
#16-0.45 T	—	10	20	30									
#16-0.45 B	—	—	20	30									
#19-0.45	0	—	—	—									
#19-0.45 T	—	10§	20	30									
#19-0.45 B	—	—	20	30									
#16-0.55	0	—	—	—	0.55	34.7 (5030)	2.5 (360)	25.4 (3680)	2.1	140 (5.5)	—	6.5† (0.3)	8

*In reference to both "beam-end" specimens and mechanical properties of concrete.
† Poisson's ratio of 0.14 was measured at the same time.
‡Mean from three molds of different height and only one mixture.
§Specimens' results were discarded due to malfunction in equipment.

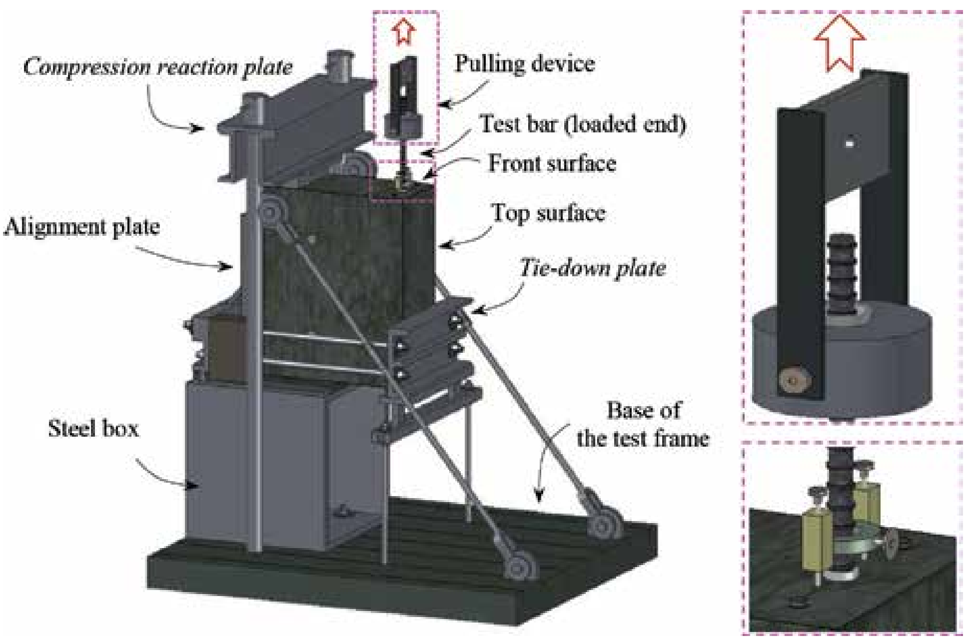


Fig. 5—Test setup of ASTM A944-10 "beam-end" specimen.

3 = 39 "beam-end" specimens were built. However, only the results of 36 of them are presented in the following section, as explained in Table 3.

RESULTS AND DISCUSSION

Stress-slip curves

The measured load P has been normalized with respect to the nominal transversal area of the test bars A_b and is plotted against the slip of the bars for the different u.p.'s under study. At the loaded end only, the elastic elongation of the portion of the test bars between the attachment of the linear position sensors and the end of the lead length was subtracted from the measured slip. Moreover, only the test bars with a "top" void configuration and a w/b of 0.45 are presented in this section. The curves of the loaded and the unloaded ends are shown in Fig. 6(a) and (b) for the No. 16 (No. 5) test bars and in Fig. 7(a) and (b) for the No. 19 (No. 6) test bars. As expected, the slip associated to the loaded end is larger than the one measured at the unloaded end as the latter captures the "stiffness" of the entire bonded length. The difference between both measures represents the lengthening of the reinforcing bar and its absolute value increases as the bonded length is increased. As can be seen in Fig. 6(a) and (b), a u.p. of 10% causes no apparent change in the overall bond behavior of a bar in comparison to a perfectly encapsulated bar (0% u.p.). Indeed, in both cases, the slope of the ascending curve (referred to as the slip stiffness henceforth), remains constant until the ultimate bond stress (P_{max}/A_b) is attained. Beyond that point, the ribs of the bar crush the concrete in front of them, creating residual stresses as the bar continues to slip relative to the concrete. In all cases, the transition from a 10% to a 30% u.p. causes the slip stiffness to decrease progressively as the ultimate bond stress is attained as can be observed in Fig. 6(a) and (b) as well as in Fig. 7(a) and (b). At a 20% u.p., the ultimate bond stress had been reduced in the range of 3 to 8% and at a 30% u.p. in the range of 20 to 25% relative to perfectly encapsulated test bars.

Despite the fact that the concrete was not actually sprayed, the bond behavior of the specimens provides useful evidence

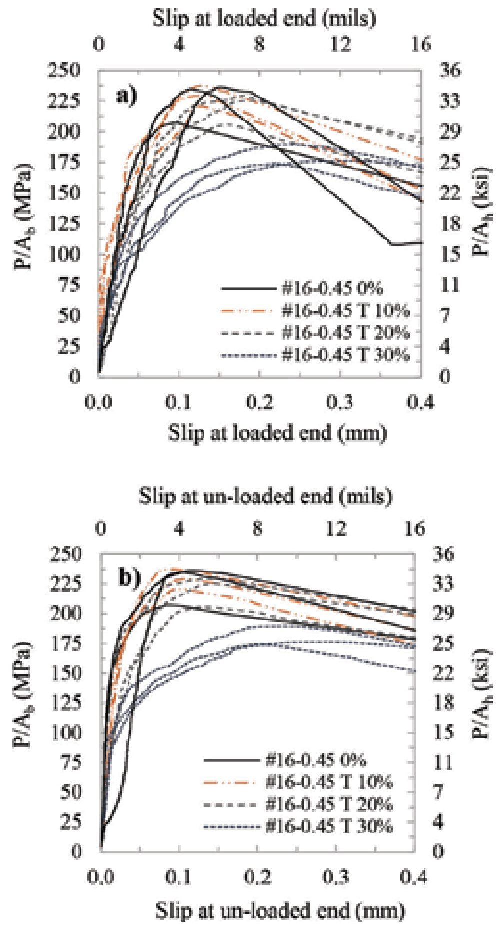


Fig. 6—(a) Stress-slip curves of No. 16 (No. 5) test bars at loaded; and (b) unloaded end.

to define threshold values defining bond behavior changes between specimens with different encapsulation qualities. In reality, according to the investigation of Basso Trujillo et al.[9] in which the bond performance of shotcrete and cast-in-place "pullout" specimens was compared, the slip stiffness of shotcrete specimens would be slightly greater than those shown in Fig. 6(a) and (b) as well as those shown in Fig. 7(a) and (b) due to the high compaction of the concrete obtained upon its impact on the forms. Nonetheless, the ultimate bond stress between both methods of concrete placement should be the same despite the different slip performance. It is for this reason that the ultimate bond stress is used subsequently for the analysis and thus the values obtained with both test bar sizes are plotted in Fig. 8 as a function of the u.p. In general, the ultimate bond stress for different qualities of encapsulation seems to be independent of the tested bar sizes (No. 16 [No. 5] and No. 19 [No. 6]) and the reduction is best characterized by a second-order polynomial regression. This model is both significant (F_0 = 28.89 and p-value < 0.000) and adequate (F_0 = 0.00 and p-value = 1.000) based on an analysis of variance[27] and possesses an adjusted Pearson coefficient (R^2_{adj}) of 0.736.

Size of bars

To support the assertion that the reduction of the ultimate bond stress is independent of the bar size, an equal variance

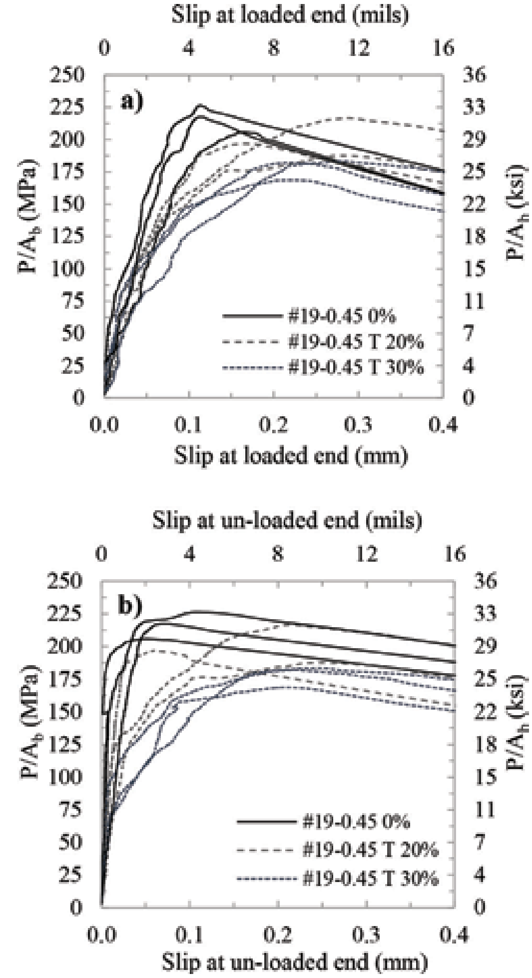


Fig. 7—(a) Stress-slip curves of No. 19 (No. 6) test bars at loaded; and (b) unloaded end.

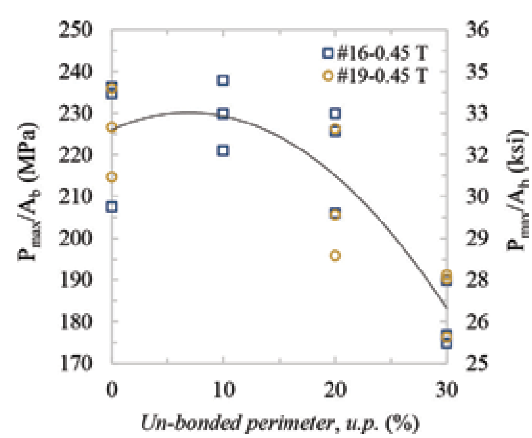


Fig. 8—Effect of u.p. on ultimate bond stress of bars No. 16 (No. 5) and No. 19 (No. 6).

pairwise comparison t-test[27] was performed. This is formally done by defining a null (H_0) and an alternative hypothesis (H_a), as expressed in Eq. (1), to determine if the ultimate bond stresses of the entire population μ_i of specimens with one bar size are equal or not to another one having a different bar size but the same u.p.

$$H_0: \mu_1 = \mu_2 \text{ versus } H_a: \mu_1 \neq \mu_2 \quad (1)$$

The outcome of the test, most frequently expressed with a p-value, determines if there is enough evidence to accept H_0 or if it should be rejected. The p-value represents the level of risk a decision-maker is willing to take at the moment H_0 is accepted or rejected; a decision based on a p-value equal to 0.05 implies taking a risk of 5% to falsely reject H_0. The p-value is obtained based on the degrees of freedom v associated with the size of the combined sample and the calculated t_0 test-statistic (distributed as t) which, in turn, is calculated using the mean of each families' ultimate bond stress (average P_{max}/A_b). In this case, v equals $n_1 + n_2 - 2 = 4$, where n_i is the size of each family. When a precise level of risk is established as the threshold to accept or to reject H_0, its value is called the *level of significance* (α) of the test. The results of the comparison based on $\alpha = 0.05$ are shown in Table 4. Because the resulting p-values are greater than any relevant level of significance ($\alpha \leq 0.05$) in all cases, there is not sufficient evidence to reject H_0 and thus we can conclude that the ultimate bond stress in the presence of voids is independent of the sizes of the bars tested herein. It is worth noticing that as the u.p. increases, the standard deviation S seems to decrease. Indeed, it is mostly due to the variability of the concrete properties that dispersion within specimens occurs and thus the lesser the concrete around the bar, the lesser the standard deviation.

Position of voids

An equal-variance t-test was also performed to assess the impact of a void's position on the bond strength of a bar. The comparisons were made between specimens having "top" and "bottom" void configurations but having the same bar size and u.p.'s. The results are shown in Fig. 9 in which the error bars represent one standard deviation away from P_{max}/A_b. The results of the test are presented in Table 5 and, based on the same analysis procedure described previously, the position of the void did not have a significant impact on the ultimate bond stress in most situations. In the case of family No. 16-0.45 30%, the test detected a difference between the population's means. Surprisingly, the mean bond stress of this family with a "bottom" void configuration presented higher values than the one obtained with an u.p. of 20% for the same bar size (208.2 versus 200.4 MPa [30.2 versus 29.1 ksi]); it is for this unexpected and unrealistic difference that the bond stresses of bar sizes No. 16 (No. 5) and No. 19 (No. 6) were not combined for a given u.p. despite the fact that results are independent of the sizes of the bars as described in the previous chapter. Because in all other three cases the results lead to the conclusion that mean bond stresses are equal between "top" and "bottom" void configurations, there is strong evidence that a void facing the surface of a structural element and another of the same size facing its interior would have approximately the same impact on the bond strength of the bar.

Table 4—Equal variance *t*-test results for size of bars

u.p., %	Bar No.	n	Average P_{max}/A_b, MPa (ksi)	S, MPa (ksi)	t_0	v	p-value	Result*
0	16	3	226.1 (32.8)	16.2 (2.3)	0.04	4	0.972	Equal
	19	3	225.7 (32.7)	10.7 (1.6)				
20	16	3	220.5 (32.0)	12.8 (1.9)	0.98	4	0.384	Equal
	19	3	209.2 (30.3)	15.5 (2.2)				
30	16	3	180.5 (26.2)	8.2 (1.2)	0.80	4	0.467	Equal
	19	3	185.9 (27.0)	8.4 (1.2)				

*Based on level of significance α = 0.05.

w/b

The visual stability index (VSI) of the 0.45 w/b mixture resulted mainly in Grade 0 values (refer to Fig. 10) and sporadic Grade 1 values; these observations provided preliminary evidence that the SCC mixture had a very low propensity to bleed. Quantitatively, this was confirmed by

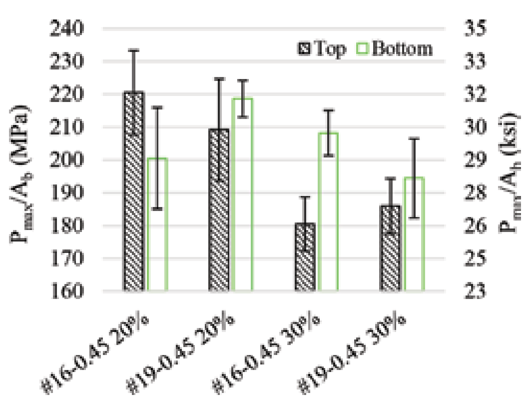


Fig. 9—Ultimate bond stress of bars with different void position.

Table 5—Equal variance *t*-test results for position of voids

Family	Position	u.p., %	n	Average P_{max}/A_b, MPa (ksi)	S, MPa (ksi)	t_0	v	p-value	Result*
No. 16-0.45	T	20	3	220.5 (32.0)	12.8 (1.9)	1.74	4	0.157	Equal
	B		3	200.4 (29.1)	15.4 (2.2)				
No. 19-0.45	T	20	3	209.2 (30.3)	15.5 (2.2)	1.00	4	0.376	Equal
	B		3	218.6 (31.7)	5.6 (0.8)				
No. 16-0.45	T	30	3	180.5 (26.2)	8.2 (1.2)	4.49	4	0.011	Not Equal
	B		3	208.2 (30.2)	6.9 (1.0)				
No. 19-0.45	T	30	3	185.9 (27.0)	8.4 (1.2)	1.00	4	0.372	Equal
	B		3	194.4 (28.2)	12.1 (1.8)				

*Based on level of significance α = 0.05.

Fig. 10—Typical consistency of 0.45 w/b *ratio mixture showing VSI of 0.*

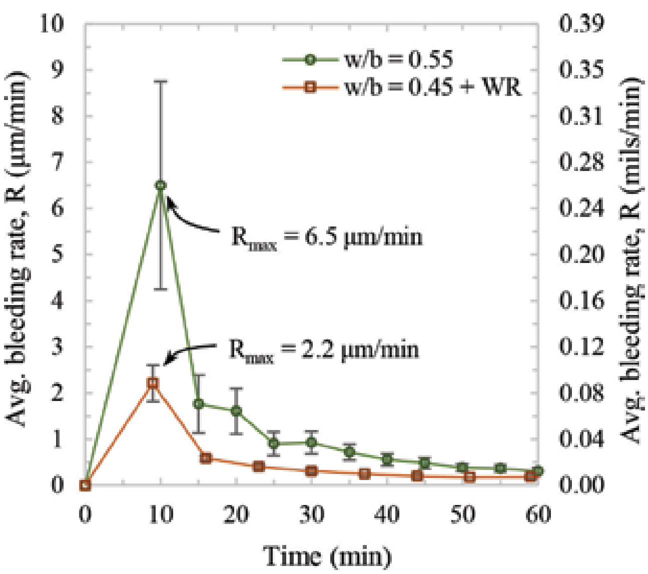


Fig. 11—Average bleeding rate of mixtures. (Note: 1 µm/min = 0.039 mils/min.)

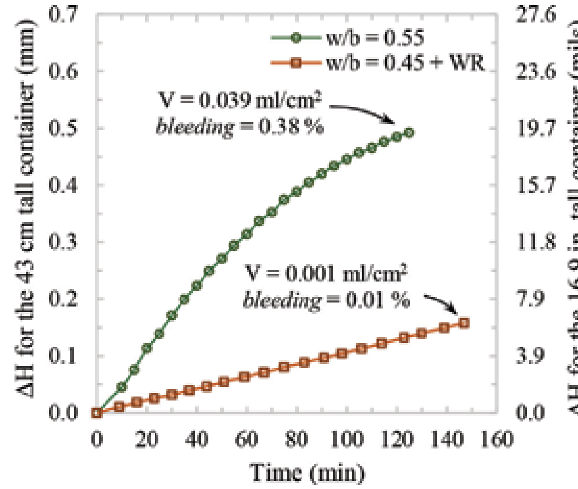


Fig. 12—Bleeding capacity of mixtures. (Note: 1 mL/cm² = 0.218 fl. oz./in.²)

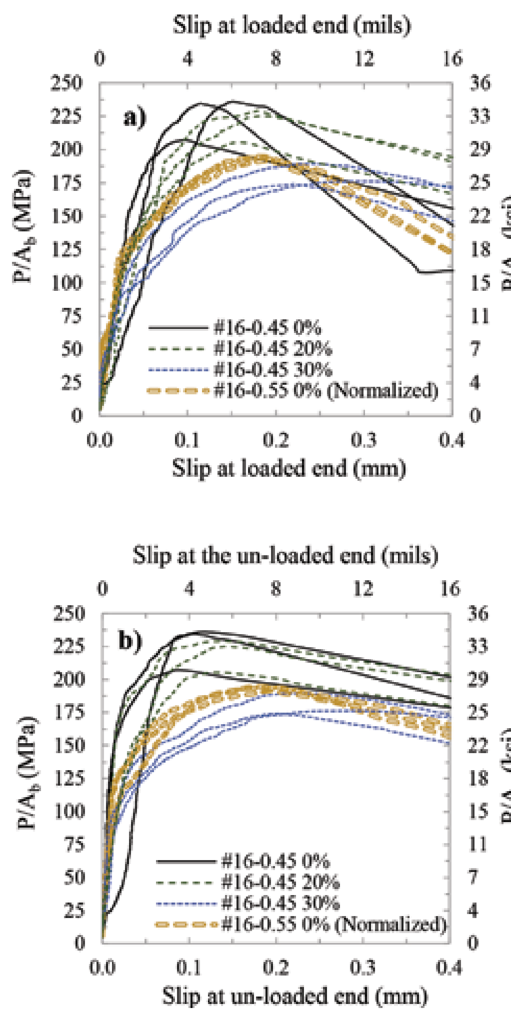


Fig. 13—(a) Stress-slip curves of 0.45 and 0.55 w/b *mixtures at loaded; and (b) unloaded end.*

the average bleeding rate *R* and the bleeding capacity (Δ*H*) measurements (shown respectively in Fig. 11 and Fig. 12) in comparison with those obtained with the 0.55 *w*/*b* mixture; in Fig. 11, the error bars represent one standard deviation away from the mean. Only the Δ*H* of the 430 mm tall container is presented because it represents the approximate height of the concrete below the test bars in the "beam-end" specimens. In addition, the volume of bleed water per unit area *V* and the accumulated bleed water (bleeding) expressed as a percentage of the mixture's net mixing water of each container are presented in Fig. 12 for both mixtures. Both V and bleeding were calculated based on the ASTM C232/C232M-14[25] standard using the total amount of bleed water collected from the containers before the concrete hardened. As can be observed, the maximum average bleeding rate R_{max} and Δ*H* were reduced by approximately 66% as the *w*/*b* was lowered by approximately 20% with the addition of the water reducer. In fact, based on the ASTM C232/C232M-14[25] standard's results (refer to Fig. 12), it can be said that the reduction of the *w*/*b* produced a mixture with "essentially no bleeding"[28] as the amount of bleeding was 0.01%. In terms of bond strength, the almost complete lack of bleeding produced a superior ultimate bond stress as can be observed in Fig. 13(a) and (b), where the stress-slip response of the "beam-end" specimens belonging to families

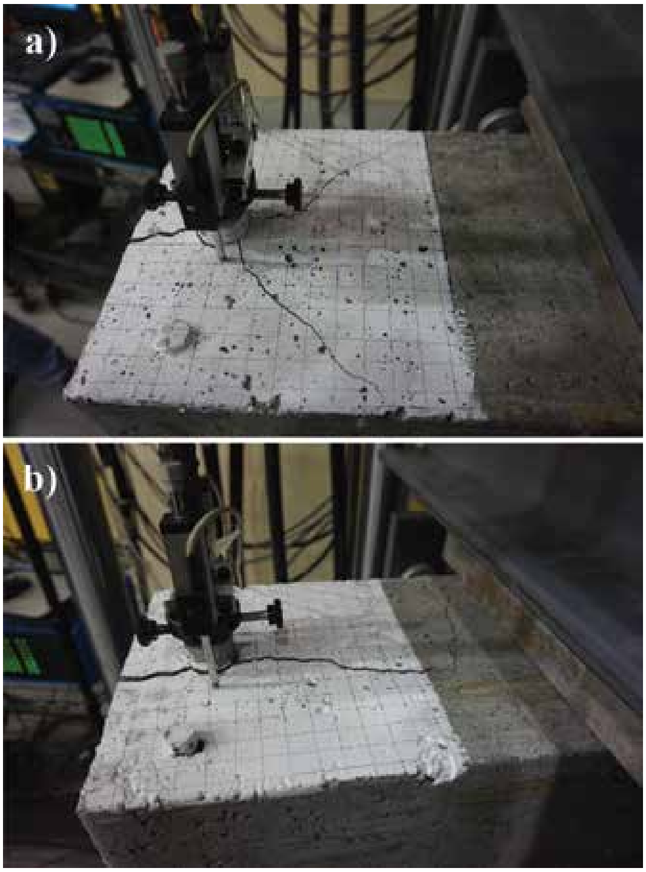


Fig. 14—(a) Y-; and (b) T-shape splitting patterns at front surface (grids are 15 x 15 mm [0.6 x 0.6 in.]).

No. 16-0.45 0%, 20%, 30% and No. 16-0.55 0% are plotted. To properly compare the response of all specimens, the bond stresses of the higher *w/b* family were normalized relative to the f_c of the lower *w/b* family. Therefore, the bond stresses of the No. 16-0.55 0% family of specimens were multiplied by $(57.7/f_c)^{1/4}$ assuming that the bond strength is proportional to the 1/4 power of the compressive strength. In past research, either a value of 1/2 or 1/4 has been used as a normalization coefficient but it has been shown that the latter is more accurate when f_c is greater than 55 MPa (7.98 ksi)[29-31]. This assured the specimens' response was equivalent in terms of bulk compressive strength with the only difference being the increased porosity around the bar of the specimens cast with a higher *w/b* mixture. As can be observed, using a 0.45 *w/b* mixture with a water reducer caused the initial branch of the stress-slip curve to have a more or less constant slope, which best approximates the behavior of shotcrete specimens.[9] This effect may be explained due to the possibly lower porosity in the vicinity of the bars obtained with the SCC mixture in comparison to regular concrete,[32] as no internal vibration is necessary with the former type of concrete. Surprisingly, besides the evident difference of the ultimate bond stress between perfectly encapsulated bars (which is strongly linked to the normalization coefficient used), the bond behavior of the bars encased with the 0.55 *w/b* was considerably degraded and produced a similar bond to bars having artificial voids in between 20 and 30% u.p.'s. This is extremely relevant because it emphasizes how crucial the properties of the bar-concrete interface are on both shotcrete and cast-in-place concrete and how each effect needs to be addressed with appropriate measures.

Failure mode

All of the specimens (except one) failed by splitting. At the top surface (refer to Fig. 1 and 5), a crack ran parallel and above the test bar and fanned out to the sides after the length of the bonded section of the bar had been passed. At the front surface, two different types of splitting patterns occurred. In the first case (Y-shape pattern), two diagonal cracks grew towards the bottom of the specimen at approximately 120 degrees between one another and with respect to the top surface crack as shown in Fig. 14(a). In the second case (T-shape pattern), one single crack grew towards the bottom of the specimen parallel to the top surface crack and then fanned out towards the sides of the specimen before the compression reaction plate was reached as shown in Fig. 14(b). The two types of splitting patterns were observed on all specimens and no correlation was found between the size of the voids or the family of the specimens. In fact, these two splitting patterns are usual and can even be observed between specimens having a concrete compressive strength difference as low as 2.5 MPa (0.36 ksi).[33] The only specimen with an unusual mode of failure belonged to family No. 16-0.45 T 30%. Initially, it failed by splitting and an initial crack appeared on the top surface of the specimen. However, as loading continued, the crack stopped to grow and the mode of failure transformed into a pullout mode. The crack did not extend all the way towards the end of the bonded length and did not appear on the front surface.

FURTHER RESEARCH

Although the results presented herein are essential to understand the impact of defects on the bond strength of reinforcing bars, the experimental campaign recreated only the "worst-case" scenario in which the defects covered the entire bonded length of the test bars. Thus, it is of vital importance to further explore the impact of "localized voids" (voids covering only a portion of the bonded length of the bar), as this may occur in congested areas of reinforcement or lap splice regions. The impact of the confinement (concrete cover and transverse reinforcement) should also be investigated, as this may influence the failure mode of the specimens. This is of prime importance, as it will allow the establishment of design and evaluation criteria considering not only the u.p. if voids might be created or are observed but also in regard of how frequently they appear in a given structural element or preconstruction panel.

CONCLUSIONS

In this research, artificial voids encased with a low *w/b* mixture were used to simulate the types of encasement deficiencies that are sometimes found in reinforced shotcrete elements when congested elements are sprayed in combination with deficient shooting techniques, inadequate mixtures, or when difficult jobsite conditions exist. The methodology not only made it possible to obtain stress-slip curves with similar characteristics to those that have been observed in shotcrete (due to the insignificant amount of the mixture's bleeding capacity) but also to obtain clear tendencies and a reduced dispersion of the results. Moreover, the results show how the slip stiffness of the stress-slip curves starts to decrease when artificial voids pass from unbonded perimeters of 10 to 20%. In terms of the ultimate bond stress, the values start decreasing at an unbonded perimeter of 20% and are considerably reduced with unbonded perimeters of 30% reaching reduction values of up to 25% in comparison with perfectly encapsulated bars. In addition, the position of the voids (either facing the exterior or the interior of the element) does not seem to have a great impact on the bond strength of the bars for equal void sizes. In terms of the mode of failure, the majority of the specimens failed by splitting in the same manner as has been reported in the literature.[33] Nonetheless, it is believed that voids with an unbonded perimeter larger than 30% might cause the mode of failure to change from splitting to pullout when voids cover the entire bonded length. The results also showed how the impact of voids is as important as the one caused by excessive bleeding in cast-in-place concrete because a bleeding increase of approximately 3 times (from a condition of almost no bleeding) caused a bond behavior similar to the one observed with specimens with artificial voids of unbonded perimeters larger than 20%.

Therefore, based on the results of this investigation and those available in the literature, it seems that actions to counteract the change in the stress-slip behavior and the ultimate bond stress reduction should be considered in the design of reinforced shotcrete structures once voids having unbonded perimeters equal to or larger than 20% are expected. Indeed, unbonded perimeters of approximately 10% u.p. have little impact on the bond performance of a bar in comparison with perfectly encapsulated bars; this holds even in the worst-case scenario in which the length of the voids covered the entire bonded length of the test bar. Unbonded perimeters equal to or larger than 20% should be carefully treated as bigger confinement provided by concrete cover or transverse reinforcement may induce a change in the mode of failure and consequently a brittle behavior of the reinforced concrete elements. It is the hope of the authors that the results can already serve as a solid background to enhance or validate the current evaluation methods intended for shotcrete structures and preconstruction panels. As future work will be completed (the effect of "localized voids", concrete cover, and transverse reinforcement), proper guidelines for the design are intended to be developed.

AUTHOR BIOS

ACI member **Pasquale Basso Trujillo** *is a PhD candidate at Université Laval, Québec, QC, Canada. He is a member of ACI Committee 506, Shotcreting, and Joint ACI-ASCE Committee 408, Bond and Development of Steel Reinforcement. His research interests include shotcrete, mixture proportioning, concrete paving, finite element analysis, and uncertainty in risk assessment.*

Marc Jolin, *FACI, is a Professor in the Department of Water and Civil Engineering at Université Laval. He is Chair of ACI Committee 506, Shotcreting, and Secretary of ACI Subcommittee C601-I, Shotcrete Inspector, and is a member and past Chair of ACI Committee C660, Shotcrete Nozzleman Certification. His research interests include shotcrete, service life, reinforcement encasement quality, admixtures, and rheology of shotcrete.*

Bruno Massicotte, *FACI, is a Professor in the Department of Civil, Geological and Mining Engineering at the École Polytechnique de Montréal, Montreal, QC, Canada. He is a member of ACI Committees 239, Ultra-High-Performance Concrete; 342, Bridge Evaluation; and 544, Fiber-Reinforced Concrete. His research interests include the structural use of fiber-reinforced concretes, bridge analysis, design and assessment, and advanced structural analysis of concrete structures.*

Benoît Bissonnette, *FACI, is a Professor in the Department of Civil and Water Engineering at Université Laval. He is a member of ACI Committees 223, Shrinkage-Compensating Concrete, and 364, Rehabilitation. His research interests include infrastructure rehabilitation, the volumetric behavior of cement materials, cracking, self-leveling concretes, shrinkage-compensating concretes, instrumentation, and development of characterization tests.*

ACKNOWLEDGMENTS

The authors are grateful to the Concrete Infrastructure Research Center (CRIB) of Québec, the Natural Sciences and Engineering Research Council of Canada (NSERC), King Packaged Materials and Co., the Canadian Council of Independent Laboratories (CCIL), The American Shotcrete Association (ASA) and the Québec and East Ontario Chapter of the American Concrete Institute (ACI) for their financial support. Furthermore, special thanks are extended to J.-D. Lemay and M. Thomassin-Mailhot (research engineers), to R. Malo (expert laboratory technician) and to P.-A. Tremblay and A. Melançon (laboratory technicians) of the Department of Civil and Water Engineering at Université Laval for their outstanding work and support during the casting and the testing operations.

NOTATION

A_b = nominal cross-sectional area of reinforcing bar
a_r = base width of reinforcing bar's ribs
b_r = top width of reinforcing bar's ribs
β = angle of reinforcing bar's ribs relative to longitudinal axis of bar
D = core diameter of reinforcing bar
d_b = nominal diameter of reinforcing bar
E_c = concrete's elastic Young's modulus at day of testing
F_0 = F-statistic calculated from sample
f_c = compressive strength of concrete at day of testing
f_s = splitting strength of concrete at day of testing
H_0 = null hypothesis of pairwise comparison test method
H_a = alternative hypothesis of pairwise comparison method
h_r = height of reinforcing bar's ribs
n = number of specimens tested per family
P = measured load
P_{max} = measured ultimate load
p-value = smallest level of significance that would lead to rejection of null hypothesis
R = average bleeding rate
R_{max} = maximum average bleeding rate
R_r = relative rib area
R^2_{adj} = adjusted Pearson coefficient of regression
S = standard deviation
s_r = spacing between reinforcing bar's ribs
t_0 = t-statistic calculated from sample
v = degrees of freedom of pairwise comparison test method
α = level of significance of statistical comparison test
ΔH = bleeding capacity
μ_i = population of sample
θ = face angle of reinforcing bar's ribs

REFERENCES

1. Warner, J., "Understanding Shotcrete—Structural Applications," *Concrete International*, V. 17, No. 10, Oct. 1995, pp. 55-61.
2. Townsend, F. E. III, "Northern Boulevard Crossing Tunnel CQ039," *Shotcrete*, V. 18, No. 1, Winter 2016, pp. 34-36.
3. Davis, B., "Holcim New Zealand Cement Terminal," *Shotcrete*, V. 19, No. 1, Winter 2017, pp. 26-30.
4. Panian, L.; Steyer, M.; and Tipping, S., "Post-Tensioned Shotcrete Shearwalls," *Concrete International*, V. 29, No. 10, Oct. 2007, pp. 39-45.
5. Townsend, F. E. III, "The Plaza Substation And Queen Structures," *Shotcrete*, V. 18, No. 1, Winter 2016, pp. 22-23.
6. ACI Committee 506, "Visual Shotcrete Core Quality Evaluation (ACI 506.6T-17)," American Concrete Institute, Farmington Hills, MI, 2017, 4 pp.

7. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)," American Concrete Institute, Farmington Hills, MI, 2014, 520 pp.

8. CSA A23.3-14, "Design of Concrete Structures," Canadian Standards Association, Mississauga, ON, Canada, 2014, 297 pp.

9. Basso Trujillo, P.; Jolin, M.; Massicotte, B.; and Bissonnette, B., "Bond Strength of Reinforcing Bars Encased with Shotcrete," *Construction and Building Materials*, V. 169, 2018, pp. 678-688. doi: 10.1016/j.conbuildmat.2018.02.218

10. ASTM A944-10, "Standard Test Method for Comparing Bond Strength of Steel Reinforcing Bars to Concrete Using Beam-End Specimens," ASTM International, West Conshohocken, PA, 2010, 4 pp. https://doi.org/10.1520/A0944-10R1510.1520/A0944-10R15

11. Joint ACI-ASCE Committee 408, "Bond and Development of Straight Reinforcing Bars in Tension (ACI 408R-03)," American Concrete Institute, Farmington Hills, MI, 2003, 49 pp.

12. Orangun, C. O.; Jirsa, J. O.; and Breen, J. E., "The Strength of Anchor Bars: A Reevaluation of the Test Data on Development Length and Splices," University of Texas at Austin, Austin, TX, 1975, 78 pp.

13. Jirsa, J. O.; Lutz, L. A.; and Gergely, P., "Rationale for Suggested Development, Splice, and Standard Hook Provisions for Deformed Bars in Tension," *Concrete International*, V. 1, No. 7, July 1979, pp. 47-61.

14. ASTM A615-16, "Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement," ASTM International, West Conshohocken, PA, 2016, 7 pp. https://doi.org/10.1520/A0615_A0615M-1610.1520/A0615_A0615M-16

15. ASTM A370-17, "Standard Test Methods and Definitions for Mechanical Testing of Steel Products," ASTM International, 2017, 49 pp. https://doi.org/10.1520/A0370-1710.1520/A0370-17

16. ASTM C494/C494M-17, "Standard Specification for Chemical Admixtures for Concrete," ASTM International, 2017, 10 pp. https://doi.org/10.1520/C0494_C0494M-1710.1520/C0494_C0494M-17

17. ASTM C192/C192M-16a, "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory," ASTM International, 2016, 8 pp. https://doi.org/10.1520/C0192_C0192M-16A10.1520/C0192_C0192M-16A

18. ASTM C39/C39M-17a, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens," ASTM International, West Conshohocken, PA, 2017, 8 pp. https://doi.org/10.1520/C0039_C0039M-17B10.1520/C0039_C0039M-17B

19. ASTM C496-11, "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," ASTM International, West Conshohocken, PA, 2011, 5 pp. https://doi.org/10.1520/C0496_C0496M-1110.1520/C0496_C0496M-11

20. ASTM C469-14, "Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression," ASTM International, West Conshohocken, PA, 2014, 5 pp. https://doi.org/10.1520/C0469_C0469M10.1520/C0469_C0469M

21. ASTM C143/C143M-15a, "Standard Test Method for Slump of Hydraulic-Cement Concrete," ASTM International, 2015, 4 pp. https://doi.org/10.1520/C0143_C0143M-15A10.1520/C0143_C0143M-15A

22. ASTM C1611-14, "Standard Test Method for Slump Flow of Self-Consolidating Concrete," ASTM International, West Conshohocken, PA, 2014, 6 pp. https://doi.org/10.1520/C1611_C1611M-1410.1520/C1611_C1611M-14

23. ASTM C231/C231M-17, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method," ASTM International, West Conshohocken, PA, 2017, 9 pp. https://doi.org/10.1520/C0231_C0231M-17A10.1520/C0231_C0231M-17A

24. Josserand, L., and de Larrard, F., "A Method for Concrete Bleeding Measurement," *Materials and Structures*, V. 37, No. 10, 2004, pp. 666-670. doi: 10.1007/BF02480511

25. ASTM C232-14, "Standard Test Method for Bleeding of Concrete," ASTM International, West Conshohocken, PA, 2014, 3 pp. https://doi.org/10.1520/C0232_C0232M10.1520/C0232_C0232M

26. Basso Trujillo, P.; Malo, R.; and Jolin, M., "Alternative Set-Up Apparatus to Test ASTM A944-10 Beam-End Specimens," *Journal of Testing and Evaluation*, V. 46, No. 4, 2018. https://doi.org/10.1520/JTE20170645

27. Montgomery, C. D., *Design and Analysis of Experiments*, seventh edition, 2009.

28. ASTM International, "Significance of Tests and Properties of Concrete and Concrete-Making Materials," 2006, 664 pp. https://doi.org/10.1520/STP169D-EB10.1520/STP169D-EB

29. Darwin, D.; Zuo, J.; Tholen, M. L.; and Idun, E. K., "Development Length Criteria for Conventional and High Relative Rib Area Reinforcing Bars," *ACI Structural Journal*, V. 93, No. 3, May-June 1996, pp. 347-359. doi: 10.14359/9694

30. Zuo, J., and Darwin, D., "Splice Strength of Conventional and High Relative Rib Area Bars in Normal And High-Strength Concrete," *ACI Structural Journal*, V. 97, No. 4, July-Aug. 2000, pp. 630-641. doi: 10.14359/7428

31. Miller, G. G.; Kepler, J. L.; and Darwin, D., "Effect of Epoxy Coating Thickness on Bond Strength of Reinforcing Bars," *ACI Structural Journal*, V. 100, No. 3, May-June 2003, pp. 314-320. doi: 10.14359/12606

32. Salem, H. M., and Maekawa, K., "Pre- and Postyield Finite Element Method Simulation of Bond of Ribbed Reinforcing Bars," *Journal of Structural Engineering*, ASCE, V. 130, No. 4, 2004, pp. 671-680. doi: 10.1061/(ASCE)0733-9445(2004)130:4(671)

33. Brettmann, B. B.; Darwin, D.; and Donahey, R. C., "Bond of Reinforcement to Superplasticized Concrete," *ACI Journal Proceedings*, V. 83, No. 1, Jan.-Feb. 1986, pp. 98-107. doi: 10.14359/1743

TECHNICAL TIP

Concrete in the Cloud

By Jason Myers

The world is becoming more and more connected and it was only a matter of time before we saw it in the concrete industry as well. In Northern California, most of the major ready mixed suppliers have developed computer website programs and online applications that are accessible from smartphones and internet-connected devices. For the past couple of decades, the internet has been identified as the cure for all of the world's ills. Through the evolution of connected technology, we finally see it making sense for concrete applications. This article discusses the advantages and disadvantages of the features that are being used in existing systems and makes recommendations for additional refinements.

ORDERING

These concrete ready mixed applications can save time in ordering concrete and then making sure orders are correct. Several of the apps allow you to order, modify, and verify orders online. Rather than calling into the concrete plant dispatch and placing an order, the online app allows a quicker and more efficient way to get orders into the system and thus a faster turnaround for the dispatchers. This also minimizes the chance of human error because of mistyping or getting the wrong mixture components ordered. Many of the apps offer ways to directly text dispatch so that once the order is setup, modifications can be made in the field without having the full job folder with you. These apps allow for the order to be reviewed at any time so people in the field can easily see what is ordered and the details of the order whenever needed.

TRACKING

One of the biggest strengths of these online tools is the truck tracking ability. The days of calling concrete dispatch and the dispatcher stating, "the truck was batched 5 minutes ago," and wondering if that was true or not are gone. Now, the dispatchers know that whatever they say is tracked and easily verifiable. The tracking ability is also beneficial in congested urban environments for finding a lost truck or sending a laborer to the opposite side of the jobsite to flag a driver down that does not know the shotcrete pump location. This also helps if you are waiting on a truck and you can see its exact location to know if it is 5 minutes or 30 minutes away. One of the apps provides additional information on the specific load including temperature, slump, and revolutions of the truck. Like many real-time information systems, there are sometimes gaps or discrepancies in the system and so you must be able to read beyond the face value of the information. Other convenient features are the ability to review the production graphs and availability of tools to verify delivery. With a quick glance, one can verify if the concrete delivery intervals match the requested spacing or to see if one of the concrete mixture components is off and needs to be modified. Often at the end of the day, you hear from the field about all the delays that they had, and when you dig into the supplier data, you find the trucks were emptying faster than the expected rate of delivery.

BILLING

One of the areas that I need to explore more and potentially use more often is the post-production portion of the apps. This is also were you get the most variation in the capabilities of the various concrete supplier systems. One allows for quick generation of invoices as well as the ability to review concrete tags within a day of the placement. This allows for a quick copy of any missed tags as well as an easy way to verify invoices. Lien releases can be requested and generated almost instantly.

While the available apps are optionally provided by the ready mixed supplier to provide and integrate into their system, they are certainly a step in the right direction. All the online systems I have seen are user-friendly and do not have a large learning curve. These apps are of value to both the office and the field. We're finally seeing the promises of connected technology for ready mixed suppliers truly being beneficial for everyone involved in the concrete construction industry.

***Jason Myers** received his bachelor's degree in civil engineering from California Polytechnic State University, San Luis Obispo, CA, and his MBA with an emphasis in project management from Golden Gate University, San Francisco, CA. Myers started his professional career working for an earth retention subcontractor where he learned the importance of budgeting, scheduling, and client relationships. Also during this time, he was introduced to the use of shotcrete and its applications. After working for a general contractor for a couple of years, he realized that he enjoyed the tighter knit of working for a subcontractor and the ability to construct multiple projects on a tighter timeframe. Myers also enjoys the process of handling most of the procedures that go into constructing a project rather than seeing only a small portion of the process. Myers joined Dees Hennessey in 2004 and has been a part owner of the company since 2007. He currently serves as the Vice President of Operations as well as the Safety Director. Myers is Chair of the ASA Membership Committee and a member of the ASA Board of Directors.*

Are Feathered Edges Ever Appropriate?

By Ryan Oakes

The perfect storm… My deadline for this article was looming and I was called to duty, as a batch truck driver injured his finger the night before. The job was 4 hours away, so I was out the door at 4:00 a.m. to get to our shop. It was for an important client who was trying to get his pool shell in before a tropical storm made landfall. You can see where this is going.

This was an 80 to 90 yd^3 (61 to 69 m^3) pool—a size our crew can handle in a day. The majority of the crew arrived the night before and the rest left at 3:00 a.m. All was well until I showed up a little late due to a couple fuel stops, school buses, major traffic slowdowns… No worries, we can still pull this off.

The tropical storm was sitting right on top of us but not doing anything threatening, so we studied the radar and pressed on. Approximately 10 miles (16 km) away, Wilmington, NC, was experiencing inclement weather with several inches of rain. We dodged the bullet, or so we thought. Later that day, the volumetric batch trucks were held up in traffic between the reload yard and the jobsite, adding more time to get the job done. Then, as we were nearly complete with only 15 yd^3 (11 m^3) to go, an auger broke on one of the batch trucks and a bearing went bad on another one.

It was late, and the crew only had 3 hours of sleep the night before, so we stopped the shotcrete placement. The crew immediately began properly prepping all shotcrete surfaces for the following day. Unfinished walls were benched off at a 45-degree angle. Receiving surfaces had laitance removed and were roughened with a notched trowel. The floor was given a broom finish. Before brooming the floor, the finishers went around the edge of the pool where walls had not been shot and lowered the surface by 1 in. (25 mm) so that there was a shoulder for the cove to meet the floor on the next day. We sent the full batch truck home and didn't put the last batch truck in the pool excavation, deciding it would be best to have it ready for the next morning while the other truck went for a reload.

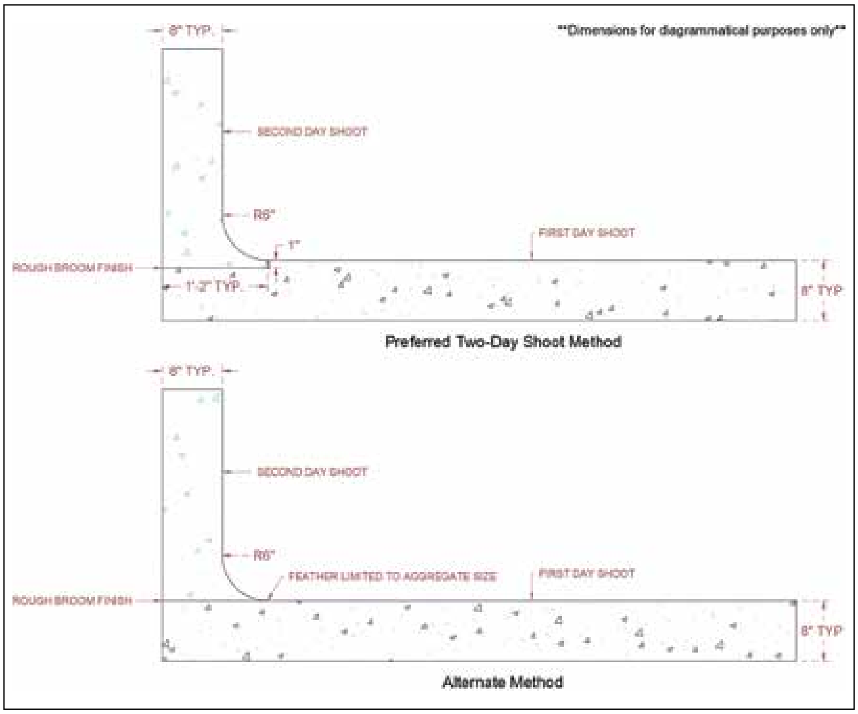


Fig. 1: Top section drawing is the preferred detail showing a 3/4 in. minimum shoulder where the cove meets the floor. The bottom section shows how the feathered approach will look when properly executed

The next morning, we started prepping the receiving surfaces and pool shell for new shotcrete placement. An hour later one of the batch trucks' tire blew out and another subcontractor on the project broke the water main, causing the loss of the on-site water supply. Fortunately, our batch trucks have water tanks so we drove to a nearby concrete plant and filled the water tanks. We finished later in the day after placing a total of 93 yd^3 (71 m^3).

THE LESSON

It probably goes without saying at this point but, things don't always go as planned. It's construction—what could possibly go wrong?

There are numerous reasons we stop and start our work in structural shotcrete placement. Pools are no exception. Pool projects are becoming more complicated. Designers add many details that make pool construction more intricate. As a result, pools are sometimes larger than can be placed in one day. On-site productivity issues such as equipment failure, materials delivery problems, or a looming rainstorm can severely affect production and shut down a job quickly. These are just a few examples of why we might have unintended placement delays or full stops.

ACI and good industry practice has established guidelines for dealing with construction joints when stopping and then restarting shooting. We completely support these guidelines. However, as noted above unplanned events can (and will) on occasion impact a job. In some cases, a solution is needed that provides the best possible quality and durability though perhaps not as optimum as it may have been without the extenuating circumstances. Particularly, I am referring to dealing with the leading edge of fresh material to existing material in an unplanned construction joint. An example of this location is the cove of a pool. The accepted practice is to create a shoulder in the initially shot concrete of at least 3/4 in. (19 mm) so that the leading edge of the subsequently placed concrete is at least 3/4 in. thick where it abuts up to the existing concrete and does not "feather" out to zero. This is the best method and should be followed whenever possible. However, when all else fails, feathering an edge in some applications, if done well and with close attention to detail, is a method of creating a serviceable construction joint in a swimming pool.

SHAPES, SIZES, AND FLOORS

In a rectangle pool with a set and specific radius cove, where one knows they are going to shoot the floor first and walls the next day, it is possible to cut a shouldered edge in the floor for the subsequent wall placement. This increases the time and effort needed to prep the joint and may require extra finishers but is needed to provide the best possible joint. In a curvilinear pool with a varying and compounded floor pitch and multiple protrusions in the wall, such as benches, swim outs, barstools, steps, and water features, it becomes more difficult to create the shoulder. It is certainly harder to predict exactly where all these termination points of the floor are going to be. Without close attention to the stopping points, the concrete may set too fast on a hot summer day for the crew to carve the shoulder at the transition.

Also, sometimes (as discussed previously) a shotcrete crew must stop unexpectedly. After the concrete in the floor has hardened, coming back and chipping or sawing just to produce the shoulder may create more internal damage to the concrete than justified by having a reduced thickness at the transition.

Often, commercial pool floors are cast by the pool contractor, calling the shotcrete contractor in only to shoot the walls. The pool contractors I've dealt with rarely spend the time and effort to produce the shoulder at the joint. Right or wrong, this is what we must deal with when we show up to shotcrete. We can ask the contractor to properly prep the joint to create the best possible joint, but some builders are unfamiliar with the industry practice or simply don't want this done as they are unwilling to spend the extra money for the labor intense demolition to create a shoulder in a hardened concrete surface. Unfortunately, some shotcrete contractors will simply shoot the walls with no prep whatsoever and without knowledge of proper procedures to create a feathered edge successfully. This bodes badly for the entire shotcrete industry. Thus, in this article I propose an alternative method of dealing with these much less than optimum conditions which may necessitate producing a feathered edge.

THE FEATHERED EDGE

To be clear, good industry practice, as documented by ASA and ACI, does not recommend using a feathered edge at a construction joint. If one encounters a situation where there are no other practical options this technique may be helpful to complete the job. However, this should never be a practice that is planned on by the shotcrete contractor *before* shooting the pool. It's like that box on the wall that says, "In emergency break glass" and you pull the alarm.

Knowing why it shouldn't be used as well as how one may best use the technique can be a valuable tool for a highly-skilled shotcrete crew when shooting swimming pools. Also, a technique that works for a dry-mix shotcrete application, may not necessarily work for a wet-mix shotcrete application, because a dry-mix application typically has smaller aggregate and therefore can allow a thinner edge.

If a shotcrete crew feathers a new edge out over an existing well-prepared concrete surface with proper application, the thickness at the edge should be limited to the size of the aggregate. Because proper shotcrete placement forces the cement-rich paste at high velocity into the existing surface the leading edge of new material is bonding to the existing material. If the nozzleman shoots past the point that is going to be feathered to zero (or close to zero), and the finishers cut back to the tapered edge, there is still the bond of the new concrete to the existing material.

This is not a new practice, and several shotcrete companies, both wet- and dry-mix, have been using this technique for years though unfortunately not always with good technique or results. I have been back to jobs that our company shot, 28 days or later (before plaster) to look for failure in using this technique on our own work and found them successful. In applications where we had excellent preparation, material placement, and curing I had difficulty finding where a feathered edge existed in the final joint. Where our application was less than perfect one can see the edge is fragile and breaks back to about 1/8 in. (3 mm) or at most 1/4 in. (6 mm) from the termination of the secondary placement. My experience suggests that variation in aggregate can significantly affect the performance of a feathered edge. Thus, understanding your concrete mixture design will help in understanding how to apply the material as well as what its limitations are. Because aggregate size in the dry-mix shotcrete process is typically a little bit smaller, it will likely work better than when using a wet-mix shotcrete with larger coarse aggregate sizes. I also have noticed that using silica fume in the concrete mixture will help improve the bond of a feathered edge.

Fig. 2: In this application the procedure was done well enough that at 28 days, the connection point is hardly perceptible

Fig. 3: This is the preferred method that a crew should be ready to install on 2-day projects when possible

During plaster prep, nuances or variations in shotcrete work are resolved by the plaster, tile, or stone prep crew; therefore, having a 1/4 in. broken edge generally falls within the acceptable finished tolerances of the shotcrete pool shell. The concrete shell is just that—it's a shell. The surface is going to be covered so a perfectly smooth surface is not necessary. A good, solid surface with no voids and a good bond between joints is necessary to create a watertight vessel that is structurally sound. You should strive to provide a final surface very close to the finished tolerances required by the pool builder to minimize prep by pool work that follows shotcreting.

It is important to understand which trade is coming behind your work. For example, with subsequent plaster application, it is ideal to minimize variance in the interior surface so that plaster does not hydrate unevenly or create small edges that can cause reentrant cracking in plaster surfaces. In tile, it is ideal to minimize variances as well, so that tile setters don't have to float the grout excessively and require an expensive buildup of materials to perfect their interior substrate.

PROBLEMS WITH FEATHERED EDGES

Problems using a feathered edge may and are likely to arise if the most stringent care and attention to detail is not used. If rebound or trimmings are not removed and the nozzleman is not willing to stop and continually clean the surface while applying the edge, then poor quality concrete materials may get incorporated at the interface. This will likely be discovered during the plaster prep through high-pressure washing, acid washing, or hammer sounding the joint with a hammer. It is also possible that these same problems will occur if the nozzleman does not use correct technique when flashing a pool for a finished surface.

PROBLEMS WITH SHOULDERED EDGES

The greatest problem with creating the shouldered edge is circumstance. Many contractors may simply not be educated on why a shouldered edge is best practice. It may be due to unexpected short staffing or running out of time in the day. Problems can also arise when a shotcrete contractor does not understand how to keep rebound away and simply traps it in the shouldered area. It is easy to trap rebound in a tight space like this and supports the idea that the shotcrete contractor should be qualified for the job and employ an ACI-Certified Shotcrete Nozzleman.

CREATING A FEATHERED EDGE

Before explaining how we have managed to successfully create a feathered edge, I want to reiterate that neither ACI nor ASA recommend using a feathered edge. The prescribed method is to cut a shoulder at least 3/4 in. deep in the existing surface. This is the method we routinely use. However, when unforeseen circumstances arise to warrant the use of the feathering technique this is what we do when using dry-mix shotcrete.

Our dry-mix nozzleman first preps the existing surface with high-pressure air and water blast from his hose. Then the air lance (blowpipe) is used during shotcrete placement to continually remove overspray and rebound. If the rebound and overspray builds up to amounts that the air lance cannot easily remove, a finisher should be readily available to pull the excess away from the shotcrete receiving surface

Fig. 4: Cleaning the surface area with high-pressure air and water. This process gets the substrate to a clean SSD state. This is essential to achieving a solid bond between the new and existing material

Fig. 6: Maintaining a clean substrate is a very active procedure. It helps to have a finisher using a Fresno to remove excessive rebound

Fig. 5: Using an air lance is critical to maintaining a clean substrate during the shotcrete process. Without the air lance the substrate will develop a layer of overspray and rebound that will prevent bonding of the new material to the existing material

Fig. 7: Once the cove is shot in place, a level and tape are used to verify the dimensions of the wall

Fig. 8: Finishers remove the excess material from the cove to handcraft the shape and feather the cove down to the floor

Fig. 9: A finished cove and wall shot in place on the second day of a shoot

and removing it from the pool. The air lance also removes excess water and can help to maintain a saturated surface dry (SSD) condition to receive the material. Laying down a nice bed of material for a long run of a joint will help the nozzleman build up the wall as if they were shooting against all new material on the floor. Constant attention is needed to achieve a good bond and an acceptable surface. Without an air lance this method is simply not possible.

All other ACI guidelines are followed to help ensure excellent bond at the joint and preventing a cold joint. Having a properly benched off surface, roughened, cleaned from all debris and laitance, and with reinforcing bar that is clean of all overspray is essential to successful performance.

A CLOSING THOUGHT

Decades of successful placement with a 3/4 in. shouldered edge has proven the ability to have construction joints that act monolithically while providing long-term strength and durability. I encourage builders to follow it whenever possible. Don't take shortcuts using a feathered edge to save time or effort on a job because it will reduce the durability and performance of the final joint. "In Case of Emergency" consider all options and if feathering a joint edge is the only solution make sure you pay careful attention to all the details in prep, placement, and curing.

Swimming pools are not simple concrete rectangular pools anymore. Pools are becoming more complicated than ever with details such as vanishing edges, perimeter overflows, raised bond beams, underwater rooms, artificial rock, built in aquariums, shallow water lounging areas, beach entries, or water features. The more people and trades we involve in any field construction project, the more likely we will run into surprises and situations that call for creative approaches. We must as an industry accept that consistent high quality and durability of our pool shells is the ultimate challenge. We must rise to that challenge and always find a way to achieve the best possible results. As shotcrete contractors we must always stress to the pool contractors before they pour a floor that the shoulder at the edge is critical to producing the best quality, most durable joint. Our reputation as contractors and our reputation as an industry depend on it!

Ryan Oakes *is a Managing Partner at Revolution Gunite and is a licensed pool contractor in North Carolina and Virginia. Oakes has been designing and building watershapes in the United States and abroad, from swimming pools to art pieces and even aquaculture systems, for the past 20 years. With a mission to change the way gunite is perceived and applied, Oakes started down a path of education for himself as well as Revolution Gunite staff. He is an active member in the National Swimming Pool Foundation's Genesis University, which educates contractors around the world in various aspects of the pool building process, including the shotcrete process. Oakes is an SWD Master (Society of Water-shape Designers) and an Allied member of the American Institute of Architects and member of the American Pool & Spa Association. Oakes is a member of ACI Committee 506, Shotcreting, and ACI Subcommittee 506-H, Shotcreting-Pools. He serves on the ASA Board of Directors and also serves as Vice Chair of the ASA Contractors Qualification Committee and ASA Pool & Recreational Shotcrete Committee.*

Understanding What Can Cause Problems with Concrete and Shotcrete—Part 2

By Raul Bracamontes

This is Part Two of a two-part series on potential causes of problems in concrete and shotcrete. Part One introduced the series, then led into an investigation into problems due to insufficient design or project specifications, and concluded with issues with the planning process. Part One of this series can be found at **www.shotcrete.org/media/Archive/2019Win_ContractorsCorner(translated)-Bracamontes.pdf**.

Part Two will discuss problems related to production, including type and quantities of materials chosen; problems during the placement process; and issues from commissioning and maintenance of the completed structure.

The origin or cause of problems in concrete arise at some point during the design, development, placement, or its service life. For the identification of the causes, it is necessary to carry out an exhaustive investigation by means of a root-cause analysis of the problem to discover the factors that could cause it.

The causes of concrete problems can be included in five categories:

1. Problems related to an insufficient design or project;
2. Problems related to the planning process;
3. Problems related to type and quantities of materials chosen;
4. Problems related to the placement process; and
5. Problems related to the operation or useful life and maintenance.

SHOTCRETE PROBLEMS RELATED TO MIXTURE DESIGN

Concrete is a synthetic rock composed of paste (made of water, cement, and sometimes admixtures) and aggregate. In concrete, the aggregate is comprised of the larger rock and smaller sand particles. Aggregate is the largest portion of concrete (70 to 80%), while the cement paste (20 to 30%) "glues" the aggregate together. The quality of concrete depends of the quality of paste and the aggregate.

Shotcrete mixture design involves setting the proportions of concrete ingredients. This includes the water-cementitious materials ratio (*w/cm*) and the quantities of admixtures, sand, and coarse aggregates to meet the project specifications.

The type of portland cement can influence the development of compressive strength of concrete and potential durability under service conditions.

Type, shape, surface texture, porosity, and maximum nominal size of aggregates to be used will affect the performance of fresh and hardened concrete. In shotcrete, with the smaller hose sizes, the coarse aggregate is typically limited to a nominal 3/8 in. (9 mm) size. In wet-mix, the workability of concrete must be satisfactory for pumping and yet facilitate shooting, reinforcement encasement, and compaction. It is important to remember the mixture design has to allow the shotcrete to be placed at high velocity and still keep its physical properties during shooting.

The problems with the concrete mixture design can be considered in two stages: first during the placement of fresh concrete; and second in its hardened state throughout its service life. The quality of the fresh concrete depends primarily on the *w/cm*, slump, the type and quantity of cementitious material, admixtures, and the air content.

Important properties of fresh concrete are:

- Workability/pumpability;
- Slump, segregation, and bleeding;
- Time of set;
- Temperature; and
- Cohesion.

Primary properties of hardened concrete are:

- Strength (compressive and sometimes flexural);
- Permeability;
- Shrinkage;
- Energy absorption; and
- Adhesion (bond strength).

W/CM Ratio

The *w/cm* indicates the amount of water that must go into the mixture to hydrate the cementitious materials. This is

Entendiendo lo que puede causar problemas con concreto y concreto lanzado—Parte 2

Por Raul Bracamontes

Esta es la segunda parte de una serie de dos partes sobre posibles causas de problemas en concreto y concreto lanzado. La primera parte introdujo la serie, luego llevó a una investigación de los problemas debidos a la falta de especificaciones del diseño o del proyecto y concluyó con problemas con el proceso de planificación. La primera parte de esta serie se puede encontrar en **www.shotcrete.org/media/Archive/2019Win_ContractorsCorner(translated)-Bracamontes.pdf**.

En la segunda parte se analizarán los problemas relacionados con la producción, incluyendo el tipo y la cantidad de materiales elegidos, los problemas durante el proceso de colocación y las cuestiones relacionadas con la habilitación y el mantenimiento de la estructura terminada.

El origen o la causa de los problemas en concreto surgen en algún momento durante el diseño, desarrollo, colocación o su vida útil. Para la identificación de las causas, es necesario llevar a cabo una investigación exhaustiva mediante un análisis de causa raíz del problema para descubrir los factores que podrían causarlo.

Las causas de los problemas del concreto pueden incluirse en cinco categorías:

1. Problemas relacionados con un diseño o proyecto insuficiente;
2. Problemas relacionados con el proceso de planificación;
3. Problemas relacionados con el tipo y la cantidad de materiales elegidos;
4. Problemas relacionados con el proceso de colocación; y
5. Problemas relacionados con la operación o vida útil y mantenimiento.

PROBLEMAS DE CONCRETO LANZADO RELACIONADOS CON EL DISEÑO DE MEZCLA

El concreto es una roca sintética compuesta de pasta (hecha de agua, cemento y, a veces, aditivos) y agregado. En concreto, el agregado se compone de rocas más grandes y partículas de arena más pequeñas. El agregado es la porción más grande de concreto (70 a 80%), mientras que la pasta de cemento (20 a 30%) "aglutina" el agregado. La calidad del concreto depende de la calidad de la pasta y el agregado.

El diseño de mezcla del concreto lanzado implica establecer las proporciones de ingredientes de concreto. Esto incluye la relación agua-materiales cementantes (*a/mc*) y las cantidades de aditivos, arena y agregado grueso para cumplir las especificaciones del proyecto.

El tipo de cemento portland puede influir en el desarrollo de la resistencia a la compresión del concreto y la durabilidad potencial bajo condiciones de servicio.

El tipo, la forma, la textura de la superficie, la porosidad y el tamaño máximo nominal del agregado utilizado afectarán el rendimiento del concreto fresco y endurecido. En concreto lanzado, con tamaños de manguera más pequeños, el agregado grueso suele limitarse a un tamaño nominal de 3/8 pulg. (9 mm). Sin embargo, en el mezclado en húmedo, la trabajabilidad del concreto debe ser satisfactoria para el bombeo y, facilitar el disparo, el recubrimiento del refuerzo y la compactación. Es importante recordar que el diseño de la mezcla debe permitir que el concreto lanzado se coloque a alta velocidad y aun así manteniendo sus propiedades físicas durante el disparo.

Los problemas con el diseño de la mezcla de concreto se pueden considerar en dos etapas: primero, durante la colocación del concreto fresco; y en su estado endurecido a lo largo de su vida útil. La calidad del concreto fresco depende principalmente de la proporción de *a/mc*, el asentamiento, el tipo y la cantidad de material cementante, los aditivos y el contenido de aire.

Las propiedades importantes del concreto fresco son:

- Trabajabilidad/bombeabilidad;
- Asentamiento, segregación y exudación;
- Tiempo de fraguado;
- Temperatura; y
- Cohesión.

Las propiedades primarias del concreto endurecido son:

- Resistencia (a la compresión y, a veces, a la flexión);
- Permeabilidad;
- Retracción de fraguado;
- Absorción de energía, y
- Adhesión (fuerza de la adherencia).

A/MC

La proporción de *a/mc* indica la cantidad de agua que debe entrar en la mezcla para hidratar los materiales simply a fraction obtained from dividing the mass of the water (lb or kg) in the concrete mixture by the mass of cementitious materials (lb or kg). Minimizing the amount of water has a large impact on production of good quality concrete. For shotcrete, the *w/cm* will generally be between 0.30 and 0.45.

As the environmental exposure becomes more aggressive, the *w/cm* should be lower. If *w/cm* is not optimized, the progressive and potentially accelerated deterioration of the concrete will be inevitable over time. Concrete with a low *w/cm* produces high strength and lower permeability, resulting in higher durability.

Aggregate

Aggregate is usually inert, meaning it is unreactive and ideal to use in concrete. However, some aggregates can react with the alkali hydroxides in concrete, causing expansion and cracking over a period of many years. This alkali-aggregate reaction has two forms: alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR). That is why it is very important to test the aggregates for ASR and ACR reactivity before the aggregates are used in concrete.

Aggregate with the 3/8 in. coarse aggregate should meet the gradation limits for combined aggregates as referenced in ACI 506R-16, "Guide to Shotcrete," Gradation No. 2.

The slump of the wet-mix should be the minimum that can still be reliably pumped. This is usually in a slump range of 1-1/2 to 3 in. (38 to 75 mm). However, in thicker, heavily congested sections, a slightly higher slump may be desirable.

Air Entrainment

Both wet-mix and dry-mix shotcrete can be air-entrained. A range of 5 to 8% of total air before pumping, air entrainment tends to make some mixtures more workable. Higher air content may help make marginal mixtures easier to pump. The air content of the in-place concrete after shooting is generally about half the original air content as delivered due to the high-velocity impact force of shotcrete placement.

Temperature

It is also important to consider restrictions on the material temperature of fresh concrete. Project specifications will often not allow placement if the concrete temperature is greater than 90 to 95°F (32 to 35°C) in hot weather. In cold-weather ACI documents require concrete temperature should be at least 50°F (10°C). The recommendations of the ACI 305 documents address placing concrete in hot weather and ACI 306 documents address placing concrete in cold weather.

PROBLEMS CREATED DURING SHOTCRETE PLACEMENT

The nozzleman is ultimately responsible for the quality of the concrete in place. Shotcrete must be applied at high velocity to create a dense and compact concrete section with the required thicknesses, full encasement of the reinforcing steel, and with minimum rebound and overspray.

Poor shotcrete placement on site can drastically reduce the final quality of any concrete structure. A structure designed to comply with all the applicable standards, with quality concrete materials, is still dependent on the skill and competence of the nozzleman. The nozzleman coordinates the shotcrete placement with the project manager, site supervisor, the pump or gun operator, and the finishers. Shotcrete can be applied on many different surfaces, such as soil, rock, masonry, concrete, wood, steel, or other surfaces, as required by the project.

These are steps the nozzleman must consider while placing quality shotcrete:

- Make sure the nozzle is clean and in good condition;
- Verify that the areas where the shotcrete is to be placed are clean, free of loose particles, dust, mud, rebound, and any foreign substance that may affect the adhesion of the concrete;
- Verify the reinforcing steel is clean, properly positioned, and will not vibrate during placement;
- If necessary, provide mockup preconstruction panels. These panels represent similar reinforcement and sections that will be in the project;
- Applies the approved shotcrete mixture at a uniform velocity to ensure adhesion of the material to the surface with minimum rebound and maximum density, layer thickness, full compaction, and encasement of steel reinforcement;
- Controls the velocity, distance, and angle of the nozzle, and the volume of placement of shotcrete;
- Controls the air flow, making sure it is uniform and has an adequate velocity for a good compaction;
- In dry-mix, controls the amount of water added at the nozzle to obtain proper consistency and adequate hydration of the concrete; and

cementantes. Esto es simplemente una fracción obtenida al dividir la masa del agua (lb o kg) en la mezcla de concreto por la masa de materiales cementantes (lb o kg). Minimizando la cantidad de agua tiene un gran impacto en la producción de concreto de buena calidad. Para concreto lanzado, la proporción de *a/mc* generalmente estará entre 0.30 y 0.45.

A medida que la exposición ambiental se vuelve más agresiva, la proporción de *a/mc* debe ser menor. Si la proporción de *a/mc* no es optimizada, el deterioro progresivo y deterioro potencialmente acelerado del concreto será inevitable con el tiempo. El concreto con una baja proporción de *a/mc* produce una alta resistencia y una menor permeabilidad, resultando en una durabilidad mayor.

Agregado

El agregado suele ser inerte, lo que significa que no es reactivo e ideal para usar en concreto. Sin embargo, algunos agregados pueden reaccionar con los hidróxidos alcalinos en concreto, causando expansión y agrietamiento durante un período de muchos años. Esta reacción del álcali al agregado tiene dos formas: reacción álcali-sílice (RAS) y reacción álcali-carbonato (RAC). Es por eso por lo que es muy importante probar los agregados para detectar la reactividad RAS y RAC antes de que los agregados sean utilizados en concreto.

El agregado como el agregado grueso de 3/8 pulg. debe cumplir los límites de gradación para los agregados combinados como se hace referencia en ACI 506R-16, “Guide to Shotcrete,” Gradation No. 2.

El asentamiento del mezclado en húmedo debe ser el mínimo que aún pueda bombearse de manera confiable. Esto suele estar en un rango de asentamiento de 1-1/2 a 3 pulg. (38 a 75 mm). Sin embargo, en secciones más gruesas y muy congestionadas, puede ser deseable un asentamiento ligeramente mayor.

Aire incorporado

Tanto el concreto lanzado de mezclado en húmedo como el mezclado en seco pueden ser incorporados con aire. En un rango del 5 al 8% de aire total antes de bombear, el aire incorporado tiende a hacer que algunas mezclas sean más trabajables. Un mayor contenido de aire puede ayudar a que las mezclas marginales sean más fáciles de bombear. El contenido de aire del concreto en el lugar después del lanzado es generalmente aproximadamente la mitad del contenido de aire original suministrado debido a la fuerza de impacto de alta velocidad de la colocación del concreto lanzado.

Temperatura

También es importante considerar restricciones en la temperatura del material del concreto fresco. Las especificaciones del proyecto a menudo no permiten la colocación si la temperatura del concreto es superior de 90 a 95°F (32 a 35°C) en climas cálidos. En climas fríos, los documentos del ACI requieren que la temperatura del concreto sea de al menos 50°F (10°C). Las recomendaciones de los documentos del ACI 305 se refieren a la colocación de concreto en climas cálidos y los documentos del ACI 306 se refieren a la colocación de concreto en climas fríos.

PROBLEMAS CREADOS DURANTE LA COLOCACIÓN DE CONCRETO LANZADO

El lanzador es en última instancia responsable por la calidad del concreto en el lugar. El concreto lanzado debe ser aplicado a alta velocidad para crear una sección de concreto densa y compacta con los espesores requeridos, revestimiento completo del acero de refuerzo y con rebote y exceso de rocío mínimo.

La mala colocación de concreto lanzado en el sitio puede reducir drásticamente la calidad final de cualquier estructura de concreto. Una estructura diseñada para cumplir con todas las normas aplicables, con materiales de concreto de calidad, sigue dependiendo de la habilidad y competencia del lanzador. El lanzador coordina la colocación de concreto lanzado con el jefe del proyecto, el supervisor del sitio, el operador de la bomba o del lanzador y los acabadores. El concreto lanzado puede ser aplicado en muchas superficies diferentes, como suelo, roca, mampostería, concreto, madera, acero u otras superficies, según lo requiera el proyecto.

Estos son los pasos que el lanzador debe tener en cuenta al colocar concreto lanzado de calidad:

- Asegúrese que la boquilla esté limpia y en buenas condiciones;
- Verifique que las áreas donde se va a colocar el concreto lanzado estén limpias, libres de partículas sueltas, polvo, barro, rebote y cualquier sustancia extraña que pueda afectar la adhesión del concreto;
- Verifique que el acero de refuerzo esté limpio, colocado correctamente y no vibre durante la colocación;
- Si es necesario, proporcione maquetas de paneles antes de la construcción. Estos paneles representan refuerzos y secciones similares que estarán en el proyecto;
- Aplique la mezcla de concreto lanzado aprobada a una velocidad uniforme para garantizar la adhesión del material a la superficie con un rebote mínimo y una densidad máxima, el espesor de capa, compactación completa y revestimiento de refuerzo de acero;
- Controle la velocidad, la distancia y el ángulo de la boquilla, y el volumen de colocación de concreto lanzado;
- Controle el flujo de aire, asegurándose que sea uniforme y tenga una velocidad adecuada para una buena compactación;
- En el mezclado en seco, controle la cantidad de agua añadida en la boquilla para obtener la consistencia adecuada y la hidratación adecuada del concreto; y

- Prepare samples for quality control. Generally, these are material panels shot daily or every 50 yd^3 (38 m^3).

Again, the nozzleman is responsible for all decisions that affect the final quality of the shotcrete concrete.

THE FIVE MOST COMMON MISTAKES MADE DURING THE PLACEMENT OF WET-MIX SHOTCRETE

Add Excess Water

The *w/cm* is very delicate and the quality of the shotcrete is highly dependent on it. When water is added, the compressive strength and durability are reduced, and thus reducing the long-term durability of the hardened concrete.

Doesn't the concrete supplier always bring the right slump? Not necessarily! This proper consistency can be affected by improper quantity of admixtures, transport time, incorrect mixture design, weather conditions, and so on. It is much better to adjust the slump by using water-reducing admixtures than simply adding water to the concrete truck. Some ready mixed companies print on their batch tickets the maximum amount of water that can be added to a **full load** truck to keep the mixture at or below the specified *w/cm*. One should note that if using accelerator, adding more water to the mixture will increase the volume of accelerator needed for similar acceleration of the set of the concrete.

Dosing of the Accelerant without Control

The admixtures are generally placed into the concrete mixture at the batch plant. However, an exception is when rapid-set shotcrete accelerators are used in wet-mix shotcrete. These must be injected at the nozzle together with the compressed air.

If accelerator is overdosed, the final strength of the shotcrete decreases drastically. Adhesion problems can occur between the concrete and the substrate and shadows can form behind the reinforcement steel, as well as porous and weak concrete. All these reduce the quality of the concrete. In addition, overdosing of accelerator increases the cost of the shotcrete. It is essential to calibrate the accelerator dosage pump with the output of the shotcrete equipment to obtain the desired dosing during shotcrete placement.

Improper Preparation of the Surface

Key factors for proper surface preparation include:

- Cleaning to remove dust, oil, or any substances that may affect the adhesion between the concrete and the surface of application; and
- Bringing the surface to a saturated surface-dry (SSD) condition prior to the placement of the shotcrete.

A properly and thoroughly prepared surface will enhance the success of a shotcrete application.

Fig. 1: Obviously too much water on top of the concrete in the hopper

Fig. 2: The admixtures play an important role in the production of this underground shotcrete placement

- Prepare muestras para el control de calidad. Generalmente, esto son paneles de material disparados diariamente o cada 50 yd^3 (38 m^3).

Nuevamente, el lanzador es responsable por todas las decisiones que afectan la calidad final del concreto lanzado.

LOS CINCO ERRORES MÁS COMUNES COMETIDOS DURANTE LA COLOCACIÓN DE CONCRETO LANZADO DE MEZCLADO EN HÚMEDO

Añadir exceso de agua

La proporción de *a/mc* es muy delicado y la calidad del concreto lanzado depende en gran medida de ello. Cuando se agrega agua, la resistencia a la compresión y la durabilidad se reducen, reduciendo así la durabilidad a largo plazo del concreto endurecido.

¿El proveedor de concreto no trae siempre concreto de asentamiento correcto? ¡No necesariamente! Esta consistencia adecuada puede verse afectada por una cantidad inadecuada de aditivos, tiempo de transporte, diseño incorrecto de la mezcla y condiciones climáticas. Es mucho mejor ajustar el asentamiento mediante el uso de aditivos reductores de agua que simplemente agregar agua al camión de concreto. Algunas compañías de concreto premezclado imprimen en sus boletos de tandas la cantidad máxima de agua que se puede agregar a un camión de carga completa para mantener la mezcla en o por debajo de la proporción de *a/mc* especificado. Cabe señalar que, si se usa un acelerador, agregar más agua a la mezcla aumentará el volumen de acelerador necesario para una aceleración similar del fraguado inicial del concreto.

Dosificación del acelerante sin control

Los aditivos generalmente se colocan en la mezcla de concreto en la planta dosificadora. Sin embargo, una excepción es cuando se utilizan aceleradores de concreto lanzado de fraguado inicial rápido en concreto lanzado de mezcla en húmedo. Estos deben inyectarse en la boquilla junto con el aire comprimido.

Si el acelerador está dosificado de más, la resistencia final del concreto lanzado disminuye drásticamente. Los problemas de adhesión pueden ocurrir entre el concreto y el sustrato, las sombras pueden formarse detrás del acero de refuerzo, así como dar lugar a concreto poroso y débil. Todo esto reduce la calidad del concreto. Además, la dosificación de más de acelerador aumenta el costo del concreto lanzado. Es esencial calibrar la bomba dosificadora del acelerador con la salida del equipo de concreto lanzado para obtener la dosificación deseada durante la colocación del concreto lanzado.

Preparación inadecuada de la superficie

Los factores clave para una preparación adecuada de la superficie incluyen:

- Limpieza para eliminar el polvo, aceite o cualquier sustancia que pueda afectar la adhesión entre el concreto y la superficie de aplicación; y
- Llevar la superficie a una condición saturada de secado superficial (SSD) antes de la colocación del concreto lanzado.

Una superficie preparada adecuadamente y a fondo mejorará el éxito de una aplicación de concreto lanzado.

Fig. 1: Obviamente demasiada agua sobre el concreto en la tolva

Fig. 2: Los aditivos juegan un papel importante en la producción de esta colocación subterránea de concreto lanzado

Fig. 3: Proper surface preparation is vital for successful application of shotcrete

Fig. 4: Shotcrete is pneumatically projected concrete accelerated to high speed before impact on the receiving surface

Fig. 5: Obviously not shooting even close to 90 degrees from the receiving surface

Inadequate Air Flow and Pressure during Shotcrete Placement

Shotcrete is pneumatically projected concrete accelerated to high speed before impact on the receiving surface. Thus, airflow is required to create the velocity. An airline is needed with a 100 psi (7 bar) pressure, and a minimum volume of 185 ft^3/min (5.2 m^3/min) for wet mix.

Two main problems can be encountered with the volume of air. One is simply the lack of airflow. With low airflow, the concrete will not be properly compacted. On the other hand, if there is an excess of airflow, it will create a greater velocity than may be necessary to properly compact the concrete, as well as increase the rebound and often produce problems in achieving relatively smooth layer thicknesses. It is important the proper airflow is provided to the nozzle, and the nozzle is kept at the correct distance from the receiving surface to minimize rebound and obtain a dense and compact concrete.

Bad Placement Technique

A bad nozzle angle or distance from the application surface will cause lesser-quality concrete. The nozzleman should always shoot perpendicular to the receiving surface. The nozzleman must also be at the right distance to optimize the impact velocity. Being too close or far away will increase the rebound. Thin layer thicknesses may also increase the rebound. Proper placement techniques are a key part of the experience and skill of the nozzleman.

PROBLEMS RELATED TO THE EXPOSURE AND MAINTENANCE OF THE CONCRETE STRUCTURE

Many factors can affect the quality of concrete. Some problems result from use of poor-quality materials, poor selection of materials, poor placement techniques, or the environmental exposures the concrete may experience during its service life.

Performance problems are divided into two large groups:

- Direct performance problems: Are the result of external loadings or exposures, such as stress cracking, earthquake, shock, chemical attack, freezing, and so on; and

Fig. 3: La preparación adecuada de la superficie es vital para la aplicación exitosa del concreto lanzado

Flujo de aire y presión inadecuados durante la colocación de concreto lanzado

El concreto lanzado es concreto lanzado acelerado neumáticamente a alta velocidad antes del impacto en la superficie receptora. Por lo tanto, se requiere flujo de aire para crear la velocidad. Se necesita una línea de aire con una presión de 100 lb/pulg.^{2} (barra 7) y un volumen mínimo de 185 ft^3/min (5.2 m^3/min) para una mezcla en húmedo.

Se pueden encontrar dos problemas principales con el volumen de aire. Uno es simplemente la falta de flujo de aire. Con un flujo bajo de aire, el concreto no se compactará correctamente. Por otro lado, si hay un exceso de flujo de aire, creará una velocidad mayor de la necesaria para compactar el concreto correctamente, a la vez aumentando el rebote y a menudo, produciendo problemas para lograr espesores de capa relativamente lisos. Es importante que se proporcione un flujo de aire adecuado a la boquilla y que la boquilla se mantenga a la distancia correcta de la superficie receptora para minimizar el rebote y obtener un concreto denso y compacto.

Técnica de colocación incorrecta

Un mal ángulo de la boquilla o una distancia a la superficie de la aplicación errónea causará concreto de menor calidad.

Fig. 4: El concreto lanzado es concreto lanzado acelerado neumáticamente a alta velocidad antes del impacto en la superficie receptora

Fig. 5: Obviamente no lanzando ni siquiera cerca de 90 grados de la superficie receptora

El lanzador siempre debe disparar perpendicularmente a la superficie receptora. El lanzador también debe estar a la distancia adecuada para optimizar la velocidad de impacto. El estar demasiado cerca o lejos aumentará el rebote. Espesores de capa delgados también pueden aumentar el rebote. Las técnicas de colocación adecuadas son una parte clave de la experiencia y habilidad del lanzador.

PROBLEMAS RELACIONADOS CON LA EXPOSICIÓN Y MANTENIMIENTO DE LA ESTRUCTURA DE CONCRETO

Muchos factores pueden afectar la calidad del concreto. Algunos problemas se deben al uso de materiales de mala calidad, la mala selección de materiales, las malas técnicas de colocación o las exposiciones ambientales que el concreto puede experimentar durante su vida útil.

Los problemas de rendimiento se dividen en dos grupos grandes:

- Problemas directos de rendimiento: El resultado de cargas externas o exposiciones, como el agrietamiento por esfuerzos, terremotos, choques, ataques químicos y congelación; y

- Indirect performance problems: Can come from design errors, improper choice of materials or execution, inadequate thickness, lack of reinforcing steel, and so on.

These factors may cause movements, deformations, wear, openings (cracks), or delamination of concrete. Depending on the conditions, shotcrete can exhibit reduced performance in the following ways:

Deformations

Deformations are any variation in the shape of the concrete because of the stresses acting on or within it when in service. These deformations can generate cracks or delaminations. The deformations may produce bulges, collapses, and warping.

Through Cracks

These are longitudinal tears through the concrete section. The cracks can be for two main reasons:

- Excess load: these are generated when the load exceeds the design capacity of the concrete element; and
- By volume reduction resulting from changing the temperature or humidity of the concrete or with internal drying shrinkage. They can be increased when no joints are used to control the expected volume changes.

Surface Cracks

These cracks are longitudinal tears that affect the surface and terminate at some point through the section thickness. Surface cracking may lead to through cracks because the section is weakened in tensile strength.

Delaminations

Delaminations are the separation of the concrete due to lack of adhesion between a substrate or layers of shotcrete. They may be introduced by the presence of other problems such as deformation or cracks. Depending on the location, delaminations can present a great risk.

Carbonation

One of the main causes of concrete deterioration is by carbonation. Carbonation is caused by the penetration of atmospheric carbon dioxide (CO_2) and oxygen. When the carbon dioxide naturally present in the air penetrates the concrete and reacts with the calcium hydroxide of the concrete paste, this reaction decreases the pH of the concrete. When the pH value is less than 10, the concrete surrounding the embedded reinforcing steel provides much less corrosion protection (state of depassivation). Carbonation has caused considerable damage to the concrete, provoking the corrosion of the reinforcing bar completely.

Chlorides

Environmental exposures with calcium or sodium chlorides are especially harmful for concrete and the embedded reinforcing steel. The reinforcing steel remains resistant to corrosion, with chlorides concentrations less than 0.3% of cement weight; however, as the percentage of chlorides increases, the passivating layer on the surface of the reinforcing bar can become porous and not protect the reinforcing steel from corrosion. The resulting corrosion can reduce the effective area of the steel bars. Calcium chloride attacks the cement paste, the water reacts with the calcium hydroxide present in the cement matrix—forming hydrated calcium oxychloride—and this reaction produces an expansion of the reinforcing bar inside the concrete that can lead to spalling of the concrete cover. The destructive action of calcium chloride increases at low temperatures.

Sulfates

Sulfates are one of the most aggressive agents for concrete. They are present in certain soils or water, such as seawater. The sulfates react chemically with the calcium hydroxide present in the concrete and transform it into gypsum with a greater volume. This product reacts with the hydrated calcium aluminate, transforming it into ettringite. This transformation produces an increase in volume, increases internal pressure, and destroys the internal structure of the concrete.

Damage by Fire

Fire has a devastating effect on concrete structures. The main effects of fire in reinforced concrete include:

- Damage to adhesion by thermal differential between the reinforcing steel and the concrete that covers them;
- Significant loss of thickness of the concrete cover due to spalling or even explosion of the surface concrete;
- A decrease in the strength of the concrete when its temperature exceeds 720°F (380°C) for prolonged periods;
- A decrease in the strength of the reinforcing steel when the temperature exceeds 480°F (250°C); and
- Damage or destruction of joints and sealants that, depending on the design of the structure, can lead to collapse.

Damage by Freezing

Freezing is considered to be probably the most destructive weathering factor in concrete. Damage occurs when saturated concrete freezes and the water freezes and expands

- Problemas indirectos de rendimiento: Pueden provenir de errores de diseño, elección inadecuada de materiales o ejecución, espesor inadecuado y falta de acero de refuerzo.

Estos factores pueden causar movimientos, deformaciones, desgaste, aberturas (grietas) o delaminación del concreto. Dependiendo de las condiciones, el concreto lanzado puede exhibir un rendimiento reducido de las siguientes maneras:

Deformaciones

Las deformaciones son cualquier variación en la forma del concreto debido a los esfuerzos que actúan sobre él o dentro de él cuando está en servicio. Estas deformaciones pueden generar grietas o delaminaciones. Las deformaciones pueden producir protuberancias, colapsos y deformaciones.

Grietas a través

Estas son desgarros longitudinales a través de la sección de concreto. Las grietas pueden ser causadas por dos razones principales:

- Exceso de carga: Estas se generan cuando la carga excede la capacidad de diseño del elemento concreto; y
- Por reducción de volumen resultante del cambio de temperatura o la humedad del concreto o con contracción interna de secado. Ellas pueden aumentarse cuando no se usan juntas para controlar los cambios de volumen esperados.

Grietas superficiales

Estas grietas son desgarros longitudinales que afectan la superficie y terminan en algún punto a través del espesor de la sección. El agrietamiento superficial puede llevar a grietas a través porque la sección está debilitada en la resistencia a la tracción.

Delaminaciones

Las delaminaciones son la separación del concreto debido a la falta de adhesión entre un sustrato o capas de concreto lanzado. Pueden ser introducidas por la presencia de otros problemas como deformación o grietas. Dependiendo de la ubicación, las delaminaciones pueden presentar un gran riesgo.

Carbonatación

Una de las principales causas del deterioro del concreto es por carbonatación. La carbonatación es causada por la penetración de dióxido de carbono atmosférico (CO_2) y oxígeno. Cuando el dióxido de carbono presente naturalmente en el aire penetra en el concreto y reacciona con el hidróxido de calcio de la pasta de concreto, la reacción disminuye el pH del concreto. Cuando el valor de pH es inferior a 10, el concreto que rodea el acero de refuerzo embebido proporciona mucho menos protección contra la corrosión (estado de despasivación). La carbonatación ha causado un daño considerable al concreto, provocando la corrosión de la barra de refuerzo por completo.

Cloruros

Las exposiciones ambientales con cloruros de calcio o sodio son especialmente perjudiciales para el concreto y el acero de refuerzo embebido. El acero de refuerzo sigue siendo resistente a la corrosión con concentraciones de cloruro inferiores al 0.3% del peso del cemento. Sin embargo, a medida que aumenta el porcentaje de cloruros, la capa pasiva en la superficie de la barra de refuerzo puede volverse porosa y no proteger el acero de refuerzo de la corrosión. La corrosión resultante puede reducir el área efectiva de las barras de acero. El cloruro de calcio ataca la pasta de cemento, el agua reacciona con el hidróxido de calcio presente en la matriz de cemento—formando oxicloruro de calcio hidratado—y esta reacción produce una expansión de la barra de refuerzo dentro del concreto que puede conducir descascaramiento de la cubierta del concreto. La acción destructiva del cloruro de calcio aumenta a bajas temperaturas.

Sulfatos

Los sulfatos son uno de los agentes más agresivos para el concreto. Están presentes en ciertos suelos o agua, como el agua de mar. Los sulfatos reaccionan químicamente con el hidróxido de calcio presente en el concreto y lo transforman en yeso con mayor volumen. Este producto reacciona con el aluminato de calcio hidratado, transformándolo en ettringita. Esta transformación produce un aumento en el volumen, aumenta la presión interna y destruye la estructura interna del concreto.

Daños por fuego

El fuego tiene un efecto devastador en las estructuras de concreto. Los principales efectos del fuego sobre el concreto reforzado incluyen:

- Daño a la adhesión por diferencial térmico entre el acero de refuerzo y el concreto que los cubre;
- Pérdida significativa de espesor de la cubierta de concreto, debido a la descascaramiento o incluso a la explosión del concreto superficial;
- Una disminución en la resistencia del concreto cuando su temperatura excede los 720°F (380°C) durante períodos prolongados;
- Disminución de la resistencia del acero de refuerzo cuando la temperatura supera los 480°F (250°C), y
- Daño o destrucción de juntas y selladores, que dependiendo del diseño de la estructura pueden conducir al colapso.

Daños por congelación

La congelación probablemente es considerada como el factor de intemperie más destructivo en el concreto. El daño ocurre cuando el concreto saturado se congela y as ice within the concrete paste. The damaging effects of repeated freezing and thawing is often evidenced by surface scaling and internal damage of concrete are greatly intensified in the presence of deicing salts used in road maintenance during winter in northern climates. Scaling is caused by the pressure exerted by the expansion of ice formed within the concrete pore network. When this pressure exceeds the tensile strength of concrete, scaling occurs. Excessive surface finishing, deicing salts, and freezing-and-thawing cycles, as well as the presence of poor aggregates, aggravate concrete scaling.

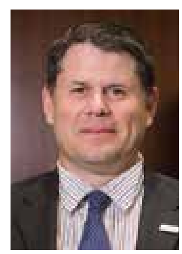
Abrasion Damage

Abrasion resistance is defined as the degree of opposition of a concrete surface to be worn by rubbing and friction. Abrasive damage can result from vehicle or equipment impacting the concrete surface or even high flow or turbulence from water. Resistance to abrasive damage can be increased using a low *w/cm* with a low-porosity concrete. This can be achieved using the well-compacted, paste-rich shotcrete placement.

Fig. 6: Severe surface scaling on the concrete

Conclusions

Concrete has proven strength and durability when using quality materials, well-designed mixtures, proper placement techniques, and adequate curing and protection. This article delineates many of the shortfalls that can occur when there is a lack of attention to the details needed to create quality concrete. Some of these details are exclusive to shotcrete placement but most are generally applicable to all concrete. It is essential that the shotcrete field team be aware of the processes needed to avoid these potential problems with concrete to provide the owner with the best quality concrete on their projects. When done correctly, concrete can easily last for 100 years or more.



***Raúl Armando Bracamontes Jiménez**, Ing., graduated from ITESO University (Instituto de Estudios Superiores de Occidente) in 1994 with a degree in civil engineering and has been working in the concrete industry ever since. Currently the owner of ADRA Ingeniería S.A. de C.V. since 2005, he is fluent in Spanish and English with multiple publications and courses given on shotcrete on his résumé. He is an ACI Certified Wet-Mix Nozzleman and Approved Examiner. Bracamontes is a member of Instituto Mexicano del Cemento y del Concreto (IMCYC), Colegio de Ingenieros Civiles de León (CICL), and the American Shotcrete Association.*

el agua se congela y se expande como hielo dentro de la pasta de concreto. Los efectos nocivos de la congelación y descongelación repetidos se manifiestan a menudo por el desconchamiento superficial y el daño interno del concreto, y se intensifican considerablemente en presencia de sales descongelantes utilizadas en el mantenimiento de carreteras durante el invierno en climas norteños. El desconchamiento es causada por la presión ejercida por la expansión del hielo formada dentro de la red de poros del concreto. Cuando esta presión excede la resistencia a la tracción del concreto, se produce el desconchamiento. El acabado excesivo de la superficie, las sales descongelantes y los ciclos de congelación y descongelación, así como la presencia de agregados pobres, agravan el desconchamiento del concreto.

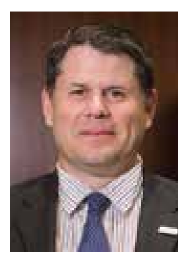
Daño por abrasión

La resistencia a la abrasión se define como el grado de oposición de una superficie de concreto al desgaste por rozamiento y fricción. Los daños por abrasión pueden ser el resultado de un vehículo o equipo que impacte la superficie de concreto o incluso un alto flujo o turbulencia del agua. La resistencia al daño abrasivo se puede aumentar mediante el uso de una baja proporción de *a/mc* con un concreto de baja porosidad. Esto se puede lograr utilizando la colocación de concreto lanzado bien compactado y rico en pasta.

Fig. 6: Desconchamiento superficial severa en el concreto

CONCLUSIONES

El concreto tiene resistencia y durabilidad comprobadas al usar materiales de calidad, mezclas bien diseñadas, técnicas de colocación adecuadas y curado y protección adecuadas. Este artículo describe muchas de las deficiencias que pueden ocurrir cuando hay una falta de atención a los detalles necesarios para crear concreto de calidad. Algunos de estos detalles son exclusivos para la colocación de concreto lanzado, pero la mayoría son generalmente aplicables a todo el concreto. Es esencial que el equipo de campo de concreto lanzado sea consciente de los procesos necesarios para evitar estos posibles problemas con el concreto para proporcionar al propietario el concreto de la mejor calidad en sus proyectos. Cuando se hace correctamente, el concreto puede durar 100 años o más fácilmente.



Raúl Armando Bracamontes Jiménez, *Ing., egresado por la Universidad ITESO (Instituto de Estudios Superiores de Occidente) en 1994, licenciado en ingeniería civil y desde entonces trabaja en la industria del concreto. Actualmente es propietario de ADRA Ingeniería S.A. de C.V. desde 2005, domina español e inglés con múltiples publicaciones y cursos impartidos en concreto lanzado en su currículum. Es un Lanzador de concreto de mezclado en húmedo certificado por ACI y Aprobado Examinador del ACI. Bracamontes es miembro del Instituto Mexicano del Cemento y del Concreto (IMCYC), del Colegio de Ingenieros Civiles de León (CICL) y de la American Shotcrete Association.*

HAYWARD BAKER OPENS NEW OFFICE FACILITY IN PHOENIX, AZ

Hayward Baker, a geotechnical construction provider, announced the opening of a new office location in Phoenix, AZ. The new Phoenix office will help further Hayward Baker's organic growth in this market with an improved local presence that supports public, commercial, and industrial clients, and also serve as a resource to the design community to address challenging geotechnical site conditions, provide comprehensive geotechnical construction solutions, and deliver enhanced services to this region.

The office is located at affiliate Case Foundation's existing location at 4050 East Cotton Center Blvd #10 in Phoenix. Hayward Baker and Case Foundation are a part of the connected companies of Keller, a world provider in geotechnical solutions. Former Western Region Ground Improvement Operations Manager **Thayne Harris** assumed the role of Area Manager for the Phoenix office. Harris has been with Hayward Baker over 30 years. In addition, he has nearly 10 years of management experience with another 25 under various roles specializing in ground modification.

Hayward Baker previously covered work remotely from both the California ground improvement and Las Vegas, NV, branches. This new office complements the existing Case office that has been successful in Phoenix for over 20 years. Together, the companies will offer expanded geotechnical solutions to clients in the Phoenix market.

For more information, call 410.551.8200 or visit **www.haywardbaker.com**.

ACI ANNOUNCES ITS 2019-2020 OFFICERS

The American Concrete Institute (ACI) introduced its 2019-2020 President, Vice President, and four board members during The Concrete Convention and Exposition in Québec City, QC, Canada. Randall W. Poston has been elected to serve as President of the Institute for 2019-2020, Cary S. Kopczynski has been elected ACI Vice President for a 2-year term, and Jeffrey W. Coleman is now the Institute's Senior Vice President, which is also a 2-year term. Additionally, four members have been elected to serve on the ACI Board of Direction, each for 3-year terms: Walter H. Flood IV, Maria G. Juenger, Michael E. Kreger, and Ishita Manjrekar.

President

Poston

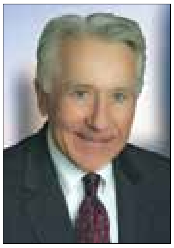
Randall W. Poston, FACI, is Senior Principal with Pivot Engineers, Austin, TX, and Neil Armstrong Distinguished Visiting Fellow in the College of Engineering at Purdue University, West Lafayette, IN. For the past 33 years, he has been engaged in the evaluation, repair, and strengthening of hundreds of structures. His expertise includes investigation of structural failures, evaluation of corrosion of steel in concrete, structural concrete repair and strengthening design, and nondestructive testing.

He is an active member of numerous technical committees, particularly ACI Committee 318, Structural Concrete Building Code, of which he was Chair during the 2014 Code cycle. He is also a Trustee of the ACI Foundation and a voting member of Advancing Organizational Excellence (AOE). Poston received the 2015 ACI Delmar L. Bloem Distinguished Service Award for his outstanding leadership of Committee 318. He has garnered numerous awards for technical papers and personal awards for service to the profession. Poston has authored more than 100 nationally and internationally recognized publications. He also was named an *Engineering News-Record* (*ENR*) Top 25 Newsmaker for 2014 for "…managing the remake of the global concrete bible…"

Poston was elected to the National Academy of Engineering (NAE) in 2017 "for development of diagnostic and repair technologies for concrete structures and leadership in concrete building code development." He is also a member of the American Society of Civil Engineers (ASCE), International Association for Bridge and Structural Engineering (IABSE), Post-Tensioning Institute (PTI), Precast/Prestressed Concrete Institute (PCI), International Federation of Structural Concrete (*fib*), and Structural Engineers Association of Texas (SEAoT).

Poston received his BS, MS, and PhD in civil engineering from The University of Texas at Austin, Austin, TX. He was named a Distinguished Engineering Graduate of The University of Texas at Austin Cockrell School of Engineering in 2014 and elected to the Academy of Distinguished Graduates of the Department of Civil, Architectural and Environmental Engineering in 2008. He is a licensed professional engineer or structural engineer in numerous states.

Vice President


Kopczynski

Cary S. Kopczynski, FACI, is CEO and Senior Principal of Cary Kopczynski & Company (CKC), a structural engineering firm with offices in Seattle, WA; San Francisco, CA; Los Angeles, CA; and Chicago, IL. CKC designs major urban buildings throughout the United States and beyond. The firm has won over 60 regional, national, and international awards, and has been selected several times by Zweig White and *Civil + Structural Engineer* magazine as a top structural engineering firm to work for.

Kopczynski is a licensed civil and structural engineer in many states and a recognized expert in the design of reinforced concrete and post-tensioned concrete building structures. He has authored numerous articles in the fields of structural analysis, design, and construction. He serves on the ACI Foundation Board of Trustees, served 3 years on ACI's Board of Direction and Financial Advisory Committee, and served for many years on ACI Committee 318, Structural Concrete Building Code, and Joint ACI-ASCE Committee 352, Joints and Connections in Monolithic Concrete Structures. He is a Fellow of ACI and was honored with the 2015 ACI Charles S. Whitney Medal and 2017 ACI Alfred E. Lindau Award. He is a Past President of the Washington State Chapter – ACI.

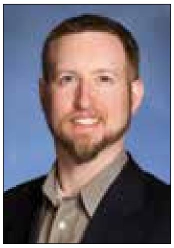
Kopczynski also serves on the Post-Tensioning Institute's (PTI) Board of Directors. He served on the PTI Executive Committee and is the past Chair of PTI's Technical Advisory Board. He is a PTI Fellow and served on PTI committees related to building design and professional development.

Kopczynski was made an Honorary Life Member of the Wire Reinforcement Institute (WRI) for his work in advancing the use of high-strength deformed wire reinforcing in buildings.

ENR magazine selected him as one of its "Top 25 Newsmakers" in both 2007 and 2016 based on CKC's pioneering work in the fields of high-strength reinforcing bar and steel fiber-reinforced concrete (SFRC). CKC has since advanced the use of SFRC by implementing it in major high-rise buildings and continues to pioneer its use in new applications.

Kopczynski serves on the Board of Directors of the Structural Engineers Foundation of Washington, is a Past President of the Structural Engineers Association of Washington (SEAW), past Chair of the SEAW Education Committee, and served as an instructor for SEAW's Structural Engineering Refresher program for many years. He received his BSCE from Washington State University, Pullman, WA, and did graduate studies in structural engineering at the University of Washington, Seattle, WA, where he occasionally serves as a guest lecturer.

Directors


Flood

Walter H. Flood IV, FACI, is an Assistant Engineer and Project Manager at his family's testing and inspection business in Chicago, IL.

He has been Chair of ACI Committee S801, Student Activities, since 2011. He is also Chair of the ACI Committee S801 Regional Student Competitions Task Group. He is a member of the ACI Chapter Activities Committee and ACI Committees 302, Construction of Concrete Floors; 327, Roller-Compacted Concrete Pavements; 363, High-Strength Concrete; and 522, Pervious Concrete. He was awarded the 2014 ACI Young Member Award for Professional Achievement and became a Fellow of ACI in 2018. Flood is Chair of ASTM International Subcommittee C09.49, Pervious Concrete, and is active on several other ASTM International committees. He is also a member of the American Society of Civil Engineers (ASCE).

His research interests include high-strength/high-modulus concrete properties, the impact of fast-paced construction schedules on the long-term behavior of concrete high-rise structures, and testing of roller-compacted and pervious concrete. He has been a speaker on high-strength concrete, pervious concrete, and maturity monitoring at the national and local level for ACI and other groups. Flood often participates at World of Concrete, educating attendees about pervious concrete. He is also continuing his quest to develop the perfect student concrete competition.

Flood received his BS in civil engineering from Rose-Hulman Institute of Technology, Terre Haute, IN, in 2003, and currently sits on its Board of Advisors. He received his MS in geotechnical engineering from the University of Colorado at Boulder, Boulder, CO, in 2005. He is a licensed professional engineer in Indiana and Illinois.

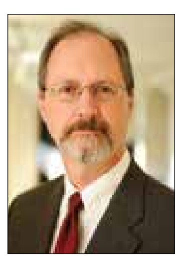

Juenger

Maria G. Juenger, FACI, is a Professor and holder of the Austin Industries Endowed Faculty Fellowship in the Department of Civil, Architectural, and Environmental Engineering at The University of Texas at Austin, Austin, TX, where she has been since 2002. Her teaching and research focus on materials used in civil engineering applications. She primarily examines chemical issues in cement-based materials; these include phase formation in cement clinkering, hydration chemistry of portland cement, calcium sulfoaluminate cement, and supplementary cementitious materials, and chemical deterioration processes in concrete. In 2005, she received a Faculty Early CAREER Award from the National Science Foundation.

Juenger is a member of ACI Committees 130, Sustainability of Concrete; 231, Properties of Concrete at Early Ages; 236, Material Science of Concrete; 240, Pozzolans; 242, Alternative Cements; 318, Structural Concrete Building Code; and S802, Teaching Methods and Educational Materials; and ACI Subcommittees 130-A, Materials, and 318-A, General, Concrete, and Construction.

She is a Fellow of ACI and the American Ceramic Society (ACerS). She has received several awards from ACI for her research, teaching, and service, including the 2009 Walter P. Moore, Jr. Faculty Achievement Award, the 2010 Young Member Award for Professional Achievement, the 2011 Wason Medal for Materials Research, and the 2018 Delmar L. Bloem Distinguished Service Award. She is an Associate Editor of *Cement and Concrete Composites* and is on the editorial boards of both *Cement and Concrete Research* and the *ACI Materials Journal*.

Juenger received her BS in chemistry from Duke University, Durham, NC, and her PhD in materials science and engineering from Northwestern University, Evanston, IL. After completing her PhD, she was a postdoctoral researcher in civil engineering at the University at California, Berkeley, Berkeley, CA.



Kreger

Michael E. Kreger, FACI, is the Garry Neil Drummond Endowed Chair in Civil Engineering at the University of Alabama, Tuscaloosa, AL. For the past 36 years, he has been actively engaged in a diverse program of structural concrete research investigating the behavior of earthquake-resistant precast and cast-in-place reinforced-concrete frame systems, and dual-plate composite shear walls; repair and strengthening methods for nonductile frame systems; behavior of post-tensioned segmental box girder bridges; durability of bridge post-tensioning systems; fatigue resistance of post-tensioned bridges; and behavior of pretensioned bridge systems.

He is Chair of ACI Committee 133, Disaster Reconnaissance, and an active member of multiple ACI technical committees, including 318, Structural Concrete Building Code, and Joint ACI-ASCE Committee 352, Joints and Connections in Monolithic Concrete Structures; and is a member of the *ACI Structural Journal* Editorial Board. He previously served on ACI's Technical Activities Committee (TAC).

Kreger received the 2011 Concrete Research Council Arthur J. Boase Award for his significant research achievements in earthquake-resistant concrete building systems and precast prestressed concrete bridge components, and for continued contributions to ACI technical committees. Two of Kreger's 100+ technical publications have been awarded the T.Y. Lin Award from the American Society of Civil Engineers (ASCE).

Kreger received his BS, MS, and PhD in civil engineering from the University of Illinois at Urbana-Champaign, Urbana, IL. Prior to joining the faculty at the University of Alabama, he was a faculty member at The University of Texas at Austin, Austin, TX, from 1983 through 2003, and at Purdue University, West Lafayette, IN, from 2004 to 2014. He is a licensed professional engineer in Texas.

He is also a member of ASCE, the Earthquake Engineering Research Institute (EERI), International Association for Bridge and Structural Engineering (IABSE), and Precast/Prestressed Concrete Institute (PCI).

Manjrekar

Ishita Manjrekar is Technical Director at Sunanda Speciality Coatings Pvt. Ltd., Mumbai, India, and oversees Sunanda's Research and Development, with a specific focus on developing and marketing Sunanda's line of sustainable construction chemicals. Her areas of expertise include durability, admixtures, corrosion protection, and waterproofing. She works actively with several professional bodies, including the Indian Green Building Council, Indian Concrete Institute, and Indian Building Congress. Manjrekar is also a member of the Board of Direction of the India Chapter – ACI, where she serves as Vice President.

She serves on the ACI Financial Advisory Committee, International Advisory Committee, Student and Young Professional Activities Committee, Membership Committee, Walter P. Moore Award Committee, and IPAC Judging Subcommittee. Manjrekar is also a member of ACI Committees 212, Chemical Admixtures, and S806, Young Professional Activities. She is also the recipient of the 2016 ACI Young Member Award for Professional Achievement.

Manjrekar regularly publishes research papers on sustainability and green construction chemicals in national and international journals. As an expert in green construction chemicals, she is often invited to be on peer-review panels for publications. Recent honors that she received for research and development work include the "Product Innovator of the Year – Construction Chemicals" award in 2012, 2013, and 2015 from the Federation of India Chambers of Commerce and Industry (FICCI) and Ministry of Chemicals and Petrochemicals, Government of India.

She has been featured on Bloomberg TV and Bloomberg Radio numerous times as a subject matter expert on sustainability and green technologies. Her expertise has also been sought by print and electronic media, including Reuters, the Financial Times, Forbes, BBC News, and Marketwatch. Manjrekar received her bachelor's degree in chemical engineering from the Institute of Chemical Technology, Mumbai, India, and her master's degree in chemical engineering from Rensselaer Polytechnic Institute, Troy, NY.

For more information, call 248.848.3700 or visit **www.concrete.org**.

ICRI BECOMES AIA APPROVED CES PROVIDER

Continuing its commitment to the professional development of the concrete repair industry, the International Concrete Repair Institute (ICRI) has become an American Institute of Architects (AIA)-approved provider for the AIA Continuing Education System (CES). By achieving this accreditation, ICRI becomes a part of the largest source of education for the design and building industry. Receiving the AIA accreditation is another milestone in the history of ICRI.

"Being an AIA-approved CES provider affords ICRI with the opportunity to inform and educate licensed architects on common problematic issues in concrete and masonry structures, many of which are addressed in ICRI's 18 Technical Guidelines," said Mark LeMay, AIA, LEED AP, and 2019 ICRI President-Elect. "To help fulfill the mandatory continuing education requirements of AIA and state licensing boards, architects will now be able obtain CE credits through ICRI's webinars, certification programs and other offerings. ICRI's recognition as an approved provider of continuing education services by the American Institute of Architects should prove to be a 'Win-Win' for both organizations!"

ICRI provides key training to its members and to the industry and currently provides Professional Development Units (PDHs) through technical presentations at its conventions and more. Concrete repair professionals are able to demonstrate their knowledge and abilities by achieving certification through ICRI's industry setting programs, Concrete Surface Repair Technician (CSRT) and Concrete Slab Moisture Testing Technician (CSMTT).

For more information, call 651.366.6095 or visit **www.icri.org**.

ACPA ANNOUNCES ELECTIONS RESULTS

The American Concrete Pumping Association (ACPA) announced the election of its new Executive Board at the ACPA Annual Meeting and Awards Presentation on January 23, 2019, in Las Vegas, NV. Elected to serve a 1-year term, the newly elected Executive Board includes: **Gary Brown**, R.L. McCoy, Inc., Indianapolis, IN, as President; **Wayne Bylsma**, Cherokee Pumping, Inc., Hampton, GA, as Vice President; **Eric Duiker**, CanCrete Equipment, Mississauga, ON, Canada, as Secretary; **Nathan Germany**, Tri-Way Concrete Pumping, Inc., Roanoke, TX, as Treasurer; and **Beth Langhauser**, Enviro-Systems, Inc., Smyrna, GA, as Past President.

The ACPA also announced results at the January 23 meeting of recent elections for the following board positions:

- Pump Directors: **Dennis Andrews**, Andrews Equipment Company, Inc., Jessup, MD; **Nick Avella**, Our Rental Pumps, LLC, Farmingdale, NY; **Daryl Dika**, Combined Concrete Pumping (2007), Ltd., Acheson, AB, Canada;

Top row: Doug Marquis, Chris Pernicano, Tony Inglese, Nathan Germany, Dennis Andrews, Beth Langhauser, Gary Brown, Todd Morgan, Eric Duiker, Bill Dwyer. Front row: Tom O'Malley, Tony Biddle, Bobby Lavender, Gabriel Ojeda, Caleb Thompson, Daryl Dika, Carl Walker, Wayne Bylsma and **Bobby Lavender**, Gant Concrete Pumping, Savannah, TN;

- Regional Directors: **Caleb Thompson**, Champion Concrete Pumping, Inc., Hauser, ID, Region 1; **Tony Biddle**, Anthony Biddle Contractors, Ambler, PA, Region 3; and **Carl Walker**, Central Concrete Pumping, Fort Worth, TX, Region 5;
- Distributor Director: **Eric Duiker**, CanCrete Equipment, Mississauga, ON, Canada; and
- Manufacturing Directors: **Bill Dwyer**, Putzmeister America, Inc., Sturtevant, WI; **Beth Langhauser**, Enviro-Systems, Inc., Smyrna, GA; and **Tom O'Malley**, Schwing America, Inc., White Bear, MN.

For more information, call 614.431.5618 or visit **www.concretepumpers.com**.

DFI TUNNELING AND UNDERGROUND COMMITTEE ANNOUNCES TECHNICAL GROUPS

The Deep Foundations Institute's (DFI) recently established Tunneling and Underground Committee has formed eight Technical Groups to address specific areas of interest associated with the tunnel industry. The Tunneling and Underground Committee will provide a professional forum to identify current industry needs and facilitate the advancement of new methods and technologies for design, construction, inspection, maintenance, and operation of tunnels and underground systems. The committee will foster technology transfer among owners, designers, contractors, material and equipment suppliers, as well as researchers/academics, and other global tunneling associations involved in the use and construction of tunnels and underground structures.

The following individuals were selected to identify and guide the committee efforts:

- DFI Tunneling and Underground Committee — Executives: Co-Chair **David R. Klug**, President, David R. Klug & Associates, Inc.; Co-Chair **James Morrison**, Vice President, COWI North America; Trustee Liaison **Conrad Felice**, President, C.W. Felice, LLC; and Technical Director **Brian Fulcher**, Principal & Tunnel Practice Leader, McMillen Jacobs Associates;
- DFI Tunneling and Underground Committee — Advisory Group: **Colin Lawrence**, Vice President, Mott MacDonald Engineers; **Frank Arland**, Partner, Mueser Rutledge Consulting Engineers; **Les Bradshaw**, President/Owner, Bradshaw Construction Corp.; **Rick Lovat**, President and Owner, Lovat Tunneling Solutions; **Matt Swinton**, Senior Vice President - Underground District, Kiewit Infrastructure Co.; **Sanja Zlatanic**, Chairman - National Tunnel Practice, HNTB; and **Steve Minassian**, Senior Vice President, Parsons;
- Mechanical Tunneling Group: Co-Chair **Shane Yanagisawa**, Project Director, Lane Healy JV; and Co-Chair **Richard McLane**, Chief Mechanical Engineer, Traylor Bros. Inc.;
- Conventional Tunneling Group: Chair **Robert Stier**, Area Manager, Drill Tech Inc.;
- Precast Tunnel Linings Group: Chair **Verya Nasri**, Vice President and Global Tunnel Lead, AECOM;
- Support of Excavation in Tunnel Construction Group: Co-Chair **Frank Arland**, Partner, Mueser Rutledge Consulting Engineers; and Co-Chair **Jan Cermak**, Associate Partner, Mueser Rutledge Consulting Engineers;
- Tunnel Waterproofing Group: Chair **Stefan Lemke**, Deputy CEO, Renesco/Marti;
- Shotcrete in Tunnels Group: Chair **Paul Madsen**, Project Manager, Kiewit Infrastructure Co.;
- Tunnel Construction Safety Group: Chair **Gerry Anderson**, Project Environmental & Safety Manager, Kiewit Infrastructure Co.; and
- Tunnel Industry Outreach, Training and Education Group: Chair **Amanda Elioff**, Vice President & National Practice Lead Tunnels, WSP Americas.

For more information about the Tunneling and Underground Committee and DFI membership, call 973.423.4030 or visit **www.dfi.org**.

Advertise in shotcrete MAGAZINE

A quarterly publication of the American Shotcrete Association

Shoot *for* New Heights!

2019 MEDIA KIT

- Over 17,000 readers
- Average savings of 25% or more
  (compared to other leading trade association magazines)

american shotcrete association | asa

www.shotcrete.org

ASSOCIATION NEWS

ASA STAFF MEMBER ALICE MCCOMAS PROMOTED TO ASSISTANT DIRECTOR

McComas

ASA is excited to announce that Alice McComas has been promoted to ASA's Assistant Director, under the leadership of Charles Hanskat, ASA Executive and Technical Director. A vital member of the ASA team, McComas has served ASA for 8 years as Programs Coordinator at the first major reorganization of the ACI Shotcrete Nozzleman Certification program. She has seen significant growth in this and other ASA initiatives, committee activity, and ASA's Outstanding Shotcrete Projects Awards program over the years. In this new position, McComas will work with Hanskat and committee members to implement and expand the new Contractor Qualification Program, Shotcrete Inspector Education (coordinating with the soon-to-be-launched ACI Shotcrete Inspector Certification program), outreach to government agencies and universities, and ASA's conventions. McComas received her master's degree in facilities planning and management from Cornell University, Ithaca, NY.

SHOTCRETE NOZZLEMAN CERTIFICATION IN AUSTRALIA

Hosted by the Concrete Pumping Association of Australia, the Shotcrete Nozzleman Certification will be available in Melbourne, VIC, Australia, July 9-10, 2019. Shotcrete Nozzleman Education is a prerequisite for those pursuing ACI Shotcrete Nozzlemen Certification. It is also a great resource for all seeking a better understanding of the shotcrete process, from concrete chemistry to safety tips. Fees (all prices are in AUD) for the education only is $2000 for CPAA members and $2500 for CPAA nonmembers; and fees for the educations with certification are $2700 for CPAA members and $3375 for CPAA nonmembers.

For more information, visit **www.cpassoc.com.au/certification/shotcrete-certification**.

BREAKTHROUGHS IN TUNNELING SHORT COURSE

12TH ANNUAL BREAKTHROUGHS IN TUNNELING SHORT COURSE

ASA is pleased to be a supporting organization of the 12th Annual Breakthroughs in Tunneling Short Course. This course will be hosted at the University of Denver, Denver, CO, September 9-11, 2019. Presented by leading practitioners from around the globe, the Breakthroughs in Tunneling Short Course will focus on real-world solutions for real-world problems. Tunneling topics such as cutting-edge case studies, developing technologies, and trends from around the globe will be presented. Ground improvement and construction grouting has become an important part of tunnel and shaft construction. This year's course will also include presentations by prominent speakers on various ground improvement techniques, including jet, compaction, permeation, consolidation, and contact grouting, as well as ground dewatering and freezing for tunnel, shaft, and cross-passage construction.

For more information, visit **www.tunnelingshortcourse.com**.

CHICAGO BUILD 2019

CHICAGO BUILD 2019 EXPO

ASA is pleased to be an event partner of Chicago Build 2019. Hosted at the McCormick Place, Chicago, IL, this event will be held September 19-20, 2019. Chicago Build is free to attend and features 200+ exhibitors showcasing the latest products and innovations, 150+ speakers, AIA CES training workshops, networking opportunities, Women in Construction and M/WBE networking events, and entertainment. This large-scale construction show will cover all sectors of the construction industry and provide an opportunity to gain valuable insight into the upcoming construction and infrastructure projects across Illinois.

For more information, visit **www.chicagobuildexpo.com**.

2019 OUTSTANDING SHOTCRETE PROJECT AWARDS PROGRAM CALL FOR ENTRIES

ASA is accepting applications for its 2019 Outstanding Shotcrete Project Awards program. These awards confirm and demonstrate the exceptional advantages of shotcrete placement of concrete. Awards are bestowed in the following six categories: architecture/new construction, infrastructure, international projects, pool & recreational, rehabilitation & repair, and underground. Take pictures during and after construction and submit your project for consideration! Look for announcements this summer for a webinar detailing the application process. The deadline for submissions is October 1, 2019. For more information about the Outstanding Shotcrete Projects Awards and to view past award-winning projects, visit **www.shotcrete.org/ASAOutstandingProjects**, or contact us at 248.848.3780 or info@shotcrete.org.

SAVE THE DATE FOR ASA FALL 2019 COMMITTEE MEETINGS

ASA Fall Committee Meetings will be held Saturday, October 19, 2019, at the Duke Energy Convention Center in Cincinnati, OH, prior to The ACI Concrete Convention and Exposition, October 20-24. ASA meetings are open and are key to our advancing the use of shotcrete in the industry. No registration is required to attend these ASA meetings. ASA welcomes and encourages participation from new faces.

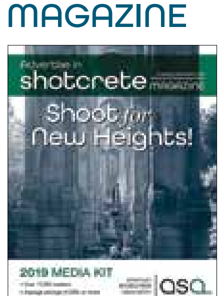
For more information, visit **www.shotcrete.org/pages/membership/committees.htm**.

SESSION FEATURING SHOTCRETE AT THE ACI CONCRETE CONVENTION AND EXPOSITION

During The ACI Concrete Convention and Exposition in Québec City, QC, Canada, several ASA members participated in the Contractors' Day Session, Modern Concrete Technology. Sponsored by the Québec & Eastern Ontario Chapter – ACI and moderated by Thomas Jacob-Vaillancourt, GHD Consultants, this session presented innovations in underground development and infrastructure repairs through shotcrete by an overview of the latest technologies available to the industry. Among the techniques used for ground support in underground applications and infrastructure repairs, shotcrete has been used successfully for many years due to its flexibility, efficiency, and robustness. Major advancements have been made to improve the mechanical performance, ease of application, and durability of shotcrete materials over the past two decades. Advancements in shotcrete materials and processes covered in this session included the durability properties of shotcrete materials used in North America to build and repair concrete infrastructures exposed to severe freezing-and-thawing cycles and severe exposure conditions due to aggressive agents such as chloride ions due to deicing salts. This session highlighted how the benefits derived from modern shotcrete technology have provided forward-thinking contractors with an economic advantage over their competitors, and specifiers have also recognized that the shotcrete process can provide a durable, long-term repair solution. Presentations in this session included: "Latest Fundamental Research in Shotcrete," Marc Jolin, Laval University; "Education and Certification in the Shotcrete Industry," Charles Hanskat, American Shotcrete Association; "Applications of Recently Developed Shotcrete Technology," Simon Reny, King Packaged Materials; and "Shotcrete—Perspective from a Contractor," Simon Maltais, Cimota Inc.

For more information, visit **www.concrete.org/events/conventions**.

ADVERTISE IN *SHOTCRETE* MAGAZINE



Grow your business by investing your marketing dollars through advertising in ASA's *Shotcrete* magazine. *Shotcrete* magazine is the only international magazine focused exclusively on the shotcrete industry. Our magazine covers all aspects of the shotcrete market and highlights shotcrete's advances and achievements—from recognizing outstanding projects, to reports on shotcrete research, to articles exemplifying the state-of-the-art of shotcrete placement. Each issue of *Shotcrete* magazine has a readership of over 17,000 subscribers in over 100 countries.

Available 2019 themes include:

- Summer – Dams/Water Structures; and
- Fall – Inspection/Testing.

Look for the 2020 *Shotcrete* magazine media kit to be released in September. For more information, rates, and deadlines, contact Lacey Stachel, ASA Editorial and Marketing Manager, at Lacey.Stachel@Shotcrete.org or 248.848.3736.

GET SOCIAL WITH ASA

In addition to ASA's Facebook and Twitter pages, ASA is excited to now be on Instagram and LinkedIn. You can find us on Facebook @AmericanShotcreteAssociation, Twitter @ShotcreteASA, Instagram @shotcreteasa, and LinkedIn at **www.linkedin.com/company/american-shotcrete-association**. We would love to have pictures or videos of your shotcrete projects, or announcements of interest to the shotcrete industry, to consider for inclusion in our posts. Please send content to Lacey.Stachel@Shotcrete.org.

NORMET LAUNCHES SMARTDRIVE

Normet launched its SmartDrive battery electric vehicle architecture featuring a design change from a diesel engine to electric power. The sophisticated and fully engineered battery architecture operates underground emission-free and additionally saves cost. SmartDrive uses industrial grade lithium-ion battery technology with a fast charging capability and electric motors designed for harsh environments. With the onboard charging system, it needs only 2.5 hours to load the batteries from 0 to 80%—the tunneling machine needs only 1 hour. The machine can also be charged from an underground AC-socket or in minutes by fast chargers. The battery is split into modules: in the case of malfunction of a module, it will be isolated, and the rest of the modules will continue operating, without forcing the machine down somewhere in the mine or tunnel.

The electric vehicle features two electric motors, providing instant torque and safe operation in underground situations, including downhill, level, or uphill tramming. There is no hot exhaust gas resulting in much lower operating costs for the ventilation. The entire driveline is optimized and all low-efficiency parts such as the gearbox, dropbox, and shafts of the machine are eliminated. The hydraulic system with rotating parts is reduced to a minimum. The optimized tuning of the electric machine's control system reduces the need to use service braking because the braking force is provided by the electric motors. There is a regeneration of power during downhill driving as the braking energy is stored back into the batteries. The machine is equipped with four-wheel drive, has a feature to hold the brakes automatically when stopping on an incline, only one pedal for driving, and three selectable speed ranges.

For more information, call 801.596.4700 or visit **www.normet.com**.

SCHWING UPGRADES OPTIONAL ON-BOARD FILTRATION FOR BOOM PUMPS

Schwing announced an optional upgrade to existing on-board hydraulic oil filtration systems to further reduce component wear and lower maintenance/operating costs.

"This new system from Precision Filter Systems (PFS) takes out water and removes solid particles from the hydraulic system," said Mark Berggren, Schwing Publications Supervisor. "Contamination from water and particles smaller than 10 microns in size is the leading cause of hydraulic system component wear and failure. We worked with PFS to design a filtration system that improves overall system performance. In fact, the filtration system manufacturer guarantees that, after 200 hours of filtration, the hydraulic oil in the system will be cleaner than brand new hydraulic oil."

The 3-micron, depth-type filters complements the 10-micron filter provided as standard by Schwing. Other benefits include a reduction in component wear; lower maintenance and operating costs; longer valve, pump, and machine life; continuous filtration during operation; and a cooler running system.

"The new system will be available on all 2019-manufactured Schwing boom pumps," added Berggren. "However, kits to retrofit existing units will also be available. Both installation and subsequent filter servicing are easy and the return on investment from making the switch will be quick. It's a nice upgrade for anyone wanting to maximize the life of their pump."

For more information, call 888.724.9464 or visit **https://schwing.com**.

QUIKRETE SOLUTIONS TO CONCRETE REPAIR

QUIKRETE's Re-Cap Concrete Resurfacer

QUIKRETE's® Re-Cap Concrete Resurfacer is designed to repair and renew existing, spalled concrete with a permanent wear-resistant surface that can withstand foot, vehicle, and other heavy traffic. The new QUIKRETE Re-Cap Concrete Resurfacer has a bond to concrete that is four times stronger than the concrete itself. A proprietary blend of portland cement, graded sand, polymer resins, and other additives, QUIKRETE Re-Cap Concrete Resurfacer is a proven shrinkage compensated repair material for making thin structural repairs to sound concrete in need of surface renewal. Applied with a squeegee, trowel, or brush, one 40 lb (18 kg) bag will cover approximately 40 ft^2 (4 m^2) at 1/8 in. (3 mm) thick and up to 80 ft^2 (7 m^2) as skim coat.

QUIKRETE Advanced Polymer Adhesives

QUIKRETE Advanced Polymer Adhesives are high-performance, commercial-grade flexible repair and bonding materials that meet ASTM C920 standards. The single-component QUIKRETE Advanced Polymer Adhesives are environmentally-friendly alternatives, including:

- Self-Leveling Sealant permanently seals horizontal cracks and expansion joints in concrete with smooth, level, tack-free finish in 20 minutes;
- Mortar Joint Sealant permanently seals and waterproofs mortar joints with textured matte, tack-free finish in 20 minutes;
- Concrete Crack Sealant permanently seals and waterproofs cracks in concrete with textured matte, tack-free finish in 20 minutes;
- Construction Adhesive permanently bonds concrete, masonry, brick, veneer stone, foamboard, drywall, wood, and plastic in minutes; and

- Non-Sag Sealant permanently seals vertical cracks and expansion joints in concrete, masonry, stucco, and brick with smooth, tack-free finish in 20 minutes.

For more information, call 800.282.5828 or visit **www.quikrete.com**.

MAPEI POLYFOAMER ECO 100 AND POLYFOAMER ECO 100 PLUS

Mapei's POLYFOAMER ECO 100 and POLYFOAMER ECO 100 PLUS are foaming agents with a very low level of impact on the environment that can be used for conditioning ground to be excavated with a TBM technology. Both foaming agents contain biodegradable anionic surfactants and natural polymers and have zero glycol content. They form highly stable foam over time with excellent lubricating properties that help reduce friction between soil particles and minimize wear of tunneling equipment. The foaming agents are non-bioaccumulable and have a very low level of ecotoxicity. POLYFOAMER ECO 100 PLUS, when used in combination with MAPEI SOLVER Q33 in the phases immediately following tunneling operations, progressively reduces the number of surfactants present in the soil until there is only a minimal amount.

For more information, visit **https://utt.mapei.com**.

ACPA RELEASES NEW CONCRETE PUMP OPERATOR VIDEO

The American Concrete Pumping Association (ACPA) created a new video, "Day in the Life of a Concrete Pump Operator," to support the ACPA Workforce Development program. Available in English and Spanish versions, the video has an intended audience of ready-mixed concrete drivers, laborers, those already in construction who may want to change fields, or those who are aware of concrete pumping and are wondering what that career path might be like. The 10-minute video is available at **www.youtube.com/watch?v=9ErMNreMGFE**. It follows a pump operator from the time he begins his work day to the time he finishes his workday. The video follows his responsibilities on the job, from clocking in at the start of the day, to getting his paperwork, working with contractors and cleaning out the pump, returning the pump, finishing inspection, and clocking out. The video is the latest effort by ACPA's Workforce Development program, which is creating and sharing new initiatives and resources to help ACPA members effectively recruit job candidates. By using the latest technology and strategic partnerships along with creating shareable, informative content, the ACPA is helping increase recruitment in the concrete pumping industry.

For more information, call 614.431.5618 or visit **www.concretepumpers.com**.

BASF LAUNCHES VIRTUAL DESIGN AND CONSTRUCTION RESOURCE CENTER

BASF has launched its Global Virtual Design and Construction (VDC) Resource Center which offers BIM digital content as well as digital construction tools to support product selection, specification, and use. The VDC Resource Center brings together a global network of construction experts with architectural, engineering, and contracting backgrounds who can support customers, planners, and architects with consultation and access to the entire construction chemicals portfolio of BASF. With more than 200 BIM objects and soon more than 400 Revit models, the BASF BIM portfolio covers 13 construction industry segments, such as waterproofing systems, performance flooring, concrete repair, protective coatings, and expansion control systems and wall systems. These digital solutions are accessible in more than 10 languages from the BASF brands Master Builders Solutions, Watson Bowman Acme, and Senergy.

For more information, call 800.526.1072 or visit **www.basf.com**.

The QUIKRETE Companies

The QUIKRETE Companies is a large manufacturer of packaged concrete and cement mixtures in the United States and Canada, as well as an innovative leader in the commercial building industry. QUIKRETE products are manufactured and bagged in more than 150 manufacturing facilities in the United States, Canada, Puerto Rico, and South America, allowing for unsurpassed distribution and product depth.

QUIKRETE®
CEMENT & CONCRETE PRODUCTS™

QUIKRETE SHOTCRETE PRODUCTS

QUIKRETE commercial-grade shotcrete products are formulated to provide rapid-strength gain and high ultimate compression strengths, minimal rebound, and low permeability. The QUIKRETE Companies possess a high level of experience in blending fibers, admixtures, and coarse aggregates into shotcrete mixtures. Product designs can be enhanced with a variety of fibers and admixtures, such as synthetic; alkali-resistant fiber-glass; or carbon steel fibers, microsilica fume, set accelerators, polymers, and various aggregate sizes.

From its standard shotcrete mixtures to custom mixtures, The QUIKRETE Companies can deliver quality-produced material to meet any specification or project needs. QUIKRETE dry- and wet-process shotcrete product designs are available in 50 and 80 lb (23 and 36 kg) bags and 3000 lb (1361 kg) bulk bags.

Part of the QUIKRETE family of companies, Target Products, Ltd. is a leading producer of dry-mix concrete and cement-related products in Western Canada. With manufacturing and distribution facilities near Vancouver, BC, Canada, and in Edmonton and Calgary, AB, Canada, Target Products offers a diverse product line and technical expertise, in addition to specialized engineering services for the mining and concrete products industry.

Fig. 1: QUIKRETE Shotcrete MS used for a tunnel relining

RECENT PROJECTS

The QUIKRETE Companies have supported a multitude of structural repair and rehabilitation projects nationwide with American Shotcrete Association (ASA) members. Some recent projects include Alcatraz Island in the San Francisco Bay, CA; Albertus L. Meyers Bridge in Allentown, PA; the Robinson Creek Tunnel in Robinson, KY; Hampton Roads Bridge-Tunnel in Hampton, VA; Spokane River Restoration in Spokane, WA; Idaho Power Tunnel in Ashton, ID; Dennis Edward Tunnel in Timber, OR; Allegheny Mineral Mine in Worthington, PA; and Pleasure Pier in Galveston, TX.

Fig. 2: QUIKRETE Shotcrete MS used for a bridge pier restoration

THE COMPANY

Originally founded in Columbus, OH, The QUIKRETE Companies is now headquartered in Atlanta, GA. Operating for nearly 80 years, customer service is a main priority for The QUIKRETE Companies. Highly trained and knowledgeable field representatives assist customers through all phases of a project. Field representatives are backed by a state-of-the-art technical center and world-class production facilities, whose goal is to provide customers with the most technically innovative products on the market. The QUIKRETE Technical Center continues to be an industry leader in new product research and development.

For more information or assistance with all your shotcrete needs, contact The QUIKRETE Companies.

THE QUIKRETE COMPANIES

Five Concourse Parkway, Suite 1900
Atlanta, GA 30328
Phone: 800.282.5828
Website: www.QUIKRETE.com
Dennis Bittner, National Sales Manager–Infrastructure
E-mail: dennis.bittner@quikrete.com

Fig. 3: QUIKRETE Shotcrete MS used for a dam rehabilitation

Knowles Industrial Services Corporation

Knowles Industrial Services Corporation (Knowles) was established in 1971 after Arthur and Mary Ellen Knowles purchased Chick Construction, which was founded in 1924. During its early stages, Chick Construction specialized in stack and chimney repair in the pulp and paper industry, as well as church steeple rehabilitation. Since 1971, Knowles has become a known concrete repair and masonry restoration contractor in the Northeast. With operations located in Gorham, ME, Knowles serves the New England region with a wide variety of specialty services such as shotcrete, concrete repair and waterproofing, masonry restoration, coatings and linings, pressure grouting, and resinous flooring.

KNOWLES TODAY

Knowles, now a 100% employee-owned company, was recognized as a pioneer of wet-mix shotcrete in New England in the early 1980s. With three professional engi-

Fig. 1: Dry-mix shotcrete repair on a paper mill stack (image from 1960s)

Fig. 3: In-house engineered structural reinforcement bar for a penstock shotcrete liner

Fig. 2: Scaffolding for Glory Hole Spillway

Fig. 4: Finished penstock shotcrete

neers and 13 ACI-certified nozzlemen on staff, Knowles provides expertise for every project and takes pride in providing dry- and wet-mix shotcrete solutions for various applications. With a long history in stack rehabilitation and rigging, Knowles has the knowledge required to tackle hard-to-access projects with quality repair methods.

PORTFOLIO

Knowles has developed an extensive portfolio in repair and restoration of various structures, especially in the hydroelectric industry, including dams and spillways, penstocks, surge chambers, retaining walls and abutments, bridge piers, and culverts. Knowles has design-build capabilities for reinforced structural shotcrete liners for hydroelectric penstock rehabilitation. Reinforcing bar calculations and shotcrete mixture designs are catered to withstand all relevant hydrostatic pressures and shear/moment forces while promoting laminar flow and minimizing power generation losses from reduced cross-sectional areas.

STEVENSON DAM

In 2016, Knowles completed a 48,000 ft^2 (4500 m^2) dry-mix shotcrete overlay on the spillway of Stevenson Dam, which is known as the largest dry-mix shotcrete project of its kind ever performed in New England. On this project, Knowles promoted the use of air-entrained dry-mix shotcrete in New England. Prior to the Stevenson Dam project, many New England-based engineering firms did not recognize the possibility of air-entrained dry-mix shotcrete. Knowles teamed up with various testing agencies to perform air void system (AVS) testing via ASTM C457/C457M to provide evidence of both air volume and consistency in air void spacing. After AVS testing was successfully completed and submitted, Knowles was awarded the contract for the work.

Beyond the requirement for air entrainment, Stevenson Dam presented several unique site challenges including long gunning distances, restricted access for ready mixed shotcrete, and elevated work on the 80 ft (24 m) spillway surface. Many placements were performed with a 2 in. (50 mm) shotcrete system at distances greater than 800 ft (240 m) from gunning operations. All elevated access was performed with a series of suspended scaffolding beds with integral electric cable climbers and skis that rode up and down the curved spillway surface (see Fig. 6).

KNOWLES TEAM

Knowles continues to be a leader in the shotcrete industry throughout New England, tackling projects of all sizes with a high level of knowledge and expertise. Knowles strives for 100% customer satisfaction and is always open to forming new working relationships and developing its work force with people who share these values. Knowles is also accepting applications for any nozzlemen or gunmen interested in pursuing a shotcrete career in New England. Contact Knowles Industrial Services Corporation for more information.

Fig. 5: Dry-mix shotcrete application in hydro penstock

Fig. 6: Stevenson Dam Spillway resurfacing

KNOWLES INDUSTRIAL SERVICES CORPORATION

295 New Portland Road
Gorham, ME 04038
Phone: 207.854.1900
Fax: 207.854.4996
Website: www.knowlesindustrial.com
E-mail: broy@knowlesindustrial.com

NEW ASA MEMBERS

american shotcrete association

SUSTAINING CORPORATE MEMBERS

CanCrete Equipment Ltd.
Mississauga, ON, Canada
www.cancrete.ca
Primary Contact: Matt Croutch
matthew@cancrete.ca

Pullman-Shared Systems Technology, Inc.
Swedesboro, NJ
www.pullman-services.com
Primary Contact: Andrew Garver
agarver@pullman-services.com

CORPORATE MEMBERS

Coggins & Sons, Inc.
Littleton, CO
cogginsandsons.com
Primary Contact: Coy Coggins
ccoggins@cogginsandsons.com

Desert Pool Accents
Tempe, AZ
Primary Contact: Frank Tsikitas
desertpoolaccents@gmail.com

Lightweight Concrete Solutions
Etobicoke, ON, Canada
www.lwcsi.com
Primary Contact: Chris Calvin
chris@lwcsi.com

Park Derochie Inc.
Edmonton, AB, Canada
parkderochie.com
Primary Contact: Mathew McNabb
mmcnabb@parkderochie.com

Robinson Concrete Pumping Inc.
Roseburg, OR
Primary Contact: Robin Robinson
rcp@q.com

SUSTAINING CORPORATE ASSOCIATES

Eric Duiker
CanCrete Equipment Ltd., Mississauga, ON, Canada

Marcia Duiker
CanCrete Equipment Ltd., Mississauga, ON, Canada

Tony Kramer
Pullman-Shared Systems Technology, Inc., Swedesboro, NJ

Jeff Loberg
CanCrete Equipment Ltd., Mississauga, ON, Canada

Dave McGee
Pullman-Shared Systems Technology, Inc., Swedesboro, NJ

Joseph Munch
Pullman-Shared Systems Technology, Inc., Swedesboro, NJ

STUDENTS

Jesus Angel
QA/QC Construccion SAC, Huancayo, Junin, Peru

Liseth Marijhorit Canchaya Cano
Universidad Continental, Huancayo, Peru

INTERESTED IN BECOMING A MEMBER OF ASA?

Read about the benefits of being a member of ASA and find a Membership Application at **www.shotcrete.org/membership**.

Elevate your business

- NETWORK with your peers in the shotcrete industry
- STAY CURRENT on the latest shotcrete industry trends, strategies, challenges, and opportunities
- Receive PROJECT LEADS through project bid alerts and project listings
- Gain EXPOSURE through a variety of tools available to corporate members, such as a listing in the ASA Buyers Guide––enhanced for Sustaining Corporate Members
- INFLUENCE ASA's direction in serving members and growing the industry
- SAVE significantly on ASA products and services

Elevate your industry

- EDUCATE the construction world on the advantages of the shotcrete process through Onsite Learning Seminars to engineers and specifiers
- PROMOTE the benefits of shotcrete at national trade shows
- COORDINATE proper specification of shotcrete in private and public specifications and national codes and standards
- ENGAGE DOT and other Public Authority officials with a variety of ASA resources and outreach efforts
- Take advantage of TARGETED MARKETING in national and regional organizations and publications
- ENABLE owners and specifiers to embrace shotcrete with a portfolio of tools designed to give them an understanding of and confidence in the shotcrete process

Take the step that will help elevate your organization and industry—become an ASA Corporate or Sustaining Corporate Member today

american shotcrete association | asa

For more information on ASA membership, visit www.shotcrete.org/membership

SHOTCRETE FAQs

As a service to our readers, each issue of *Shotcrete* magazine will include selected questions and provide answers by the American Shotcrete Association (ASA). Questions can be submitted to info@shotcrete.org. Selected FAQs can also be found on the ASA website at http://shotcrete.org/pages/products-services/technical-questions.htm.

Question: *What is the cure time for shotcrete before paint can be sprayed? And what type of paint (latex or oil-based) would work best?*

Answer: Shotcrete is a placement method for concrete. Thus, cure time is the same as what the coating manufacturer recommends for new concrete surfaces. Because moisture in the concrete surface is part of the concern of bond from manufacturers, a water-based latex may be preferable to oil-based, but you should discuss the appropriate time and materials with your coating supplier.

Question: *What is the minimum spacing between reinforcing bar recommended in a shotcrete swimming pool deep-end wall. The engineer is calling out for 12 in. (300 mm) walls with a double mat of No. 5 bars at 4 in. (100 mm) on center each way. In my opinion, this does not give enough space to properly encase the reinforcing bar with shotcrete without creating voids and trapping uncontrollable rebound.*

Answer: The engineer designs the wall based on the loads anticipated on it throughout its service life. The minimum spacing for noncontact lap splices as indicated in ACI 506.2, "Specification for Shotcrete," is:

> "Clearance of at least three times the diameter of the largest reinforcing bar; three times the maximum size aggregate; or 2 in., whichever is least"

In your case with No. 5 bars, the 2 in. (50 mm) minimum probably controls and would then provide a 2.6 in. (64 mm) center-to-center spacing. No. 5 bars at 4 in. spacing can be shot properly with proper materials and technique. An ACI-certified shotcrete nozzleman will have had education that explains how this configuration or even closer spacing can be shot properly. Experienced shotcrete contractors doing structural concrete walls do this type of work routinely with excellent results. If you are concerned about encasement of the reinforcing steel in the back curtain of steel you may consider erecting only the back curtain of steel, shooting the wall out to the location of the outer curtain of reinforcement, erecting the outer curtain, and then shooting out to the final surface. Experienced shotcrete contractors have shot in thick sections (36 in. [900 mm] thick or more) with heavy reinforcement (No. 11 at 4 in.) using this technique.

Question: *One quick question regarding the "grading" of cores based on 506.2: I imagine the 1995 standard-based 1 through 5 grading system is no longer valid? In one case the special inspector has failed a core (score of 5) simply because a piece of it broke off during the coring and removal from the coring cylinder. I'm leery of that type of failed rating. What do you think about that, and core grading in general?*

Answer: The current version of the ACI "Specification for Shotcrete" is ACI 506.2-13 and purposely eliminated the core grading due to many problems that arose in the field in trying to equitably apply the procedure. ACI 506 has a new document ACI 506.6T-17, "Visual Shotcrete Core Quality Evaluation Technote," that is intended to assist specifiers with evaluating shotcrete core quality for an intended use. So yes, the 506.2-95 version of the specification and the grading system it included is no longer supported as an industry standard.

Regarding grading, a shotcrete score of 5 under the deprecated grading system just because the core broke during coring is unreasonable. The coring operation exerts a massive force on the core, as it basically rips it out of the concrete. We have seen many instances where the core snapped where a large reinforcing bar horizontally crossed the core and effectively created a slip plane that reduced the shear resistance of the core section to the torque created by the coring. In those cases, examining the core hole for any evidence of shotcrete problems would be appropriate and then discounting the core itself.

In summary, my position and the ACI 506 Committee's position is that core grading should not be used for evaluating shotcrete quality. The ACI 506.6T-17 Technote document should be the current reference for making a reasonable evaluation of shotcrete quality for the intended use.

Question: *I would like to better understand the limitations related to the height of install when it comes to the gunite application. Because gunite is a dry concrete mixed with water at the nozzle of the applying apparatus, I have been told by others in the industry that the application is only intended for use of walls less than 4 or 5 ft tall. If that is the case, is it safe to assume that the gunite application strategy should not be used for below-grade vaults exceeding a height of 5 ft? I am looking for design literature specific to gunite.*

Answer: Dry-mix shotcrete adds mixing water to the dry concrete materials as the concrete materials flow through and out the nozzle. Gunite is the original tradename for dry-mix shotcrete. Though you may not find design information using the old gunite name, you will find numerous current design references to dry-mix shotcrete. This includes ACI 506R-16, "Guide to Shotcrete"; ACI 506.2-13, "Specification for Shotcrete"; ACI 506.6T-17, "Visual Shotcrete Core Quality Evaluation Technote"; ACI 372, "Design and Construction of Circular Wrapped Prestressed Concrete Tanks"; ACI 350-06, "Code Requirements for Environmental Engineering Concrete Structures"; ACI 350.5, "Specifications for Environmental Concrete Structures"; and seven ASTMs that directly cover shotcrete. ACI 318-19, "Building Code Requirements for Structural Concrete," has also added specific shotcrete provisions. Dry-mix shotcrete has been used for decades to build structural concrete walls over 50 ft high in circular pre-stressed concrete tanks that withstand a full head of water pressure. This is a substantially greater water pressure than your 5 ft vault wall would experience. There are no limitations in the dry-mix placement process that would preclude use in high walls. Both dry-mix and wet-mix shotcrete using quality materials, proper equipment, and experienced placement crews will produce in-place concrete of equal strength, durability, and low permeability. However, generally wet-mix shotcrete can offer placement rates up to four times higher than dry-mix. Thus, in thicker, longer walls, wet-mix shotcrete may be more cost-effective because it can be placed faster.

Question: *What is the best way to check the sand-to-cement ratio in gunite batch trucks? Is it normal (common) to get up to 10% air straight from the mixing auger? I had a gunite truck fill a 5 gal. (19 L) bucket with mixed material (sand and cement) then put it in my lab mixer and wetted it up to a 3 in. (75 mm) slump and ran a test for air, unit weight, and cast a set of cylinders. I am trying to figure out the sand-to-cement ratio, but I don't have a cement diverter to run a real-time sand-to-cement ratio test, so I am testing dispensed material to see if it makes 70% strength in 7 days, which indicates a good mixture. Are there any other ways of checking sand-to-cement proportions? I tested the mixed material in a lab about 5 minutes after it was dispensed.*

Answer: By "gunite batch truck" we assume you are referring to a volumetric mixer supplying material for a dry-mix shotcrete operation. Gunite is the original tradename for what we now call dry-mix shotcrete. Here's the description from an *ACI Materials Journal* (January-February 1991 issue) article about the calibration of volumetric mixers:

"To insure production of quality concrete, each volumetric-measuring unit must be calibrated for each respective concrete ingredient, following the manufacturer's recommendations and ASTM C 685. These ingredients must be the same as those to be used in actual concrete production. The measuring devices for aggregates, cement, and dry admixtures are calibrated by weighing the discharged ingredient. Devices for water, latex modifier (if required), and liquid admixtures such as air-entraining and water-reducing admixtures generally are calibrated by weighing or measuring the volume of the discharged ingredient. The objective of calibration is to coordinate the discharge of all concrete ingredients to produce the proper mixture."

ASTM C685/C685M states, "The proportioning and indicating devices shall be individually checked by following the equipment manufacturer's recommendations as related to each individual concrete batching and mixing unit. Adequate standard volume measures, scales, and weights shall be made available for the checking accuracy of the proportioning mechanism." Thus, you need to check with your equipment supplier for their recommended procedures to verify batching. Because concrete mixtures always are based on weight of ingredients there you will need to weigh a given volume to confirm the batching is accurate.

The air content test is a measure of total air so includes both entrapped and entrained air. Ten percent is definitely high. The 10% air is likely not representative of the in-place shotcrete. It may have been an issue with the lab mixer introducing more entrapped air for some reason. Estimating the air content from the unit weight test requires a good value for the theoretical unit weight. I'm not sure if you have that with the volumetric batching. You should run the air meter test (ASTM C231/C231M) to measure the air content to get a more accurate assessment.

Regarding the verification of mixture proportions, this is from ASTM C685/C685M:

"7.5 Proportioning Check—Whenever the sources or characteristics of the ingredients are changed, or the characteristics of the mixture are noted to have changed, the purchaser is permitted to require a check of the fine aggregate content and the coarse aggregate content by use of the washout test. Essentially, in the washout test, 1 ft^3 [0.03 m^3] of concrete is washed through a No. 4 [4.75-mm] sieve and through a No. 100 [150-μm] sieve; that retained on the No. 4 sieve is normally considered coarse aggregate whereas that passing the No. 4 and retained on the No. 100 sieve is considered fine aggregate. Corrections to the quantity of aggregates (per cubic foot or cubic meter of concrete) shall be made if the original sieve analysis of each aggregate is available."

Because you are only interested in the sand and cement, you can simply weigh the sample of concrete, then wash out all the cement, and then weigh the remaining sand. You would need to bring the sand to roughly the same moisture content as the sand in the truck, so you aren't including in the weight of excess water in the sand. You should note that with shotcrete impact during placement we will generally lose 50% of the air content, so your final in-place air should be around 5%. That is a reasonable value for good freezing-and-thawing durability.

Question: *How much shotcrete coverage over No. 4 reinforcing bar is required?*

Answer: Shotcrete is simply a placement method for concrete. The specified concrete cover over reinforcing bar is usually included in contract documents for construction and values vary depending on exposure conditions. ACI 318 provides cover requirements for structural concrete in buildings, and ACI 350 provides cover requirements for concrete liquid-containing structures. Local building codes and fire codes may also require specific cover in concrete construction. If your project doesn't specify the cover requirements, we recommend you consult with a professional engineer experienced in the type of project you are working on to learn what the code requirements may be.

Question: *I am working on a restoration of a small 1870s train station constructed of serpentine stone in the Philadelphia, PA, area. In many areas the stone has deteriorated, leaving deep "divets" in the exterior wall faces and, in some cases, there is no stone at all. Our intent is to build (infill) the walls back to a flush face for stucco treatment for the lower portions of the wall and to repair or replace stone above that point. Is there a minimum amount of treatment recommended for a shotcrete application? If it can be used for such an application, is reinforcement required? The stone is rather friable and I don't want to attach too much to it for fear of further damaging the stone.*

Answer: This is a great application for shotcrete placement of high-quality concrete without formwork. If you are merely adding shotcrete to fill out to a uniform surface profile without any structural requirements you may not need reinforcement. However, it may still be advisable to include fibers in the shotcrete mixture to help control plastic shrinkage cracking. Generally, you would want to keep a minimum thickness of 1 in. (25 mm) to provide enough thickness for finishing. If you need the shotcreted sections to be self-supporting and carry loads as structural concrete, you should consult with a structural engineer to determine the appropriate thickness and reinforcement for the expected loads. Shotcrete is a placement method for concrete, so standard reinforced concrete design is appropriate for shotcreted sections.

SHOTCRETE CALENDAR

JULY 9-10, 2019	**Wet-Mix Shotcrete Nozzleman Certification in Australia** Concrete Pumping Association of Australia | Melbourne, VIC, Australia **www.shotcrete.org | www.cpassoc.com.au**
JULY 22-26, 2019	**Professors' Workshop** ACI Headquarters | Farmington Hills, MI **www.concrete.org**
AUGUST 27-29, 2019	**SDC Technology Forum 46 | Concrete 2029** Kimpton Hotel Monaco Pittsburgh | Pittsburgh, PA **www.acifoundation.org/sdc**
SEPTEMBER 9-11, 2019	**Breakthroughs in Tunneling Short Course** University of Denver | Denver, CO **https://tunnelingshortcourse.com**
SEPTEMBER 19-20, 2019	**Chicago Build** McCormick Place | Chicago, IL **www.chicagobuildexpo.com**
SEPTEMBER 28, 2019	**ASA Shotcrete Contractor Education** ASA Headquarters | Farmington Hills, MI **www.shotcrete.org**
OCTOBER 19, 2019	**ASA Fall 2019 Committee Meetings** Duke Energy Convention Center | Cincinnati, OH **www.shotcrete.org**
OCTOBER 20-24, 2019	**The ACI Concrete Convention and Exposition – Fall 2019** Theme: "A River of Knowledge" Convention Center and Hyatt Regency Cincinnati | Cincinnati, OH **www.aciconvention.org**
OCTOBER 23, 2019	**ASA Shotcrete Inspector Education** The ACI Concrete Convention and Exposition | Cincinnati, OH **www.shotcrete.org**
NOVEMBER 5-7, 2019	**International Pool | Spa | Patio Expo** Ernest N. Morial Convention Center | New Orleans, LA **www.poolspapatio.com**
NOVEMBER 6, 2019	**ASA Shotcrete Nozzleman Education at the PSP Expo** Ernest N. Morial Convention Center | New Orleans, LA **www.poolspapatio.com**
NOVEMBER 11-13, 2019	**ICRI Fall Convention** Theme: "Historic Restoration" Doubletree Hilton Philadelphia Center City | Philadelphia, PA **www.icri.org**
DECEMBER 8-11, 2019	**ASTM International Committee C09, Concrete and Concrete Aggregates** Marriott Marquis Houston | Houston, TX **www.astm.org**

FEBRUARY 4-7, 2020	**World of Concrete 2020** Las Vegas Convention Center | Las Vegas, NV **www.worldofconcrete.com**
FEBRUARY 23-26, 2020	**2020 SME Annual Conference & Expo** Phoenix Convention Center | Phoenix, AZ **www.smeannualconference.com**
MARCH 10-14, 2020	**CONEXPO – CON/AGG 2020** Las Vegas Convention Center | Las Vegas, NV **www.conexpoconagg.com**
MARCH 29 – APRIL 2, 2020	**The ACI Concrete Convention and Exposition – Spring 2020** Theme: "Concrete in the Windy City" Hyatt Regency O'Hare | Chicago/Rosemont, IL **www.aciconvention.org**
JUNE 28 – JULY 1, 2020	**ASTM International Committee C09, Concrete and Concrete Aggregates** Boston Marriott Copley Place | Boston, MA **www.astm.org**
SEPTEMBER 28-30, 2020	**MINExpo International** Las Vegas, NV **www.minexpo.com**
OCTOBER 25-29, 2020	**The ACI Concrete Convention and Exposition – Fall 2020** Theme: "Carolina Style Concrete" Raleigh Convention Center & Raleigh Marriott | Raleigh, NC **www.aciconvention.org**
DECEMBER 6-9, 2020	**ASTM International Committee C09, Concrete and Concrete Aggregates** Renaissance Orlando at SeaWorld | Orlando, FL **www.astm.org**
MORE INFORMATION	To see a full list with active links to each event, visit www.shotcrete.org/calendar.

INDEX OF ADVERTISERS