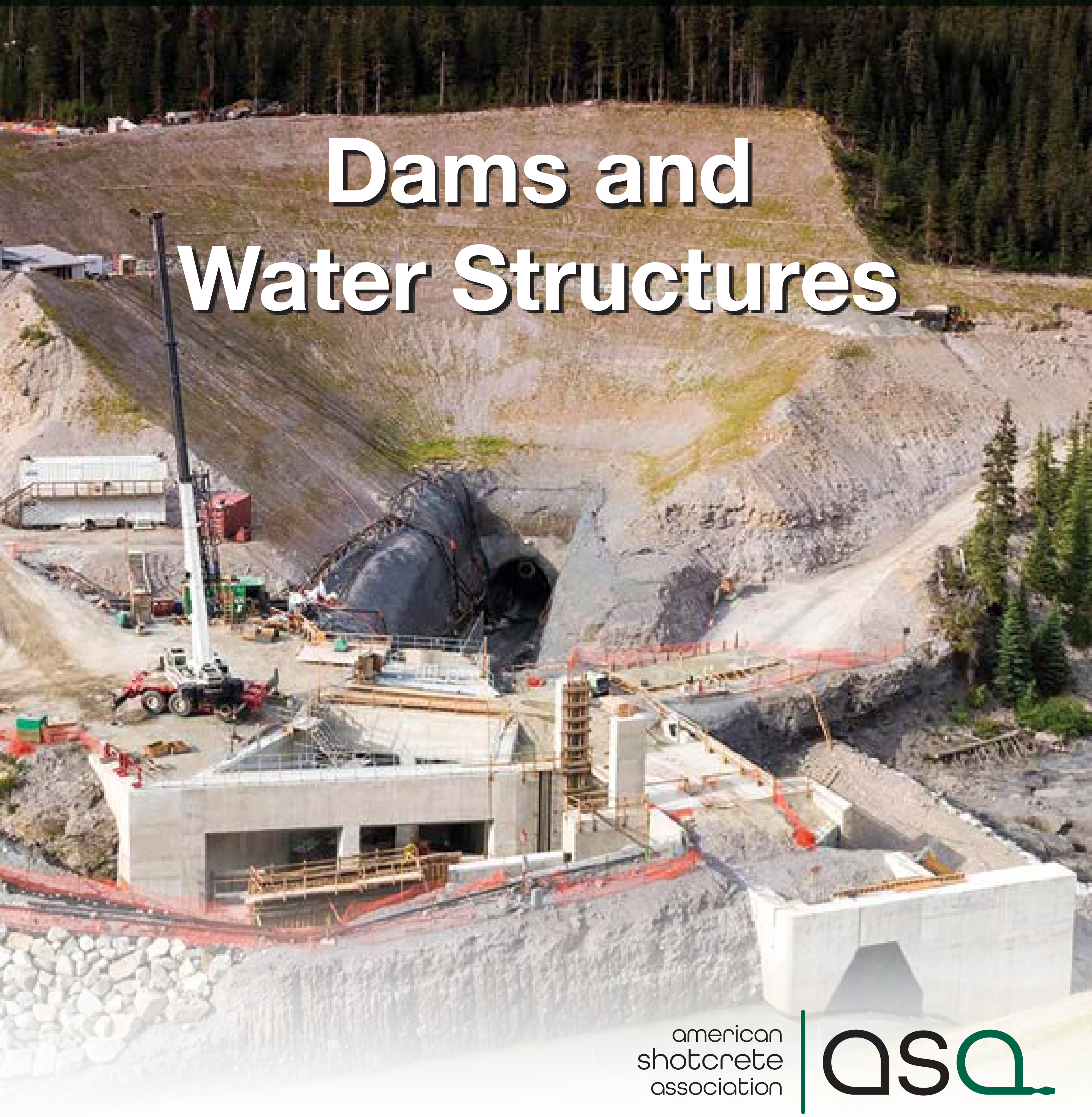
# shotcrete MAGAZINE

A quarterly publication of the American Shotcrete Association

VOLUME 21, NUMBER 3 • SUMMER 2019

www.shotcrete.org


# Dams and Water Structures



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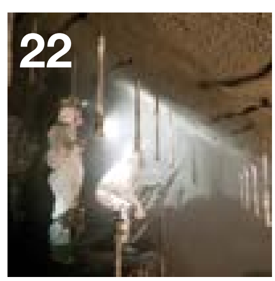
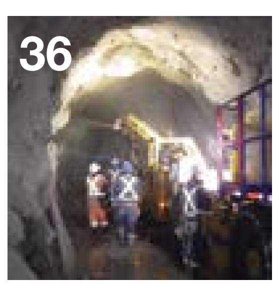
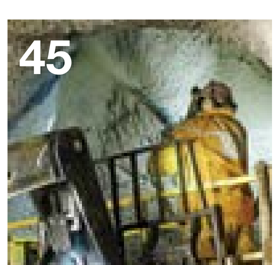
## FEATURES





*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:

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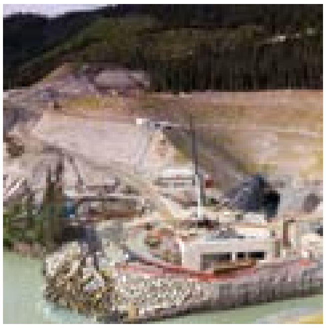
**Editor's Note:** Shotcrete is a placement method for concrete. However, for the sake of readability, the word "shotcrete" is often used either to identify the shotcrete process (method of placement) or the shotcrete mixture (product materials).





# DEPARTMENTS





*On the cover: Upstream tunnel portal for Upper Lillooet Hydroelectric project, British Columbia, Canada. Read the article on page 36.*

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# What is a True Shotcrete Contractor?

*By Cathy Burkert*

I receive several calls a year from around the country asking if I would be interested in lending my nozzleman. Upon further discussion, it is typically similar to "Hello, my name is (blank) and I was asked to do shotcrete on a project. I was wondering if I could borrow your nozzleman. I found a pump I can rent but the specification says I need an ACI-Certified Nozzleman."

As unfathomable as these types of requests are, it is difficult for me to not laugh about a concrete contractor who pours concrete driveways and sidewalks who thinks they can simply rent a concrete pump, somehow get a certified nozzleman, and then just shoot shotcrete. I have been working with shotcrete for almost 15 years. I started in the shotcrete business, as most do, shoveling rebound, but I worked hard and moved up the ladder. I'm now one of the first female ACI-Certified Nozzleman. This business keeps me on my toes and I learn something new every day. When you are truly in the shotcrete business you must be flexible, adaptable, and creative to consistently place quality shotcrete in a variety of different projects.

*When you are truly in the shotcrete business you must be flexible, adaptable, and creative to consistently place quality shotcrete...*

The ASA Contractor Qualification Program (CQP) was established to help the owner and specifier assure they were getting quality structural concrete produced by a shotcrete contractor who has proven quality work. For many years and still to this day, I hear a lot of engineers express their bad experiences with shotcrete, and therefore only allow the form-and-pour method on a job. As a shotcrete contractor, I must explain that shotcrete is a process, not a product, and that perhaps their experiences wasn't with the end product but with the contractor that placed it. Prior to the ACI-Certified Nozzleman Program, shotcrete specifications often required a list of the contractor's previous projects, references, and resumes. Now many specifiers have removed those "qualifications" thinking that simply requiring an ACI-Certified Nozzleman will ensure a quality job.

So, consider the contractor who calls me out of the blue. A contractor who has maybe poured concrete but, who has never placed shotcrete in their career. They expect they can rent a concrete pump, order concrete, and see who's willing to "lend" them a nozzleman. Quality shotcrete placement is dependent on getting all the details right. There are no easy shortcuts. Even if this contractor does find a nozzleman, do you really think their job will leave a better impression about the use of shotcrete than a true shotcrete contractor who has invested time, effort, and money in securing and maintaining a fully trained crew and proper equipment, knows the details to do the job right, and has proven it on their past shotcrete projects?

The following quoted text comes from the ASA Board Position Statement #1, "Shotcrete Contractor and Crew Qualification." Position Statement #1 became the basis for our CQP and I feel summarizes and highlights the importance our CQ program has for the shotcrete industry.

"...It is apparent that a contractor offering to place quality shotcrete must have specific knowledge, equipment, training, and hands-on experience of the entire construction team—from company management through the field crew—to truly be considered a Shotcrete Contractor.

"The quality of a completed shotcrete application results from the combined skills and knowledge of the shotcrete crew. The foreman and crew should have performed satisfactory work in similar capacities for a specified period. The entire crew is responsible for the safety of each member and others on any particular project.

"To consistently produce quality shotcrete work, the shotcrete contractor, key personnel, material, equipment, placement methods, curing, and protection all require proper training and qualification to handle your particular project. It must be stressed that any one of the elements alone cannot guarantee success, and poor performance or lack of shotcrete knowledge by any member of the crew can cause a substandard finished product.

"Simply specifying the use of an ACI-Certified Nozzleman WILL NOT guarantee successful shotcrete placement on a project. The ACI Nozzleman Certification program was designed to establish that the tested nozzleman is capable of shooting at an "entry" level. The nozzleman receives his certificate for each process and orientation if he succeeds in the written and the performance exam. It is plainly evident that the performance exam is not representative of the shotcrete application experience needed to consistently and properly place shotcrete. The shotcrete construction market has a wide range of project needs from basic, lightly reinforced, thin shotcrete sections to complex, and congested structural systems requiring substantially more experience and sophisticated techniques. The wide spectrum of construction practices, shotcrete processes, performance requirements, and geographic differences can impact shotcrete placement in many ways. No certification program can address all potential variables. The ACI Nozzleman Certification program simply verifies the cer-tified nozzleman has basic shotcrete knowledge and has adequately shot a shallow, flat, relatively lightly reinforced test panel. This establishes that the nozzleman has the potential for doing a satisfactory job, once he has gained the experience required for a specific type of project.

"Only by selecting a quality shotcrete construction team comprised of a qualified shotcrete contractor, a trained and experienced crew (including the ACI-Certified Nozzleman), and the proper equipment and materials can you be reasonably assured your shotcrete project will produce the high-quality, durable concrete structures that shotcrete is capable of creating."

One of the requirements for applying to be an ASA-qualified shotcrete contractor under the CQP is attendance at an ASA Shotcrete Contractor education seminar and passing a written exam. The Shotcrete Contractor Education program covers best practices by the contractor for quality shotcrete construction. Not only is the teaching component of the course by industry experts valuable, but the attendees also find sharing experiences and networking with other attendees provides a great overall learning experience. The next seminar will be available at ASA headquarters, Farmington Hills, MI, September 28, 2019. It will be presented by Charles Hanskat, P.E., FACI, FASCE. He is the ASA Executive Director and Technical Director and has been involved in the design, construction, evaluation, and repair of environmental concrete, marine, building, and shotcrete structures for 40 years. The seminar covers materials, equipment, personnel, application, QC/QA, curing, protection, and project management. In addition, this seminar will provide the opportunity to take the required written exam for those pursuing ASA Shotcrete Contractor Qualification. This is a valuable course for contractors to learn more about the details and requirements for quality shotcrete placement, regardless of their intent to pursue qualification. The shotcrete process offers many quality, efficiency, and sustainability advantages, but proper knowledge of the process is critical to the creation of a quality specification and for the success of any specifier/owner employing the process. Maintaining a high level of quality for concrete placed via the shotcrete method is ASA's primary concern. To become an ASA-qualified shotcrete contractor and for more information, visit **www.shotcrete.org/pages/education-certification/cq-program.htm**.

# Education Committee

The difference between ordinary and extraordinary is that little extra.
*—Jimmy Johnson, NFL coaching legend*

*By Oscar Duckworth*

Like many of us, I wear several hats in my personal life. Husband, father, shotcrete professional, farmer, and shop mechanic. So, like many of us, I'm busy all day. And for me, it's the same scenario every evening. It's already dark, but I get that tugging feeling that I should have accomplished more. Did I get enough done? Perhaps. Could I have accomplished more? Absolutely.

Doing that little extra is the foundation to the success of anything. That tugging feeling reminds us that extraordinary accomplishments never occur from doing only what is necessary.

Extraordinary accurately describes the profound ASA outreach of increasing the exposure and acceptance of the shotcrete process in concrete construction. Our members are certainly meeting the ASA mission of providing "knowledge resources, qualification, certification, education, and leadership to increase the acceptance, quality, and safe practices of the shotcrete process."

This tremendous success has occurred through only one thing: the cumulative effect of that little extra that each of us give through our volunteer involvement. We are all busy with our personal lives, but somehow we find a way to give a little extra to ASA outreach activities.

## ASA EDUCATION COMMITTEE ACTIVITIES

Members of the Education Committee are updating our education program for shotcrete nozzleman candidates pursuing ACI Certification. All nozzlemen must attend this ASA education session as a prerequisite to certification. Because technological advances continually occur, the materials, methodology, and safe best practices within this important educational tool must be kept current.

The Education Committee is working with Safety Committee members to develop a series of short safety alerts focusing on the specific hazards of the shotcrete industry. When completed, these could be distributed to employees of ASA member companies. Safety alerts may be either handouts or short presentations such as toolbox talks on recognizing and diminishing the various safety risks that are unique to shotcrete placement.

## DID WE GET ENOUGH DONE? COULD WE ACCOMPLISH MORE?

Education and certification are some of the things that ASA does best. Our volunteer members and staff are always busy educating or certifying owners, engineers, inspectors, specifiers, contractors, nozzlemen, and other shotcrete professionals. Outreach through the Shotcrete Inspector

## ASA EDUCATION COMMITTEE

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Andrea Scott, Secretary | Hydro-Arch

William Allen | Mapei UTT
Lars Balck | Consultant
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Lihe (John) Zhang | LZhang Consulting & Testing Ltd.

*Fig. 1: ASA Technology Conference and committee meetings*

Education program, Shotcrete Contractor Education sessions, and other available seminars and sessions are covering nearly every facet of the shotcrete industry.

In 2018, ASA conducted 87 Nozzleman Certification sessions and certified a record 607 nozzlemen. This is 100 certifications more than *any* year in the history of ASA.

Equally impressive was the incredible outreach of the other ASA activities. Through more than 20 on-site presentations, members and staff have had the opportunity to educate over 1000 owners, designers, engineers, inspectors, and contractors on the proper use of the shotcrete process in various venues throughout the country.

Thanks to tireless efforts by volunteers and staff, ASA held an extremely successful Shotcrete Convention & Technology Conference in Amelia Island, FL. Relevant topics presented by industry leaders were enthusiastically received by construction professionals from several countries.

Want more? The shotcrete process is now included within the concrete industry's most valuable concrete design resource, ACI 318, "Building Code Requirements for Structural Concrete". This high mark, along with all of the other accomplishments of 2018, reflect a true milestone in increasing the acceptance of shotcrete globally.

All of us work with or are connected with various owners, universities, municipalities, engineers, specifiers, or inspectors. Our membership reflects a significant portion of shotcrete construction. The potential outreach of ASA is only limited by the level of extra effort we choose to put forth in our daily interactions with the construction community.

We are all volunteers. We are busy all day. Did we get enough done? Perhaps. Could we have accomplished more? Absolutely. This is the common trait of extraordinary people. And extraordinary organizations.

## UPCOMING ASA EDUCATION OPPORTUNITIES

### Shotcrete Contractor Education

**September 28, 2019**
**ASA Headquarters, Farmington Hills, MI**

This program covers best practices by the contractor for quality shotcrete construction. Topics of this seminar will include materials, equipment, personnel, application, QC/QA, curing, protection, and project management. A required first step in the ASA Contractor Qualification Program, this seminar will provide the opportunity to take the required written exam. This is a valuable course for contractors to learn more about the details and requirements for quality shotcrete placement, regardless of their intent to pursue qualification. For more information, visit **www.shotcrete.org/pages/education-certification/education-event-6.htm**.

### Shotcrete Inspector Program

**October 23, 2019**
**The ACI Concrete Convention and Exposition, Cincinnati, OH**

The Shotcrete Inspector program covers critical elements of shotcrete applications that on-site inspectors must know to evaluate and sign off on acceptance documents for shotcrete. Topics of this seminar will include material selections, equipment, placement techniques, finishing, curing, protection, testing, and safety as it relates to the building official or inspector. This seminar is the recommended educational component to ACI's new Shotcrete Inspector Certification Program that is expected to be launched in 2019. The seminar will count as a portion of the work experience required for the ACI certification and review the reference materials required for the ACI certification examination. For more information, visit **www.shotcrete.org/pages/education-certification/education-event-2.htm**.

# The Value of American Shotcrete Association Membership

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

As Executive Director (and de facto Technical Director) I regularly get calls or emails from owners, engineers, or contractors needing more information about shotcrete. Often, it's because of a problem on a job or a question about best practices with shotcrete placement. A few recent questions have included:

- How do I get the work of my nozzlemen-in-training accepted on a structural job?
- What's considered proper curing on a project?
- Why are my boiled water absorption results unable to meet ACI 506 recommendations?
- How do I convince my inspector that my daily production panels shouldn't use reinforcing bars?
- Why is my shotcrete not reaching the needed strength?
- Why would an engineer require producing a mockup panel 20 ft high?
- How do I increase the durability of shotcrete in marine exposures?
- Would shotcrete be an appropriate placement process for this type of project?
- What ACI 506 or ASTM document should be referenced in our specification and why?

The list goes on. But the point is that the concrete industry—people purchasing, specifying, building, or inspecting shotcrete today—often needs answers to get the job done. And in our fast-moving world of Twitter and cell phones, many, if not most, expect answers now. Many inquiries are from ASA members, but most are not. In supporting our Mission—"ASA provides knowledge resources, qualification, certification, education, and leadership to increase the acceptance, quality, and safe practices of the shotcrete process"—we have chosen to make our shotcrete knowledge resources available publicly in a wide variety of formats, including:

- *Shotcrete* magazine with articles, columns, and FAQs provided for free to anyone subscribing;
- The ASA website with archival search of *Shotcrete* articles and all past technical inquiries, as well as position papers and reference materials;
- The technical inquiry submission page on our website;
- Free 1-hour on-site seminars for specifiers and owners; and
- Telephone support with a direct line to me as Executive/Technical Director and over 40 years of experience in shotcrete design, construction, and evaluation.

Each knowledge resource has a response time. The archive searches on the website may be quick but may not exactly fit the question at hand. The technical inquiry submissions are generally answered in less than a week, but sometimes, that isn't timely enough for the specific project. Though face-to-face interaction with a larger group of engineers or inspectors and a shotcrete expert may allow for a much more in-depth discussion, setting up an on-site seminar may take weeks to schedule a mutually agreeable time. Thus, many if not most people find calling us is the best solution for quick answers to their shotcrete questions today.

As Executive Director for the past 4+ years, I have fielded many dozens of calls from contractor members faced with a problem that has stopped or impeded work on a job. They often need help confirming or explaining shotcrete best practices to a project engineer (or inspector) on their job as the engineer, possibly suspecting the contractor is trying to cut corners, is not accepting their answers. Also, the project engineer will often not have the time or resources to thoroughly search for answers to a specific question on the shotcrete work. However, with the credibility of ASA as an association and decades of successful shotcrete experience, the engineer or inspector will often accept and value input from me as the voice of ASA, essentially conveying the standard of practice in the shotcrete industry. ASA spends the time to find the appropriate reference, formulates answers from years of experience, and with a phone call or e-mail to the engineer or inspector, finds this will often allow the job to move forward. Removing a project logjam can save the contractor member many times the cost of an ASA annual membership in profitability on the job. Yet, we provide this service upon request in a timely manner with no additional cost.

Providing these resources to make owners, specifiers, inspectors, and contractors more comfortable in accepting a shotcrete solution is a primary part of our mission, and we have made great progress in advancing the acceptance of shotcrete in a wide variety of concrete construction. However, providing the infrastructure to produce these resources requires time, staff with expertise, and facilities, each of these with their supporting cost.

So, ASA foots the bill to provide these very practical resources and tangible benefits to the industry. Who supports ASA to accomplish our mission? Our over 500 paying members provide a substantial portion of our annual operating budget through their dues and sponsorships. Our members are the individuals and companies who recognize that the shotcrete business needs increased visibility and acceptance. And, in perspective, our members find tremendous value in the price of an ASA membership. For no more than the cost of a single 10 yd$^3$ (8 m$^3$) truck of ready-mix concrete, our Corporate and Sustaining Corporate Members know that their support of ASA, together as a unified voice, we are substantially advancing the acceptance and use of shotcrete in the concrete industry.

Are you a Sustaining/Corporate or Individual Member? If you are, my sincere Thank You! Many of you have—for over 20 years—recognized the potential and value of ASA and supported our growth. However, if you are not yet a member, please consider the value ASA provides to your company and the shotcrete industry and join us (**www.shotcrete.org/membership**).

# asa Sustaining Corporate Members

Thank you, Sustaining Corporate Members, for your investment in the industry! ASA Sustaining Corporate Members show true dedication to ASA's vision to see "structures built or repaired with the shotcrete process accepted as equal or superior to cast concrete." These industry leaders are recognized for their exemplary level of support for the Association in a variety of ways.

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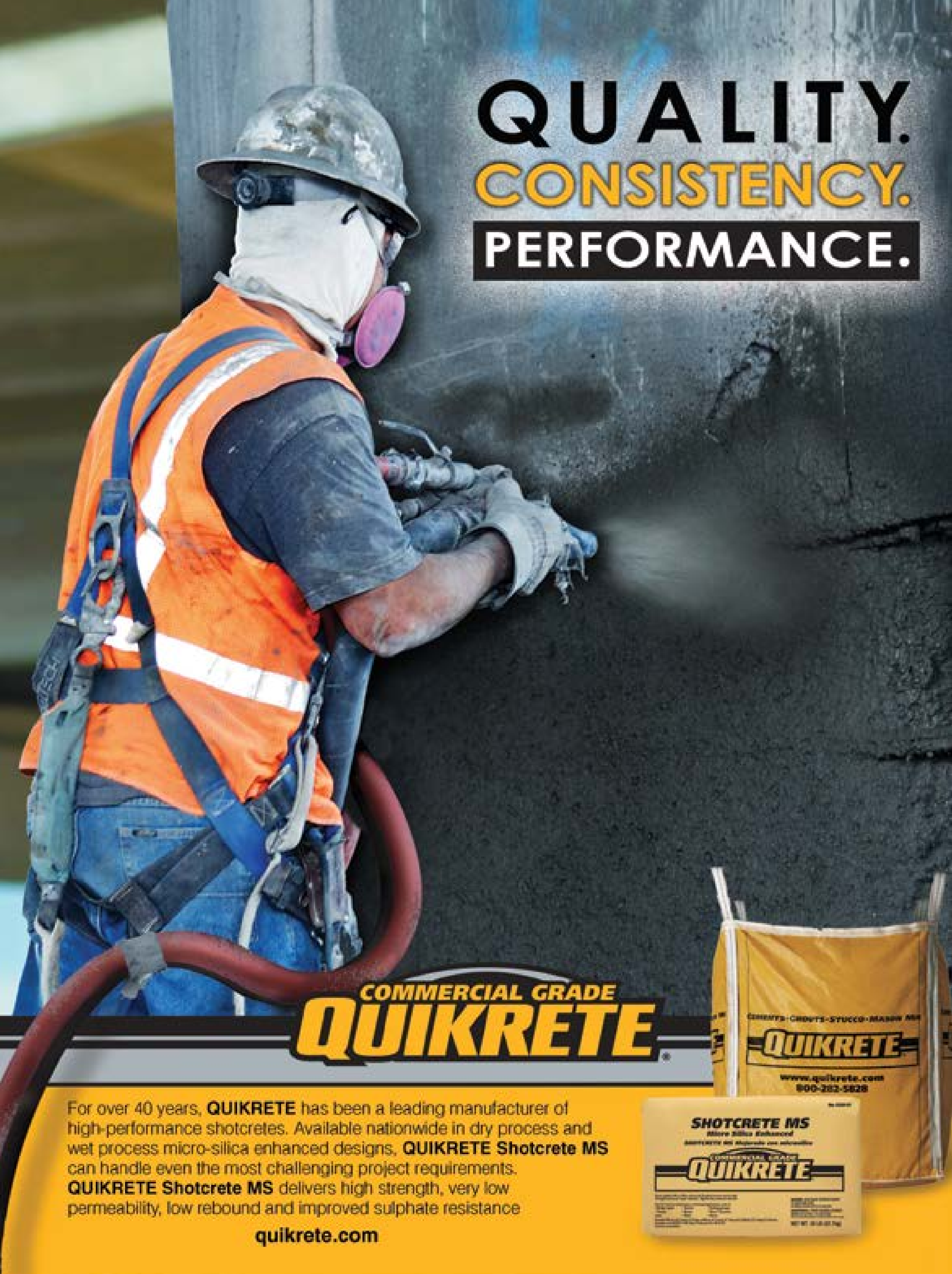
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# The Use of Shotcrete as a Repair Process for Marine Structures

*By Liam Ireland*

Concrete marine structures include dams, canals, docks, piers, and seawalls that are regularly exposed to either fresh or salt water. Marine structures are normally exposed to harsh environmental conditions and require periodic maintenance to meet their expected service life. In normal service they may be exposed to more aggressive deterioration processes such as freezing and thawing, wetting and drying, chloride intrusion from salt or brackish water, erosion, and abrasion impact from ice flows. Maintenance and repairs of marine structures are generally more challenging than those on land due to site access, tides, winds, waves, and other related issues. The impact of repairs on the adjacent land and marine life must also be considered. This requires planning and proper execution of measures to mitigate contamination of the surrounding water and land. This article illustrates how shotcrete provides a more versatile and cost-effective solution for repairing concrete marine structures than traditional form-and-pour concrete.

## Challenges

The combined effect of gravitational forces exerted by the sun and moon along with the rotation of the earth results in the rise and fall of sea levels known as tides. The ocean is constantly moving from high tide to low tide, providing an approximately 12-hour window between high tides. This phenomenon poses a challenge for both the designer and the contractor to maximize productivity and efficiency while timing a work schedule between high tides.

Access to the repair locations on concrete marine structures can also be quite challenging. To be a successful bidder, contractors must be creative and come up with innovative methods to execute the repair work in a cost-efficient and timely manner. When there's no road access to the repair locations, boats and barges are required to transport materials and equipment from the shore (Fig. 1). The reduction or elimination of formwork associated with the shotcrete process results in reduced barge size and frequency of trips required. An accelerated construction schedule and reduced material handling costs are only two of the resulting benefits. The use of shotcrete may also eliminate the need for dive crews to set up formwork underwater, and then return later for removal.

For submerged concrete repairs on dam structures with little or no tidal effects, mobile cofferdam systems can be set up to provide a work area for the shotcrete crews (Fig. 2), as was done on the McCormick Dam in Sept-Iles, QC, Canada, in 2014 (as reported by Côté et al.[1]).

*Fig. 1: Shotcrete material and equipment transported by barge*

*Fig. 2: Mobile cofferdam system on dam repair project*

When the shotcrete process is chosen for the repair of dams and other marine structures, wet-mix shotcrete pumps, dry-mix shotcrete guns, compressors, and materials can be set up on land, and the material conveyed through small-diameter delivery hoses over long distances to the repair areas if required. This eliminates the need for cranes, concrete buckets, and other lifting equipment required for form-and-pour concrete applications, making shotcrete a much more efficient and sustainable repair solution.

## DRY OR WET?

The decision of opting for a wet-mix process or dry-mix process shotcrete should be left up to the contractor. An experienced shotcrete contractor is able to gather the necessary information about the project and determine which process will be most suitable. The project specifications prepared by the design professional should be strictly performance-based and must include key properties such as strength and durability of the final in-place concrete. Once the material is in place, there is no difference between dry-mix and wet-mix, as both produce high-strength, low-permeability concrete when applied correctly.

When using the dry-mix process, shotcrete material (often supplied in a prepackaged form) is conveyed through the hose by a high-velocity air stream from a compressor, and water for hydration is added at the nozzle. The distance that the dry material can be conveyed is dependent on the volume of air from the compressor. Dry-mix shotcrete can be conveyed over 400 ft (121 m), allowing the nozzleman to access repair locations even when they are well away from the equipment and operator setup.

Dry-mix hoses are lighter weight than wet-mix hoses, making them easier to set up and manipulate when pumping material over long distances. When placing dry-mix shotcrete, the nozzleman has the ability to start and stop material flow without cleaning out the hoses. This provides flexibility on projects where repair patches are spaced far apart. Dry-mix shotcrete also allows the nozzleman to manually provide the required material consistency and to build thicker passes overhead without accelerator.

In the presence of tides, set accelerators are often required to prevent the fresh shotcrete from being washed away by rising tides and splashing waves. For dry-mix shotcrete, powdered set accelerator is typically added to the dry prepackaged material; however, it can also be added at the nozzle through a dosing pump.

Another advantage of dry-mix shotcrete is the ability to use ultra-rapid strength gain mixtures capable of reaching compressive strengths of 3000 psi (21 MPa) after 3 hours. This technology is practical for concrete structures exposed to vibration, or for structures that need to be put rapidly back into service. Ultra-rapid strength gain mixtures are typically not compatible with wet-process shotcrete due to the limited working time once the powder comes in contact with water. Whether placing concrete using the dry-mix or wet-mix process, quality ready mix supply might not be available on marine structure repair projects in remote locations. In cases such as these, prepackaged shotcrete products are always preferred.

When using wet-mix shotcrete, freshly mixed concrete is pumped through a hose and air is added at the nozzle to increase velocity and maximize compaction. The benefits of wet-mix in terms of access are similar to those of the dry-mix system because material can be pumped over long distances to hard-to-access repair areas. Pumping distance is dependent on the size of concrete pump, the size and type of delivery line, as well as the shotcrete mixture design. To pump over long distances, the mixture design must be optimized with high-range water-reducing admixtures (HRWRAs) to increase the slump without increasing the water-cementitious materials ratio (*w/cm*). When using set accelerators in wet-mix shotcrete, they must be added at the nozzle with a properly calibrated dosage pump. Under-dosage of accelerator will result in slower set times. Over-dosage of accelerator will reduce the quality of in-place shotcrete and can result in lower strengths. The wet-mix process allows for concrete volumetric placement at a rate approximately three to four times faster than dry-mix. This faster production rate favors wet-mix shotcrete for high-volume applications most of the time, such as new construction and large-scale repair projects.

## ENVIRONMENT

When shotcreting on or near waterways, it's critical to consider the effect on the nearby environment and take necessary measures to reduce water contamination and protect marine life. Owners or government code requirements will often impose strict measures requiring use of enclosed work sections, protective barriers, and floating booms (Fig. 3) to prevent rebound and dust from entering the water.

*Fig. 3: Protective barrier and floating boom*

## SPECIFICATION

Concrete marine structures are subjected to harsher environmental conditions than concrete structures on land. The correct shotcrete repair material must be specified to ensure a long lasting, durable repair solution. The in-place shotcrete material must be able to withstand the applicable exposure conditions such as freezing and thawing, wetting and drying, chloride intrusion from salt or brackish water, erosion, and abrasion impact from ice flows.

In structures located in climates that experience extensive freezing-and-thawing cycles, it is imperative that the shotcrete material contains properly dosed air-entraining admixtures creating a consistent, quality air-void system.

Concrete structures located in saltwater or exposed deicing salts must be able to resist chlorides that will penetrate into the concrete and attack the embedded reinforcing steel. To increase resistance to chloride penetration, the shotcrete material must have a lower permeability. Supplementary cementitious materials such as silica fume, fly ash, or slag are often used to lower the concrete's porosity by creating a denser binder matrix.

In climates with extended freezing weather, dams and bridge piers may be exposed to impact from ice flows. A common technique for preventing abrasion and impact damage caused by ice movement is to protect the concrete element with a steel plate. This method can be extremely costly and is often less effective than alternative methods available using the shotcrete process. Increased abrasion and impact resistance can be achieved by incorporating granite-based aggregates and steel fiber reinforcement with the shotcrete mixture design. The shotcrete material manufacturer should be able to provide data on impact and abrasion resistance as well as examples of successful projects that have been completed on structures with similar exposure conditions. For example, shotcrete has been proven to be an effective repair method for lighthouse foundations (Fig. 4), as reported by Gendreau et al.[2] and Giroux and Reny.[3]

*Fig. 4: Lighthouse foundation repair with abrasion-resistant shotcrete*

When new shotcrete placement is exposed to tides, preventive measures must be taken to ensure the freshly placed shotcrete doesn't wash away before it sets. High-early-strength cement and set accelerators are commonly used for shotcrete repairs in tidal zones to speed up set times and reduce the potential for washout from the rising tides. Some dry-mix shotcrete material suppliers provide precise set times at various accelerator dosages, making it easy for the design professional to specify the required dosage for the project. Specifiers should also ask for examples of successful projects that have been completed in similar exposure conditions with the process, equipment, and material being proposed for a project.

Some concrete marine structures must be rapidly returned to service.

Others may be exposed at an early age to vibrations or abrasion from heavy water flow. Tunnel sluices in lock structures may require maintenance and may need to be put back into service rapidly to minimize closure of the seaway and allow boats to pass through. When traditional accelerated shotcrete cannot provide sufficient early strength to resist vibration or heavy water flow through the tunnel sluices, ultra-rapid-strength-gain shotcrete can provide an optimal solution. The ability to reach compressive strengths of 3000 psi (21 MPa) after 3 hours allows the structure to be put back into service quickly, resulting in a shorter construction schedule and a more rapid return to service.

## Conclusions

The flexibility of the shotcrete process provides a practical, cost-effective competitive advantage for contractors that face the challenge of repairing dams and other water structures. It also provides owners and specifiers with a long-term, effective solution for repairing those same structures. The reduction or elimination of formwork and a dramatic reduction in the need for cranes and lifting equipment makes shotcrete a more versatile, cost-effective and sustainable repair solution with considerable advantages over concrete placed using traditional cast-in-place methods.

## References


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# Flood Control Channels Made with Shotcrete

*By Raúl Bracamontes*

Flooding is a temporary overflow of water onto land that is normally dry. Floods are the most common natural disaster in the United States. This year, we have seen severe flooding in the Midwest that has cost countless millions of dollars in damage to property or restriction of use of our waterways. Floods may:

- Result from rain, snow, coastal storms, storm surges, and overflows of dams and other water systems;
- Develop slowly or quickly and can occur with no warning;
- Cause outages, disrupt transportation, damage buildings, and create landslides; and
- In the worst case, kill people.

*Fig. 1: Casting the arched culvert floor*

## FLOOD CONTROL CHANNELS

Flood control structures such as arch culverts and concrete-lined channels are built to control the flow of water from flooding events to prevent or minimize damage to structures and infrastructure. Flood control channels are large, open-topped canals that direct the excessive water flow during flood conditions. They commonly are empty or have a minimal flow of water in normal service. In large metropolitan areas, we have seen underground tunnels or conduits to collect the excess water and eventually drain into a stormwater containment structure, river, or other body of water. There is a distinct trend away from letting stormwater just run into our oceans, rivers, or wetlands as it is often loaded with contaminants that reduce water quality. These structures are usually built with reinforced concrete. They may also contain grade-control sills or weirs to prevent erosion and maintain a level water level in the streambed.

## BENEFITS OF SHOTCRETE

Shotcrete is becoming more popular among contractors and builders as it is extremely economical and flexible. Shotcrete placement produces a finished product that exhibits superior hardened properties when compared to form-and-pour applications and allows a wide variety of surface finishes. Some of the inherent benefits of shotcrete include high strength, low permeability, and thus increased durability.

*Fig. 2: Forms ready to receive reinforcing steel*

*Fig. 3: Reinforcing steel in place over the supporting arch form*

Fig. 4: Shotcrete placement starting at the bottom of the arched wall

Fig. 5: Shotcrete placement further up the arched wall

Prime application areas for shotcrete in water-retaining structures include sea and river walls, aqueducts, reservoirs, tanks, dams, canal linings, and irrigation and drainage channels. Using shotcrete for construction of arched culverts has also become popular. The shotcrete process provides several advantages in comparison with form-and-pour construction of these arched culverts, such as reducing construction time, form material and costs; lowering material handling; and producing excellent bond with most substrates, particularly on complex forms or shapes.

## CONSTRUCTION PROCESS OF THE LEBARON CHANNEL

The Lebaron channel in Nevada described herein was constructed by Hydro-Arch, a shotcrete contractor focused

Fig. 6: Cleaning and roughening the construction joint before shotcrete placement starts on the top of the arch

on the concrete arched culvert business. The construction process for the arched culvert began with the excavation of the subgrade soils to the desired level, placement of the subbase material and reinforcing steel, and casting of the concrete slab that forms the floor of the culvert. Once the concrete floor gains enough strength, the prefabricated arch forms are placed and bolted together to create a continuous form. Sometimes, a custom wood form is fabricated to fit the radius of the tunnel. The steel reinforcing is then placed on top of the culvert form. Now, the forms are ready to receive the shotcrete placement of concrete on top of the arched form.

Shotcrete placement starts at the bottom of the walls and then moves to the top to complete the arch section. The joint between placements is always properly prepared to facilitate the bond and water tightness for the next placement. Construction joints must always be roughened, cleaned, and brought to saturated surface-dry (SSD) condition before the subsequent placement commences.

A 3 in. (75 mm) slump and 4500 psi (31 MPa) concrete mixture design was used for the wet-mix shotcrete placement. Proper placement of shotcrete is critical to achieve high-quality, durable concrete. The thickness of the shotcrete ranges from 6 to 18 in. (150 to 450 mm), depending on the section and dimension of the arch. Quality shotcrete placement requires full compaction of the concrete, with forms and reinforcement free of overspray and rebound, and proper encasement of reinforcement.

The shotcrete nozzleman is the crew member most directly responsible for placing quality shotcrete. Use of

Fig. 7: Shooting the top section of the arch

Fig. 8: An overview of shooting the top of the arched culvert

an ACI-certified shotcrete nozzleman can help ensure that this critical member of the field crew has the knowledge and experience to place high-quality shotcrete.

Once the shotcrete is placed, a fresno trowel finish is provided. Immediately after finishing, the surface is coated with a spray-on curing membrane to help the concrete reach its desired strength, reduce cracking potential, and provide

*Fig. 9: A fresno trowel finish is provided on the shotcrete surface*

lower permeability. A liquid waterproofing membrane is often applied after the concrete has reached the desired age and surface moisture content.

## Conclusions

Shotcrete placement for construction of these arched culverts provides faster construction, simplified formwork requirements, and allows ease of creating any curves desired. Overall, this means shotcrete saves the owner money while providing superior concrete that has higher strength, lower permeability, and will provide better long-term durability than conventional form-and-pour solutions.

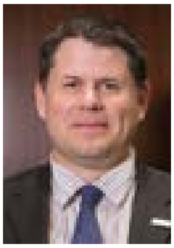

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*Fig. 10: A membrane curing compound being sprayed on the fresh shotcrete surface*

*Fig. 11: Backfilling of the culvert*

*Fig. 12: An interior view of the finished culvert*

# Structural Modifications to Hydroelectric Turbine Draft Tube Ceiling

## Using Accelerated Wet-Mix Steel Fiber-Reinforced Shotcrete Applied Up to 2 m Thick Overhead

*By Shaun M. Radomski, Dudley R. (Rusty) Morgan, Lihe (John) Zhang, and David Graham*

The U.S. Army Corps of Engineers (USACE) is engaged in structural modifications to the reinforced concrete draft tube exits from the turbines in the Ice Harbor Lock and Dam located on the Snake River near Burbank, WA. These structural modifications, along with new advanced technology hydroelectric-generating turbines, are intended to improve hydraulic conditions for fish passage, as well as provide improved electrical generating efficiency. As part of this reshaping of the draft tubes, there was a need to apply an accelerated wet-mix shotcrete, with 100 lb/yd$^3$ (59 kg/m$^3$) of steel fiber, up to 6.5 ft (2 m) thick overhead. Overhead application of shotcrete to such thickness is seldom done and posed a challenge for the designer and contractor. This article describes the measures taken to develop a suitable shotcrete mixture design, consistent concrete supply, and proper application procedures to successfully meet this challenge. The draft tube modification design and a rigorous set of project specifications were prepared by the USACE. The specification required the construction and testing of large mockups with dimensions of 7.9 x 5.9 ft (2.4 x 1.8 m) and varied in thickness from 3.9 to 6.2 ft (1.2 to 1.9 m). One mockup panel was required for each nozzleman proposed to shoot on the job to prequalify the mixture designs, nozzlemen skills, and construction procedures. This paper describes construction and testing of both the mockups and the actual work.

*Fig. 1: Shaft for Turbine Unit No. 2*

The structural modification to the draft tube was completed using wet-mix shotcrete, except for the final finish shotcrete layer, which used dry-mix shotcrete. Quality control testing, including compressive strength of cores and bond strength to the prepared concrete substrate and between layers of shotcrete, demonstrated that the completed work satisfied the project specification requirements.

### PROJECT BACKGROUND

Ice Harbor Lock and Dam was constructed in 1956 and is located along the Snake River near the confluence with the Columbia River, approximately 12 miles (19 km) east of Pasco, WA. The dam is a concrete gravity run of the river dam operated by the USACE and provides electrical power through six turbines for electrical distribution through the Bonneville Power Administration in the state of Washington.

Accelerated silica-fume-modified wet-mix shotcrete with 100 lb/yd$^3$ (59 kg/m$^3$) of steel fibers was applied overhead up to 6.5 ft thick as part of a structural modification made to a draft tube ceiling downstream of Turbine Unit No. 2. This shotcrete application posed challenges for the contractor performing the work. Rigorous shotcrete specifications were developed by USACE for this work. This article details:

- Development of the shotcrete mixture designs;
- Optimizing accelerator dosage for this application;
- Shotcrete application procedures developed during the preconstruction mockups;
- Equipment setup;
- Construction sequencing and challenges to overcome while shooting the draft tube; and
- Quality control test data.

Applying shotcrete up to 6.5 ft thick overhead is challenging and seldom done. Because of proper attention to the materials, equipment, and shotcrete placement, the work

Fig. 2: Illustration of draft tube

was completed successfully and fully satisfied the project requirements. The USACE approved the work following the final inspection.

## DRAFT TUBE

The draft tube is 100 ft (30.5 m) below the surface, based on measuring the distance between the draft tube floor at the downstream exit door and the tailrace deck located at the surface. The draft tube is 91.5 ft (27.9 m) long and is split into two sections (Barrels A and C) by a concrete pier nose. Barrel A and Barrel C are each 34.1 ft (10.4 m) wide at the stop logs (furthest downstream). The structural modification was completed to the ceiling from the location of the draft tube exit doors and upstream to approximately 36.7 ft (11.2 m) away from the exit doors. Figure 2 shows a cross-sectional model of the draft tube and Fig. 3 shows a cross-sectional illustration of the draft tube modification.

## DESIGN

The USACE designed structural modifications to the turbine draft tube to improve hydraulic conditions for fish passage and electrical power-generating efficiency. This required the ceiling at the draft tube (furthest downstream) to drop by approximately 6.5 ft, while maintaining an overall slope of 22 degrees in Barrel A and 23 degrees in Barrel C until the shotcrete terminated at a 2.5 in. (65 mm) cut notch, which was to be built out flush with the existing ceiling. The design included the drilling of 1 in. (25 mm) diameter (Type 1) and 1/2 in. (13 mm) diameter (Type 2) anchors into the existing ceiling concrete and installing No. 5 reinforcing steel positioned 2.5 in. from the concrete substrate and No. 9 reinforcing steel positioned approximately 4 in. (100 mm) from the final finished shotcrete surface. Figure 4 shows a reflective ceiling plan for structural design details for the shotcrete modification. Figure 5 shows a sectional view of reinforced shotcrete modifications to the draft tube.

## SHOTCRETE SPECIFICATIONS

### Performance-Based Specification

The USACE required the contractor to assume all responsibilities for the shotcrete mixture design and application and meet the following performance requirements:

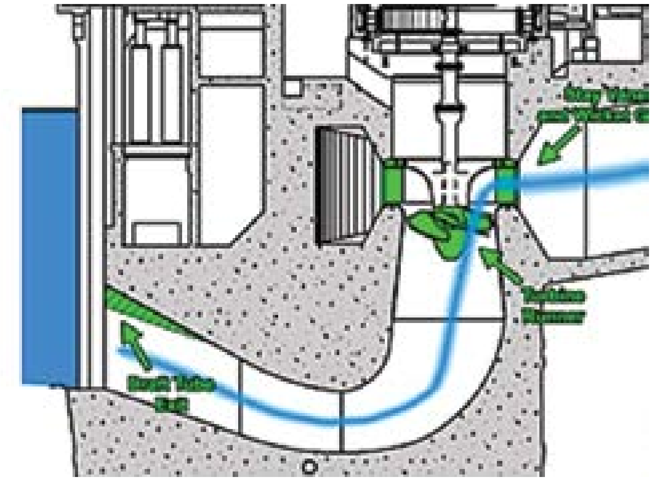

Fig. 3: Illustration of draft tube modification

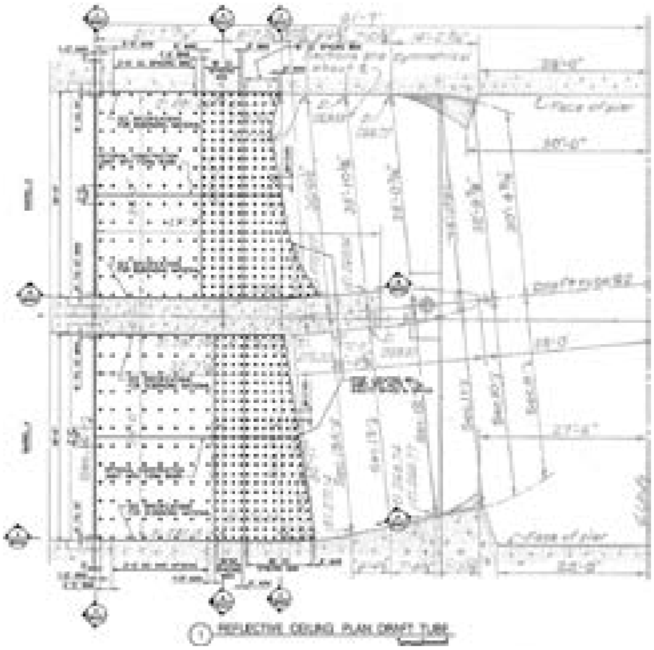

Fig. 4: Reflective ceiling plan for reinforced shotcrete modifications to draft tube

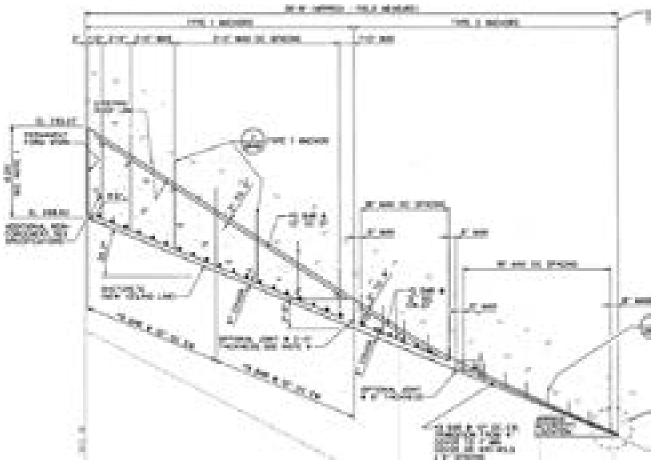

Fig. 5: Sectional view of reinforced shotcrete modifications to draft tube

- A minimum specified shotcrete compressive strength of 5000 psi (35 MPa) at 28 days and a minimum bond strength to the prepared concrete substrate of 100 psi (0.7 MPa);
- Demonstrate that the specification requirements could be achieved by constructing large full-scale mockups 7.9 x 5.9 ft and varying in thickness from 3.9 to 6.2 ft, one for each nozzleman proposed to shoot on the job; and
- Prequalify the mixture designs, accelerator dosage, nozzleman technique, and shooting procedures (Fig. 6 through 9) with mockups. Two different sets of three mockups were constructed using two different brands of accelerators to optimize accelerator type and addition rate for the job.

*Fig. 6: Start of preconstruction mockup construction*

*Fig. 7: Nozzleman building out shotcrete to cover reinforcing bar and around anchor rods of preconstruction mockup*

*Fig. 8: View of preconstruction mockup after completion of installation of wood forms*

## Shotcrete Mixture Design

The Shotcrete Consultant, Wood Environment & Infrastructure Solutions, provided the Shotcrete Contractor, PCiRoads, LLC, with a steel fiber-reinforced wet-mix shotcrete mixture design using local aggregates. The mixture was proportioned with the following materials and designed to meet the following materials and plastic shotcrete properties:

- Local aggregates with 3/8 in. (10 mm) maximum size meeting the ACI 506 Grading No. 2 requirements;
- Steel fiber 100 lb/yd$^3$ or 0.75% by volume;
- ASTM Type I normal portland cement;
- 8.3% fly ash by mass of cementing material;
- 9% silica fume by mass of cementing material;
- 7 to 9 in. (180 to 230 mm) slump at discharge into the shotcrete pump;
- 7 to 10% plastic air content at discharge into the shotcrete pump; and
- 2 to 5% air content as-shot.

The shotcrete supplier hauled the shotcrete loads in transit mixers approximately 45 to 60 minutes from the batch plant to the jobsite. With additional staging and offload time, this required the use of a hydration control admixture to delay the onset of hydration and extend the working life of the shotcrete. A rapid-set accelerator was added at the nozzle to "wake up" the shotcrete from the effects of the hydration control admixture so that the shotcrete would nearly instantly set upon impacting the overhead receiving surface. After 180 minutes from addition of water to the transit mixers, the slump consistency in the shotcrete loads was found to be maintained at close to the initial slump tested upon arrival at the jobsite.

## Preconstruction Mockups

Full-scale mockups were constructed for each nozzleman as part of the prequalification process using the reinforcing details specified for the work (Fig. 6 through 9). An initial set of three mockups was shot using one brand of an alkali-free shotcrete accelerator added at the nozzle. It was found necessary to build the shotcrete up in no more than 4 in. thick layers, with the shotcrete being allowed to achieve initial set before shooting the next layer to prevent shotcrete delamination and fallout. The initial alkali-free accelerator used had to be added at an additional rate of 8% by mass of cement to achieve an initial set time of 13 minutes and final set time of 46 minutes as measured by the ASTM C403/C403M penetration resistance test. There was, however, a concern that this rate of setting would slow down productivity excessively. Also, this high accelerator addition rate resulted in a considerable compressive strength reduction compared to shotcrete without accelerator, or a lower (6%) accelerator addition rate. Consequently, a second set of three mockups was constructed, using a different brand of alkali-free accelerator. This second accelerator, when added at 6% by mass of cement, achieved an initial set time of 8 minutes and final set time of 32 minutes, which was considered to be satisfactory for productivity purposes.

*Fig. 9: Nozzleman shooting final lift of full-scale mockup*

*Fig. 10: Diamond wire-cut section of full-scale mockup showing excellent shotcrete consolidation around reinforcing bar and saw-cut prisms for bond testing*

Also, the shotcrete readily satisfied the USACE specification requirements for a minimum compressive strength of 5000 psi at 28 days and minimum bond strength between shotcrete layers of 100 psi at 7 days. Following visual examination of reinforcement encasement across diamond wire saw-cut cross sections of the mockups (Fig. 10), the shotcrete used in the second set of mockups was approved for reprofiling of the draft tubes.

## Accelerator Dosing Pump Calibration

One of the most critical aspects of the fiber-reinforced wet-mix shotcrete overhead application was obtaining an adequate dispersion of alkali-free accelerator in the shotcrete stream at the nozzle and introducing the correct amount of accelerator so that the shotcrete mixture would rapidly stiffen as it impacted the overhead receiving surface without any sloughing or fallouts, while maintaining adequate compressive strength and overall quality of the hardened shotcrete. This was achieved by pumping the mixture at a slump ranging between 8 and 9 in. (200 and 230 mm) (Fig. 11) and performing a calibration of the peristaltic accelerator dosing pump using the proposed construction setup prior to overhead application, so that an accurate accelerator addition rate would be provided during shooting of the draft tubes at specific dial settings on the dosing pump.

The calibration process included having a nozzleman shotcrete into a 4 ft$^3$ (0.11 m$^3$) box. Accelerator consumption was measured to verify the accelerator addition rate as a percent by mass of cement at different dial settings on the accelerator dosing pump. Initially, flow rates were measured at various dial settings on the accelerator dosing pump and accelerator consumption was recorded in L/minute. Based on the known portland cement content in the shotcrete mixture and the specific gravities of the cement and accelerator, a desired accelerator addition rate was calculated. Measuring just the flow rates at different dial settings alone, however, did not provide an accurate accelerator addition rate (as a percent by mass of cement) due to back pressures from the airflow in the nozzle impacting the accelerator injection into the shotcrete stream. The accelerator dosing pump dial had to be set at a suitable pump motor speed (rpm) to overcome this back pressure, but without overdosing the accelerator amount entering the shotcrete stream.

*Fig. 11: Slump of approximately 9 in. confirmed based on testing in accordance with ASTM C143/C143M*

The calibration procedure was completed by the contractor prior to shooting the mockups and the production on-site. The time measured to completely fill the 4 ft$^3$ box and the volume of accelerator pumped from sufficiently sized measuring flasks was recorded. The calibration procedure included testing for the initial and final set times (Fig. 12) and early-age compressive strengths measured at 2, 4, 6, 8, and 24 hours (Fig. 13) to confirm the addition of the appropriate amount of accelerator necessary to shoot the draft tube ceiling safely.

*Fig. 12: Determination of initial and final set based on testing in accordance with ASTM C403/C403M*

*Fig. 13: Determination of early-age compressive strength based on testing in accordance with ASTM C116*

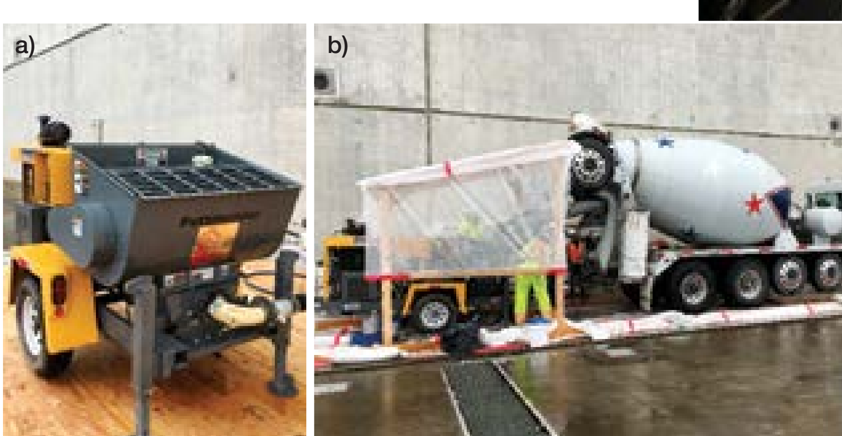


*Fig. 14(a) and (b): Shotcrete pump and supply setup outside powerhouse*

## CONSTRUCTION
### Equipment and Crew

Shotcrete equipment included a Putzmeister TK20 Shotcrete pump (Fig. 14), a 325 ft$^3$/minute (9200 L/minute) air compressor, 3 in. (75 mm) steel slick lines, and 2 in. (50 mm) rubber hoses. Three nozzlemen and eight laborers made up the crew. Shotcrete was pumped into a long 3 in. diameter steel line which fed shotcrete into the power house, down a 50 to 75 ft (15 to 23 m) vertical shaft to a narrow corridor leading to an egress to access a 50 ft high scaffold stairway down to the bottom of the draft tube (Fig. 15 and 16). The steel line contained several turns and 90-degree elbows to reach the bottom of the draft tube from the power house. The steel line transitioned into a 2 in. rubber hose at the shotcrete work area. Approximately 200 ft (60 m) of slickline

*Fig. 15: Steel line entering draft tube from powerhouse*

*Fig. 16: Steel line entering shotcrete application area inside draft tube*

Fig. 17: Nozzleman shooting overhead on scaffold platform in crouching position maintaining adequate shooting angle and distance to receiving surface and building out shotcrete to shooting wires

Fig. 18: ICRI CSP7 surface roughness profile

Fig. 19: Concrete substrate, formwork, 1 in. anchors, and No. 5 reinforcing bars installed and ready for shotcrete application

Fig. 20: A 1 in. diameter anchor embedded in shotcrete and shooting wire positioned to show nozzleman how thick to build out next layer of shotcrete

Fig. 21: A 1/2 in. anchor embedded in shotcrete

and rubber hoses were used to feed the shotcrete to the nozzlemen in the draft tube. The shotcrete work area had several levels of scaffold decks supported on a sloped floor (Fig. 17). The scaffold decks were adjusted up or down so that the nozzlemen could apply shotcrete overhead while shooting in an upright position where possible. Nozzlemen found that shooting in a crouching position was necessary at some locations to enable an adequate shooting angle during application to the sloped ceiling (Fig. 17).

## Scaffold Setup

Several scaffold platforms were set up consecutively and in a stepped pattern to complete the overhead shotcrete application. Each platform was positioned at an elevation dictated by the slope angle of the existing concrete ceiling and required adjusting following installation of anchors, reinforcing bar, and the thickness of daily shotcrete application. Scaffold platform elevations were adjusted as necessary so that nozzlemen could shoot in a position that enabled satisfactory shooting techniques.

## Concrete Surface Preparation

The existing concrete ceiling surfaces of the draft tubes located in Barrels A and C were generally found to be in good condition based on visual inspection of the concrete surfaces. Abrasive blasting using silica glass provided an ICRI CSP 7 surface roughness profile (Fig. 18). Visual inspection and hammer sounding techniques were completed by Wood Environment & Infrastructure Solutions to ensure a sound and clean surface was provided. Surfaces were brought to a saturated surface-dry (SSD) condition prior to shotcrete application.

## Reinforcing Steel and Anchors

The reinforcing steel was inspected for size, spacing, and rigidity prior to shotcrete application. Positioning of anchors into the concrete ceiling required some offsetting to avoid existing reinforcing bar following ground-penetrating radar scanning. Anchor Types 1 and 2 were required to be drilled at 3 ft (1 m) on-center and 18 in. (460 mm) spacing, respectively. The drawings allowed for a tolerance of ±4 in. spacing for anchors. The No. 5 and No. 9 reinforcing steel bars were spaced at 12 in. (300 mm) each way. Refer to Fig. 19 through 23.

All reinforcing steel inspected generally satisfied the design requirements in the structural drawings and was secure for overhead shotcrete application. A compressed air blowpipe was used during shotcrete application to enable removal of overspray from the reinforcing bars adjacent to the shotcrete placement. In addition, the anchors were protected from overspray by plastic wrap.

## Placement Sequence

The original draft tube concrete substrate and the most recently applied shotcrete layer were cleaned using a pressure washer and allowed to dry back to an SSD condition

*Fig. 22: Number 9 reinforcing bars installed and ready for shotcrete application*

*Fig. 23: Nozzleman ready to begin shotcrete application to prepared concrete substrate*

immediately prior to shotcrete application. A compressed air blowpipe was used to accelerate drying of the surfaces where necessary.

At the start of each day, initial and final set times were tested to confirm the accelerator addition rate was adequate for overhead shotcrete application. Beam molds were shot to provide specimens for testing early-age compressive strength at 2, 4, 6, 8, and 24 hours. A square test panel was shot to test for compressive strength at 7, 28, and 56 days, and boiled absorption and volume of permeable voids to ASTM C642.

Shotcrete nozzlemen began shooting the prepared concrete substrate behind the No. 5 reinforcing bar by "picture framing" the edge of the work. Nozzlemen would fill in behind the reinforcing bar and wrap the bars with shotcrete by manipulating the nozzle in a side-to-side motion, adjusting the angle of the nozzle so that shotcrete would wrap around the reinforcing bar adequately. After the edge of the work was shot, the nozzlemen would work inward from the edge, using the same sequencing as described previously.

Anchor rod extensions were installed and protected with plastic wrap and shotcrete was built out in maximum 4 in. layers beyond the No. 5 bars. Shooting wires installed at a 3 ft spacing provided guidance to the nozzlemen on how thick the work should be built out in a single pass. Nozzlemen generally shoot at 90 degrees to the receiving surface, manipulating the nozzle in a slight side-to-side movement and with a small circular motion to fully encapsulate reinforcing bar and anchors.

Nozzlemen were required to wait until the shotcrete had reached final set prior to shooting the next layer of shotcrete, as confirmed by testing for initial and final set times. Surfaces of shotcrete were also evaluated by touch prior to applying the next layer of shotcrete to confirm the set.

Number 9 bars were installed approximately 10 in. (250 mm) from the final finish surface.

A dry-mix shotcrete mixture with synthetic fibers (without accelerator) was used to shoot the final layers around the No. 9 bars instead of the accelerated steel fiber reinforced wet-mix shotcrete mixture. With the lower-volume output provided by the dry-mix shotcrete process, the nozzlemen were able to work carefully around the No. 9 bars and provide full encapsulation of this heavily congested reinforcing bar (Fig. 24).

Nozzlemen applied dry-mix shotcrete out to the final shooting wires to provide the 4 in. specified cover for the No. 9 reinforcing bar. The shotcrete was trimmed to the wires with a cutting screed, troweled, and sponge floated. The final finish was a sponge float finish and satisfied the specification surface tolerance requirements of 2 in. over a 10 ft (3 m) straight edge (Fig. 25).

## Thickness Control

Piano wire installed at a 3 ft spacing was offset approximately 4 in. from the surface of the preceding layer of shotcrete to control line and grade.

Fig. 24: Nozzleman shooting dry-mix shotcrete at the No. 9 reinforcing bar

### Curing

Sprinklers were set up on the scaffold deck to apply water to the surface to cure the freshly applied shotcrete overnight. High humidity in the work area and no sun or wind exposure made the shotcrete curing conditions favorable.

Fig. 25: Sponge float finish satisfying specification requirements for finishing tolerance

## CHALLENGES ENCOUNTERED

Due to using a different shotcrete setup than the one used during the initial calibration of the peristaltic accelerator dosing pump, accelerator consumption was measured daily from the accelerator tote to verify accelerator addition rates. The dial setting was adjusted based on observed flow rates at different dial settings, initial and final set times achieved at various dial settings, and the accelerator consumption measured daily at the selected dial setting used during production. This method was repeated on several occasions to confirm that a suitable addition rate of accelerator was being provided by the accelerator dosing pump so that shotcrete would stick overhead without sloughing or fallouts at the target maximum thickness of 4 in.

Balls or clumps of material were sometimes observed coming off the concrete truck delivery chute. These clumps occasionally plugged up the steel line at the reducer where the steel line transitions to a rubber hose. This issue was corrected by adjusting the silica fume and steel fiber material addition techniques at the batch plant.

Blockages in the shotcrete delivery lines sometimes occurred. A regular preventative maintenance routine of opening up the steel lines and rubber hoses at the connections and removing any buildup of mortar proved helpful in reducing line plugging.

Fallouts were occasionally observed when nozzlemen attempted to shoot at thicknesses greater than the target maximum 4 in. in a single layer. When fallouts occurred, the fallout area was prepared for reapplication with shotcrete by using a compressed air blowpipe to remove any loosely bonded shotcrete or carefully scraping any loose shotcrete around the perimeter of the fallout area with a steel trowel. Shotcrete was required to achieve initial set before reshooting in the fallout area.

Entry into the draft tube was designated as a confined space and this required all personnel who entered into the draft tube to follow USACE safety regulations for confined space entry. Lockouts and sign-in/sign-out reports were required to ensure that everyone inside the draft tube was accounted for.

## QUALITY CONTROL

### Preconstruction Testing

Two different alkali-free accelerator brands were investigated during the preconstruction mockup trials. Initial and final set times, early-age compressive strength, and compressive strength at 7, 28, and 56 days were evaluated using each brand of accelerator and at several dosages measured in percent by mass of cement: 0, 4, 6, and 8%.

Evaluation of the initial and final set times and compressive strength testing of cores from test panels was completed on every load of shotcrete used to construct the mockups. Compressive strength of shotcrete cores without any accelerator addition was found to be significantly higher than in shotcrete with accelerator. The lowest compressive strength was found to occur in shotcrete with 8% accelerator.

### Production Testing

Tests were conducted to record the ambient temperature, shotcrete temperature, as-batched and as-shot air contents, and initial and final set times. End beam tests were carried out to determine early-age compressive strength development.

The contractor shot one production test panel for every 50 $yd^3$ (38 $m^3$) of shotcrete placed, or one per day, whichever occurred more frequently. Cores were extracted from these test panels to determine:

- Compressive strength at 7, 28, and 56 days; and
- Boiled absorption and volume of permeable voids to ASTM C642 at 28 days.

The contractor performed bond pulloff testing to determine the shotcrete bond strength to the prepared concrete substrate. Bond strength testing was conducted after the shotcrete shot on the original prepared concrete substrate had cured for a minimum of 7 days. Bond strength tests were also performed to measure bond between shotcrete layers.

## COMPRESSIVE STRENGTH TEST RESULTS

### Wet-Mix Shotcrete

Compressive strength tested at 7 days ranged between 4470 psi and 6220 psi (30.8 and 42.9 MPa), and averaged 5180 psi (35.7 MPa) in Barrel A. Compressive strength tested at 28 days ranged between 7240 and 9500 psi (49.9 and 65.5 MPa), and averaged 8150 psi (56.2 MPa) in Barrel A. Refer to Table 1.

### Table 1: Compressive Strength of Shotcrete Cores

| Turbine Unit No. 2 Barrel A | | | | | |
|---|---|---|---|---|---|
| Compressive strength, MPa | | | | | |
| | | | Age, Days | | |
| | Panel No. | Date shot | 7 | 28 | 56 |
| Wet-mix | 1 | 24-Mar-17 | 33.0 | 58.4 | 64.2 |
| | 2 | 24-Mar-17 | 35.0 | 53.1 | 59.2 |
| | 3 | 24-Mar-17 | 31.9 | 50.2 | 58.9 |
| | 4 | 27-Mar-17 | 32.2 | 49.9 | 54.8 |
| | 5 | 29-Mar-17 | 34.1 | 57.2 | 62.9 |
| | 6 | 31-Mar-17 | 37.0 | 56.2 | 61.1 |
| | 7 | 24-Mar-17 | 39.7 | 60.6 | 60.4 |
| | 8 | 4-Apr-17 | 42.9 | 65.5 | 67.9 |
| | 9 | 6-Apr-17 | 33.8 | 55.9 | 55.6 |
| | 10 | 7-Apr-17 | 30.8 | 54.5 | 58.9 |
| | 11 | 10-Apr-17 | 41.4 | 61.2 | 65.2 |
| | 12 | 11-Apr-17 | 37.4 | 56.1 | 59.7 |
| | 13 | 19-Apr-17 | 35.5 | 52.4 | 54.0 |
| | Mean | | 35.7 | 56.2 | 60.2 |
| | Standard deviation | | 3.7 | 4.5 | 4.1 |
| | Specs | | — | Min 34.5 | — |
| Dry-mix | 14 | 24-Apr-17 | 38.5 | 49.5 | 51.0 |
| | 15 | 25-Apr-17 | 39.8 | 52.4 | 54.3 |
| | 16 | 26-Apr-17 | 38.9 | 58.1 | 59.6 |
| | 17 | 27-Apr-17 | 38.1 | 51.4 | 56.8 |
| | 18 | 28-Apr-17 | 38.9 | 52.5 | 54.6 |
| | 19 | 29-Apr-17 | 38.6 | 52.4 | 54.7 |
| | 20 | 3-May-17 | 43.6 | 56.0 | 59.0 |
| | 21 | 5-May-17 | 39.4 | 47.9 | 50.2 |
| | 22 | 6-May-17 | 42.4 | 53.3 | 56.3 |
| | 23 | 13-May-17 | 61.0 | 64.1 | 67.1 |
| | 24 | 19-May-17 | 52.8 | 62.1 | 63.8 |
| | 25 | 20-May-17 | 53.9 | 62.3 | 64.5 |
| | Mean | | 43.8 | 55.1 | 57.6 |
| | Standard deviation | | 7.70 | 5.32 | 5.33 |
| | Specs | | — | Min 34.5 | — |

| Turbine Unit No. 2 Barrel C | | | | | |
|---|---|---|---|---|---|
| Compressive strength, MPa | | | | | |
| | | | Age, Days | | |
| | Panel No. | Date shot | 7 | 28 | 56 |
| Wet-mix | 1 | 1-May-17 | 31.8 | 45.0 | 48.5 |
| | 2 | 2-May-17 | 23.3 | 43.8 | 47.9 |
| | 3 | 4-May-17 | 41.3 | 52.7 | 54.0 |
| | 4 | 8-May-17 | 39.4 | 54.5 | 57.3 |
| | 5 | 9-May-17 | 36.8 | 61.4 | 66.4 |
| | 6 | 10-May-17 | 34.9 | 56.4 | 58.9 |
| | 7 | 11-May-17 | 39.3 | 49.1 | 50.5 |
| | 8 | 11-May-17 | 34.8 | 50.8 | 51.9 |
| | 9 | 12-May-17 | 32.2 | 39.8 | 54.9 |
| | 10 | 15-May-17 | 32.0 | 36.0 | 52.9 |
| | 11 | 16-May-17 | 29.2 | 55.4 | 58.6 |
| | 12 | 17-May-17 | 44.9 | 55.7 | 65.3 |
| | 13 | 18-May-17 | 37.4 | 54.8 | 65.3 |
| | Mean | | 35.2 | 50.4 | 56.3 |
| | Standard deviation | | 5.6 | 7.3 | 6.2 |
| | Specs | | — | Min 34.5 | — |
| Dry-mix | 14 | 22-May-17 | 51.1 | 59.8 | 61.2 |
| | 15 | 23-May-17 | 44.3 | 66.1 | 69.8 |
| | 16 | 24-May-17 | 56.4 | 60.0 | 64.8 |
| | 17 | 25-May-17 | 51.5 | 59.6 | 68.7 |
| | 18 | 30-May-17 | 43.8 | 61.1 | 68.3 |
| | 19 | 31-May-17 | 41.7 | 60.6 | 61.5 |
| | 20 | 1-Jun-17 | 43.3 | 47.9 | 54.8 |
| | 21 | 2-Jun-17 | 38.1 | 52.4 | 64.6 |
| | Mean | | 46.3 | 58.4 | 64.2 |
| | Standard deviation | | 6.09 | 5.65 | 4.97 |
| | Specs | | — | Min 34.5 | — |

Note: 1 MPa = 145 psi

Compressive strength tested at 7 days ranged between 3380 and 6510 psi (23.3 and 44.9 MPa), and averaged 5110 psi (35.2 MPa) in Barrel C. Compressive strength tested at 28 days ranged between 5220 and 8910 psi (36 and 61.4 MPa), and averaged 7310 psi (50.4 MPa) in Barrel C. Refer to Table 1.

As shown in Table 1, the 28-day compressive strength test results well exceeded the specified minimum compressive strength requirement of 5000 psi at 28 days.

## Dry-Mix Shotcrete

Compressive strength tested at 7 days ranged between 5530 and 8850 psi (38.1 and 61.0 MPa), and averaged 6250 psi (43.8 MPa) in Barrel A. Compressive strength tested at 28 days ranged between 6950 and 9300 psi (47.9 and 64.1 MPa), and averaged 7990 psi (55.1 MPa) in Barrel A. Refer to Table 1.

Compressive strength tested at 7 days ranged between 5530 and 8180 psi (38.1 and 56.4 MPa), and averaged 6720 psi (46.3 MPa) in Barrel C. Compressive strength tested at 28 days ranged between 6950 and 9590 psi (47.9 and 66.1 MPa), and averaged 8470 psi (58.4 MPa) in Barrel C. Refer to Table 1.

As shown in Table 1, the 28-day compressive strength test results well exceeded the specified minimum compressive strength requirement of 5000 psi at 28 days.

## BOILED ABSORPTION AND VOLUME OF PERMEABLE VOIDS

### Wet-Mix Shotcrete

Boiled absorption tested at 28 days ranged between 6.4 and 10.0%, and averaged 7.6% in Barrel A. Volume of permeable voids tested at 28 days ranged between 14.2 and 21.9%, and averaged 17.0% in Barrel A. Refer to Table 2.

Boiled absorption tested at 28 days ranged between 4.6 and 8.7%, and averaged 7.6% in Barrel C. Volume of permeable voids tested at 28 days ranged between 10.2 and 19.3%, and averaged 17.1% in Barrel C. Refer to Table 2.

### Dry-Mix Shotcrete

Boiled absorption tested at 28 days ranged between 4.3 and 7.4%, and averaged 5.5% in Barrel A. Volume of permeable voids tested at 28 days ranged between 9.8 and 16.6%, and averaged 12.2% in Barrel A. Refer to Table 2.

Boiled absorption tested at 28 days ranged between 4.3 and 6.6%, and averaged 4.9% in Barrel C. Volume of permeable voids tested at 28 days ranged between 9.7 and 14.3%, and averaged 12.1% in Barrel C. Refer to Table 2.

While the USACE specification did not have a requirement to test the shotcrete to ASTM C642 for boiled absorption and

### Table 2: ASTM C642 Boiled Absorption and Volume of Permeable Voids Data

| Turbine Unit No. 2 Barrel A | | | | |
|---|---|---|---|---|
| | Panel No. | Date shot | Boiled absorption, % | Volume permeable voids, % |
| Wet-mix | 1 | 24-Mar-17 | 7.8 | 17.0 |
| | 2 | 24-Mar-17 | 8.6 | 19.0 |
| | 3 | 24-Mar-17 | 8.2 | 18.3 |
| | 4 | 27-Mar-17 | 6.9 | 15.5 |
| | 5 | 29-Mar-17 | 10.0 | 21.9 |
| | 6 | 31-Mar-17 | 7.9 | 17.9 |
| | 7 | 24-Mar-17 | 6.2 | 14.2 |
| | 8 | 4-Apr-17 | 7.2 | 16.3 |
| | 9 | 6-Apr-17 | 7.3 | 16.5 |
| | 10 | 7-Apr-17 | 7.4 | 16.7 |
| | 11 | 10-Apr-17 | 6.4 | 14.6 |
| | 12 | 11-Apr-17 | 6.9 | 15.6 |
| | 13 | 19-Apr-17 | 7.9 | 17.6 |
| | Mean | | 7.6 | 17.0 |
| | Standard deviation | | 1.0 | 2.0 |
| | ACI 506 | | Max 9.0 | Max 17.0 |
| Dry-mix | 14 | 24-Apr-17 | 5.4 | 11.9 |
| | 15 | 25-Apr-17 | 6.0 | 13.0 |
| | 16 | 26-Apr-17 | 4.7 | 10.6 |
| | 17 | 27-Apr-17 | 5.6 | 12.4 |
| | 18 | 28-Apr-17 | 6.3 | 13.7 |
| | 19 | 29-Apr-17 | 5.4 | 11.8 |
| | 20 | 3-May-17 | 4.9 | 11.0 |
| | 21 | 5-May-17 | 5.3 | 11.7 |
| | 22 | 6-May-17 | 7.4 | 16.6 |
| | 23 | 13-May-17 | 4.9 | 10.8 |
| | 24 | 19-May-17 | 4.3 | 9.8 |
| | 25 | 20-May-17 | 5.8 | 12.9 |
| | Mean | | 5.5 | 12.2 |
| | Standard deviation | | 0.81 | 1.79 |
| | ACI 506 | | Max 9.0 | Max 17.0 |

| Turbine Unit No. 2 Barrel C | | | | |
|---|---|---|---|---|
| | Panel No. | Date shot | Boiled absorption, % | Volume permeable voids, % |
| Wet-mix | 1 | 1-May-17 | 7.0 | 15.6 |
| | 2 | 2-May-17 | 8.7 | 18.8 |
| | 3 | 4-May-17 | 4.6 | 10.2 |
| | 4 | 8-May-17 | 7.8 | 17.8 |
| | 5 | 9-May-17 | 7.2 | 16.6 |
| | 6 | 10-May-17 | 8.1 | 18.1 |
| | 7 | 11-May-17 | 8.1 | 18.3 |
| | 8 | 11-May-17 | 8.6 | 19.3 |
| | 9 | 12-May-17 | 8.3 | 18.5 |
| | 10 | 15-May-17 | 8.2 | 18.3 |
| | 11 | 16-May-17 | 7.8 | 17.4 |
| | 12 | 17-May-17 | 7.4 | 16.7 |
| | 13 | 18-May-17 | 7.5 | 17.1 |
| | Mean | | 7.6 | 17.1 |
| | Standard deviation | | 1.1 | 2.3 |
| | ACI 506 | | Max 9.0 | Max 17.0 |
| Dry-mix | 14 | 22-May-17 | 5.2 | 12.7 |
| | 15 | 23-May-17 | 5.0 | 12.6 |
| | 16 | 24-May-17 | 5.1 | 12.7 |
| | 17 | 25-May-17 | 4.8 | 11.7 |
| | 18 | 30-May-17 | 4.3 | 9.7 |
| | 19 | 31-May-17 | 6.6 | 14.3 |
| | 20 | 1-Jun-17 | 4.9 | 10.9 |
| | 21 | 2-Jun-17 | 5.7 | 12.6 |
| | Mean | | 4.9 | 12.1 |
| | Standard deviation | | 0.38 | 1.39 |
| | ACI 506 | | Max 9.0 | Max 17.0 |

volume of permeable voids, it has been found to be a useful test to evaluate the inherent durability of concrete and shotcrete.[1] ACI 506R-05 states that "Typical Boiled Absorption values are 6-9%." All the wet-mix shotcrete test results (with one exception) are within this range and test results for the nonaccelerated dry-mix shotcrete are even lower, as shown in Table 2.

## BOND TESTING

Shotcrete bond strength to the prepared concrete substrate was tested after a minimum of 7 days in Barrel A. Bond strength tested at 9 days ranged between 129 and 174 psi (0.89 and 1.20 MPa), and averaged 152 psi (1.05 MPa) in Barrel A. Bond strength tested at 15 days ranged between 184 and 273 psi (1.27 and 1.88 MPa), and averaged 231 psi (1.59 MPa) in Barrel A.

Shotcrete bond strength to the prepared concrete substrate was tested after a minimum of 7 days in Barrel C. Bond strength tested at 9 days ranged between 151 and 244 psi (1.04 and 1.68 MPa), and averaged 194 psi (1.34 MPa) in Barrel C. Bond strength tested at 11 days ranged between 183 and 189 psi (1.26 and 1.30 MPa), and averaged 186 psi (1.28 MPa) in Barrel A.

As shown in Table 3, the bond strength test results exceeded the specified minimum shotcrete bond strength requirement of 100 psi.

## CONCLUSIONS

This article demonstrates that a successful execution of such challenging projects requires a rigorous design specification and comprehensive preconstruction mockup construction which includes the prequalification of the:

a. Shotcrete mixture design;
b. Shotcrete accelerator brand and dispensing system and calibrate the accelerator addition rate;
c. Shotcrete nozzlemen, shotcrete application, and finishing system; and

### Table 3: Bond Pull Off Testing Results

| Turbine Unit No. 2 Barrel A | | |
|---|---|---|
| Bond strength, MPa | | |
| | Age, Days | |
| Test No. | 9 | 15 |
| 1 | 1.20 | — |
| 2 | 0.89 | — |
| 3 | — | 1.88 |
| 4 | — | 1.69 |
| 5 | — | 1.27 |
| 6 | — | 1.52 |
| Mean | 1.05 | 1.59 |
| Standard deviation | 0.219 | 0.259 |
| Specs | Min 0.7 | |
| ACI 506 | Min 1.0 | |

| Turbine Unit No. 2 Barrel C | | |
|---|---|---|
| Bond strength, MPa | | |
| | Age, Days | |
| Test No. | 9 | 11 |
| 1 | 1.47 | — |
| 2 | 1.68 | — |
| 3 | 1.04 | — |
| 4 | 1.18 | — |
| 5 | — | 1.30 |
| 6 | — | 1.26 |
| Mean | 1.34 | 1.28 |
| Standard deviation | 0.288 | 0.028 |
| Specs | Min 0.7 | |
| ACI 506 | Min 1.0 | |

Note: 1 MPa = 145 psi

d. Shotcrete quality assurance monitoring, quality control inspection, and testing plan.

This project showcased that with proper materials, equipment, and placement techniques, a high-quality, accelerated, wet-mix, steel fiber-reinforced, silica fume shotcrete up to 6.5 ft thick overhead is achievable. The USACE approved the results of the mockup construction and authorized construction of the work in the draft tube.

There were logistical, access, and scaffolding challenges in the draft tube, but the shotcrete subcontractor successfully overcame these challenges and completed the reshaping of the draft tube to the satisfaction of the USACE. This is the first of three draft tubes to be reshaped on the Ice Harbour Lock and Dam and it is expected that the same products and processes will be used for reshaping the next two draft tubes.

## References

1. Zhang, L.; Morgan, D.R.; and Mindess S., "Comparative Evaluation of the Transport Properties of Shotcrete Compared to Cast-in-Place Concrete," *ACI Materials Journal*, V. 113, No. 3, May-June 2016, 373-384 pp.

### PROJECT TEAM FOR DESIGN AND CONSTRUCTION OF THE STRUCTURAL MODIFICATION OF THE DRAFT TUBE EXITS

*Owner and Design Engineer*
**United States Army Corps of Engineers**

*General Contractor*
**Voith Hydro**

*Shotcrete Subcontractor*
**PCiRoads, LLC**

*Wet-Mix Shotcrete Supplier*
**American Rock Products**

*Steel Fiber Supplier*
**FRC Industries**

*Dry-Mix Shotcrete Supplier*
**TCC Materials**

*Steel Fiber-Reinforced Accelerated Wet-Mix Shotcrete Mixture Design Development, Technical Submittal Reviews, Inspection and Monitoring of the Shotcrete Preconstruction Mockups, and Shotcrete Application in the Draft Tube*
**Wood Environment & Infrastructure Solutions**

*Accelerator Dosing Pump Calibration and Shotcrete Quality Testing for the Preconstruction Mockups and for the Draft Tube Application*
**LZhang Consulting and Testing**

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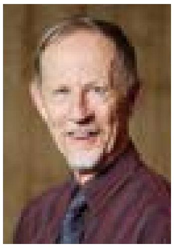

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# Tunnel Shotcrete Lining for Hydroelectric Projects

## British Columbia, Canada

*By Lihe (John) Zhang, Dudley R. (Rusty) Morgan, Serge Moalli, David Gagnon, and Danny Dugas*

In British Columbia (BC), Canada, the primary source of power supply is hydroelectricity. The BC government, through its Crown corporation, BC Hydro, has worked with private-sector companies to provide sustainable and renewable energy. As a result, private-sector companies are building hydroelectric projects throughout the province of BC. One such company, Innergex, built two hydroelectric projects: one in the Upper Lillooet area, about 150 miles (250 km) north of Vancouver and 50 miles (80 km) north of Whistler, and the other in the Big Silver area, which is about 150 miles east of Vancouver and 30 miles (50 km) north of Harrison Lake. All of these tunnels are in hard rock and have been constructed by the drill-and-blast method with rock bolts and fiber-reinforced shotcrete lining. At the start of the projects, dry-mix shotcrete was used based on the contractor's previous underground project experience. Soon after the start, wet-mix shotcrete was introduced as an alternative method. The contractor was impressed with wet-mix shotcrete's productivity and performance along with its major dust reduction and safety aspects. As a result, wet-mix was adopted as the primary shotcrete placement method. With increased productivity using wet-mix, the construction schedule was significantly reduced, resulting in substantial cost savings. Of note, dry-mix shotcrete continued to be used for special ground conditions. Specifically, dry-mix shotcrete was very useful in very wet conditions where the water could not be easily controlled using drainage pipes. Dry-mix shotcrete allowed the contractor to seal off the area while completing the installation of drainage pipes.

The wet-mix shotcrete was initially reinforced with wire mesh and applied by remote control robotic sprayer. Shortly after, the tunnel lining method was changed to use macrosynthetic fiber-reinforced wet-mix shotcrete. A silica-fume-modified shotcrete mixture was designed and then shot in a trial application. Test results met the project specification requirements for tunnel construction. Wet-mix macrosynthetic fiber-reinforced shotcrete placed between October 2014 and September 2015 used prebagged materials supplied from Vancouver and mixed with water on site. The contractor then set up a concrete batch plant on site and started producing shotcrete using local aggregates. The shotcrete mixture was qualified for use on the project by testing for compressive strength, boiled absorption, and volume of permeable voids to ASTM C642, and flexural toughness based on use of the round circularly loaded panel to ASTM C1550. The effect on shotcrete performance using different addition rates of alkali-free accelerator was tested in trial shooting. An addition rate of 6% alkali-free accelerator by mass of cement was selected.

Shotcrete nozzlemen were trained with a specially designed shotcrete training program. All shotcrete nozzlemen were qualified to shoot a basic Level I for shotcrete without reinforcing steel, and a more challenging Level II, for shotcrete with reinforcing steel or lattice girders. The construction quality control test results for all three tunnels from August 2014 to December 2016 demonstrated that the shotcrete quality consistently met the project specification requirements. The projects were completed on schedule because of productivity gains achieved from using wet-mix macrosynthetic fiber-reinforced shotcrete. The contractors used proper skills and techniques for application of wet-mix macrosynthetic fiber-reinforced shotcrete applied by robotic sprayers with zero safety incidents or accidents.

### INTRODUCTION

For both the Upper Lillooet and the Big Silver projects, the drill and blast tunneling method was used. Depending on the ground conditions, the tunnel construction progress varied. The Big Silver Hydro Power project involved a tunnel 1.1 miles (1.8 km) long. The ground condition is primarily hard rock, and construction of the tunnel was completed within 5 months. For the Upper Lillooet project, two tunnels were built at the same time: the Boulder Creek tunnel and the Upper Lillooet tunnel. Project tunneling work started in June 2014 and was completed by October 2016.

During the tunneling construction of the Big Silver and Upper Lillooet projects, shotcrete was used as the primary lining support, and also served as the final lining. The Boulder Creek D-shape tunnel had dimensions of 12 x 15 ft (3.6 x 4.5 m) and total length of 9593 ft (2924 m), and a total volume of 2047 $yd^3$ (1565 $m^3$) of wet-mix shotcrete and 820 $yd^3$ (627 $m^3$) of dry-mix shotcrete were applied. The Upper Lillooet D-shaped tunnel had dimensions of 20 x 18 ft (6 x 5.5 m) and total length of 8399 ft (2560 m), and a total of 11,254 $yd^3$ (8604 $m^3$) of wet-mix shotcrete and 362 $yd^3$ (277 $m^3$) of dry-mix shotcrete were applied.

*Fig. 1: Upstream tunnel portal for Upper Lillooet Hydroelectric project*

Rock anchors and shotcrete were used as the primary ground support. This article focuses on technical aspects of the shotcrete used in the Upper Lillooet tunnel project.

## SHOTCRETE SOLUTION

The project contractor, tunnel design engineer, and consulting engineer worked together to develop the shotcrete specification. Performance characteristics included:

- Minimum compressive strength: 1500 psi (10 MPa) at 3 days, 2900 psi (20 MPa) at 7 days, and 5100 psi (35 MPa) at 28 days;
- Boiled absorption to ASTM C642: maximum 8% at 7 days;
- Volume of permeable voids to ASTM C642: maximum 17% at 7 days;
- Flexural toughness based on ASTM C1550 Round Panel Test Method: 350 Joules at 7 days; and
- Shotcrete nozzlemen: nozzlemen must be prequalified to shoot the shotcrete.

## SHOTCRETE MIXTURE

Dry-mix shotcrete was used in the tunnel at the beginning of the project. A total of three trial mixtures were shot and tested. The mixture with moderate early-age strength development was selected for production.

As the project proceeded, the contractor and consulting engineer entertained the idea of using the wet-mix shotcrete process. This was introduced to the project as a new approach because the contractor's project engineer and nozzlemen did not have much wet-mix shotcrete experience. The wet-mix shotcrete mixture design proposed for use is shown in Table 1.

### Table 1: Wet-Mix Shotcrete Mixture Design

| Material | Mass per m³ (kg) |
|---|---|
| Cement Type GU | 410 |
| Silica fume | 40 |
| Coarse aggregate (10 to 5 mm, saturated surface dry (SSD)) | 430 |
| Fine aggregate (SSD) | 1320 |
| Estimated water, L | 185 |
| High-range water-reducing admixture,* L | 1.00 |
| Macrosynthetic fiber | 7.0 |
| Hydration control admixture,† L | 1.00 |
| Air content (4.5 to 6.5%) | 3.5 |
| Total | 2394 |

*Add high-range water-reducing admixture at dosage required to achieve the maximum allowable water-cementitious materials ratio (*w/cm*) ratio and required slump.

†Add hydration-controlling admixture if required to provide extended workability.

Note: Add alkali-free accelerator at nozzle at dosages to meet set time and early-age strength development requirement.

| Performance Requirements | |
|---|---|
| Minimum compressive strength | 10 MPa at 3 days, 15 MPa at 7 days, 35 MPa at 28 days |
| Boiled absorption | Maximum 8% |
| Volume of permeable voids | Maximum 17% |
| Slump | 170±20 mm before accelerator addition |
| Maximum *w/cm* | 0.45 |
| Air content | 2.5 to 5.5% by volume |
| Maximum size of aggregate | 10 mm |

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

a)

b)

Fig. 2(a) and (b): On-site shotcrete batching; note that the batch plant and concrete truck were insulated for the cold weather

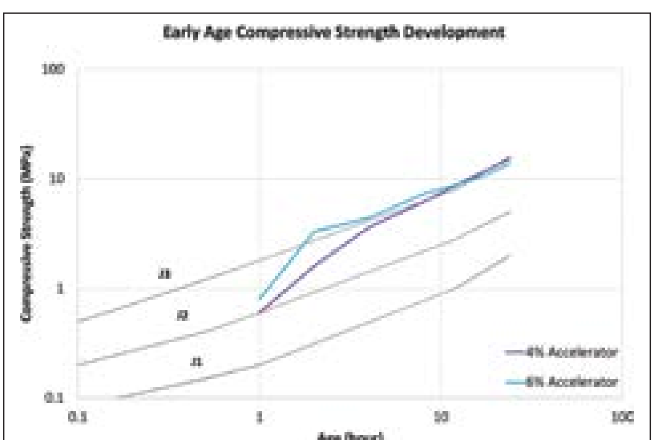


Fig. 3: Early-age compressive strength development

## Table 2: Compressive Strength, MPa

| Accelerator dosage (by mass of cement %) | 3 days | 7 days | 28 days |
|---|---|---|---|
| 4% | 33.5 | 44.2 | 48.7 |
| 6% | 23.3 | 30.2 | 39.3 |

Note: 1 MPa = 145 psi

## PRECONSTRUCTION MOCKUP TRIAL SHOOT AND MIXTURE QUALIFICATION

Prior to the shotcrete application in the tunnel, the wet-mix shotcrete mixture was prequalified by a trial shoot in the field. Materials and equipment to be used for the tunnel construction were used for the prequalification shooting. An experienced nozzleman conducted the trial shoot. The trial shoot evaluated the batching, mixing, delivery, pumping, and placement characteristics of the shotcrete. Chemical admixtures were added and adjusted as needed. High-range water-reducing admixture was added to adjust the workability (slump) and hydration control admixture was added to control the slump retention time (also called *pot life* in the field). Alkali-free accelerator was added at the nozzle at two dosages to evaluate setting time and early-age compressive strength development. At a dosage rate of 0.2 gal./yd$^3$ (1 L/m$^3$), the hydration control admixture extended the slump retention time by about 1 to 1.5 hours. The slump retention time is also affected by the ambient temperature and radiant heat effects from the sun.

The early age (up to 24 hours) compressive strength data is plotted in Fig. 3. It shows that the shotcrete mixture with both 4 and 6% accelerator achieved the Austrian Guideline for Sprayed Concrete J2 level. An accelerator addition rate of 6% by mass of cement was selected for the shotcrete construction.

## COMPRESSIVE STRENGTH

During the trial shoot, test panels were shot, and cores were extracted for compressive strength testing at 3, 7, and 28 days. Compressive strength test results are shown in Table 2. Table 2 shows the compressive strength for shotcrete with 4% accelerator is higher than the shotcrete with 6% accelerator at 3, 7, and 28 days. This shows that although the accelerator increases the early-age strength during the first 24 hours, the compressive strength for shotcrete with a higher accelerator dosage results in lower strength at 3, 7, and 28 days. These test results met the specified 35 MPa at 28 days requirement.

The boiled absorption (BA) and volume of permeable voids (VPV) test results (Table 3) are dependent on the accelerator dosage, nozzleman shooting technique,

### Table 3: Boiled Absorption (BA) and Volume of Permeable Voids (VPV)

| Volume of permeable voids (VPV) | Boiled absorption, % | Suggested quality indicator |
|---|---|---|
| <14 | <6 | Excellent |
| 14 to 17 | 6 to 8 | Good |
| 17 to 19 | 8 to 9 | Fair |
| >19 | >9 | Marginal |

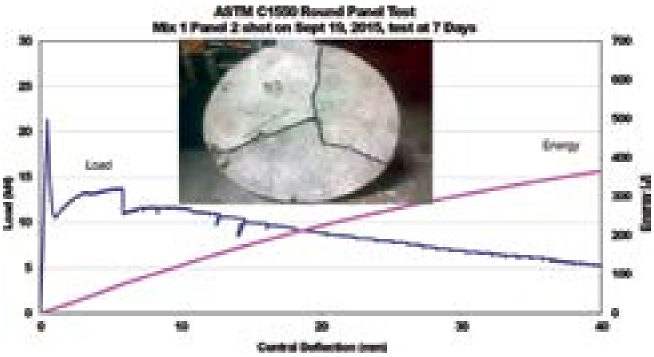

*Fig. 4: Flexural toughness test result to ASTM C1550, round determinate panel test*

*Fig. 5: Putzmeister SPM 4210 robotic sprayer*

overspray and rebound, and other factors. The BA and VPV values for 4% accelerator were 5% and 11%, respectively, and the BA and VPV values for 6% accelerator were 7% and 17%, respectively. The specified maximum allowable BA and VPV values were 8% and 17%, respectively. This is considered to be in the Good category in the quality indicator.[1]

## FLEXURAL TOUGHNESS

Macrosynthetic fiber was used for the wet-mix shotcrete. Flexural toughness was tested using the ASTM C1550 round panel test method. Test results for three round panels averaged 372 Joules. Figure 4 shows a typical load-versus-deflection curve for the round panel test at 7 days.

## SHOTCRETE EQUIPMENT

Wet-mix shotcrete was applied using a robotic sprayer rig provided by Putzmeister. The sprayer model was SPM 4210. This model operates electrically and includes an electric air compressor in the chassis. This robot has a variable pump flow between 5 and 26 $yd^3$/h (4 and 20 $m^3$/h). The required concrete pump flow is adjusted by the nozzleman using the robotic sprayer computer. Once calibrated, the accelerator dosage is adjusted automatically by the computer according to the concrete pump flow.

Dry-mix shotcrete was applied by hand nozzling application using an Aliva 252 dry-mix shotcrete machine.

## NOZZLEMAN QUALIFICATION

The tunnel shotcrete lining required shotcrete application with a remote-controlled robotic sprayer. This sprayer provided a higher production rate and increased safety for the nozzleman. Operation of the robotic sprayer for placing quality shotcrete requires qualified nozzlemen. The project-specific shotcrete nozzleman qualification program was


*Fig. 6: Robotic sprayer applied wet-mix shotcrete at the tunnel heading*


*Fig. 7: Hand-nozzling qualification for dry-mix shotcrete*

custom-designed to give the nozzlemen shotcrete knowledge including:

1. Understanding the basics of concrete and shotcrete. This includes how cement hydrates and shotcrete temperature effects on the required dosage of accelerator and other chemicals;
2. Workability, pumpability, and shootability. Nozzlemen should understand that the slump (or consistency of the shotcrete mixture) is critical for transport, pumping, and shooting. Overhead application and vertical application pose different challenges for shotcrete application;
3. Preparation of the substrate, including cleanliness and roughness (surface moisture condition to achieve optimized bond);
4. Calibration of accelerator dosing pump;
5. Methods to build up overhead and vertical thickness properly;
6. Proper control of nozzle angle, distance, and shooting pattern to optimize shotcrete consolidation and minimize rebound and overspray;
7. Proper procedures for multilayer shotcrete application; and
8. If shotcrete falls off, from either overhead or vertical surfaces, nozzlemen should be able to immediately determine what is being done wrong and take the required corrective actions.

Two levels of shotcrete nozzlemen qualification were designed and implemented as follows:

**Classroom seminar:** A half-day classroom education session specifically targeted to the underground shotcrete application.

**Level I Qualification:** This was the basic level of qualification. Each nozzleman was required to shoot one vertical test panel and overhead test panel without reinforcement using the concrete mixtures and equipment on the project. This level was designed to qualify the nozzleman's basic shooting skills. The nozzleman was required to demonstrate proper use of accelerator; proper judgement of shotcrete slump; understanding of set properties; and safe operation procedures, including how to handle blockages. Cores were extracted for compressive strength testing at 3, 7, and 28 days and BA and VPV testing at 7 days.

**Level II Qualification:** Each nozzleman was required to operate the robotic sprayer to shoot one vertical mockup test panel and one overhead mockup test panel with reinforcement. Cores were extracted for visual inspection of the quality of shotcrete encapsulation of reinforcement. The reinforcement selected in the project qualification program was a section of lattice girder.

During the Level I and Level II qualification shooting, both fiber-reinforced wet-mix shotcrete (FRS) and dry-mix shotcrete were used.

Figure 8 shows nozzleman qualification shooting with FRS for a section of lattice girder. Note that the robotic sprayer shot macrosynthetic FRS with 6% accelerator. Cores show shotcrete properly consolidated around the reinforcement.

With more than 20 nozzlemen candidates on the project, the qualification program proved quite challenging. These nozzleman candidates came from different sectors of the shotcrete industry and most of them had more than 5 years of shotcrete experience. Some of them had been certified for hand nozzling by the American Concrete Institute (ACI). A total of 16 nozzlemen were qualified for both Level I and Level II qualifications and they worked in shifts on the projects. The rigorous shotcrete nozzleman qualification program ensured that quality shotcrete was placed during the construction stage. No shotcrete-related accidents or incidents occurred during the projects.

## SHOTCRETE QC TESTING AND STRENGTH TEST RESULTS

Shotcrete test panels were shot for every day of shotcrete application or every 65 $yd^3$ (50 $m^3$), whichever came first. Cores were extracted for testing at 3, 7, and 28 days for compressive strength. If the test panel core strength did not meet the specified strength, cores were extracted from the in-place tunnel lining to verify the compressive strength. If the in-place shotcrete strength did not meet the specified


*Fig. 8(a), (b), (c), and (d): Nozzleman qualification shooting and core evaluation*

### Table 4: Compressive Strength of Shotcrete During Construction Stage

| Year | No. of cores | Average compressive strength, MPa | Standard deviation | % of Design strength |
|---|---|---|---|---|
| 3 days | | | | |
| 2014 | 45 | 24.2 | 5.3 | 242 |
| 2015 | 16 | 32.2 | 9.8 | 322 |
| 2016 | 19 | 21.2 | 3.8 | 212 |
| Average | 80 | 24.9 | 7.2 | 249 |
| 7 days | | | | |
| 2014 | 68 | 30.5 | 4.7 | 203 |
| 2015 | 19 | 31.7 | 7.1 | 211 |
| 2016 | 105 | 31.2 | 5.7 | 208 |
| Average | 192 | 31.0 | 5.5 | 207 |
| 28 days | | | | |
| 2014 | 70 | 40.2 | 6.7 | 115 |
| 2015 | 19 | 44.5 | 6.8 | 127 |
| 2016 | 107 | 48.9 | 6.8 | 140 |
| Average | 196 | 45.2 | 7.9 | 129 |

Note: 1 MPa = 145 psi




strength, then the shotcrete was considered deficient and would be required to be removed and replaced. During the project construction stage, some quality test panels did not meet the specified compressive strength. Cores were extracted from the in-place shotcrete lining and tested. They all met the specified compressive strength requirements so no removal and replacement was required.

Table 4 summarizes the shotcrete core compressive strength test results from the Upper Lillooet project during the project stage. Compressive strength is, on average, 3610 psi (24.9 MPa) at 3 days, 4500 psi (31.0 MPa) at 7 days, and 6560 psi (45.2 MPa) at 28 days. This readily satisfied the specified minimum compressive strength requirements.

## Conclusions

The projects started using the dry-mix shotcrete application process exclusively, but shortly switched to using wet-mix shotcrete as the primary process. Wet-mix shotcrete provided major advantages in the production rate and allowed the project to meet the rapid construction schedule required for tunneling advancement.

A properly designed preconstruction trial shooting program qualified the shotcrete mixture, equipment, nozzlemen, and the shotcrete production system. The rigorous shotcrete nozzleman qualification program ensured the installation of quality shotcrete during construction. No shotcrete-related accidents or incidents occurred.

In summary, the use of wet-mix macrosynthetic fiber-reinforced shotcrete applied by remotely controlled nozzle equipment proved to be an effective and economical means of tunnel lining. It provided safety and productivity in tunnel advancement.

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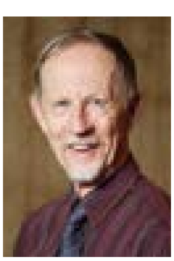

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# Spraying Shotcrete Overhead in Underground Applications

## INTRODUCTION

### General

In underground applications, spraying shotcrete overhead is a standard and daily operation but successful application is challenging. Shotcrete placement propels concrete at high velocity against the overhead surface and the dynamic energy compacts the concrete in place. However, because the plastic shotcrete has no immediate strength, its own weight wants to pull it down. Depending on its thickness, the weight of the shotcrete layer can be significant. The density of plastic shotcrete is in the order of 150 $lb/ft^3$ (2400 $kg/m^3$). One inch of a 1 $ft^2$ area weighs around 12 lb (5.5 kg). Each additional inch of thickness adds an additional 12 lb (5.5 kg). The weight of a single layer or multiple layers of shotcrete can be enough to pull the shotcrete down and cause local or large-scale fallouts, which may pose a significant safety hazard. In addition, improper application of overhead shotcrete and other circumstances can lead to delamination and voids in the installed shotcrete.

This position paper discusses the basic elements of the adhesion and cohesion of overhead shotcrete, proper application techniques, and a discussion about so-called "re-entry criteria" under freshly installed shotcrete. The position paper also provides recommendations for contractors and owners from ASA's perspective on not only how to properly apply shotcrete, but also on how to specify and inspect overhead shotcrete in underground projects and summarizes the topic in a conclusion.

### Adhesion and Cohesion

The phase immediately after application, when the shotcrete has not gained any significant strength prior to the initial set, is referred to as "plastic shotcrete." What is holding the plastic shotcrete in place until it gains strength? During the plastic shotcrete phase, the adhesion of the plastic material to the ground surface in combination with the cohesion of the plastic shotcrete material to itself are the forces acting against the self-weight of the plastic shotcrete. Because the chemical reaction of the cement in the mixture is still in progress and has not yet created significant strength, the plastic shotcrete sticks overhead only if the conditions for adhesion and cohesion are right.

To achieve proper adhesion to the substrate, for example, for initial tunnel linings or for shotcrete applied against an existing concrete surface, the receiving surface must be properly conditioned. If the substrate surface is too dry, water can be sucked out of the shotcrete mixture, reducing the adhesive bonding to the substrate. This can lead to a failure in adhesion. Therefore, the surface should have a so-called "saturated-surface-dry (SSD)" condition, which neither sucks water out of the mixture nor adds excess water at the bond interface.

On the other hand, if the surface is too wet, for example, due to running water or fresh washing down of the surface with water, the adhesion of the plastic overhead shotcrete is also diminished. Effectively, a thin water layer builds up between the substrate and the shotcrete and the adhesion is too small to act against the plastic shotcrete's weight and fails, creating shotcrete fallouts or delaminations and voids.

Another type of adhesion failure appears if the shotcrete is not applied directly onto a properly prepared bearing substrate, but on a thin layer of dust, debris, or overspray covering it. The thin layer prevents adhesion of the shotcrete to the substrate. It is essential that the surface be cleaned prior to receiving any fresh shotcrete.

Cohesion failure does not appear at the interface of two different materials but within the substrate or shotcrete material. There are two scenarios for a cohesion failure creating shotcrete fallouts.

Cohesion failure in the plastic shotcrete can either appear if the mixture's consistency is too wet or too dry. Slump is a generally good indicator of consistency, but it is not the only factor, especially if plasticizers and water-reducing admixtures are used to control consistency.

Cohesion failure can also appear in the substrate itself. This is a known phenomenon, for example, in soft ground tunneling for cohesionless sands, where the bonding fails within the sand due to the added weight of the shotcrete. Similar effects can also be observed in rock tunneling, for example, in highly fractured rock or fault zones. Therefore, the geotechnical conditions must be considered too when evaluating shotcrete fallouts. In addition, the geotechnical parameters are not proactively controllable. Rather, the shotcrete applicator must recognize and react to changes in geotechnical conditions as they appear.

### Interlocking

If shotcrete is sprayed overhead on an ideal macroscopically and microscopically smooth surface, the only resisting force acting against the weight of the material is provided by adhesion and cohesion. However, this assumption is unrealistic in underground projects, where the substrate is neither macroscopically nor microscopically homogeneous and horizontal. Typically, a ground surface is irregular, blocky, or porous and the shotcrete interlocks mechanically with smaller and larger niches and pores of the rock or ground surface, allowing the shotcrete material to fill and bridge over these irregularities. The use of this interlocking effect is one of the major aspects controlling the shotcrete bond when spraying in mining or tunnel applications and experienced underground nozzlemen take advantage of "reading the rock."

Interlocking also appears in a similar manner with man-made "irregularities" such as lattice girders, spider plates on rock bolts, or reinforcement. In addition, these man-made structural elements are typically anchored into the ground, allowing relatively large forces to be transferred into the ground via these anchor points and so expediting the shotcrete application process by not solely depending on adhesion and cohesion.

## PROPER APPLICATION OF SHOTCRETE OVERHEAD

### Mixture Proportion and Slump

For overhead shotcrete application, the wet shotcrete must have sufficient "stickiness" to provide the required adhesion and cohesion.

In general, mixtures with a higher fines content (for example, due to the addition of silica fume or similar materials) are advantageous for overhead applications, because the fine material increases cohesion and adhesion of the freshly applied shotcrete.

In addition, the use of accelerator improves the needed application properties, because the initial set of the shotcrete starts earlier and replaces the sole reliance on adhesion and cohesion of the plastic shotcrete to prevent fallouts. However, too much accelerator can be detrimental, because if the material sets up too quickly, it can adversely affect proper compaction of the plastic shotcrete, effectively reducing the adhesion to the substrate and cohesion of the plastic shotcrete.

The slump needs to be in the right range and should not be too high or too low. Higher slumps are necessary if the material must be pumped over longer distances. Higher slumps also are needed to help uniformly disperse the accelerator added at the nozzle and therefore enhance the effect of fast set and quick development of early-age compressive strength in the shotcrete. However, if the slump is too high, such as 10 in. (250 mm) and above, the mixture could segregate and cause problems during pumping and shooting. Therefore, the slump is typically between 6 and 8 in. (150 and 200 mm) for most underground applications when using accelerator.

High-range water-reducing admixtures, hydration control admixtures, and other admixtures are frequently used to make the mixture more pumpable and shootable to meet the operational challenges of the project. Effects of these admixtures and accelerators will depend on the mixture design, environmental conditions, and other factors. The required dosages of these admixtures and accelerators should be determined by preconstruction laboratory and field testing.

### Surface Preparation

Before the application of shotcrete, the receiving surface must be free of loose debris and dust. Loose rock should be scaled and brought to SSD conditions. If shotcrete is installed on a previously shotcreted surface, the older shotcrete also must have SSD conditions. If the surface is older, a thorough cleaning may be required to remove dust and any soot from diesel engines.

Dripping or running water needs to be channeled off and controlled before and during shotcrete placement. If groundwater runs out of joints or pores that is sealed off by shotcrete, the increasing water pressure acts from the extrados (area facing the rock or ground) on the lining in addition to the shotcrete weight and increases the risks for shotcrete fallouts. The buildup of water pressure needs to be prevented by water control measures such as drainage mats, weep pipes or holes, or similar measures.

### Thickness of Each Pass

As compared to vertically applied shotcrete, the thickness of each pass in overhead shotcrete application is much more critical. To avoid too much weight per pass, the overhead shotcrete is typically applied in thin layers of around 2 to 4 in. (50 to 100 mm) thickness per pass, depending on the mixture design and application method (wet- or dry-mix shotcrete). Thicker passes up to 6 in. (150 mm) are possible, but acceptability should be verified on a mockup for each nozzleman under site-specific conditions. After the shotcrete of the previous layer starts to set and gains initial strength, additional thin layers may be applied in subsequent passes. The total thickness installed per shift, however, should typically not exceed about 12 in. (300 mm).

To maintain sufficient cohesion between these passes, the previous layer should always have proper SSD conditions and be prepared as outlined previously. The typical rough, as-applied shotcrete surface provides additional interlocking between the layers and is therefore also advantageous. This should be taken into consideration during the spraying of subsequent layers and when planning surface finishing.

## Anchors, Lattice Girders, and Reinforcement

If spider plates are used or reinforcement is tied to anchors, building the shotcrete up around the anchor points is the first step during shotcrete installation. From there, thin shotcrete layers bridging the gaps between the anchor points should be created. After this shotcrete material has initially set and starts developing strength, additional thin layers may be applied in following passes. If the area is large enough, the additional passes may follow without interrupting the shooting process by simply varying the locations of shotcrete installation within the section, allowing freshly shot areas time to set before additional shotcrete is applied in the same area again.

If lattice girders are used, the girders should be embedded first from the bottom up, followed by closing the gap between the girders, in several passes as needed. Shooting from multiple angles and working the shotcrete like a key way from the bottom to top, always focusing on shooting into the previous layer, is essential. Lattice girders pose a challenge for proper encapsulation with shotcrete. Proper embedment of lattice girders requires the nozzleman and air lance operator to frequently move during shooting. Shooting from multiple angles and using a series of thin placements are key elements to good shotcrete encapsulation of lattice girders.

Reinforcement must be rigid. In addition, the reinforcement must be tied sufficiently to the bearing members such as the lattice girders or anchors, because these supporting members must carry the weight of the reinforcing bars plus the weight of the wet shotcrete. If the reinforcement sags or is loose, it will vibrate and cause voids around the reinforcement and potentially lead to shotcrete fallout.

## Waterproofing Membranes

Installation of overhead shotcrete on waterproofing membranes presents extra challenges and is covered in a separate ASA position paper.[1] Too much sagging or spanning of the membrane between the fixation points must be avoided. Different than form-and-pour concrete, where the liquid pressure of the poured concrete pushes and holds the membrane against the substrate, shotcrete does not provide any significant pressure against the membrane immediately after the shotcrete has been placed. If the membrane sags too much or is loose, the impact energy of the shotcrete will not push and hold the waterproofing against the substrate. If the membrane is not properly secured and loosely spans between the anchors, it may vibrate during the shooting, preventing the plastic shotcrete from adhering. This can cause fallouts, or result in defective shotcrete that may need massive grouting on the extrados of the shotcrete lining. Therefore, extensive inspection and quality control prior to the shotcrete application are required to assure the waterproofing membrane is installed and secured tightly to the substrate. This tight installation must be provided either by a sufficiently tight anchor spacing, chairs, and/or distancers from lattice girders and reinforcement actively pushing the membrane against the substrate.

In addition, waterproofing admixtures added integrally to the applied shotcrete are being used in some areas and may prevent problems associated with the use of classic waterproofing membranes. Another option is the use of spray-applied waterproofing membranes. The use of spray-applied waterproofing membranes is relatively new in North America but has been used on many underground projects around the world. A discussion of the advantages and challenges of spray-applied waterproofing membranes is, however, beyond the scope of this document.

## Overhead Shotcreting Procedures and Techniques

Due to the technical challenges and potential safety hazards, overhead shotcrete should only be applied by qualified shotcrete nozzlemen. The nozzlemen must be properly trained, experienced, and certified as ACI Certified Nozzleman for overhead application of wet- or dry-mix shotcrete. ACI Certified Nozzlemen must shoot overhead panels during the certification process and provide documentation of a minimum of 500 qualifying shotcreting hours experience prior to taking the ACI shotcrete certification exams.

However, it should be noted that the ACI overhead shotcrete nozzleman certification is the minimum requirement. The shotcrete nozzleman must also attend and pass project specific preconstruction qualification processes, which typically involve mockup shooting with the project-specific mixtures, equipment, procedures, and construction methodology. There could also be a two- or multiple-tier qualification process involving a basic level, project-specific level, and an additional level depending on the complexity of the project. The contractor and the engineers should develop a proper but rigorous project specific qualification program to qualify the shotcrete nozzlemen properly for their specific project.

To ensure proper preparation and inspection of the substrate and sufficiently close proximity of the shotcrete nozzle to the substrate, either scaffolds or manlifts are required in taller cross sections. If no surface finish is needed (for example, for a shotcrete initial lining), a manlift typically provides sufficient access and flexibility for manually applied shotcrete. A scaffold is typically needed when a more work-intense finish such as a rubber float or steel trowel or stamped or carved finish is required. A shotcrete robot or shotcrete nozzle manipulator is a typical alternative to a manlift if large volumes of shotcrete are required to be sprayed.[2] In addition, robots and manipulators also allow the nozzleman to remotely control the machine and to stay out of the potential fallout zone for the freshly applied shotcrete.

Underground applications of shotcrete often present difficult access for equipment and the steel pipe and/or rubber hoses. Special attention and planning are required to assure the safe and efficient movement of the equipment. Good air flow is required and the delivery lines should be placed out of the way in access roads.

A key element for propelling shotcrete material overhead at a sufficient impacting velocity is the air flow. Air pressure and flow losses due to wear and other uses of air must be considered. It is therefore important that sufficient air flow is received and maintained at the nozzle.

Generally, a higher amount of rebound is to be expected when applying shotcrete overhead versus vertical. However, the amount of rebound varies greatly and is dependent on numerous factors, especially the experience and skill of the nozzleman and his team.

## RE-ENTRY CRITERIA

Shotcrete fallouts from freshly applied overhead shotcrete pose a potential safety hazard. The occurrence of fallout is hard to predict, especially in underground conditions, where multiple factors can cause the fallout. Therefore, no one should stand, work, or move under freshly installed overhead shotcrete. The entire team should be trained and aware of the fallout hazard. Safety barriers or tapes should be installed.

Early-age compressive strength development is often used as an indicator of when to allow the re-entry into the previously restricted area under freshly applied shotcrete. The so-called “re-entry criteria” is based on the early strength, either tested in the field or a time period based on a previously tested early strength development graph. When a time period is used, it should be understood that the early-age strength development is also dependent on materials supply and environmental and operational conditions. Therefore, the early strength development and time to reach specific early-age strength under project conditions may vary from the conditions which prevailed during the preconstruction tests. Therefore, it is generally preferred to develop re-entry criteria based on actual early-age strength development, rather than a predetermined time period. However, it is emphasized that neither a strength- nor a time-based re-entry criterion provides a guarantee against fallouts because fallouts are influenced by a multitude of factors, as discussed previously.

The early strength development of the shotcrete should, therefore, be tested in preconstruction tests and/or mock-ups mimicking the project conditions. If factors such as shotcrete and ambient temperature, mixture design, equipment, and accelerator dosage vary, then these tests should be repeated to gather a better understanding of their influence on the early strength development.

There are testing methods available to monitor the initial set and strength development of shotcrete, but these do not test the amount of adhesion and cohesion of the plastic shotcrete. Adhesion and cohesion cannot be measured in a practical and safe manner in the field.

The initial and final set are defined as a degree of stiffening of a cementitious mixture based on empirical values to resist the penetration of a weighted test device.[3] Both the initial set and the final set are used to determine the state of the chemical reaction of the cementitious materials with the water and the accelerator, but not strength development.

Because the early-age compressive strength is typically considered to develop after the final set, the initial set and final set are used as indicators that the early age compressive strength will develop accordingly. Typical values for an early compressive strength-based re-entry criteria range between 150 to 500 psi (1 to 3.5 MPa) and are typically measured with a penetrometer or end-beam tester. However, a re-entry criteria for the general public (for example, in a rehabilitation project) should be significantly higher.

The accelerator dosage is defined as a percentage by mass of cement (not the cementitious materials, as in the water-cementitious materials ratio) in the shotcrete mixtures. Accelerator use and dosage have a very large impact on the rate of early-age strength development and with it, the re-entry criteria. The accelerator dosage is based on the amount of cement in the concrete and the amount of accelerator pumped per time unit. To maintain a constant accelerator dosage, the accelerator dosing pump must, therefore, be properly calibrated relative to the pumping rate of the concrete pump and closely controlled during shotcrete application to ensure that the planned accelerator dosage is achieved. If the concrete pumping rate is changed, the accelerator pumping rate needs to be adjusted accordingly to maintain the same accelerator dosage. Sophisticated equipment, including synchronized accelerator dosing pumps and concrete pumps, automates these adjustments and reduces the potential for over or under dosing accelerator and are therefore the best system to achieve consistently high quality while maintaining flexibility in the concrete pump rate. It should be noted that in an intermittent wet-mix pump, the flow (and pressure) of concrete can oppose the flow of accelerator (and air), resulting in layers of accelerator between pump strokes. It also means that the flow of accelerator can be higher when there is no concrete going through the air ring and nozzle.

## RECOMMENDATIONS FOR THE CONTRACTOR

The contractor is in charge of the project's safe working conditions and the quality of the placed shotcrete. It is therefore recommended that the contractor follows the guidelines provided by ACI 506 and the recommendations provided herein with regard to proper surface preparation, maximum thickness in each pass and shift, and quality control of the condition of the receiving surface.[4-6] The shotcrete application work should be conducted by ACI certified shotcrete nozzlemen, only.

Preconstruction testing and mockups are essential to test the mixture design, strength development, equipment operation, and setup, in particular the accelerator dosing pump calibration, and project conditions. If the tests show inadequate results, the process must be optimized and the tests should be repeated. The tests should be seen as a beneficial tool to avoid safety hazards and rework during execution and not simply a contractual obligation.

## RECOMMENDATIONS FOR THE OWNER

The owner and the designer should be aware of the challenges and restrictions for overhead shotcrete installation and should specify the project accordingly. It is strongly recommended that the specification follows the ACI 506 guidelines and involve personnel familiar and experienced with the application of shotcrete in the underground environment.[4-6]

Requirements recommended herein should be specified. Preconstruction testing and mockups are highly recommended and provide an efficient tool to optimize the system before applying shotcrete at the project and are money well spent.

The owner's inspection team should ensure the shotcrete operation follows the specified requirements, but should also understand the reasons behind the specified properties. Proper surface preparation, especially if the surface preparation is provided by others, is a key element.

## CONCLUSIONS

Installation of overhead shotcrete in underground applications is a challenge and requires special experience and skills to be successful. This position paper discussed the basics of overhead shotcrete installation and provides recommendations for dos and don'ts along with guidance for the development of safe re-entry criteria under shotcrete applied overhead in an underground setting.

Overhead shotcrete can be executed safely and with high quality, if the process parameters defined in this position paper are consistently and correctly executed.

### Acknowledgments

This position paper was developed by a task group of the American Shotcrete Association's Underground Committee by Frank E. Townsend, Axel G. Nitschke, and Lihe John Zhang. The position paper was reviewed by the following voting members of the Underground Committee: Dudley Rusty Morgan, Kristian Loevlie, Marcus H. von der Hofen, Nicholas Mitchell, Raymond Schallom, Roberto J. Guardia, William G. Allen, William Geers, and William T. Drakeley.

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Visit **http://www.shotcrete.org/pages/products-services/shotcrete-resources.htm.**

# Norick State Fair Arena Structural Repairs

## Oklahoma State Fair, Inc., Oklahoma City, OK

*By Dean Brunken*

Norick State Fair Arena is a multipurpose arena located on the grounds of the Oklahoma State Fair in Oklahoma City, OK. Construction on the arena was completed in 1965. The structure is elliptically shaped, 70 ft (21 m) high, 402 ft (123 m) long, and 318 ft (97 m) wide. The arena exterior was constructed with 42 monumental concrete columns that support a massive concrete ring beam. The ring beam anchors a unique and innovative cable net and precast concrete panel roof system that was designed by T.Y. Lin and Associates at a time when the technology for the design and construction of large cable net structures was in its infancy. The arena has had two major improvement projects that included repositioning and expanding the entrance, adding a 28,000 ft$^2$ (2600 m$^2$) exhibit hall, adding an additional handicap ramp, new arena lighting, and a new four-sided scoreboard with four color video screens and sound system.

The arena hosted the National Finals Rodeo from 1965 until 1978 and for over 40 years has hosted the Oklahoma State High School Basketball Championships. For those games, the arena is referred to as “The Big House.”

*Fig. 1: Cracking in monumental concrete column*

## PROBLEMS THAT PROMPTED REPAIR

During an examination of the roof structure in 2010, cracks were identified in the monumental concrete columns surrounding the arena. Because these concrete columns provide the main support for the roof structure, a structural engineer was consulted to investigate the cracking and make recommendations regarding the significance of the cracks and necessity of repairs.

## INSPECTION/EVALUATION METHODS

A visual inspection of the structure and selective demolition at the lower level of the columns determined the source and anticipated extent of cracking and delamination in the concrete columns. Due to the lower-level structure surrounding the arena, all upper columns could not initially be evaluated. It was specified that during the repair contract the concrete columns would be acoustically sounded by the contractor to determine the extent of subsurface concrete delamination.

*Fig. 2: Crack in monumental concrete column*

## TEST RESULTS/CAUSES OF DETERIORATION

After selective demolition and evaluation, the primary source of the concrete cracking was identified as corrosion of the embedded steel reinforcement in the concrete columns. The cause of the corrosion was determined to be due to a construction detail that allowed water to enter the concrete columns at upper levels and over time percolate through the steel reinforcement network, resulting in corrosion of the steel reinforcement and subsequent cracking and delamination of the concrete.

## REPAIR SYSTEM SELECTION

The repair procedure selected by the design team required sounding the concrete columns prior to selective concrete removal to determine the extent of demolition required, followed by removal of all delaminated concrete. All aspects of the concrete repair work were specified to conform to ICRI 310.1R-2008, "Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion."

Surface cracks were selected for epoxy injection if subsurface concrete delamination was not evident after sounding. Following removal of delaminated concrete, steel reinforcement was sandblasted and examined for adequate critical section. If an inadequate section was identified, additional steel reinforcement was added. The steel reinforcement was coated with an anticorrosion primer. A penetrating corrosion inhibitor was applied to the concrete surface, followed by the application of dry-mix, fiber-reinforced shotcrete.

All sealants in the structure were removed and replaced during construction. Following all structural repairs and sealant removal and replacement, a volatile organic compound (VOC)-compliant, 100% acrylic emulsion elastomeric coating was applied to all exterior surfaces of the arena and supported concrete ring beam to improve the aesthetic appearance of the arena and to mitigate water intrusion into the concrete structure.

## SITE PREPARATION

The arena exterior is surrounded by lower roofed exhibit areas. The lower-level structures required the development of innovative scaffolding solutions to access and complete repairs. After using ground-penetrating radar (GPR) to locate embedded steel and post-tensioned steel bundles in the structure's concrete ring beam, holes were cored through the concrete ring beam to allow suspension of swing-stage scaffolding necessary for completing project repairs. All lower-level structures were protected by installing plywood protective measures.

## DEMOLITION METHOD

Small electric and pneumatic hammers were used for concrete demolition to mitigate damage to surrounding sound concrete. After selective demolition to expose at least 1 in. (25 mm) around steel reinforcement, the limits of the

*Fig. 3: Epoxy injection and removal of delaminated concrete of concrete columns*

*Fig. 4: Applying elastomeric coating to concrete ring beam*

*Fig. 5: Demolition of delaminated concrete*

*Fig. 6: Column section following demolition*

repair were saw-cut to a depth of 0.75 in. (19 mm) to provide a defined area for repairs.

## SURFACE PREPARATION

Structural steel was sandblasted to remove all rust and scale. All concrete surfaces were mechanically cleaned to obtain an exposed aggregate surface profile of ±0.0625 in. (2 mm). Concrete surfaces were cleaned and saturated to saturated surface-dry (SSD) conditions using high-pressure power washing immediately before shotcrete placement.

## APPLICATION METHOD SELECTION

Dry-mix shotcrete was selected as the concrete repair method due to the depth, size, and location of the anticipated repairs. Dry-mix had significant advantage over form-and-pour in reducing time and formwork materials required for the project. Dry-mix shotcrete also provided increased consolidation of the concrete repair. Material test panels were produced daily to test for compressive strengths. Mockup panels were constructed to simulate the reinforcement within the columns and shot to qualify the materials, equipment, and nozzleman on the project. The design team


*Fig. 7(a) and (b): Dry-mix shotcrete installation*

allowed hand patching with a specified high-build repair mortar in areas 2 ft$^2$ (0.2 m$^2$) or smaller.

## REPAIR PROCESS EXECUTION/ UNFORESEEN CONDITIONS

The repair process for this project required an "adapt and overcome" mentality. The arena remained open during construction and hosted many horse- and cattle-centered events. The horse and cattle were not too tolerant of the construction process and construction activities were constantly being juggled to minimize impact on the animals.

Early in the construction process it was determined that the extent of corrosion was greater than originally anticipated. Due to the large areas affected, the depth of concrete delamination, and the absence of critical steel section in the reinforcement, a new construction sequence was developed that limited the size of an area that could be repaired on an individual column and created an overall schedule that designated column location, area size, and sequencing of repairs. These changes dramatically affected the construction productivity, requiring many more mobilizations to complete repairs than originally anticipated and close coordination with the design team to monitor construction progress.

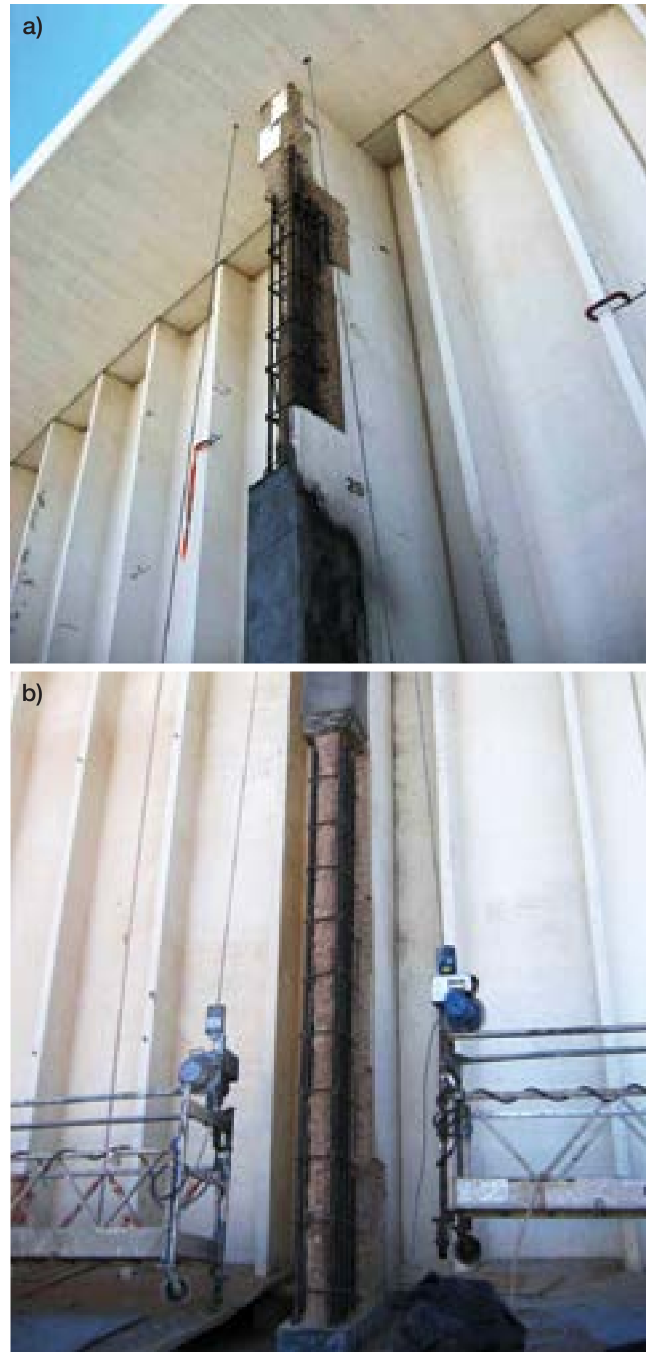



*Fig. 8(a) and (b): Phasing structural column repairs. Note cored holes in upper ring beam to support our swing stages*

Although the construction sequence was altered dramatically, all repairs were completed satisfactorily with minimum impact to the owner's operations and met the repair designer's objective of repairing the arena's structural problems.

Many projects can be completed with a construction schedule that requires minimal changes from original planning other than allowances for weather. This project required dramatic scheduling changes due to the unique construction environment that required working in close proximity to horses, cattle, and their owners.

The project also required the willingness to adapt to the challenge of dramatically changing construction requirements

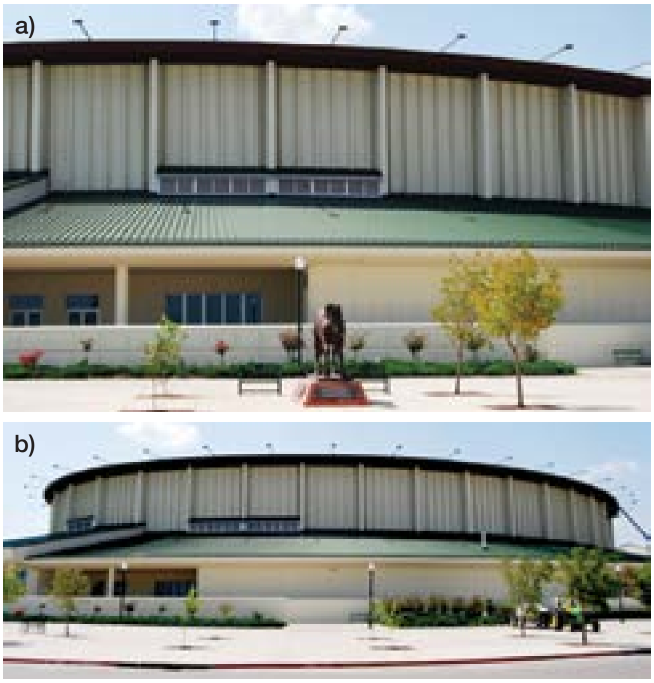


Fig. 9(a) and (b): Norick State Fair Arena repairs complete

that required balancing productivity with limited access to the structure.

This was an ideal project for shotcrete placement of the repair concrete. Shotcrete allowed the repairs to be accomplished with no formwork to erect or remove that made the work less expensive, more sustainable, and quicker. It also provided high-strength, low-permeability concrete that will likely be much more durable than the original concrete. Thus, shotcrete's quality, efficiency, and durability have helped to extend the service life of the arena for decades to come.


***Dean Brunken*** *is Executive Vice President of Restek, Inc. He received his BS from the University of Oklahoma, Norman, OK. He and Ellery Brown started Restek, Inc., in 1995. Restek, Inc., is a contractor specializing in structural repairs including wet and dry shotcrete, carbon fiber, epoxy injection, and waterproofing coatings, to name a few. Restek, Inc., maintains offices in Oklahoma and Texas.*

# When Cement Turns Against You

*By Jason Myers*

Cement is at the center of our industry. A common safety issue and hazard with it is cement burns. This is an issue that we all face and can be a year-round problem. It is essential that workers understand the hazard cement exposure creates and the treatments recommended when they are in a situation that puts them at a higher risk.

Dry cement is mainly calcium oxide (lime or quicklime) but when water is added it takes the form of calcium hydroxide (hydrated lime), which is highly alkaline with a pH of up to 13. As wet cement dries it absorbs water from any source that it can, including your skin. Basically, it will suck water from your skin and body. Because of its high alkalinity it can also cause a caustic (chemical) burn. It is one or both of these effects that result in cement burns.

## RECOGNIZING THE SYMPTOMS

In some cases, dermatitis can result from an allergic reaction to the salts or other trace metals within the cement. The worst part about cement burns is that the employee may not even be aware of the effects until several hours after the initial exposure and one of the major factors is duration of the exposure. Skin discoloration and irritation are the primary symptoms of cement burns. These symptoms can worsen over time depending on the severity of the injury. Skin redness and severe blistering is not uncommon and severe burns could lead to discoloration into purple/blue colors and progress to ulcerations and symptoms similar to third-degree burns.

## PREVENTION

The best way to prevent cement burns is to not take any shortcuts with your personal protection equipment (PPE) even when you are trying to stay cool on a hot day. The Occupational Safety and Health Administration (OSHA) recommends that workers wear protective eyewear, long sleeve shirts, long pants, rubber boots, and waterproof alkali resistant gloves. Contaminated clothing needs to be removed and any wet concrete or shotcrete materials that get on the skin need to be washed off immediately. Another aspect of prevention is to be aware of the jobsite surroundings. Employees must be aware of their own exposure conditions. An employee can easily see if concrete has splashed up on their skin or clothing from a slab pour or shotcrete placement. However, they may not be as aware of dry cement that collected at the collar line of their shirt and then becomes wet from conditions such as humid environment, sweat, or rain. Most workers think about cement burns more when they are hot than in a potentially cooler situation such as rain or tunnel work.

## WHAT TO DO IF EXPOSED

If an area of the skin is potentially exposed to cement burns, there are two important steps to take. First remove any dry cement from the body (you do not want to add to the wet cement issue) and then wash the area thoroughly for at least 15 to 20 minutes. To counteract the high alkalinity a common practice is to wash with a mild acid in addition to the water such as vinegar or citrus juice, for example lemon. There are commercial neutralizing agents available in a spray bottle that can be used to neutralize initial exposure or relieve mild cases of cement burns. Prevention of further exposure is essential and requires close monitoring to avoid further exposure and harm. For example, if the exposure is from a tear in the employee's boots, do not just put duct tape on the boot and consider it handled. Replace the boots, thoroughly wash the exposed areas, put on clean dry socks, and depending on the exposure and risk, consider having the employee stop work for the day. If a minor cement burn has occurred, remedies to treat typical sunburns can be used such as aloe vera gel or calendula lotion. For anything beyond a mild cement burn it is important to seek medical attention and understand that time is a critical issue. Remember that part of what is causing the burn is the caustic portion of the burn and must be neutralized as early as possible, otherwise the damage has been done and the healing process will have to start.

# Cuando el cemento se vuelve en contra tuya

*By Jason Myers*

El cemento está en el centro de nuestra industria. Un problema de seguridad común y el peligro con él son las quemaduras de cemento. Este es un problema que todos enfrentamos y puede ser durante todo el año. Es esencial que los trabajadores comprendan el peligro que crea la exposición al cemento y los tratamientos recomendados cuando se encuentren en una situación que los pongan en mayor riesgo.

El cemento seco es principalmente óxido de calcio (cal o cal viva), pero cuando se agrega agua, toma la forma de hidróxido de calcio (cal hidratada), que es altamente alcalina con un pH de hasta 13. A medida que el cemento húmedo se seca, absorbe el agua de cualquier fuente que pueda, incluyendo tu piel. Básicamente, absorberá el agua de tu piel y cuerpo. Debido a su alta alcalinidad, también puede causar una quemadura cáustica (química). Es uno o ambos de estos efectos que resultan en quemaduras de cemento.

## RECONOCIENDO LOS SÍNTOMAS

En algunos casos, dermatitis puede resultar de una reacción alérgica a las sales u otros rastros de metales dentro del cemento. La peor parte de las quemaduras de cemento, es que el empleado puede no estar consciente de los efectos hasta por varias horas después de la exposición inicial, y uno de los factores principales es la duración de la exposición. La decoloración de la piel y la irritación son los síntomas principales de las quemaduras de cemento. Estos síntomas pueden empeorar con el tiempo dependiendo de la gravedad de la lesión. El enrojecimiento de la piel y la formación de ampollas severas no son raros y quemaduras graves pueden provocar una decoloración hasta de colores morado y/o azul y progresar a ulceraciones y síntomas similares a las quemaduras de tercer grado.

## PREVENCIÓN

La mejor manera de prevenir quemaduras de cemento es no tomar atajos con tu equipo de protección personal (PPE por su siglas en inglés), incluso cuando estás tratando de mantenerte fresco en un día caluroso. OSHA recomienda que los trabajadores usen gafas protectoras, camisas de manga larga, pantalones largos, botas de caucho y guantes impermeables resistentes a los álcalis. La ropa contaminada necesita ser removida y todo el concreto húmedo o los materiales del concreto lanzado que toquen la piel deben ser lavados inmediatamente. Otro aspecto de la prevención es estar al tanto del entorno del lugar de trabajo. Los empleados deben ser conscientes de sus propias condiciones de exposición. Un empleado puede ver fácilmente si el concreto ha salpicado en la piel o la ropa de una colocación de losa o de concreto lanzado. Sin embargo, es posible que no sean tan conscientes del cemento seco que se acumula en la línea del cuello de su camisa y luego se humedece debido a condiciones como el ambiente húmedo, el sudor o la lluvia. La mayoría de los trabajadores piensan más acerca quemaduras de cemento cuando tienen calor que en una situación potencialmente más fresca, como en la lluvia o en trabajo de túnel.

## QUÉ HACER SI ES EXPUESTO

Si un área de la piel está potencialmente expuesta a quemaduras de cemento, hay dos pasos importantes a seguir. Primero, remueva el cemento seco del cuerpo (no desea agregarlo al problema del cemento húmedo) y luego lave el área a fondo durante al menos 15 a 20 minutos. Para contrarrestar la alta alcalinidad, una práctica común es lavarse con un ácido suave además del agua, como el vinagre o jugo cítrico, por ejemplo, de limón. Hay agentes neutralizadores comerciales disponibles en botella rociadora que pueden ser usados para neutralizar la exposición inicial o aliviar casos leves de quemaduras de cemento. La prevención de una exposición adicional es esencial y requiere una observación estricta para evitar una exposición y daños adicionales. Por ejemplo, si la exposición es debida a un desgarre en las botas del empleado, no solamente coloque cinta adhesiva sobre la bota y considérelo arreglado. Reemplace las botas, lave bien las áreas expuestas, póngase medias limpias y secas y, dependiendo de la exposición y el riesgo, considere que el empleado deje de trabajar por el día. Si una quemadura de cemento menor ha ocurrido, remedios para curar quemaduras típicas de sol, como el gel de áloe vera o la loción de caléndula pueden ser usados. Para cualquier cosa más allá de una leve quemadura de cemento, es importante buscar atención médica y entender que el tiempo es un asunto crítico. Recuerde que parte de lo que está causando la quemadura es la parte cáustica de la quemadura y debe neutralizarse lo antes posible; de lo contrario, el daño ha sido hecho y el proceso de curación deberá comenzar.

## PREVENTION EDUCATION

The best prevention is education. All employees must have proper training and an understanding of how to work safely with cement. Concrete and cementitious materials should be treated just as any other hazardous chemical. Cement burns are a common hazard in the concrete industry but are preventable. With quick response, the harmful effects can be kept to the minimum. All employees should feel free to speak out about the potential for exposure and employers should also make sure that all jobsites have access to the proper safety plans and remedies such as water and a neutralizing agent.

*__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 time-frame. 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.*

## EDUCACIÓN PREVENTIVA

La mejor prevención es la educación. Todos los empleados deben tener capacitación y comprensión adecuadas de cómo trabajar de manera segura con cemento. El concreto y los materiales cementosos deben ser tratados como cualquier otro químico peligroso. Quemaduras de cemento son un peligro común en la industria del concreto, pero son prevenibles. Con una respuesta rápida, los efectos dañinos se pueden mantener al mínimo. Todos los empleados deben sentirse libres para hablar sobre el potencial de exposición y los empleadores también deben asegurarse que todos los sitios de trabajo tengan acceso a los planes de seguridad y recursos adecuados, como agua y un agente neutralizante.

***Jason Myers*** *recibió su licenciatura en ingeniería civil de California Polytechnic State University en San Luis Obispo, California, y su maestría en administración de empresas con énfasis en gestión de proyectos de Golden Gate University, San Francisco, California. Myers comenzó su carrera profesional trabajando para un subcontratista de contención de tierras, donde aprendió la importancia de presupuestos, programación y relaciones con los clientes. Además, durante este tiempo, fue introducido al uso del concreto lanzado y sus aplicaciones. Después de trabajar para un contratista general durante un par de años, se dio cuenta que disfrutaba más la relación cercana al trabajar para un subcontratista y la habilidad de construir múltiples proyectos en un marco de tiempo más ajustado. Myers también disfruta el proceso de manejar la mayoría de los procedimientos utilizados al construir un proyecto en vez de solo una pequeña parte del proceso. Myers se unió a Dees Hennessey en el 2004 y es copropietario de la empresa desde el 2007. Actualmente se desempeña como Vicepresidente de Operaciones y Director de Seguridad. Myers es Presidente del Comité de Membresía de ASA y miembro de la Junta Directiva de ASA.*

# The Importance of ASA's Outstanding Shotcrete Project Awards Program

*By Bill Drakeley and Kerri Allmer*

If you're anything like me, you have probably asked yourself, "Why bother with award programs?" Most of the time, my company skips these award applications for the simple fact that we have found the judging process for most programs is victim to bias and untrained eyes posing as expert judges. The pool and skatepark industries are full of award programs from a variety of groups, regions, associations, and construction techniques; however, they all seem to have the following in common: the artistic impression, quality of design, and competence of construction practices are left up to judges who may or may not be qualified to judge these elements. For example, there is a disconnect in having a roundtable voting committee made up of pool retailers, liner builders, or manufacturers' representatives when selecting the best quality in-ground shotcrete pool construction. The full scope of this work just isn't in their wheelhouse and would be better judged by qualified shotcrete contractors instead. The intricacies and rigors entailed in the sprayed concrete process are really only known and understood by those doing this type of work.

My unvarnished opinions are based in the thought that our industry does not get the credit it deserves for a quality water feature installation. Specialty plaster, tile color, masonry, fun add-on features, or unsightly faux rocks or volcano imitations belching a pressurized water flume in the air take the credit away from the shotcrete builder who creates the structural core of the pool.

To prove my point, my company entered a three-tiered vanishing-edge pool into a competition down south. The home design mimicked Falling Water by Frank Lloyd Wright, so to complement this, we incorporated three different geometric changes of water flow spanning 25 ft (7.6 m) of elevation change. This multi-pool water flow followed organic architecture design theory, providing a continuation of space and blending into the environment that was already established by the house. We received rave reviews from a slew of people associated with publications such as *Architectural Digest*, *The New Yorker*, and *WaterShapes* magazine, yet we didn't pique the interest of the judging panel. The winning pool was a basic 40 x 20 ft (12 x 6 m) with tiny fiber lighting in the floor and in the ceiling above the pool. When comparing the difficulty, design theory, and construction techniques required for each project, there should have been no competition between the two pools. Yet, the judging panel's decision proves my point that our industry does not get the credit it deserves when installing a well-thought-out, expertly crafted, liquid-tight, quality water feature that will serve its owner for decades to come.

Since then, we have taken a hard look at promoting our wares to the public. While we recognize that promotion of the product was always helped by some type of outside recognition, we are also keenly aware that the watered-down pool industry version was not really a selling point to the buying public. In my extensive travel around the country performing expert witness services and consulting on construction defect court cases, I have seen a lot of firms' promotional materials. All have plaques and awards of merit from their related associations, as do we. This, however, is not considered "credibility" by the buying public.

The solution to this issue comes from the American Shotcrete Association's awards program and recognition banquet. Our ASA awards program takes into account all the basic recognized elements that deem a project a winner: looks, difficulty, textures, and colors. Where ASA differs from other award programs is the requirement to explain how a project was built. A nice picture of the pool is not the top priority. The priority is the overall process—from concept to final product in-place. Engineering, soil or geotechnical analysis, steel, and concrete placement are all paramount to recognition. Did you use ACI-certified nozzlemen? What was the mixture design and why did you choose this for the installation? The application process makes you really consider the overall quality of the product as the application questions really do make you scrutinize each phase of the construction.

In my opinion, the real credibility of an awards program stems from the judges. The ASA judges are shotcrete-focused experts—they are not "pool people" (except for the occasional Neanderthal like me who barges into the wrong room). The judges are academics, contractors, suppliers, or engineers that represent decades of experience in the shotcrete process. They know the materials, equipment, placement processes, and construction challenges that must be addressed for a high-quality, durable structure. No one with suspect practices from the pool industry will sneak by this judging panel and that's a good thing! If you are lucky enough to be considered in the top few securing an honorable mention or the annual winning entry, it means that your product is structurally and functionally worthy of recognized credibility.  To us in the pool and recreational industry, it means that we passed the test.

Entering ASA's award application process helped our company not only get national recognition but also helped our construction process down the line. The application process and the questions asked are a true learning process. The first time I read an award application I decided against submission. We would have had to answer "no" for too many questions. Today, things like curing, strength gain, porosity, and bond planes are all part of our building approach and to be honest, some of it started with the careful introspection of our business that came from completing ASA award submissions.

I wanted to highlight a few past award-winning projects submitted by ASA members that really deserve recognition. I also included one of ours, just because I can.

As you can see, these structures are extremely involved. The judging panel is looking at the internal structure and its

## 2012 Outstanding Pool & Recreational Project: Coastal Maine Negative-Edge Pool by South Shore Gunite Pools & Spas, Inc.

*Elaborate reinforcing required by the pool design as we start the second phase of shotcrete*

*Deep excavation required for forming and, subsequently, filling with free-draining stone to prevent frost heave. Also seen is the dowel reinforcing bar that was tied into the pool floor in the second phase*

*Completed pool from the beach-entry end*

## 2016 Outstanding Pool & Recreational Project: Covleigh Club in Rye, NY by South Shore Gunite Pools & Spas, Inc.

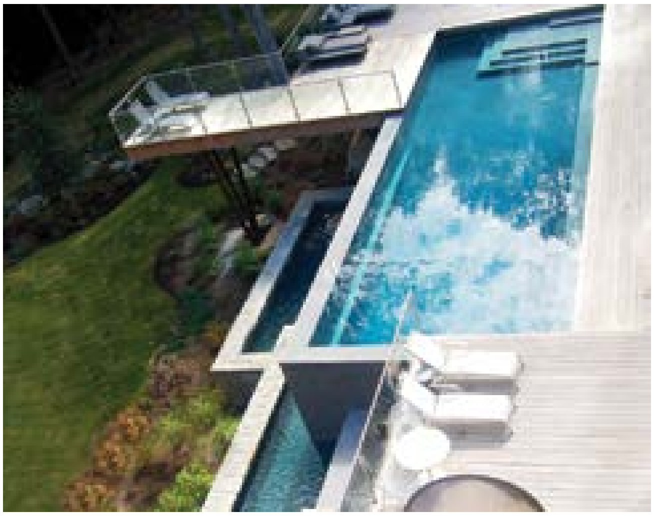
*50 tons (45 metric tons) of reinforcing bar being installed*

*Completed pool*

## 2017 Outstanding Pool & Recreational Project: The Scheinberg Residence in Bridgewater, CT by Drakeley Pool Company

*Although intricate forming was required for this out-of-ground pool construction, the use of sustainable shotcrete resulted in a material savings of 50% due to needing only one-sided forming*

*Reinforcing bars, non-vibrating rigid forming, and a roughened SSD bond plane were installed to connect the cast concrete foundation and the shotcreted portions of the pool structures*



*Beautiful reflection of clouds*

## 2018 Outstanding Pool & Recreational Project: City of Frisco Texas Northeast Community Skate Park by SPA Skateparks

*ACI-Certified Nozzleman and blow pipe operator. Stucco lathe placed between reinforcement curtains. Shotcrete pump and equipment in background*

*Second (final) concrete layer with Class A steel-trowelled finish. Over-vertical concrete capsule protected from overspray*

*Over-vertical, cantilevered concrete wave feature in foreground* ability to withstand forces—not the final coating of texture. Backfill, hydrostatic, and thermal loads must be successfully carried throughout the pool's lifetime. Through quality shotcrete placement, we create pools and recreational facilities that easily meet the compressive and tensile forces that we must account and build for to create a durable concrete structure, and these are the criteria that projects are judged on for this competition. These winners are judged for their contribution to the future of the industry, not just the present pretty picture. The past ASA Outstanding Shotcrete Project Award winners in the pool and recreational industry exemplify how substantially we've evolved from the rectangular concrete pond in the ground to the creative masterpieces we can create today. Hopefully, with increased awareness of the judging process and its criteria, the ASA's Outstanding Shotcrete Project Awards can provide the real credibility we as pool and skatepark builders are looking to present to our clients.

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***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.*

***Kerri Allmer*** *is the Office Manager of Drakeley Industries, a design and structural shotcrete consulting firm specializing in swimming pools, water tanks, tunneling, and other infrastructural shotcrete applications. She also serves as Office Manager of Drakeley Pool Company, a specialty watershape design, construction, and service firm in Bethlehem, CT. Allmer has developed and produced educational materials on pool shotcrete construction for multiple pool trade associations including NSPF/Genesis and NESPA. She has also partnered with Bill Drakeley on technical presentations given to the architectural and landscape architectural industries. Allmer received her bachelor's degree from Quinnipiac University, Hamden, CT, and her master's degree from West Virginia University, Morgantown, WV. She is currently a student of Genesis 3 University, pursuing membership in the Society of Watershape Designers.*

# Properly Securing Hoses to Manlifts and Scaffold

*By Ray Schallom III*

Decades ago, a seasoned carpenter showed me how to tie 2x4s and reinforcing bar together so I could lower it down a shaft without losing the load. Prior to my lesson, I lost a load down the shaft. Fortunately for me, no one was underneath the falling material.

When I got the opportunity to learn how to shotcrete a couple of years later (back then it was called gunite), it was always difficult securing the hoses in the manlift, swing stages, and scaffolding without the ropes loosening. Anyone who has ever experienced this knows that it is tough shooting properly while fighting to keep the hose in the basket, whether on a manlift, swing stage, or a scaffold platform.

*Fig. 1: Slipknot is the first knot wrapped around the shotcrete hoses*

## SLIPKNOTS AND OVERHAND KNOTS

When I learned how to apply shotcrete several decades ago, it took me several attempts to perfect the combination of knots that prevented my hoses from kinking, sliding off the scaffold planks, or move when the wet-mix hose surged between strokes. I used to call the knot configuration the "labor" knot only to find out the official names of each knot years later. You first start out with a slipknot around the hose as shown in Fig. 1, then you add two overhand knots as shown in Fig. 2. Next, you wrap the rope tight around the rail pipe of the manlift, scaffold, or swing stage so that the weight of the hose is suspended by the rope.

Figures 3 through 6 show the hoses tied off to the boom, manlift basket, and work platform in different environments. In all cases, the knots used are the knots shown in Fig. 1 and 2. As OSHA's safety requirements increase every year in all construction work, what remains compliant is the combination slipknot with overhand knots together to secure hoses or loads.

With the vibration of the dry-mix hose or the surging of the wet-mix hose between strokes of the pump, the knots tighten to prevent slippage. Using 5/8 or 3/4 in. (16 or 19 mm) nylon rope works the best in all weather conditions. The rope needs to be taped at the end before cutting to the desired length. This will prevent the rope from unraveling.

I have tried all kinds of knots to secure hoses over the years. The knot that has performed the best for me and other contractors that I consult for is the slip with two

*Fig. 2: (a) Overhand knot; and (b) adding two overhand knots, also known as Marline Hitching, above the slipknot gives you a combination that is OSHA-compliant*

overhand knots. It's very difficult for me to watch shotcrete crews and nozzlemen struggle with the dry-mix and wet-mix hoses when the hoses are not secured tight enough.

## Conclusions

Try the knots out. Maybe make it a part of one of your toolbox talks. It may take the crew a few tries to perfect it but once they get the hang of tying these knots, I know it will save you time and money on the job every day. The extra security of attaching the hose will also make the nozzleman's job a little easier so they can concentrate on shotcrete placement. It's somewhat amazing that just knowing how to tie a few simple knots can make your jobs safer, more productive, and allow your nozzlemen to concentrate on the shooting and not manhandling the hose.

*Fig. 3: Wet-mix shotcrete hose secured to the boom and basket while shooting a concrete dome (Rain CII, Gramercy, LA)*

*Fig. 4: Dry-mix shotcrete and water hose secured to the manlift basket 60 ft (18 m) in the air (Buchannan Dam, Llano County, TX)*

*Fig. 5: Close-up of dry-mix shotcrete and water hose secured to the manlift while moving. The rope keeps the hose from pulling out of the basket (Buchanan Dam, Llano County, TX)*

*Fig. 6: Wet-mix shotcrete and accelerator hose secured to the work platform (GAB Pedestrian Tunnel, Richmond, VA)*

*Fig. 7: Wet-mix shotcrete and air hoses secured to the manlift basket (Shotcrete Technology Transfer Expo, Santiago, Chili)*

***Ray Schallom III** is a shotcrete application specialist and President of RCS Consulting & Construction Co. Inc. He has over 40 years of experience as a Project Manager, Owner, and Superintendent. Schallom works with State DOT departments with their shotcrete specifications and trains engineering companies' inspectors in the field of shotcrete. He is a Past President of the American Shotcrete Association (ASA), Past Chair of the ASA Education Committee, and a member of the ASA Underground, Marketing, Sustainability, and Pool & Recreational Shotcrete Committees. He is also a member of ACI Committee 506, Shotcreting (as well as many of the 506 Subcommittees); and ACI C660, Shotcrete Nozzleman Certification. With over 36 years of shotcrete nozzle experience in wet- and dry-mix handheld and robotic applications, Schallom is an ACI Certified Nozzleman in the wet- and dry-mix process for vertical and overhead applications and an ASA/ACI-approved Shotcrete Examiner for wet- and dry-mix applications. He is a member of ASTM Committee C09, Concrete and Concrete Aggregates, and ASTM Subcommittee C09.46, Shotcrete.*

# Superior Gunite

Superior Gunite has been in business since 1930 and is an industry leader in structural shotcrete placement. Superior Gunite has built its reputation on alternative, creative, and cost-effective building solutions. Depending on the application, shotcrete can eliminate two-sided form construction or one-sided forms against existing concrete masonry units, unreinforced masonry, and form-and-pour walls. Shotcrete is the superior form-and-pour concrete alternative.

## BACKGROUND

Founded in 1956, Superior Gunite began its business specializing in swimming pool construction. Today Superior Gunite is one of the largest shotcrete companies in the world. Its rise to the top began when Tony Federico joined the company in 1966 and began to expand the company's market into the structural field. By 1976, Superior Gunite's founder retired and Federico took the helm as its new owner. His course remained steady through the years, pioneering

Fig. 1: Hudson Yards, 12,000 lb/in.$^2$ (83 MPa) foundation

Fig. 2: East Side Access tunnel section


Fig. 3(a) and (b): Brattleboro Bridge, VT, shot and carved the flared architectural treatment 100 ft (30 m) off the ground

*Fig. 4: Staples Center foundation walls*

the acceptance of shotcrete as a cost-effective alternative to conventional form-and-pour methods in the structural concrete market. After proving the time and cost saving advantages on some of the largest civic and civil projects in Los Angeles and across California, Superior Gunite began to expand its geographic reach. Superior Gunite now serves the entire continental U.S., Hawaii, and locations abroad. One bridge, one tunnel, one building at a time, Superior Gunite and its talented team members have had the opportunity to prove the viability of the shotcrete alternative as it has helped build the vital infrastructure of the communities it serves.

## SUPERIOR GUNITE TODAY

Superior Gunite has built its reputation on innovative and cost-effective building solutions. The range of its applications include, but are not limited to, infrastructure for essential transportation and water management systems; critical institutional resources, such as hospitals and universities; major civic, industrial, and commercial projects; rehabilitated and rebuilt dry docks; railroad and highway tunnels; repair of unreinforced and under-reinforced buildings, seismic strengthening, bridges, and many other concrete or masonry structures; and construction of new retaining walls, commercial building basements, structural walls, pipe linings, tunnel linings, canals, reservoirs, and dam spillways.

Combining cost savings and project duration reduction are just a few attributes of the shotcrete advantage.

Superior Gunite's guiding principles include integrity, responsibility, teamwork, quality, communication, and most of all loving and enjoying the work it does which is the company's foundation and continues to make it a top choice in shotcrete. The company looks forward to the opportunity to introduce you to the innovative method it calls the shotcrete advantage. Together we can build relationships and foundations that will last a lifetime.

**Superior Gunite**

**West Coast to East Coast and beyond**

**www.shotcrete.com**


*Fig. 5(a), (b), and (c): Seismic retrofit work around the United States, from tight spaces, to high-early strength, to irregular shapes*

# WESTERN SHOTCRETE EQUIPMENT

Western Shotcrete Equipment has been a leader in shotcrete pumping technology for over 30 years. It produces and sells shotcrete pumps, nozzles, and other accessories. The company's goal is to continue to grow as a leader in shotcrete pumping technology as it strives to produce quality products that are designed to be simple, easy to use, and durable.

## BACKGROUND

The company started when the founder, Joe Harpole, worked in the industry as a concrete pump mechanic. Over the years of servicing concrete pumps, he believed the machines could be improved upon so that they would be more reliable and easier to work on. This belief has been at the foundation and core of every product the company has produced since the very first Warrior shotcrete pump that was launched in 1985.

Western Shotcrete Equipment has remained a private, family business since its inception. Today, Joe Harpole's sons manage the different aspects of the business and share the same core beliefs as their father when he founded the company. They have leaned on his many years of experience in the field of shotcrete as the company continues to grow and develop new products. To support this growth, the company is looking to expand its dealer network.

San Fernando, CA, is where the company started and remains the location of its sales and service facility, servicing the greater Los Angeles area. For several years, the

*Fig. 1: Warrior shotcrete pumps being assembled inside the Utah manufacturing facility*

headquarters office and manufacturing plant resided in Missouri. However, in 2017, the company relocated its operations to West Haven, UT, to expand and better support its customers. Here, the shotcrete pumps and their components are manufactured in-house, as well as many accessories.

## Western Shotcrete Equipment Products and Services

The company designs and produces many offerings for the shotcrete industry. What began as an ambitious goal to build class-leading shotcrete pumps eventually led to designing additional products and accessories built with the same philosophy of quality and value. The lineup of shotcrete pumps consists of the flagship Warrior X600 (previously the 3050 HP) and newly released X500. In the upcoming months, several new machines will be unveiled. Each of these machines will cater to different sectors of the market. They will focus on class-leading performance and efficiency. One of the main challenges that has affected the entire industry in recent years has been the constant change in emissions regulations. This concern has required forward thinking and an added emphasis on protecting the environment. In response to this, all the company's shotcrete pumps are now powered by Cummins engines with either Tier 4 Final or Stage V packages. This will ensure that the machines remain compliant and keep air pollution to a minimum. All new models will feature both standard and high-pressure options to meet customer requirements.

The industry has taken notice of the quality products from Western Shotcrete Equipment. The company was recognized as a supplier on three projects that were selected as 2018 ASA Outstanding Shotcrete Project Award recipients. It is a privilege to provide these companies with the tools they need to accomplish their jobs. Contact Western Shotcrete Equipment to find out more about the products and services provided including shotcrete pumps, nozzles, hoses, couplings, reducers, and other shotcrete products.


**Western Shotcrete Equipment**

wseshotcrete.com

Sales and Service
525 Jessie St., San Fernando, CA 91340
Main Office
3026 Scott Lane, West Haven, UT 84401

Phone: 385.389.2630


*Fig. 2: The new Model X500*

## INTRODUCING THE ALL-NEW ACUBATCH FIBER DISPENSER BY FIBERFORCE

Helena, AB—ABC Polymer, a leading manufacturer of over 30 types of concrete fibers, is pleased to announce their all-new AcuBatch Fiber Dispenser™. This innovative solution, created to reliably enhance quality assurance, prioritize safety, and increase productivity, boasts that companies who choose FiberForce AcuBatch can save an average of $4.50 per fiber load!

Through the new AcuBatch Fiber Dispenser, you can expect:

- Quality—through properly weighed, marked, and dispensed batches that eliminate balling or nesting of fibers.
- Safety—as operators do not have to manually load product, thus diminishing back injuries, slips, trips, and falls.


- Productivity and Efficiency—by reducing labor costs through an automated delivery system that dispenses fibers directly to the truck while batching at the ready mix plant, simultaneously eliminating boxes and eradicating on-site work.

ABC Polymer is committed to excellence and innovation, and the AcuBatch Fiber Dispenser proves their dedication to producing the highest-quality, cost-effective products available that dispensers, contractors, and customers have faced.

Founded in September 1994, ABC Polymer produces extruded polypropylene products, including microsynthetic and macrosynthetic concrete fibers. They are also a major distributor of bulk bags, fibrillated yarns, synthetic snow, and more. Visit **www.abcpolymerindustries.com**.

## PUTZMEISTER AMERICA, INC., UPDATES EXPERTS APP

The "Putzmeister Experts" App has added new features to create a more hands-on experience for all users. The new "Calculators" function allows users to determine the Pump Output, Flow Speed, and Volume from the ease of their mobile phone. The app features all generations of Putzmeister boom pumps, both domestically and internationally. Putzmeister aims to provide customers with the proper resources to teach best practices, tips, and maintenance for their products.

The Putzmeister Experts App is free and available on the Apple App Store and Google Play. For more information about the Experts App and other Putzmeister programs, please visit **www.putzmeisteramerica.com** or call your local sales representative.

## SIKA-KING: TRANSACTION COMPLETED

Sika has officially completed the acquisition of King Packaged Materials Company, a large independent Canadian manufacturer of dry shotcrete, mortars, and concrete solutions. King is a family-owned business and a well-established manufacturer of products for the construction and mining industry as well as for the home improvement distribution channel. The portfolio includes shotcrete solutions, grouts, and repair and masonry mortars.

The company has an excellent reputation for its recognized brands, its high-quality and reliable product solutions, and its strong technical sales expertise. King operates three large, state-of-the-art plants: one located in Boisbriand, QC, Canada, close to Montreal; another in Brantford, ON, Canada, near Toronto; and the third one in Sudbury, ON, Canada.

Christoph Ganz, Regional Manager Americas: "With the acquisition of King and its broad and highly complementary product offering, we will further strengthen our presence in Canada and open up exciting new cross-selling opportunities. Especially in the home improvement market and in the growing tunneling and mining market segments, the acquisition of King Packaged Materials will make Sika Canada one of the leading suppliers of concrete solutions. We look forward to a successful joint future and would like to extend a very warm welcome to all King employees as they join the Sika team."

The owners of King Packaged Materials Company, the Hutter and Macpherson families, strongly believe that Sika is the ideal partner to continue the growth of King products in all of their market sectors. They look forward to the joint business and sales activities, which offer great potential to expand the product portfolio across Canada and internationally.

Sika Canada Inc. is a wholly owned subsidiary of Sika AG, located in Baar, Switzerland. Sika is a globally active specialty chemicals company supplying the building and construction industries as well as manufacturing sector.

For more information about King Shotcrete Solutions, call 800.461.0566 or visit **www.kpmindustries.com/KingShotcreteSolutions**. For more information about Sika Canada, call 800.933.7452 or visit **www.sika.ca**.

## WAGMAN HONORED AS WINNER OF CONTRACTOR SAFETY AWARD AT VTCA

Wagman Heavy Civil, Inc., received a Contractor Safety Award during the 2019 Virginia Transportation Construction Alliance (VTCA) Spring Transportation Construction Conference in Norfolk, VA. Wagman was the "Category Winner," the top honor for the Contractor Safety Award in the "100,000 – 250,000 Man Hours" category. The award recognizes companies who successfully demonstrate their commitment to a safe and healthy working environment. To qualify, applicants submitted a Safety Philosophy Profile, a Safety Operating Profile, and documented EMR numbers.

Wagman is a multi-faceted construction firm with major operations in heavy civil, general construction, and geotechnical construction services. Founded in 1902, Wagman is a fourth-generation family-owned company with offices in Pennsylvania and Virginia and is headquartered in York, PA.

For more information about Wagman, call 717.764.8521 or visit **www.wagman.com**. For more information about VTCA, visit **www.vtca.org**.

## GEOSTABILIZATION INTERNATIONAL ANNOUNCES APPOINTMENT OF CHIEF FINANCIAL OFFICER

GeoStabilization International® (GSI), a provider of geohazard mitigation services in the United States and Canada, announced the appointment of **Chris Howard** as Chief Financial Officer effective May 20, 2019.

Howard was most recently Vice President, Finance at Accudyne, a manufacturer of centrifugal pumps and compressors, with financial oversight for the Sundyne division. He received his bachelor's of business administration in accounting from the University of Texas.

"We are excited to welcome Chris to the GSI team. He is an experienced financial leader who brings a depth of strategic finance and leadership capabilities," said Colby Barrett, Chief Executive Officer of GSI. "Chris' experiences in key financial leadership roles within performance-oriented companies positions him well to take on this important role as GSI enters the next chapter of our growth. I am looking forward to partnering with Chris to build upon GSI's achievements and enable even greater abilities to serve our customers and expand our reach."

## GCP APPLIED TECHNOLOGIES ANNOUNCES LEADERSHIP TRANSITION

The Board of Directors of GCP Applied Technologies Inc., a global provider of construction products technologies, announced a leadership transition plan that supports the Board's commitment to executing the company's existing strategic and financial plan while remaining open to other opportunities that deliver value to GCP shareholders.

**Randall S. Dearth**, President and Chief Operating Officer, has been appointed Chief Executive Officer and a member of the Board, effective August 1, 2019. Since joining GCP in September 2018, Dearth has led commercial, manufacturing, and supply chain operations for the company.

**Gregory E. Poling** assumed the role of Executive Chairman, with a particular focus on ongoing evaluation of strategic opportunities. Poling has 40 years of experience, including the successful launch of GCP as an independent public company and transitioning GCP into its next successful stage of growth.

**Elizabeth Mora** is now Lead Independent Director. GCP's Board of Directors believes Mora will add real value as an ombudsman for the Company's outside directors and help to ensure the most effective operation of the Board.

**Ronald Cambre**, Chairman, retired from the Board of Directors of GCP Applied Technologies effective August 1, 2019. He has served on the Board since its separation from W.R. Grace & Co., where he had previously served as a Director and has been a tremendous supporter of the company.

For more information about GCP Applied Technologies, visit **www.gcpat.com**.

## NORMET APPOINTS PRESIDENT AND CEO

Normet Board of Directors appointed **Ed Santamaria** as President and CEO of Normet Group. Santamaria takes over from Interim President and CEO **Aaro Cantell**, and he will begin his new role in November this year. He will be based in Normet's Espoo, Finland, office.


*Santamaria*

Santamaria has a wealth of experience from the mining industry. He is currently President, Parts & Services Division, at Sandvik Mining & Rock Technology. He has spent in total 13 years in different management roles within Sandvik.

"I am extremely pleased that we have found a new CEO of this high caliber from our own industry sector. Ed knows well how to lead people in this kind of a global matrix organization. He also knows personally many of our customers and their future plans. I believe he can help us find areas to improve our operational efficiency as well as help identify new growth areas," said Aaro Cantell, Chairman of Normet Group.

## ACI RELEASES NEW ACI 562-19 REPAIR CODE

The American Concrete Institute (ACI) announced that ACI 562-19, "Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures and Commentary," is now available in print and digital formats. ACI 562-19 was specifically developed to integrate with the International Code Council's (ICC) International Existing Building Code or to be adopted as a stand-alone code. ACI 562 was written specifically to be integrated into building codes as a mechanism for building officials to have increased confidence that repairs are performed in a manner which provides an acceptable level of protection for the public.


The ACI 562 code requirements combine the Institute's 100 years of historical knowledge with advanced resources on concrete repair. Key changes to the 2019 version include improved integration with ACI 318, "Building Code Requirements for Structural Concrete and Commentary"; improved integration with the ICC International Existing Building Code; more context provided regarding durability; improved text and commentary related to load combinations during fire events; improved text and commentary related to applicability of ACI 562; simplified requirements for the basis of design report; and clarification of requirements related to detailing of existing reinforcing steel.

ACI 562 is available to subscribers of both the online ACI Collection of Concrete Codes, Specifications, and Practices and the new ACI Concrete Repair Subscription, or can be purchased individually in print or digital formats.

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

## ACI CERTIFICATION VERIFY APP FOR IOS NOW AVAILABLE FOR DOWNLOAD

ACI released its new ACI Certification Verify app. The app allows users to quickly and easily verify the status of ACI-certified individuals through three search options: 1) verify an individual's certification ID number; 2) search by an individual's name; and 3) find the total number of ACI-certified individuals in an area.

ACI has certified more than 400,000 concrete finishers, technicians, supervisors, inspectors, managers, and more since the 1980s. Currently, there are more than 123,000 active ACI certifications across 25+ popular programs worldwide.

"The ACI Certification Verify app is the perfect tool to use on the jobsite," said John W. Nehasil, ACI Managing Director, Certification. "Using simply a phone or tablet, anyone can easily verify the status of people working on a particular project or find the total number of ACI-certified individuals in an area."

Creating this app provides further value to those working in the field, who may not have quick and easy access to a computer. The ACI Certification Verify app helps the entire verification process move more quickly and easily so jobs can move forward, with the same functionality of the popular **www.concrete.org/verify** web-based verification tool.

The app is currently available on iOS platforms. An Android version is expected to be available soon.

"ACI-certified workers are critically important to the concrete industry, as they provide assurance that testing, placing, and inspecting are performed correctly. Through our certification programs, ACI is strengthening the workforce with competent and proven individuals who can perform their jobs in a way that will help ensure longevity for the industry," continued Nehasil.

To learn more about ACI Certification or to download the app, visit **whyACIcertification.org**.

## AMERICAN CONCRETE PUMPING ASSOCIATION (ACPA) RELEASES NEW SAFE DRIVING VIDEO

The American Concrete Pumping Association (ACPA) announced its newly updated Proper Driving Techniques video. The video is available in both English- and Spanish-language versions and addresses safety practices proven to help pumpers avoid driving accidents—the most common types of accidents involving concrete pumps. Produced in conjunction with Nations Builders Insurance Services Inc. (NBIS), the video's new content addresses the most current driving practices of concrete pumpers.


"Approximately two-thirds of incidents involving pumps occur on the roadway," says Kyle Rask, Program Manager – Concrete Pumping, NBIS. "The biggest hazard pump operators face every day is driving to and from the jobsite, according to statistics. Our goal for the video is to bring a renewed focus to safe driving practices. If pumpers can't get to the jobsite safely, they can't do the job."

The video is available on the ACPA website free of charge and also on the ACPA YouTube channel at: **http://bit.ly/PumpDriving**.

"We are proud to offer the video free of charge—not just to the industry, but also to the public—because concrete pumps make use of public roadways which affect all drivers on our highways and roads," says Tom O'Malley, Chair of the ACPA Safety Equipment and Applications Committee. "Our goal is that people would not just view the video, but also share the video with others. Together, we can help keep our nation's roadways safe."

For more information about the Proper Driving Techniques video, contact the ACPA National Office at 614.431.5618 or e-mail acpa@concretepumpers.com. For more information about ACPA, visit **www.concretepumpers.com**.

## AMERICAN SOCIETY OF CONCRETE CONTRACTORS PUBLISHES 44TH POSITION STATEMENT

The American Society of Concrete Contractors (ASCC), St. Louis, MO, has published its 44th Position Statement, "Measuring Air Content in Non-Air-Entrained Concrete." ASCC Position Statements clarify the concrete contractors' point of view for architects, engineers, owners, and others.

Position Statement #44 explains that while air content is reported in the mixture design submitted for air-entrained concrete and measured in the field for compliance, air content measurements are rarely specified or measured for non-air-entrained concrete.

Specifications such as ACI 301 and MasterSpec 033000 – Cast-in-Place Concrete, require a maximum air content in concrete floors to receive a hard-troweled finish, and for good reason, according to ASCC Technical Director Bruce Suprenant, PE, PhD, FACI. "Air-entraining admixtures should not be specified or used in concrete to be given a smooth, dense, hard-troweled finish," says Suprenant, "due to the probability of blistering or delamination occurring as a result."

ASCC contractors have observed that when water-reducing and/or waterproofing admixtures are used in concrete to receive a hard-troweled finish, air contents often exceed the 3% maximum set out in ACI 302.1R-15, "Guide to Concrete Floor and Slab Construction."

Often, contractors are not alerted to this issue because the air content is not measured, says Suprenant. Thus, Position Statement #44 concludes, ASCC contractors encourage owners to direct specifiers to require measuring the air content of concrete to receive a hard-troweled finish.

ASCC is a nonprofit organization dedicated to enhancing the capabilities of those who build with concrete, and to providing them a unified voice in the construction industry. For more information, visit their website at **www.ascconline.org** or call 866.788.2722.

# SHOTCRETE CALENDAR

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|---|---|
| SEPTEMBER 9-11, 2019 | **Breakthroughs in Tunneling Short Course**<br>University of Denver \| Denver, CO<br>**https://tunnelingshortcourse.com** |
| SEPTEMBER 19, 2019 | **AIA/CES-approved Workshop at Chicago Build**<br>Architectural Shotcrete – Creative, Sustainable, and Durable Concrete Structures Using Shotcrete<br>McCormick Place \| Chicago, IL<br>**www.chicagobuildexpo.com/ces-training-workshops** |
| SEPTEMBER 19-20, 2019 | **Chicago Build**<br>McCormick Place \| Chicago, IL<br>**www.chicagobuildexpo.com** |
| SEPTEMBER 28, 2019 | **ASA Shotcrete Contractor Education**<br>ASA Headquarters \| Farmington Hills, MI<br>**www.shotcrete.org** |
| OCTOBER 19, 2019 | **ASA Fall 2019 Committee Meetings**<br>Duke Energy Convention Center \| Cincinnati, OH<br>**www.shotcrete.org** |
| OCTOBER 20-24, 2019 | **The ACI Concrete Convention and Exposition – Fall 2019**<br>Theme: "A River of Knowledge"<br>Convention Center and Hyatt Regency Cincinnati \| Cincinnati, OH<br>**www.aciconvention.org** |
| OCTOBER 23, 2019 | **ASA Shotcrete Inspector Education**<br>The ACI Concrete Convention and Exposition \| Cincinnati, OH<br>**www.shotcrete.org** |
| NOVEMBER 5-7, 2019 | **International Pool \| Spa \| Patio Expo**<br>Ernest N. Morial Convention Center \| New Orleans, LA<br>**www.poolspapatio.com** |
| NOVEMBER 6, 2019 | **ASA Shotcrete Nozzleman Education at the PSP Expo**<br>Ernest N. Morial Convention Center \| New Orleans, LA<br>**www.poolspapatio.com** |
| NOVEMBER 11-13, 2019 | **ICRI Fall Convention**<br>Theme: "Historic Restoration"<br>Doubletree Hilton Philadelphia Center City \| Philadelphia, PA<br>**www.icri.org** |
| DECEMBER 8-11, 2019 | **ASTM International Committee C09, Concrete and Concrete Aggregates**<br>Marriott Marquis Houston \| Houston, TX<br>**www.astm.org** |
| JANUARY 22-25, 2020 | **Southwest Pool & Spa Show**<br>George R. Brown Convention Center \| Houston, TX<br>**www.swpsshow.com** |
| JANUARY 28-30, 2020 | **The Pool & Spa Show 2020**<br>The Atlantic City Convention Center \| Atlantic City, NJ<br>**www.nespapool.org** |

| | |
|---|---|
| FEBRUARY 3, 2020 | **ASA 90-Minute Shotcrete Seminar at World of Concrete**<br>Shotcrete Technology for Diverse and Cost-Saving Projects<br>Las Vegas Convention Center \| Las Vegas, NV<br>**www.worldofconcrete.com** |
| FEBRUARY 4, 2020 | **ASA Shotcrete Nozzleman Education at World of Concrete**<br>Las Vegas Convention Center \| Las Vegas, NV<br>**www.shotcrete.org/WOC** |
| FEBRUARY 4, 2020 | **ASA Outstanding Shotcrete Project Awards Banquet**<br>Venue TBD \| Las Vegas, NV<br>**www.shotcrete.org/WOC** |
| FEBRUARY 4-7, 2020 | **World of Concrete 2020**<br>Las Vegas Convention Center \| Las Vegas, NV<br>**www.worldofconcrete.com** |
| FEBRUARY 5, 2020 | **ASA Shotcrete Contractor Education at World of Concrete**<br>Las Vegas Convention Center \| Las Vegas, NV<br>**www.shotcrete.org/WOC** |
| FEBRUARY 23-26, 2020 | **2020 SME Annual Conference & Expo**<br>Phoenix Convention Center \| Phoenix, AZ<br>**www.smeannualconference.com** |
| MARCH 10-14, 2020 | **CONEXPO – CON/AGG 2020**<br>Las Vegas Convention Center \| Las Vegas, NV<br>**www.conexpoconagg.com** |
| MARCH 29 – APRIL 2, 2020 | **The ACI Concrete Convention and Exposition – Spring 2020**<br>Theme: "Concrete in the Windy City"<br>Hyatt Regency O'Hare \| Chicago/Rosemont, IL<br>**www.aciconvention.org** |
| JUNE 7-10, 2020 | **North American Tunneling Conference (NAT) 2020**<br>Nashville, TN<br>**www.natconference.com** |
| JUNE 28 – JULY 1, 2020 | **ASTM International Committee C09, Concrete and Concrete Aggregates**<br>Boston Marriott Copley Place \| Boston, MA<br>**www.astm.org** |
| SEPTEMBER 28-30, 2020 | **MINExpo International**<br>Las Vegas, NV<br>**www.minexpo.com** |
| OCTOBER 25-29, 2020 | **The ACI Concrete Convention and Exposition – Fall 2020**<br>Theme: "Carolina Style Concrete"<br>Raleigh Convention Center & Raleigh Marriott \| Raleigh, NC<br>**www.aciconvention.org** |
| MORE INFORMATION | To see a full list with active links to each event, visit **www.shotcrete.org/calendar**. |

## CHICAGO BUILD 2019 EXPO

ASA's Executive Director, Charles Hanskat, will present "Architectural Shotcrete – Creative, Sustainable, and Durable Concrete Structures Using Shotcrete," on Thursday, September 19, at Chicago Build 2019, Chicago, IL. Register at no cost for this AIA-/CES-approved workshop at this Illinois-focused construction show. This is one of the latest additions to the internationally known global Build series in major cities around the world, including New York, London, Sydney, Glasgow, and Auckland. For more information, visit **www.chicagobuildexpo.com**.

## ASA SHOTCRETE CONTRACTOR EDUCATION AT ASA HEADQUARTERS

ASA will host the Shotcrete Contractors Education seminar on Saturday, September 28, 2019, in Farmington Hills, MI. This seminar covers the essential aspects to operate as a successful shotcrete contractor. Topics include materials, equipment, personnel, application, QC/QA, curing, protection, and project management. It is also a required first step in the ASA Shotcrete Contractor Qualification program, providing the opportunity to take the required written exam and learn more about the details and requirements for quality shotcrete placement. This is a valuable course for contractors regardless of your desire to pursue qualification. However, guidance for completion of the application is provided. Lunch is included. For more information, visit **www.shotcrete.org/events**.

## ASA FALL 2019 COMMITTEE MEETINGS

ASA Fall Committee Meetings will be held Saturday, October 19, 2019, in Cincinnati, OH, prior to The ACI Concrete Convention and Exposition, October 20-24. The meeting schedule is now available, and Convention registration is not required to attend the ASA meetings. All are invited to attend ASA meetings to learn more of Association activities and become involved! The work of the Association is only as strong as the efforts of our membership. The ASA meetings at the ACI Convention will be at the Duke Energy Convention Center. ACI's theme for the convention is "A River of Knowledge."

## ASA SHOTCRETE INSPECTOR EDUCATION AT THE ACI CONVENTION

ASA will present the Shotcrete Inspector Education seminar on Wednesday, October 23, in Cincinnati, OH, at The ACI Concrete Convention and Exposition. Registration for the Convention is not required if you will be attending the seminar only.

Shotcrete's growing use in construction and its inclusion in ACI 318-19, "Building Code Requirements for Structural Concrete," necessitates on-site inspectors who are knowledgeable about shotcrete materials, application, and quality. This course is the recommended educational component to ACI's Shotcrete Inspector Certification Program, ready for release 3Q 2019. The application and exam will be available at the seminar. Exam costs are separate; please e-mail info@shotcrete.org if you are interested. For more information and registration, visit **www.shotcrete.org/events**.

## ASA AT PSP 2019—REGISTRATION NOW OPEN!

Shotcrete Nozzleman Education will be available at the International Pool | Spa | Patio Expo on November 6, 2019, at the Ernest N. Morial Convention Center, New Orleans, LA. Required for those pursuing ACI Shotcrete Nozzleman Certification through ASA, this is a valuable class for pool contractors, project managers, and supervisors using shotcrete on their pool projects even if they are not pursuing certification. This 7-hour class comes with the CP-60(15) Craftsman Workbook for ACI Certification of Shotcrete Nozzleman and a complimentary Nozzleman membership with ASA. For more information, visit **www.poolspapatio.com**.

Use discount code ASSOC18 for a 20% discount on Conference Super Pass or Free Expo Pass.

## SUSTAINING CORPORATE MEMBERSHIP FIRST ANNIVERSARY

Last July, ASA launched a new membership category, the Sustaining Corporate member, which represents the first change in memberships since the Association started 20 years ago! We would like to take this opportunity to thank our Sustaining Corporate members who have stepped up to show true dedication to ASA's vision to see "Structures built or repaired with the shotcrete process accepted as equal or superior to cast concrete." These members are recognized on our website: **www.shotcrete.org/pages/membership/sustaining-corporate-members.html**, in our publications (refer to page 10), and at the various venues where ASA exhibits. For additional information on the benefits of this membership category, please visit **www.shotcrete.org/pages/membership/sustaining-corporate-benefits.html**.

## "TIPS FOR WINNING" WEBINAR

ASA hosted a webinar this summer to help those interested in entering this year's Outstanding Shotcrete Projects Awards Program raise their chances for success. The webinar discussed items judges look for and how best to present your entry. If you missed this informative webinar, you can find the recording of it on our website here: **www.shotcrete.org/ASAOutstandingProjects**.

## THE 15TH ANNUAL OUTSTANDING SHOTCRETE PROJECTS AWARDS BANQUET

**Save the Date!** ASA will host its 2020 Awards Banquet in Las Vegas, NV, on Tuesday, February 4, in conjunction with World of Concrete 2020. Venue to be determined; we look forward to announcing the winners from the 2019 Awards Program and celebrating with you!

## NOZZLEMAN CERTIFICATION FOR ACI WET-MIX CERTIFICATION AVAILABLE AT WORLD OF CONCRETE 2020

Tuesday, February 4, ASA will again present the Shotcrete Nozzleman Education at the Las Vegas Convention Center in NV. The written and practical exams will also be offered to allow participants the opportunity to pursue either nozzleman-in-training, new certification, or recertification in the wet-mix process. Registration for the education and the exams are separate. Please see **www.shotcrete.org/WOC** for further details. Questions may be directed to ASA at info@shotcrete.org or 248.848.3780.

## SPANISH RESOURCES

Recognizing the need for Spanish materials in the shotcrete industry, ASA started providing an article translated into Spanish with each issue of *Shotcrete* magazine. Articles of particular interest to nozzlemen were chosen. We've collected these articles along with the other resources currently available in Spanish and put them together as a resource on our website; you may find them at **www.shotcrete.org/pages/products-services/spanish-resources.htm**.

## RECURSOS EN ESPAÑOL

Reconociendo la necesidad de materiales en español en la industria del concreto lanzado, ASA comenzó a proporcionar un artículo traducido al español con cada edición de la revista Shotcrete. Se eligen los artículos que son de interés particular para los lanzadores. Hemos recopilado estos artículos junto con otros recursos actualmente disponibles en español y los hemos reunido como un recurso en nuestro sitio web, puede encontrarlos aquí: **www.shotcrete.org/pages/products-services/spanish-resources.htm**.

# NEW ASA MEMBERS

## SUSTAINING CORPORATE MEMBERS

**Coastal Gunite Construction Company**
Bradenton, FL
**www.coastalgunite.com**
Primary Contact: Randle Emmrich
randle@coastalgunite.com

**CCP Shotcrete + Pumping**
Austin, TX
**www.curtisconcretepumping.com**
Primary Contact: Jamie Curtis
info@curtisconcretepumping.com

## CORPORATE MEMBERS

**Advanced Shotcrete Inc.**
Palmdale, CA
Primary Contact: Edgar Cardenas
advanced1000k@gmail.com

**AVM Industries Inc.**
Canoga Park, CA
Primary Contact: Vince Caserta
vince@avmindustries.com

**Kordsa Inc.**
Chattanooga, TN
**www.kordsa.com**
Primary Contact: Altan Gocmen
altan.gocmen@kordsa.com

**Marubeni Specialty Chemicals, Inc.**
White Plains, NY
**www.marubenisci.com**
Primary Contact: Ronald Q. Ruffer
rqruffer@ix.netcom.com

**South Industries**
Menan, ID
**www.southindustries.com**
Primary Contact: Alexis Benson
alexis@southindustries.com

**Southland Holdings LLC**
Toronto, ON, Canada
**www.southlandholdings.com**
Primary Contact: Curtis Bahten
curtis@southlandholdings.com

**West Coast Shotcrete**
Riverside, CA
**www.westcoastshotcrete.com**
Primary Contact: Laura De la Torre
laura-westcoast@att.net

## SUSTAINING CORPORATE ASSOCIATES

**Marcus von der Hofen**
Coastal Gunite Construction Company, Bradenton, FL

**Curt White**
Coastal Gunite Construction Company, Bradenton, FL

## SUSTAINING CORPORATE COMPANY

**SPA Skateparks**
Austin, TX

## CORPORATE ADDITIONAL INDIVIDUALS

**Anthony Aldykiewicz**
GCP Applied Technologies
Cambridge, MA

## INDIVIDUALS

**Randy Murray**
Aquacrete L.C.
Bella Vista, AR

## INTERESTED IN BECOMING A MEMBER OF ASA?

Read about the benefits of being a member of ASA and find a Membership Application under the ASA Membership tab of **www.shotcrete.org**.

# UPCOMING ISSUES

OF shotcrete MAGAZINE

Fall 2019
Inspection/Testing

Winter 2020
Outstanding Shotcrete Project Awards

Spring 2020
Innovations of Shotcrete

# 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:** *We're building a pool 25 x 45 ft (7.6 x 14 m) and had a massive cave-in on our deep end. The builder wants to build temporary walls to shoot the shotcrete against, then remove the plywood walls and backfill with gravel. I'm wondering if this will work and if they will be able to remove the plywood without damaging the shotcrete walls. I know with typical forms you would prep the form with oil so the concrete doesn't stick. Would that be necessary for shotcrete, too?*

*Also, is there a recommended wait time for curing before we backfill?*

**Answer:** Shooting shotcrete against a one-sided form (what you called a temporary wall) is a common way to build a shotcrete wall. Once the shotcrete sets and builds strength, the plywood form can easily be stripped off the back of the wall. Form release agents (not oil) can be applied to the plywood to make the stripping easier. Once the forms are removed and the concrete has gained adequate strength, the walls can be backfilled with compacted soil or gravel, depending on the drainage needs.

We recommend 7 days of curing. Continuous water curing is best, but if impractical, applying a curing compound on the exposed surface at twice the manufacturer's recommended rate for a good seal is acceptable. If they remove the forms before 7 days, they should also water cure or apply curing compound to that newly exposed surface. The shotcrete needs to build up enough strength to resist the external force of the backfill, so check with the pool designer to see what they need for the required strength of the concrete before backfilling. With most good-quality shotcrete materials and placement techniques, you can expect about 4000 psi (28 MPa) compressive strength in 7 days.

**Question:** *We are constructing a new custom roundabout with water running through the bridges on the Coast of Zintan, Tripoli, Libya, using a three-dimensional (3-D) panel system. It's basically a system with an expanded polystyrene (EPS) panel with a wire mesh and shotcrete on both sides. Because of the heat, sea salt, and high humidity of the region, we are looking for a mixture formula for a waterproof shotcrete for the exterior coating with the right aggregate size to help prevent moisture migration to the interior and prevent cracks. Do you have any recommendations for the shotcrete?*

**Answer:** If looking for a low-permeability concrete mixture for shotcrete placement, you should consider using supplementary cementitious materials (SCMs) such as silica fume, fly ash, or slag to reduce the permeability. You should also be sure to require a minimum 4000 psi 28-day compressive strength to assure good paste content and the ability to fully encase your reinforcement. The addition of microfibers and early wetting of the finished shotcrete surface will help to reduce the potential for early-age plastic shrinkage cracking. Proper curing for at least 7 days is also important to help increase strength gain and reduce the potential for drying shrinkage cracking. You can consult our Buyer's Guide (www.shotcrete.org/BuyersGuide) to locate our corporate members, who may consult with you on the mixture design. However, please be aware that many of the panel systems with an EPS core don't use high-velocity (60 to 80 mph) shotcrete for consolidation and compaction of the sprayed concrete, but use a low-velocity sprayed mortar (LVSM). Because LVSM doesn't have the compaction of shotcrete impact, it depends on a more sophisticated and expensive cementitious mixture, often with a latex or other admixture to improve adhesion and reduce permeability. You'll need to consult with the material supplier of the LVSM product to verify the permeability of their in-place product.

**Question:** *A contractor has proposed using shotcrete to repair the concrete in the elbows of a draft tube. I have not heard of shotcrete being used in a draft tube. Velocities would range from 10.5 to 3.8 ft/s (3.2 to 1.2 m/s). I am concerned about whether the shotcrete would delaminate after time or be abraded away, as there is considerable abrasion present where the concrete cover has been abraded away on the floor of the elbow. Any guidance would be helpful.*

**Answer:** Shotcrete has been used in many dam repairs, including large-diameter draft tubes. Shotcrete is high-velocity (60 to 80 mph [100 to 130 km/h]) placement of concrete. When shotcreting with proper concrete materials, equipment, placement, and curing techniques, along with complete surface preparation, you can expect a tensile bond strength of at least 150 psi (1 MPa) between the existing concrete and the newly shotcreted material. Original Portland Cement Association research by Felt from 1956 showed that 200 psi (1.4 MPa) bond shear strength is required for bonded overlays to act monolithically in flexure. Research by Silfwerbrand in 2003 showed that the ratio of bond shear strength to direct tensile bond strength ranges from 1.9 to 3.1. Thus, using the low value of the range with a 150 psi tensile bond strength yields a shear strength of at least 285 psi (2 MPa), well above the 200 psi needed. You may find more information on the bond between concrete and shotcrete layers in the article "Shotcrete Placed in Multiple Layers does NOT Create Cold Joints" that can be found in our article archive at **www.shotcrete.org/media/Archive/2014Spr_TechnicalTip.pdf**.

Regarding the abrasion, shotcrete displays good toughness in a wide variety of demanding applications. Quality shotcrete should have at least a 4000 psi 28-day compressive strength and, with attention to mixture design using silica fume and a low water-cementitious materials ratio (*w/cm*), can comfortably reach 6000 to 8000 psi (40 to 55 MPa) or more. Shotcrete also can easily use steel or synthetic fiber to significantly increase the toughness of the in-place concrete.

Finally, because shotcrete requires no formwork or bonding agent for a high-quality repair, you will find the shotcrete process provides an economical solution.

*[Editor's note: By chance, this issue features an article on a draft tube modification project. Refer to page 22.]*

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