Shotcrete MAGAZINE

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AMERICAN SHOTCRETE ASSOCIATION

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Volume 16, Number 3
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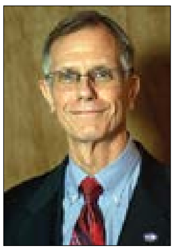
Features

Departments

On the cover: Herbert C. Bonner Bridge
Photo Courtesy of Coastal Gunite Construction Company

But Shotcrete IS Concrete...

By Charles S. Hanskat



Have you ever been asked how shotcrete will perform in a particular application or exposure condition, and the answer is simply "it's the same as any other concrete"? I am constantly running into this question in my consulting practice and in reviewing technical inquiries that come to ASA. Somehow, there is a fundamental misconception by otherwise concrete-knowledgeable engineers, architects, and inspectors that shotcrete is a different material than concrete, yet we know it really isn't.

We mix portland cement, sand, and gravel with water to initiate hydration and ultimately create hardened concrete. Simply shooting concrete in place using high velocity does not change the basic properties of our materials. While it is true that some of our applications require specialized admixtures, such as accelerators or hydration control, and we commonly use silica fume along with the cement, these are well-documented concrete supplements that can be and are routinely used in normal cast concrete, too.

Unfortunately, convincing the specifier or inspector of shotcrete's equivalence to concrete sometimes requires a lot of time and effort to substantiate shotcrete's performance. If we added up all the times you and I, along with all the rest of the shotcrete industry, have had to make this argument in e-mails, letters, reports, meetings, and phone calls, I'd bet we'd find over 10,000 worker-hours and dollars were spent.

And this is where an association like ASA has distinct benefit to all of us in the industry. We can be the central conduit to feed this knowledge to the construction industry. Many of the things we do now support this. We have a system to receive, review, and answer technical inquiries. We conduct on-site seminars upon request about shotcrete. We facilitate annual seminars at World of Concrete. We answer questions at shows where we exhibit. These things help, but the basic problem of lack of shotcrete knowledge and awareness is still quite prevalent. We obviously aren't reaching everyone in the construction world.

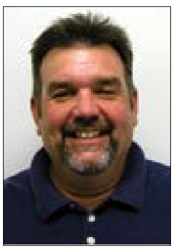
Looking forward, some of our upcoming ASA programs will help. We are establishing a shotcrete inspector training session. The first one is to be held at World of Concrete 2015. We also recently helped fund a basic research effort in shotcrete durability evaluation.

But can we do more? It would be great to get shotcrete adequately covered (or at least mentioned) in civil engineering and construction college classes, so young engineers and construction managers have at least heard some of the facts about shotcrete. Perhaps we should consider *actively* reaching out to engineering and architecture groups doing concrete structures, such as the American Society of Civil Engineers (ASCE), National Council of Structural Engineers Associations (NCSEA), the American Institute of Architects (AIA), state Departments of Transportation (DOTs), and contractor associations such as the Associated General Contractors of America (AGC), Associated Builders & Contractors (ABC), and the Design-Build Institute of America (DBIA) to provide shotcrete education sessions.

We as an association must constantly work to improve the recognition and accurate knowledge of shotcrete to users and specifiers. If you have some ideas you'd like to share with me on ways we can achieve this, I'd welcome your comments via e-mail at CHanskat@HanskatCG.com.

ASA Membership Committee

By Tom Norman



Formed in 1998, ASA has gone through many changes as it grew and adjusted to accommodate the shifting demands of the market and industry. After 15 years, ASA is again looking to reevaluate its role in the shotcrete industry as evidenced by many things, including a reorganization of committees. As newly appointed Chair of ASA's recently formed Membership Committee, I invite you to consider joining this organization at a time of great opportunities. Becoming an ASA Corporate Member today gives you the opportunity to *grow*.

Grow in Awareness: ASA Corporate membership exposes you to many opportunities to increase your customer base. Your company and specialty information are listed in ASA's Buyers Guide, both online and in hard copy. You'll be able to include the ASA logo on your business letterhead, business cards, and website.

Grow in Business: Members have the opportunity to respond to bid requests from the Online Project Bid Submittal Tool. By doing so, you have access to new customers who require your area of expertise/specialty.

Grow in Community: Be a part of a community of like industry contributors. Networking and information exchanges provide you the opportunity to share and learn what's going on in the industry and in your region, brainstorm on issues and solutions that could benefit you or others within the organization, and help increase awareness of shotcrete as a viable means of concrete placement. You'll have additional networking and participation opportunities at the Annual Membership Meeting and committee meetings, as well as be invited to participate in and Chair the various committees. You will find that growing in ASA's community also provides opportunities to grow and gain exposure within the communities you serve.

Grow in Influence: Enjoy opportunities to participate in the organization's direction and gain exposure among your peers and across the industry. As an ASA Corporate Member, you can submit items for Industry News and New Products & Processes sections of *Shotcrete* magazine at no charge, have voting privileges at meetings and Director/Officer elections, submit entries for the annual Outstanding Shotcrete Project Awards Program, and more, as outlined on ASA's website.

Grow in Advantages: Take advantage of discounts on ACI Nozzleman certifications and education as well as all ASA products. A recent addition to Corporate Member benefits includes a complimentary copy of ASA's new *Safety Guidelines for Shotcrete*—a valuable resource for contractors as well as a marketing tool for manufacturing firms.

These are just some of the benefits that you receive directly as a member of ASA. However, ASA's mission to inform and educate the industry is freely available to all. ASA provides a wealth of resources to help you in your business to communicate the benefits of shotcrete to your clients. You may access this information or link directly to our website, **whyshotcrete.org**, to help you promote shotcrete. ASA also offers FREE AIA-accredited seminars to your engineers, architects, and specifiers to help communicate shotcrete's benefits as well as specification resources to those in the position to specify shotcrete. ASA's many developing programs include a Shotcrete Inspector's program to inform those whose jobs are to maintain the high quality of work that builds on the increasingly good reputation of shotcrete-specified projects. But these all require your help, expertise, and support. Membership allows this to happen and brings long-term value to your business and ultimately the industry.

For questions or additional information about ASA (**http://shotcrete.org/membership/index.htm**) and the ways in which you can grow with us, please contact me at tnorman@airplaco.com. We look forward to welcoming you as a member of ASA as well as this new committee.

***Tom Norman**, Senior Production Manager at Airplaco Equipment Company, has been named ASA's Membership Committee Chair. A member since ASA's inception, his goal as Chair is to bring awareness of ASA's existence to the industry and encourage growth in membership.*

Investing in the Future of ASA and Shotcrete

By Mark A. Campo, ASA Executive Director

ASA Leadership Holds Strategic Planning Session

In a proactive effort to successfully lead this association into the next 5 to 10 years, the ASA Executive Committee and select committee members participated in a Strategic Planning session at ASA's headquarters in Farmington Hills, MI, August 2-3, 2014. The goal at this session was to establish an updated vision, mission, and future plan for the Association—one that will drive the association and the entire shotcrete industry to the next level of visibility and acceptance.

Steering the direction of the association requires us to know where we have been, where we are, and where we should be going. Along with the guidance of a professional strategic planning facilitator, the planning group reviewed the association's charter documents and membership trends to know where we have been. They looked at ASA's financial standing and at concrete industry trends to know where we are. And finally—yet, most importantly—the planning group reviewed detailed feedback from members and customers in the shotcrete industry to determine where we should be going.

A survey to all ASA members asked, "How likely are you to recommend membership in ASA to a colleague"; "How effective is ASA at providing a strong unified voice for the shotcrete industry"; and "How effective is ASA at positively influencing industry policy and perceptions about the quality of shotcrete?" It further investigated members' opinions about programs, products, and services that ASA should consider offering to better support the shotcrete industry.

Another survey to ASA's actively participating committee members—many of whom are founding members of the association—asked, "What do you most value about ASA"; "What is the greatest value ASA can provide to the shotcrete industry"; and "What do you see as the priorities for ASA in the next 3 to 5 years? 10 years?"

The outcome of this planning session is a reaffirmed set of core values and mission—essentially an updated roadmap charting the focus of ASA's efforts for the next several years. This renewed strategic plan is expected to be finalized before the Board of Direction at the fall meetings in Washington, DC.

What should we expect to come as a result of an updated strategic plan? Refined membership benefits to meet the current and ever-changing needs of ASA's members; more focused attention toward programs that increase awareness and acceptance of the shotcrete process; and an overall greater focus toward meeting the needs of today's—and tomorrow's—shotcrete industry. Many thanks to ASA's leadership for contributing to this effort, and for setting the course for ASA to enrich the shotcrete industry through its services and products in the coming years.

ASA Pays it Forward by Sponsoring Shotcrete Research and Education Initiatives

In preparing ASA's annual budget for 2014, then-President Michael Cotter asked the Board of Direction to set aside funds that would be used to support projects of significant importance to the shotcrete industry. Providing financial support to projects of strategic importance demonstrates the steadfast commitment by the current leadership of ASA to give back to the shotcrete industry and to promote the industry though research and education. Following are two recent examples of such commitment to shotcrete research and education that have benefitted from the generosity and support of ASA.

Comparative Evaluation of the Transport Properties of Shotcrete

ASA has provided generous support to a research project by LZhang Consulting & Testing Ltd. that compares the transport properties (that is, durability and service life) of concrete placed by the shotcrete method versus "traditional" cast-in-place concrete.

One of the most difficult challenges facing the shotcrete industry has been to prove the durability and reliability of shotcrete as the preferred placement method for many types of concrete construction. This research intends to address those challenges specifically, answering the concerns of many specifiers who may not fully understand the performance, cost, and sustainability advantages of shotcrete. Results from this research are expected to outline those benefits in quantifiable terms.

Colorado School of Mines Shotcrete 3-Day Course

ASA is also a proud sponsor of a shotcrete "short course" being offered at the Colorado School of Mines on September 3-5, 2014. This course will offer a comprehensive look at effective and sustainable shotcrete applications, and is intended for all parties involved in the design and implementation of all types of shotcrete projects.

Take just a quick glance at the course agenda and you will see that at least half of the presenters are notable ASA members, including current and former ASA presidents, officers, committee chairs, and examiners. It goes without saying that this course is expected to provide an excellent opportunity to meet and learn from the leading professionals in today's shotcrete industry.

Please visit the Association News feature in this issue on page 58 for further details on these ASA-sponsored research and education initiatives.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Top of the Class

By William Drakeley

Last year, the project team planning Canterbury High School's new aquatic center brought in watershaper William Drakeley to discuss the facility's state-of-the-art competition pool. Before he could start, however, questions about how it should be built involved Drakeley educating the project team about the distinctions between shotcrete and cast-in-place concrete and which should be used in creating what was to be a huge, monolithic shell

Every so often, our company is confronted by the belief among certain design professionals that, as it is used by the pool industry, shotcrete is simply not viable for use as structural concrete in high-profile watershaping projects. The assumption, I've learned, is that the pool industry is filled with contractors and specification writers who know little about the material and therefore tend to produce substandard results.

I could argue the merits of the case, but let it suffice to say that the upshot of this widespread belief is that institutions and commercial clients hesitate to use shotcrete and instead prefer cast-in-place concrete, which they perceive as having greater quality and reliability in watershape applications.

We at Drakeley Swimming Pool Co. (Bethlehem, CT) recently encountered exactly that prejudice: A private high school that was in the process of designing and building a state-of-the-art aquatic center and an eight-lane, all-tile competition pool offered bid specifications that called for use of cast-in-place concrete, with shotcrete allowed as an alternative.

In approaching the project team, my challenge was two-fold: I had to make our company attrac-


Delivering on the commitments made to the design team was largely a matter of following usual procedures for shotcrete application, including construction of solid, non-vibrating forms; installation of reinforcing steel to ensure complete concrete coverage; and a systematic, patterned approach to what was to be a multi-day shoot


In this case, the pool was so deep that an excavator was kept on hand to ease removal of any concrete spoils or incidental rebound. Frequent tests were also conducted to make certain the shotcrete material was being applied at (or beyond) the specified strength

tive as a fully qualified contractor, but also and more important in my view, I had to convince them that, done properly, a shell made using the shotcrete-application process would be their better choice.

Core Values

Canterbury High School is a prestigious institution in the hills of western Connecticut. Built at the turn of the last century, the campus boasts architecture clad in dark-gray fieldstone and has the look of something out of a Harry Potter movie. An Ivy League ambiance resonates at every turn, belying the fact that the facilities behind the walls are as up-to-date and modern as can be—including an array of first-rate sports facilities.

Before this project, however, the one glaring exception was the school's aquatic center. Our company had done some renovation work on the original pool—an antiquated tub old enough that at one time it used draw-and-fill circulation. At some point after our work was completed, an alumnus who'd been on the school's swim team in the 1950s passed away; in his memory, his family dedicated a multi-million-dollar bequest towards the construction of a new facility.

From the start, the design team made it clear to us that they were after the state of the art. The surrounding structure and amenities for swimmers and spectators were in the hands of top-flight architects, and the pool itself had been designed by Gary Schultz of Aquatica Pools & Water Parks (New York), which, as we observed, had done a wonderful job with the plans and specifications. The one exception, we believed, was their favoring of cast-in-place concrete for the pool's shell.

For bidding purposes, we'd been asked to submit information on a shotcrete structure for comparison to the cast-in-place architectural specification. They might have thought of this as a pro forma exercise, but we jumped at the chance to show why a monolithic shell made using the shotcrete process would be superior in many ways to a typical placed shell. (We were also motivated, of course, by the fact that we had the opportunity to build a top-quality competition pool that would serve a high-profile institution for decades to come.)

We felt we were operating from a position of strength. History has shown time and again, for example, that cast concrete pools have issues with expansion joints and watertightness that sooner or later produce water losses that can never fully be addressed. Our aim was to prove to the project team and Aquatica's specification writers that shotcrete was a viable alternative if only because of its watertightness and structural longevity—not to mention the superior bonding it allowed with finish materials.

Our presentation obviously spurred a response. During the interview with the design group, in fact, the engineering committee quizzed us on what we were going to use as expansion or movement joints, thereby enabling us to explore with them one of the primary advantages of shotcrete: There are no expansion joints, nor is there any need for using bonding adhesive between areas of concrete placed on subsequent days.

This bonding, we know, is a common concern among engineers, who often wonder how it's possible to create monolithic structures when material is placed over the course of many days.

Optimal concrete strength is encouraged when surface evaporation is discouraged, so we do all it takes to keep the surface saturated during the shoot and throughout the 28-day curing period. Done properly, the integrity of the shotcrete surface is so high that the finish can be applied directly to the substrate without bonding or damp-proofing agents

Digging In

Now we were on a roll.

Using the opening they gave us, we explained that transitioning applications from one day to the next included preparing the concrete in a construction-joint format that sets us a 45-degree angle treated with a gun or broom finish.

Before new material is applied, any overspray or miscellaneous dirt would be carefully removed from all exposed steel, and the already-applied material would be maintained in what is known as "saturated surface dry" (SSD) condition so there would be no moisture or liquid changes between already-applied and new material.

We further explained that, by using proper velocity (that is, 375 ft^3/min [10.62 m^3/min]) in the shotcrete process and thereby driving fresh cementitious material into the pores of the previous day's shoot, the result would be a tremendous physical and chemical bond attributable to the properties of cement paste.

Once that issue was cleared away, they raised a second question about what we were going to add to the concrete as a water- or damp-proofing agent to prevent leaks or possible damage to finish materials. (We knew this would be an issue for them, because test holes dug previously indicated that the water table rose to a level 2 ft [0.61 m] higher than the bottom of the dig elevation during certain seasons.)

My team's response was simple: If pursued correctly, the shotcrete process is such that there would be no call for any water- or damp-proofing agent. This was another great opening, enabling us to explain that we would be applying a high-density, low-permeability, low-porosity material; the shell mixture itself would be designed, engineered, and installed to hold water on its own.

Now we called in our big guns, referring to three key documents published by the American

Concrete Institute: CP-60 (02), Nozzleman Certification; 506R, "Guide to Shotcrete"; and 506-4R, "Guide to Evaluating Shotcrete." These publications defined the intended strengths and characteristics of properly placed concrete and completed the process of education we'd begun when our meeting started.

But while the project team knew a good bit more now than they had before, they were still hesitant to go out on a limb—either for me or for shotcrete—so I ended up taking that big step for them.

In retrospect, my proposal was really quite bold: We would guarantee that the pool would reach a defined minimum-acceptable concrete strength in 28 days and that the shell would be demonstrably watertight before finish application—all without any water- or damp-proofing agents. If those criteria were not met, we would rip the pool out and proceed anew with cast-in-place materials.

Basically, they couldn't lose and had lots to gain, so the design team ultimately awarded the job to us and the shotcrete process we advocated.

On Site at Last

By that time, the old facility had been razed, leaving all of us to start with a blank slate. Many trades were to be working on site for the duration of the project, so one of the primary challenges was working with and around the scheduling of other activities—a calendar that involved sporadic stops and starts.

As it turned out, we were first to get going, based on the concept that whoever goes deepest goes first. We began with extensive excavation, and then installed a drainage/dewatering system to take care of any potential issues with the water table. Next, we installed a base of gravel atop which we began installing construction forms, steel, and pool plumbing.

All forms included solid, non-vibrating members to eliminate the possibility of inviting any voids or shadowing in shotcrete application. Once that was complete, we installed the steel reinforcement for walls and floors that were to be 12 in. (305 mm) thick with offset, double mats of No. 5 and No. 4 (No. 16 and No. 13) bars set at 12 in. (305 mm) on center. We used PVC chairs and wheel spacers for proper reinforcing bar separation and full concrete coverage, and set guide wires for elevations, the multiple levels of the bond beam, the floor's slope, and the walls' radiuses.

In all, the application required 350 yd^3 (268 m^3) of material applied in 7 days of shooting spread out over ten days in all. The mixture design was set to achieve a minimum strength of 4000 psi (28 MPa) after a 28-day wet cure.


The finished pool is a triumph on all levels—and testimony to the fact that shotcrete, when applied (as it should be) according to basic concrete-industry standards and procedures, produces non-porous, ready-to-finish surfaces that truly hold water

We started in the radius sections where the walls and floor met to establish critical transition points, then shot the floor in sections. We chose to work with the wet-shotcrete process rather than the dry-shotcrete (gunite) process because we had some control over the environment, and could easily apply a high volume of material without straining our finishers and while achieving the specified minimum strengths.

Once in the pool, we consolidated and leveled off each shot section with a power screed and then applied a light broom finish. Everyone was well aware that the pool was to be lined with 1 in. (25 mm) square tiles, so critical tolerances were maintained throughout. After each day's shoot, we'd place soaker hoses to keep the concrete in a saturated condition. This allowed the mix water to stay within the concrete matrix, thus encouraging optimal strength gain with no surface evaporation.

As mentioned previously, each construction joint was kept in an SSD condition, providing us with moist receiving surfaces—but not ones that were dripping wet, as we wanted to avoid changes in chemistry and water-cement ratios relative to new material we were applying. The pool was quite deep (sloping down from 7 to 12 ft [2 to 4 m]), so we used scaffolds to work on the walls. We also kept an excavator with a long reach on site to facilitate removal of concrete spoils left behind by cutting and trimming and to dispose of small amounts of rebound.

Test samples of the concrete were extracted by an independent service hired by the design team. Technicians performed routine concrete analyses including assessments of the compressive strengths of sample blanks. The first test sample was assessed after 7 days at the lab, and we were all thrilled by the results, which came in at 6200 psi (43 MPa).

Back on site, we let the concrete cure for 28 days. In the week that followed, we filled most of the raw shell with water and found no signs of leakage.

A Smooth Finish

After the mechanical systems were installed (see the sidebar), we applied the tile interior by placing its setting bed directly on the shot product.

This was possible because of the low permeability and high density of the concrete substrate: there were no issues at all with bleed water or bonding ability; indeed, use of bonding agents or water-/damp-proofing agents would only have added a potential bond-breaker to the project. (This approach worked so well that, in fact, the design team is now using these specifications in other commercial projects throughout New England.)

It also helped that, even given the size of the project, the entire process went off in rapid order with very few glitches or delays. We began construction in June 2007 and the pool was commissioned in September 2008 inside a sparkling new building.

One factor that might have helped keep everyone on track was a "Netcast" arranged by the alumni association: they set up cameras on nearby buildings and displayed the entire project on the Internet, 24 hours a day, 7 days a week. Knowing that we were being "watched," all crews were aware that any on-site shenanigans were strictly off limits.

Everyone views the project as a triumph, from the school, its students, and alumni to the architects and design team who pulled everything together. For us, however, everything was sweetened by overcoming misconceptions about the shotcrete process in winning the contract: it was an effort that, we hope, will come to exemplify what the pool industry must do to change perceptions of the way we work. It's also a clarion call urging pool designers, engineers, and builders to pay attention to basic standards and procedures recommended by the American Concrete Institute.

I know that entire organizations have built themselves on the notion that pool concrete is supposed to be porous, have strengths of less than 4000 psi (28 MPa), and can be made adequate by applying some topcoat to make the vessel hold water. The plain truth is that this sort of approach has prejudiced much of the commercial design/construction community against the pool industry.

I'd say it's time to accept higher standards—and then exceed them, project after project.

William T. Drakeley Jr. *is President of Drakeley Industries and W. Drakeley Swimming Pool Company. Drakeley Industries is a shotcrete consulting firm that is dedicated to the training and implementation of the shotcrete process in regards to building water-retaining structures, ground support, and underground shotcrete application. Drakeley Pool Company is a design/build construction and service firm specializing in in-ground, high-end commercial and residential pools. Drakeley is an active member of ACI Committee 506, Shotcreting. He is the first ACI Certified Shotcrete Examiner from the pool industry nationwide. Drakeley is also an ACI Certified Nozzleman, ASA Technical Advisor, Chair of the ASA Pool & Recreational Shotcrete Committee, and serves as Treasurer to the ASA Executive Committee. His writings have been published in national and international trade magazines, including* Shotcrete*,* WaterShapes*,* Pool and Spa*, and* Luxury Pools*. In addition, Drakeley is a Platinum Member of the Genesis 3 Group, a licensed member of the Society of Water Shape Designers, and a member of the Association of Pool and Spa Professionals (APSP). He is also the Concrete/Shotcrete Instructor at the Genesis 3 Pool Construction Schools and NESPA Region 1 Show in Atlantic City. As an Instructor/Trainer, Drakeley has given lectures on shotcrete applications for various pool trade shows and for World of Concrete. Drakeley is an Expert Witness regarding shotcrete applications for the swimming pool industry.*

Durable Efficiency

To the casual observer, the watershape at Canterbury High School looks like any other competition swimming pool—a standard 25 m (82 ft), eight-lane rectangle—but closer examination reveals every feature of this particular facility as being first-rate, from the lighting and HVAC systems to the pool's all-tile finish and surrounding decks.

The pool also boasts wonderful circulation and water-treatment systems more than capable of handling its 308,000 gal. (1,165,907 L) capacity and turnover of 1100 gal./min (4164 L/min) (that is, once every 4 hours, 40 minutes). The system is driven by a 20 hp (15 kW) flooded-suction pump from Paco Pumps (Brookshire, TX), while filtration is handled by a 60 ft^2 (6 m^2) stainless steel vacuum sand filter from Paddock Industries (Rock Hill, SC). The filter is a huge, open tank, fully automated with a 300 gal./min (1136 L/min) backwash flow that uses an air-scour blower. This sub-grade filter also has ample capacity to handle the bather surge.

The IFRS-ASR System 3 stainless steel gutter system, also supplied by Paddock, includes a tile fascia and combines the gutter with the return-plumbing system—meaning all the flow back into the pool is handled via the gutter, thus minimizing penetrations of the pool shell.

The overall system is designed for speed, minimizing wave action during competition and allowing for "automatic surge recovery," which means that if there's a sudden bather surge, an auxiliary pump activates, evacuates the gutter, and momentarily reverses flow through three 24 in. (610 mm) square main drains (each of which is equipped with a hydrostatic relief valve). This way, the gutters never flood to the point at which they might cause waves to rebound into swimming lanes.

Chemical treatment is handled by an automatic sodium hypochlorite system from PPG (Pittsburgh, PA) managed by a PC 6000 ORP controller from Chemtrol (Santa Barbara, CA). That primary system is supported by an ultraviolet treatment system supplied by Hanovia Ltd. (Slough, Berkshire, United Kingdom) that reduces chlorine demand.

—W.D.

Using Galvanic Anodes in Shotcrete Repairs

By David W. Whitmore and J. Chris Ball

In recent years, the use of embedded galvanic anodes in concrete repair has continued to increase. Corrosion of reinforced concrete structures such as bridges and marine piers is typically caused by penetration of chlorides into the concrete. When sufficient chloride reaches the reinforcing steel, typically 0.03% by weight of concrete in noncarbonated concrete, the natural protection afforded to the steel in alkaline concrete breaks down and corrosion is initiated. Because the corrosion by-product, iron oxide, occupies a greater volume than the steel, internal concrete tensile forces from expansion of the reinforcing steel cause concrete cracking, delaminations, and spalling.

Fig. 1: Corrosion damage on concrete bridge pier

Patch-Accelerated Corrosion

When these structures are repaired, chloride-contaminated but sound concrete remains in place. An electrochemical incompatibility can occur between the new chloride-free repair and the remaining chloride-contaminated concrete. These new corrosion sites can eventually cause new concrete damage adjacent to the previous repairs.

Embedded Galvanic Anodes

The purpose of using embedded galvanic anodes is to mitigate this patch-accelerated corrosion activity. Embedded anodes can be used around the perimeter of the repair or on a grid pattern throughout the repair area. When the anode is connected to the reinforcing steel, a protective current is provided to the steel, which will prevent or control corrosion in the area around the anode.

A good reference for those specifying and applying embedded galvanic anodes is "Repair

Fig. 2: Patch-accelerated corrosion in parent concrete around previous repair

Fig. 3: Galvanic anode for concrete repair

Application Bulletin (RAP) 8—Installation of Embedded Galvanic Anodes," which is a free download from the American Concrete Institute (ACI) (**http://www.concrete.org/Store/ProductDetail.aspx?ItemID=ERAP8**). This guideline details anode nomenclature and installation guidelines. For example, Type 1 anodes are attached inside the patch repair and Type 2 anodes are placed into drilled holes in sound concrete.

Resistivity of Repair Materials

As detailed in the ACI RAP 8 document, concrete repair material selection is an important consideration for repairs that include Type 1 galvanic anodes installed inside repairs.

> *"Resistivity of repair materials or concrete for use with embedded galvanic anodes should be less than 15,000 ohm-cm. High-resistivity materials such as epoxies or highly polymer-modified repair mortars greatly reduce the available galvanic current or prevent the anodes from functioning properly. If a low-resistivity material is not suitable for the full repair, anodes can be embedded in individual pockets of low-resistivity material. These pockets should completely encapsulate the anode and completely fill the space between the anode and the concrete substrate."*

The recommendation for repair materials to have a resistivity of less than 15,000 ohm-cm allows sufficient protective current to flow from the anode to the steel. Based on our experience, a maximum of 15,000 ohm-cm resistivity approximates to roughly a minimum rating of 1500 coulombs using the Rapid Chloride Permeability Test (ASTM C1202). Figure 4 shows a graph based upon data compiled from various sources and could be used as a general guide; however, actual resistivity testing of the repair material is recommended. As a service to the industry, our company will test submitted repair material samples at no charge.

Anode Installation Methods

On the surface, the resistivity requirement may cause a problem for many shotcrete mixture designs, especially if it contains significant levels of silica fume to densify the mortar and to improve shotcrete build. But as the ACI RAP 8 guide suggests, it is acceptable to place lower-resistivity mortar between the anode and the concrete substrate to create a conductive bridge between the anode and the concrete substrate. When anodes are used with shotcrete, using a conductive bridge of embedding mortar will also eliminate the possibility of shadowing and overspray pockets behind the anode (more on that later).

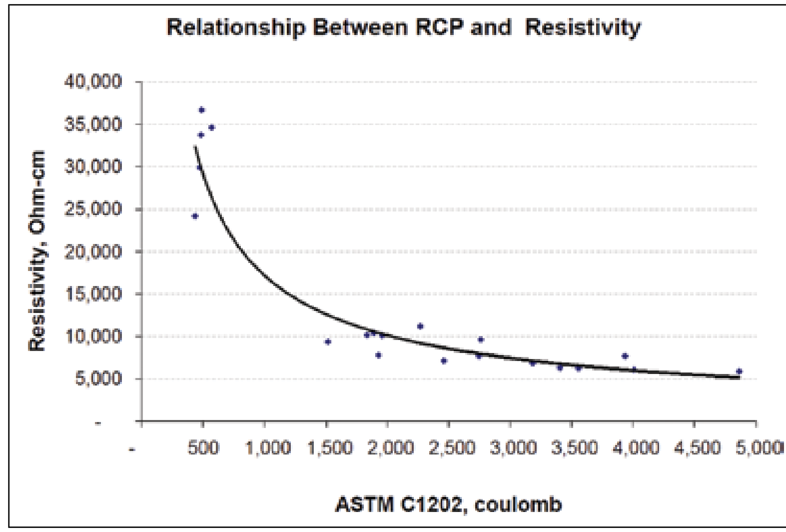


Fig. 4: Approximate relationship between resistivity and rapid chloride permeability

Fig. 5: Embedding mortar used to create a conductive path between the anode and the concrete substrate

Fig. 6: Type 2 anodes placed into holes drilled into the parent concrete and connected to the steel in the repair

Another option is the use of Type 2 anodes. In this case, holes for the anodes are drilled around or adjacent to the repair. In some instances, using Type 2 anodes may be preferred for repairs where concrete removal behind the reinforcing steel is limited for structural reasons or where low cover is present. If the use of Type 1 anodes with embedding mortar is acceptable to the designer, this process would be preferred, as it is considerably less labor-intensive.

Fig. 7: Type 2 anode repairs completed with dry spray shotcrete

As mentioned previously, the use of embedding mortar to create a conductive bridge between the anode and the parent concrete allows anodes to be used with higher resistivity repair materials and to prevent the risk of shadowing behind the anode. If a shotcrete material with resistivity below 15,000 ohm-cm is used, it still may be preferred to use the embedding mortar to prevent shadowing.

If embedding mortar is not used, it is recommended to install the anode such that the flat side faces the steel. This process reduces the cross-sectional area of the anode facing the nozzleman and can be helpful in minimizing any shadowing which may occur. Another option would be to use thin, elongated anodes that fit nicely beside the reinforcing steel.

Summary

The use of embedded galvanic anodes in shotcrete repairs provides an added level of

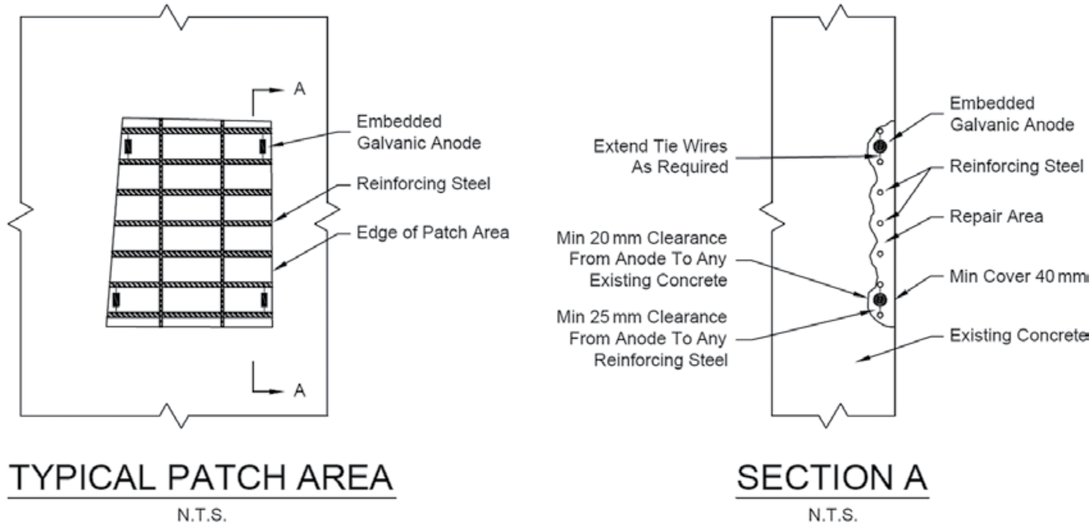


Fig. 8: Installation of disc-shaped anodes with narrow side toward nozzleman to minimize area behind the anode

protection from future corrosion. If repair materials have a resistance higher than 15,000 ohm-cm then a conductive mortar bridge should be used. Alternately, anodes can be placed outside of the repair and connected to exposed steel within the repair area.

The use of embedding mortar can also be beneficial to prevent shadowing even if the repair material resistivity is less than 15,000 ohm-cm. If no embedding mortar is used, then using thin elongated anodes or installing disc- or oval-shaped anodes so that the narrow side faces the nozzleman will reduce the area behind the anode.

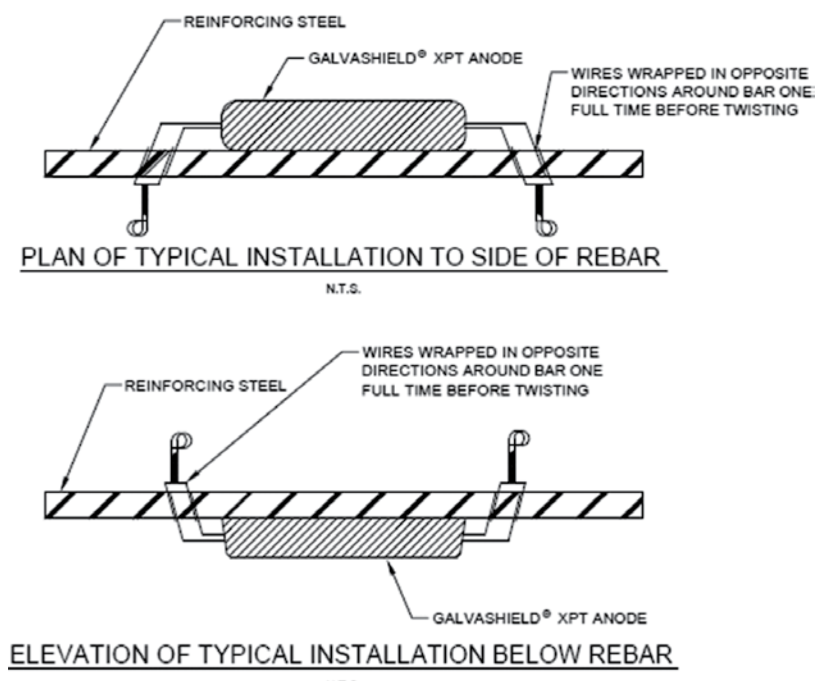
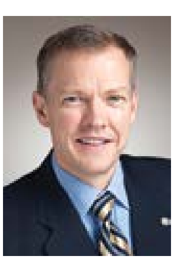


Fig. 9: Thin elongated anodes are ideal for shotcrete repairs

Fig. 10: Thin elongated anodes installed prior to shotcrete repair. Installation behind the reinforcing bar further reduces cross-sectional area



***David W. Whitmore**, P.Eng, is President of Vector Corrosion Technologies, a company which specializes in the corrosion protection of steel in reinforced concrete structures. Whitmore is a licensed professional engineer and a NACE Certified Cathodic Protection Specialist. He has been an ICRI member for over 20 years and is a Fellow of ACI and CSCE.*

***J. Chris Ball** is Vice President of Marketing and Innovation for Vector Corrosion Technologies based in Tampa, FL. Ball has over 20 years of construction industry experience with a specialty in concrete repair and corrosion protection systems. He is a member of ACI, ICRI, and NACE.*

Bridge Preservation over the Oregon Inlet

A History of Concrete Rehabilitation on North Carolina’s Outer Banks

By Martin Emmrich

Fig. 1: Herbert C. Bonner Bridge
Photo by Smkybear, courtesy of Flickr.com via Wikimedia Commons

Along North Carolina’s Outer Banks, the Oregon Inlet joins the Pamlico Sound with the Atlantic Ocean and separates Bodie Island to the north from Pea Island to the south. It is traversed by a 2.5 mile (4 km) bridge, the Herbert C. Bonner Bridge, which serves as a lifeline for thousands of residents (Fig. 1).

Over 2 million cars cross the bridge annually, providing islanders access to work, schools, and health care on the mainland while also providing access for an important part of North Carolina’s annual $19.4 billion tourism industry. With landmarks such as the Cape Hatteras Lighthouse, one-quarter of Dare County’s overall economic impact comes from Outer Banks tourism alone.

The Bridge’s History

The bridge was built by the North Carolina Department of Transportation (NCDOT) in 1963 for $4.1 million to replace the existing ferry route that could no longer keep up with the growing traffic. It was built without technology and methods considered standard practice today—no epoxy-coated reinforcing steel, no advanced paint coatings for steel members, no enhanced concrete mixture designs, and only a minimal amount of concrete cover over reinforcing steel.

Like many of today’s bridges, it has out-lived its intended 30-year lifespan. Over the course of over 50 years, the bridge has taken a beating, including weathering many storms, withstanding corrosive saltwater and air, enduring harsh current, and sustaining numerous boat crashes. The chloride-laden salt air has taken a toll on the bridge’s embedded reinforcing steel, creating concrete spalling, and the turbulent waters of the inlet are constantly shifting the sand on the ocean floor, undermining the piers that support the bridge.

“The concrete is essentially rotting from the inside out as salt has found its way to the internal reinforcing steel causing the steel to corrode,” said State Bridge Management Engineer Greg Perfetti. “We’ve also had problems with scour over the years, where the sand around the piers gets washed away” (NCDOT Press Release, 9/4/2013).

Bridge Preservation Efforts

NCDOT wants to replace the structure, but a replacement is on hold due to lawsuits. In the interim, NCDOT started repair work to keep this essential connection to the barrier island open. To date, Coastal Gunite Construction Company has performed three separate concrete rehabilitation projects on the structure.

The first rehabilitation project began in 1987, nearly 25 years after the bridge first opened. Coastal Gunite repaired spalled concrete and damaged reinforcing steel on the bridge bents—everything from the support bearings to the waterline, including bent caps, columns, and footers (Fig. 2).

The project took 2 years, and all distressed concrete was identified, removed, and replaced. The shotcrete mixture used for the repair was a simple 3:1 sand-cement mixture that was batched on-site by the contractor.

"We thought that would be our one and only rehab on the Bonner Bridge. We repaired everything on the substructure and figured they'd build a replacement before anyone had to do more concrete repair," said Curt White, President and Founder of Coastal Gunite Construction Company. "Well, 20 years later, there was no replacement and we were contracted to perform more repairs," he continued.

In 2008 and 2009, Coastal Gunite repaired spalled concrete and damaged reinforcing steel on the bridge bents. In addition, the underside of the superstructure was repaired, including the concrete beams and the underdeck. Interestingly, all the repair work done in this phase was on concrete NOT repaired 20 years earlier. All of the earlier concrete repairs were still in sound condition (Fig. 3).

Then, in 2013 and 2014, Coastal Gunite performed a third round of repairs on the bent caps and underdeck. This repair addressed new areas that were not previously identified for repairs. Both the second and third repair iterations were performed with a prepackaged shotcrete mixture enhanced with silica fume and polypropylene fibers.

Tim Ayers, Coastal Gunite Project Superintendent, oversaw the concrete rehabilitation in both 2008 to 2009 and 2013 to 2014. During these projects, he became intimately familiar with the structure and its past repairs. As a testament to the durability of shotcrete in marine conditions, Ayers maintains that all previous shotcrete repair work has remained intact and all repair work in return visits consisted of newly identified damage to the original concrete.

"We've gone back to spots on the bridge and saw shotcrete patches that were placed 20-plus years ago," said Ayers. "And you know what?

Fig. 2: Chipping of unsound concrete

Fig. 3: Unsound concrete removed

Interesting Fact

Oregon Inlet was formed when a hurricane lashed the Outer Banks in 1846, separating Bodie Island from Pea Island. Similar to other inlets along the Outer Banks, Oregon Inlet moves southward due to drifting sands during tides and storms. It has moved south over 2 miles since 1846, averaging around 66 ft (20 m) per year.


Fig. 4: Freshly shot pier column

Those spots are still solid. They look like they were just shot last week" (Fig. 4).

Repair Challenges

The shotcrete crews faced many challenges performing the bridge repairs over the years. These included finding safe access to hard-to-reach locations as well as dealing with the same site conditions that make it a harsh environment for a bridge. "It's a tough place to work sometimes. There is rain, wind, tides, and fast currents. There's no hiding from the elements on this bridge," remarked Ayers.

Coastal Gunite employed a truck-mounted aerial platform to access a majority of the underdeck work and swing-stage scaffolding to access the columns and footers (Fig. 5). Where feasible, barges were also used to access bent footers.

In some locations, the current was too strong for access by water. "We had to get a snooper truck with a platform attached to get to some spots that we just couldn't reach with our systems," said Ayers. "Also, we had to design our own access system for some spots because of some unique features of the bridge," he added.

Another obstacle was the requirement to vacate the bridge for regular survey inspections. The department installed a series of points marked along 150 of the bridge's 200 spans and uses mobile scanning technology to determine if any of those points have moved. Movement would indicate pile settling, among other things.


Fig. 5: Shotcreting pier cap

On December 3, 2013, Coastal Gunite's crew was working on the bridge substructure when NCDOT determined that the bridge deck had dropped an unsafe level—scour had caused a set of piles to settle. The bridge was immediately closed to traffic and the shotcrete crew was forced to evacuate the project. NCDOT instituted its emergency protocol and implemented ferry service for vehicle access to the island. After an aggressive dredging effort that placed approximately 30,000 yd^3 (22,937 m^3) of sand around piles that were severely scoured, the bridge reopened to traffic on December 15, 2013.

*Major Repairs Since 1990**

Year	Description
1991	Replaced spans
1992	Scour protection
1994	Riprap
2005	Scour repair
2006	Repair concrete girders
2009	Repair fender system
2008	Add concrete subcaps and pile jackets
2008	Concrete rehabilitation and repair (shotcrete)
2011	Steel repair on channel spans
2011	Scour protection
2012	Install crutch bent and scour protection
2013	Concrete rehabilitation and repair (shotcrete)
2014	Steel crutch bent repairs

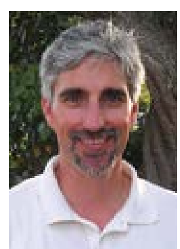
*Repair projects in excess of $500,000.
Source: North Carolina Department of Transportation

Replacement on the Horizon?

NCDOT first began the process of investing in a new bridge in 1989. Over the course of over two decades, NCDOT has completed many detailed studies analyzing options for replacing the bridge. While several permits have been obtained to proceed with a replacement, lawsuits continue to plague the process.

If all legal and administrative hurdles were cleared today, according to Pablo Hernandez, Resident Engineer for NCDOT, it would take at least 4 years for a replacement to be in place. Therefore, continued evaluation and maintenance of the structure is required.

"You never know," says White, "with required bridge inspections and safety concerns, we may come back yet again to repair more concrete before a replacement is built."



***Martin Emmrich** is a Project Manager for Coastal Gunite Construction Company. Based in Bradenton, FL, he has overseen dozens of concrete rehabilitation projects including shotcrete services from New York to Florida. Among others, he is currently managing projects for the Florida Department of Transportation featuring shotcrete repair coupled with cathodic protection.*

Marine Structures: Pier Projects

By Tommy Pirkle and Randell Ogburn

Marine piers are abundant in the United States and are generally made of concrete. While composite materials, steel, treated wood support piles, and thick rubber fender systems are commonplace, concrete remains the main component of most pier structures. The majority of these structures were constructed long ago, and given their constant exposure to destructive elements, they require routine maintenance. This includes repairing the deteriorated concrete, which is exacerbated by inclement weather, freezing-and-thawing cycles, continuous wetting and drying from tidal action and, especially, the chlorides in salt water, which will eventually take a heavy toll on concrete and its embedded reinforcement. The shotcrete process has been the restoration method of choice by many to restore the concrete on a large number of these facilities seeking to combat the accelerated deterioration process that is part and parcel of concrete marine structures.

The single most important factor when bidding or working on a saltwater pier is having a complete understanding of the perpetually changing tides. Each day, as the sun, moon, and earth interact with each other, ocean levels fluctuate, yielding two high tides and two low tides. The ocean is constantly moving from high tide to low tide and then back to high tide, and there are approximately 12 hours and 25 minutes between the two high tides. Given that a considerable amount of marine repair work requires physically being on the water underneath the structure itself, the ever-changing tides cause a number of issues not confronted on more conventional job sites, including shortened work days and a work schedule that is constantly changing according to the tide (Fig. 1).

There are two main types of tides: spring tides and neap tides. Spring tides (which, contrary to their name, do not have anything to do with the season) are very strong and occur when the moon is full or new. Neap tides occur during the quarter moon phases and are very weak. This results in a smaller difference between high and low tides during a neap tide.

Another key factor to take into consideration during the bidding process for pier work is access. Using work floats to navigate throughout the site is preferred, but simple, provisional decking made out of lumber or cables and scaffold boards works well on higher-volume jobs or where the work is too high to reach safely from the float stage. Float platforms are the most cost effective if the work is accessible at both low and high tide. However, many times a wide float will not be able to get around the existing piles or can become grounded on unseen impediments in the water as the tide lets out. This is especially true in situations where additional piles were installed to support today's heavy cranes that are necessary to unload the ships' cargo (Fig. 2).

Fig. 1: Night work as a result of the constantly changing schedules

Port Elizabeth

Elizabeth Marine Terminal is located on the Newark Bay in Jersey City, NJ. It is operated by the NY/NJ Port Authority. This port is the 22nd busiest in the world and is the largest container port in the eastern United States. Port Elizabeth is comprised of a large pier with 10,128 ft (3088 m) of ship berth space. Work must be performed around docked ships from all over the world, which are in a constant state of loading and unloading their cargo. The design engineer's method of repair for this concrete structure is shotcrete, and the work generally consists of pile cap and underside deck repairs.

The scope of work includes deteriorated concrete removal, cleaning or replacement of severely rusted reinforcement, and the installation of welded wire reinforcement with anchors. Shotcrete is then applied and cured. Where the

Fig. 2: Preparation of the work barge

work is not visible, a natural gun finish is specified. Another typical, yet more difficult repair is the total encapsulation of the top of a support pile to a concrete pile cap with shotcrete. The piles have to be recentered underneath the pile cap using a come-along and wedges to secure it in place. After the removal of barnacles and other contaminates, any unsound concrete is removed and welded wire reinforcement is wrapped around the pile cap and the support pile, thus “bridging” or “locking” them together. Expansion anchor bolts are installed to secure the welded wire reinforcement and shotcrete is then applied with a minimum thickness of 6 in. (150 mm). This jacket type of repair is extremely tidal-affected, as the top of the pile and pile caps are often completely submerged during certain high-tide cycles.

Ferry Slip Renovations at Liberty State Park

Liberty State Park is located on the Upper New York Bay and is one of New Jersey’s most dramatic and popular parks. This park is the only location in New Jersey with ferry service to Ellis Island and the Statue of Liberty. Passengers board the ferries from loading platform piers adjacent to the Ferry House Building. Ferry House Platform #2 is a concrete box structure built on timber piles and supported by large triangle-shaped concrete pile caps, also supported by timber piles (Fig. 3 and 4). The only access to the underside or inside of the structure is through a small hatch deck door on top of the platform deck. Spalled concrete including severely eroded pile caps below the platform deck and along the length of the inside and outside walls were repaired with shotcrete. Various spalls along the outside walls were over 9 in. (225 mm) deep and only accessible during a low spring tide elevation, thus allowing only 2 hours of productive work time. Concrete underdeck beams were also repaired. The beams ran the width of the pier and were only reachable by the workforce during neap tide cycles. Narrow, lightweight float stages were used to execute this work because the only access was limited by the small hatch door. Surprisingly, the inside walls of the structure were in decent shape, with minor spalling but with substantial concrete erosion. The spalls were chipped, walls pressure-washed, and galvanized welded wire reinforcement installed and supported with expansion anchor bolts attached to the substrate. Shotcrete was then applied to a thickness of 3 in. (75 mm) to fill the spalls and add additional coverage over the existing reinforcement on the eroded sections of the walls (Fig. 5).

Fig. 3: Spalls along the outside wall of the Ferry House Platform #2

Fig. 4: Triangle-shaped piles and underdeck beams repaired and encased with shotcrete

Safety Concerns

Typically, when there is ship activity, pier security is very strict. A current Transportation

Workers Identification Credential (TWIC) card along with a Secure Worker Consortium (SWAC) card for NY/NJ Port Authority work are generally required for every person to enter a facility or work on a ship pier.

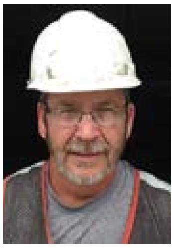
Working on a pier structure is dangerous and safety should be a top priority. A Health & Safety Plan (HSPA) and a Job Hazard Analysis (JHA) should be written before mobilization and issued to all employees.

Besides the normal safety concerns related to any shotcrete project, a JHA for working on a pier should include the hazards associated with working on a work barge or float stages, with special considerations to access and egress. The JHA should also include workers wearing and maintaining a coast guard-approved Personal Flotation Device (PFD), instruction on boat safety, and education for handling unexpected wakes generated from water traffic.

Fig. 5: Unsound concrete removed with pneumatic chipping hammers

The destructive effects of water, especially salt water, mean that concrete-based marine structures such as piers require constant upkeep. Freezing-and-thawing cycles, tidal wetting-and-drying action, inclement weather, and chloride exposure often accelerate the damage and erosion sustained by concrete exposed to the marine environment. At the same time, pier work, by its very nature, creates a number of atypical issues not encountered on non-marine job sites. Productive work days are shorter. Access is typically limited. Workers have to work from unstable floats rather than solid ground. Unforeseen impediments to working can abruptly arise, more so than at on-land sites. Because of these conditions and issues, pier work requires an understanding of marine science, creative solutions, and most importantly, patience.

Tommy Pirkle *has over 30 years of experience in the shotcrete industry and is Co-Owner of Eastco Shotcrete LLC. He is an ACI Certified Nozzleman and oversees company sales and operations.*



Randell Ogburn *is a Supervisor for Eastco Shotcrete, LLC, with over 30 years in the shotcrete business. His area of expertise and primary focus is on marine structures. At Eastco, he is responsible for developing and executing the work plans for marine and other projects.*

Saltwater Pools

By Mason Guarino

By now, most people who have a pool or have been around pools in the last few years have heard about the "new" technology of using salt water in pools. Comments often include how great they are and how good the water feels. Saltwater pools do typically have a soft water feel to them, but chlorine is still needed in a saltwater pool. There are a few misconceptions, however, surrounding saltwater pools that need to be considered.

Fig. 1: Pools with salt still look the same as pools without

The saltwater technology was originally invented in the 1960s in Australia and brought to America in the mid-1980s. So this "new" technology is not so new. In fact, it is has already been around long enough to make it illegal to connect a saltwater pool system to the city sewer system in certain parts of the country. Santa Clarita Valley, CA, has put this ban into effect to meet their state-mandated chloride limits in wastewater discharge. Other municipalities have banned the technology all together. When saltwater pools are drained, the salt is discharged into parts of the ecosystem that are damaged by the high-chloride salt, including plants, animals, and drinking water supplies.

Saltwater pools use what is called a saltwater chlorine generator. This device, in the plumbing system end of the equipment, takes the dissolved salt in the pool water and separates the sodium ions from the chloride ions using positive and negative electrical charges. The chloride ions then turn into chlorine gas that reacts with the water creating hypochlorous acid, or what is typically referred to as chlorine, in the swimming pool. However, in addition to the chlorine being created in the pool water, sodium hydroxide is also created when the sodium ions are separated from the chloride ions. Sodium hydroxide is very alkaline and will raise the pH of a swimming pool. When the pH is raised by the sodium hydroxide, the hypochlorous acid ions will separate. This separation significantly reduces the bacteria- and germ-fighting chlorine because the hydrogen ion wanders off and the hypochlorite ion starts to be corrosive to its environment, namely the pool itself. This is combatted by adding muriatic acid on a regular basis instead of chlorine. This keeps the pH level normal and keeps the hypochlorous acid (chlorine) intact and able to fight off the bacteria and germs in the pool.

As with every pool, maintenance and upkeep are essential to allowing the pool a long service life. As we all know, sometimes maintenance can be neglected. The effects of neglecting the maintenance on a typical chlorine pool will become obvious quickly—the pool will turn green and things will start to grow in a short period of time. Neglecting the maintenance on a saltwater pool

Fig. 2: This is one brand of salt that is used—they all work pretty much the same. These are 40 lb (19 kg) bags; residential swimming pools typically need 25 to 30 bags (roughly 1000 to 1200 lb [454 to 544 kg]) to get a salt system started

will do the same; however, it will take much longer to see the effects and for the pool to turn green. Salt needs to be added to the pool occasionally along with muriatic acid to maintain the correct pH level of 7.2 to 7.8. When muriatic acid is not added to a saltwater pool, the pH will rise, and the pool will become low in chlorine and high in the oxidizer ion, hypochlorite. This will not be nearly as visually obvious as the pool turning green when using with chlorine. The hypochlorite is a very aggressive chemical and will begin to eat away at everything it can—the pool plaster, metal railings, heater internals, and just about anything around the pool that is susceptible to corrosion—while the low chlorine level will keep the pool from turning green.

Based on personal experience, when a residential pool is well-maintained, a saltwater system makes for very nice and soft water. The salt cannot typically be tasted because the level of salt in a residential pool is under 4000 ppm, which is the typical human taste level of salt. In comparison, ocean water is around 35,000 ppm.

The commercial saltwater pool is difficult to design, sell, and then to maintain correctly to prevent premature deterioration due to the salt. There are two different types of commercial saltwater pools. One system has a separate tank in

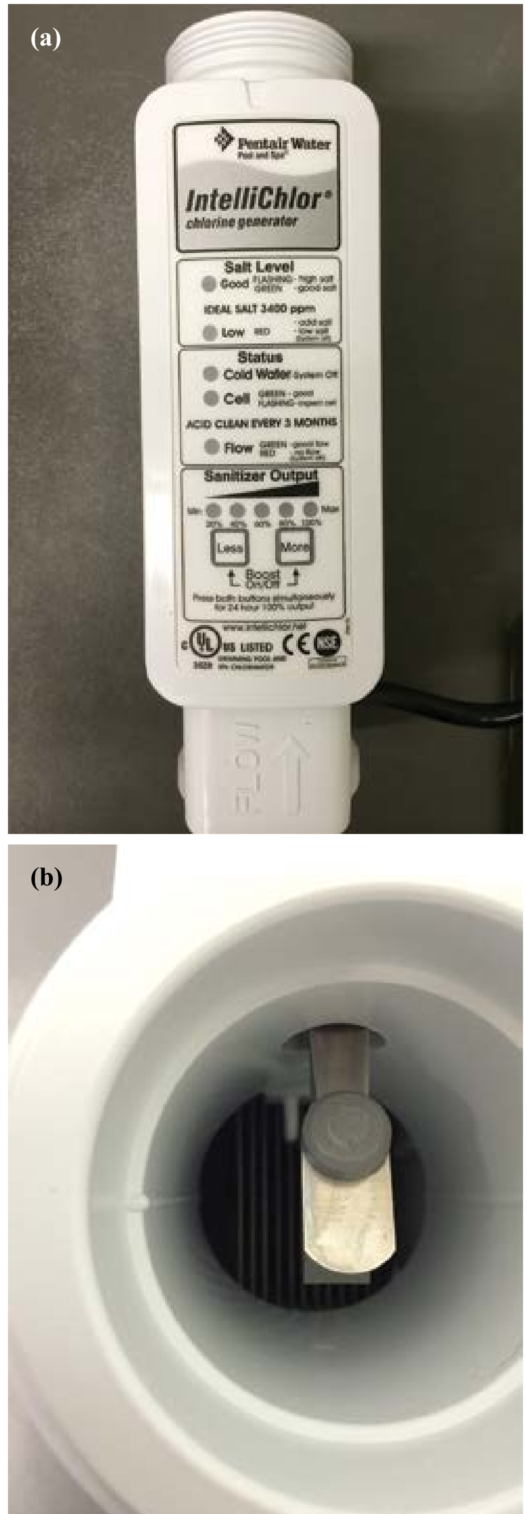


Fig. 3: Close-up views of a residential salt cell: (a) information it provides and the adjustments that can be made; and (b) close-up of the flow sensor which shuts the cell off when there is insufficient flow. Also shows the fins that provide the charges that separate the ions as the salt water passes through

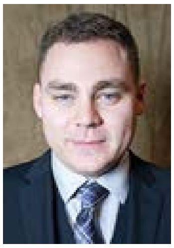
the equipment room containing a high concentrate of salt water that is mixed to create a low-concentration salt/chlorine-water solution. This chlorinated water solution is then injected into the pool, which is similar to the way liquid chlorine would be injected into the pool. This type of system for a large pool is quite large and takes up a lot of space in the equipment room. During the pool design process, the salt chlorination system is not always taken into account and the area for the chlorine salt-generation tank ends up under-sized and uses a smaller tank that cannot keep up with the demand of a large commercial pool.

The other commercial-style saltwater system is similar to the residential version with a generator that ionizes the molecules. This requires a very large unit. The unit is so large that it can send an ionizing electrical current throughout the entire pool and as a result, attacks anything metal, including the heaters, pump components, railings, lane line components, and lights. Thus, pools using this type of system need to be built with all-plastic components that can resist the ionizing currents. The items that cannot be plastic, such as heaters, flow meters, and other sensors, must be specifically designed for service in saltwater pools. Additionally, sacrificial anodes need to be installed to try to compensate for the ionizing current. On top of all the saltwater requirements for a commercial pool, some states and municipalities still require a backup chlorine system which is powerful enough to keep the pool online should the salt system fail. As a result, salt systems for commercial pools can be costly to install.

The alternative to a saltwater pool is the more common liquid or pelletized chlorine. However, there are also other technologies used in municipal water treatment facilities being brought to swimming pool disinfection systems. Ultraviolet (UV) and ozone disinfection are two systems that, in combination with conventionally chlorinated pools, actually maintain a lower chlorine level than with salt systems. In turn, a pool ends up with as little chlorine as legally possible. The UV system is simple. The water passes through a chamber exposed to correctly powered UV light that kills the bacteria and germs in the water system. It can even destroy the chlorine if it is turned up too high. The ozone disinfection system creates ozone and injects it into the pool water system at the pump. The ozone also kills the bacteria and germs, as well as actively breaks down non-living waste products in the pool water that can combine with chlorine, causing unhealthy by-products that can irritate the skin submerged in the water and respiratory issues for exposures just above the water. Each of these devices greatly reduces the demand for chlorine and, when combined, can significantly reduce chlorine consumption, making it easier to safely maintain a very low level of chlorine in the pool.

A lot of these items are specific to all types of swimming pools, whether they are shotcrete, liner, cast-in-place, or any other method. However, properly placed shotcrete is the best product to withstand any of the negative effects that salt can have on the structure. Liner pools typically have more exposed metal pieces and cast-in-place pools have planned construction joints. Shotcrete pools are monolithic and the only metal portion is the embedded reinforcing bars. With a suitable concrete mixture design and proper nozzling technique, the opportunity for the chlorides in the salt water to penetrate to the reinforcement is substantially reduced. Cast-in-place pools have construction joints that have a higher chance of allowing the salt water to penetrate to the reinforcement and cause corrosion problems, especially if the waterstop is improperly placed or poorly encased. Epoxy-coated reinforcing bars can be used if there is concern regarding the salt water reaching the bars, but if not properly handled, breeches in the coated reinforcing bars in the field can actually cause more corrosion problems than uncoated reinforcing bars. Epoxy-coated reinforcement is not necessary when proper construction methods are used.

In summary, saltwater pools certainly have some comfort benefits for the user. However, the challenges in designing, building, and maintaining these systems need to be considered in the overall cost-effectiveness of the pools. Though saltwater pools do reduce the amount of chlorine needed for disinfection, alternative systems like UV and ozone can be just as (or even more) effective.



Mason Guarino *started in the pool industry when he was 14, learning how to install reinforcing bar. Since then, he has worked on all phases of swimming pool construction. Guarino has been with South Shore Gunite Pools & Spas, Inc., full-time since graduating from the Wentworth Institute of Technology with his BS in construction management in 2009. Guarino currently serves on ASA's Board of Direction and is an ACI Certified Nozzleman.*

Warning!

Part I of a Two-Part Series on Wet-Mix Equipment Maintenance

Improper On-Job Lubrication Will Dramatically Reduce Wet-Mix Equipment Service Life

Do you know how to properly lubricate your wet-mix pump?

By Oscar Duckworth

Two new wet-mix shotcrete pumps are ordered by different clients. Although both pumps are identical in every way, one pump will cost less to operate and last far longer than the other. Why? Wet-mix pumps require specific on-the-job lubrication procedures which are unique to this type of equipment. But many operators possess very little knowledge on how to properly perform these critical maintenance steps.

Specific lubrication procedures must be properly performed at every use or frequent component failures and diminished service life will result. Do you know what these essential procedures are and how to properly perform them?

Understanding the Lubrication System

Wet-mix pumping equipment is a costly investment. Its long-term performance and durability will ultimately be determined by the effectiveness of the equipment's various lubrication systems.

Typical wet-mix pumping equipment uses at least four individual lubrication systems. Each system possesses specific maintenance requirements.

Diesel engine internal components are lubricated and cooled by a pressurized oiling system that circulates oils with specific properties necessary for diesel engine longevity. The hydraulic system is protected by special high-pressure hydraulic fluids which are continuously supplied to critical components, then cooled and filtered during operation. Aside from recommended maintenance intervals and monitoring fluid levels, both of these sophisticated lubrication systems require little on-the-job maintenance.

Engine and hydraulic systems power the concrete pumping components that do the work of supplying high-pressure concrete to the placement system. The concrete pumping components—concrete cylinders and piston cups, shift valve bearings, seals, and/or outlet flange bearings—and the hopper re-mixer, must operate while fully immersed in concrete. Additionally, these parts must function without the benefits of a sophisticated lubrication system. Even the most modern pumping equipment relies on comparably primitive forms of lubrication to prevent wear and corrosion of precision concrete-pumping component surfaces.

The concrete-pumping piston cups and hard-chromed material cylinders are typically lubricated and cooled by water. The use of other lubricants, however, such as water-soluble oils or hydraulic fluid, can greatly increase component service life. An ample volume of water-box lubricant (typically filled to the centerline of the piston shafts) is required to adequately cool and protect these critical components.

Depending on internal wear, water-box lubricants slowly bypass the concrete piston cups and are lost during pumping. Although quite robust by design, if a pump is operated for even a few moments without adequate water-box lubricant, concrete cylinders and piston cups can become scored and permanently damaged. Lubricant levels within the water box must be checked, refilled, or topped off daily before startup. This mandatory pre-start ritual must never be overlooked by the operator and crew.

The Essential Function of Grease

Casual research indicates that many operators improperly grease their equipment, often with destructive results. To the untrained eye, correct and incorrect greasing methods appear the same. Operators and crew must understand the function of grease to properly lubricate wet-mix pumping equipment.

Grease is typically a petroleum product that is suspended in a soap-like thickening agent. Greases are rated for their temperature and melting rate, the ability to inhibit oxidation and corrosion, and their level of protection for metals in the presence of water. Greases are application-specific (think submerged boat trailer axle versus very hot truck disc brake rotor).

It is important to understand the various functions that grease must accomplish within wet-mix pumps. If properly applied, grease prevents metal-to-metal contact at the critical internal bearing surfaces of concrete pumping components. Greases provide lubrication and corrosion protection by coating action. Its viscous fluid component lubricates clearances between parts that are relatively large, but for small clearances, the molecular soap layers provide the lubrication. Water-resistant greases may be used for a wide range of equipment and are very good choices for wet-mix equipment. However, grease must be applied properly within a bearing surface, or it will not provide adequate protection.

Unlike typical oils, greases do not easily flow at normal temperatures. This means that to be effective, grease must be installed by force, directly to wear surfaces through small ports or passageways within the bearing surface or housing. Grease must then completely coat all the surfaces which require protection from corrosion and wear, and be routinely replenished as mechanical energy pushes the product aside. As the grease coating diminishes, the protective layer is lost. Wear and corrosion begin immediately.

When used properly, grease will reduce or even completely eliminate corrosion and wear at critical surfaces. Many critical bearing surfaces are required on typical wet-mix pump designs. Any component within the material hopper that must rotate or slide will possess some form of bearing surface. All of these surfaces are continuously exposed to abrasive concrete slurries during daily operation.

Why Wet-Mix Equipment Requires Specific Lubrication Techniques

All machinery applications require some form of lubrication. Typically, lubricants are provided under pressure to critical bearing and seal surfaces through a recirculating oiling system. This method is impractical in a wet-mix pump application (excluding engine and hydraulic components) due to the constant exposure and potential contamination from abrasive, corrosive, concrete slurries. Lubrication by grease is common for machinery undercarriage components, sliding surfaces, and articulating arm pivot bearings. If grease is applied at the proper interval, it offers excellent lubrication for these applications. But greasing requirements differ for wet-mix pump applications due to the near-continuous immersion of components within the abrasive, corrosive, concrete slurries.

Wet-mix shotcrete pumps are usually positive displacement swing valve configurations. Swing valve designs (swing tube, rock valve, or gate valve) use very large sealed shaft bearings that

Fig. 1: Unnecessary corrosion and wear on critical bearing surface is likely caused by improper grease application

Fig. 2: Typical S tube shaft bearing

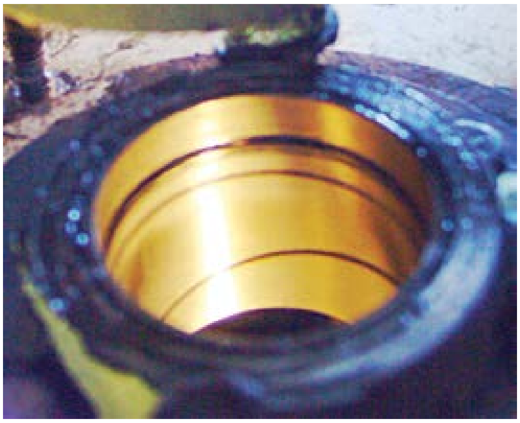


Fig. 3: Properly lubricated shaft bearing at 3000 hours

permit valve rotation between material cylinders during pumping.

Additionally, swing-tube-type pumps use large, sealed outlet bearings that are directly exposed to and vulnerable to damage from pressurized abrasive slurries. Insufficient or contaminated grease within any of these critical points can cause immediate, severe damage.

When grease is properly applied at seal and bearing surfaces, it lubricates and protects, but also acts to fill available space between the bearing, shaft, and sealing surface, thus denying access to incoming abrasive slurries. To accomplish this, a greasing device must be connected to a permanently affixed grease fitting. Applied under pressure, grease must flow through a series of small drilled passageways that direct grease to completely fill and coat the bearing surfaces. Because functioning grease fittings act as one-way valves, greases cannot be pushed backward and out of the way by pressurized slurries attempting to flow into the bearing surfaces.

Why Grease Doesn't Work

Applying grease does not provide permanent lubrication. When grease is used in wet-mix pump applications, its benefits are temporary at best. Grease within a bearing area does not break down or disappear from use. Rather, as the bearing surfaces are rotated, grease is slowly pushed aside. With continued movement, contamination in the form of concrete slurry can enter the bearing area and mix with the remaining grease to form a corrosive, abrasive paste. Even though grease is present, the protective properties of the grease are lost. Contaminated grease has the abrasive properties of sandpaper, so continued movement causes severe wear and permanent damage to the affected bearing and seal surfaces.

Because greases' protective properties in wet-mix pump applications are temporary, to be effective, grease must be continuously replenished before mixing actions alter the grease layers' beneficial properties. To accomplish this, grease intervals must occur far more frequently than most operators realize. Because unintentional mixing of concrete slurries and grease does not occur with typical construction equipment, most mechanics and operators are unaware of the required timing of grease replenishment for wet-mix pumps. Even veteran operators may not be able to accurately pinpoint the optimum interval to replenish grease.

Wet-Mix Grease Requirements Are Unique

Experience proves, despite a rigorous greasing regimen, abrasive concrete slurries will still manage to enter, contaminate, and damage critical seal and bearing surfaces.

Once past the seal, concrete slurries tend to harden, and will quickly plug the small grease replenishment grooves within the bearing surface, effectively ending the component's ability to accept future grease. Without sufficient grease, abrasion and corrosion will permanently damage the affected bearing surfaces.

At this point, complete breakdown and disassembly is the only viable option to prevent a major bearing failure.

This is why wet-mix pump grease requirements are unique. In addition to normal replenishment, greasing during the washout process is required to flush accumulated slurry residue from bearing surfaces before it can harden.

During each washout, concrete slurries and contaminated grease must be flushed from seal and bearing surfaces by vigorously adding additional grease until a clean flow of grease is visible outside the seal surface. If this critical step is omitted even once, slurry residue can remain and harden within the sealed bearing assembly. Countless major failures can be directly attributed to improper on-the-job wet-mix pump greasing/flushing procedures.

To provide optimum bearing service life, lubrication of the greaseable components of a wet-mix pump requires two distinct steps. The first step is rigorous grease replenishment during use. Manufacturers may recommend specific intervals; however, veteran operators replenish grease far more often. Because excess greasing cannot damage wet-mix equipment, it is best to be safe.

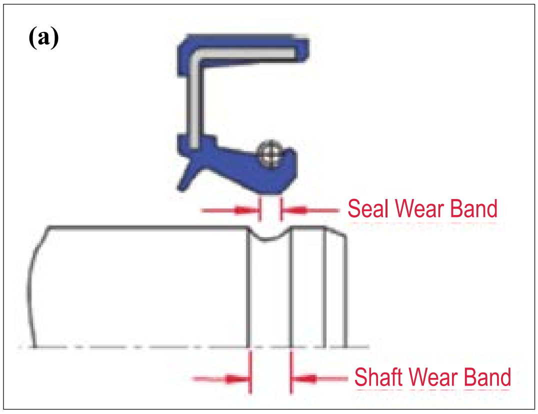


Fig. 4: (a) Note tight conditions within sealed bearing assembly; (b) bearing shaft showing significant corrosion and wear

The second step, flushing at the washout, is time-sensitive. To be effective, concrete slurries must be flushed from bearing and seal surfaces before they begin to harden. Stroke the pump in reverse and add grease until fresh, clean grease exits all bearing surfaces. If this critical step is missed even once, trapped concrete slurry residue can harden and clog grease replenishment channels within the bearing, making future greasing impossible.

Generic automatic lubricating devices are available and can be fitted to wet-mix pumps. Unfortunately, these devices can provide a false sense of security. Although effective at replenishing grease, their proper operation is difficult to validate; a costly bearing assembly failure may be the first sign of an automatic lubricator malfunction. Additionally, lubricators are not programmable to facilitate flushing during the washout procedure. Pumps fitted with automatic lubricators must use the manual override feature to flush bearing assemblies during washout.

What if a Fitting Will Not Accept Grease?

At normal temperatures, all grease fittings should readily accept grease. Wear, contami-

Fig. 5: Properly lubricated outlet bearing assembly at 3000 hours displays no visible wear

Fig. 6(a) and (b): Swing-tube shaft and outlet bearing assembly is totally destroyed at 1600 hours due to poor on-the-job lubrication practices. Note hardened concrete residue has clogged grease grooves of outlet housing on right

nants, or external damage can prevent a fitting from accepting grease. Try a new fitting and a more powerful greasing device in conjunction with heat and vibration to free up clogged grease channels. However, bearing assemblies which will not accept grease are often blocked with hardened residue and will require complete disassembly.

The most common cause of major bearing failure, hardened concrete residue within bearing assembly, is completely preventable by the use of proper on-the-job lubrication practices.

In closing, wet-mix pumps, properly lubricated, may provide many years of trouble-free service, or conversely if not maintained require frequent major repairs. Proper daily on-the-job lubrication procedures are the single largest factor determining your pump's long-term performance and durability.

Wet-Mix Lubrication Checklist

- Verify oil, hydraulic fluid, and water-box lubricant levels before every startup.
- Use the manufacturer-recommended grease or a good-quality, water-resistant grease.
- Train all operators of on-the-job lubrication requirements. Be sure a functioning grease gun and a supply of grease is ALWAYS available.
- Know the location of all grease fittings, even the hidden ones.
- Be sure ALL grease fittings are functioning properly and readily accepting grease. If a fitting will not accept grease, immediately take necessary steps to restore greasing function.
- During EVERY washout, completely flush all concrete residue from bearing assemblies before it can harden. Stroke the pump in reverse and add grease until fresh, clean grease exits all bearing surfaces.

*ACI Certified Nozzleman **Oscar Duckworth** is an ASA and American Concrete Institute (ACI) member with over 15,000 hours of nozzle time. He has worked as a nozzleman on over 2000 projects. Duckworth is currently an ACI Examiner for the wet- and dry-mix processes. He currently serves as ASA Executive Committee Secretary and newly appointed Chair of ASA's Education Committee. He continues to work as a shotcrete consultant and certified nozzleman.*

The Use of Shotcrete for Construction of Backfill Barricades in Mining Environments

By Craig McDonald and Joe Hutter

As we all know, the mining process is essentially the excavation and extraction of rock, ore, gems, or other minerals from the earth's surface. In an open-pit mining excavation, the hole in the ground simply increases in size until the resources are exhausted and often a new lake will be created by the crater left behind.

In underground mines, however, as the deposits are extracted, the voids left behind (also known as stopes) must be filled to maintain the integrity of the surrounding rock or earth mass. If these stopes were left empty, the stresses from the surrounding rock mass would result in ground collapses. To avoid these collapses, mining companies use a backfill system, of which there are many different types, depending on the mining method. There is, however, one constant. The entrance point to the excavation must be blocked and sealed off using a barricade to contain the backfill material within the stope.

For many years, the underground mining industry relied on timber for many purposes. Timber was used to support the tunnels as they advanced in length and also to construct barricades used to restrict or block the flow of backfill.

Many of the backfilling operations involve a three-step process, the most important (after construction of the barricade) being construction of "the plug." The plug is always filled using a higher binder content, which provides a higher-strength backfill mixture to withstand the vertical hydraulic head pressures created by the placement of subsequent backfill steps.

The second step involves filling "the body," a process that uses multiple lifts of a lower binder content mixture and fills the major portion of the stope.

The third step is to fill "the cap," a final section of backfill material that uses higher binder content similar to that used in the plug. For each step, the barricade must be strong enough to contain the backfill material in the stope and allow the water needed to transport the backfill solution to the stope to drain.

For many years, the timely and labor-intensive process of constructing backfill barricades changed very little. However, as advanced tools and technology improved processes in other areas of the mining industry, engineers began to look closer at the shotcrete process to solve problems and improve labor efficiency underground. Shotcrete was beginning to play an increasingly dominant role in many areas, including ground support and other forms of underground construction. It was not long before the benefits from the use of shotcrete quickly expanded to the construction of backfill barricades.

Construction of original shotcrete backfill barricades involved the use of panels constructed using two layers of welded wire reinforcement, separated with spacers to act as a vehicle for the shotcrete (Fig. 1). An engineered, high-quality coated woven polyolefin-based fabric, 24/11 weave Fabrene®, was usually fastened to the back of the first layer of mesh to provide a receiving surface for the shotcrete. Reinforcing bar was fastened to the mesh to provide structural reinforcement and dowels were installed in the surrounding rock to secure the barricade. After this preparation was complete, shotcrete placement was completed in less than one shift, allowing for a significant reduction in cost of the barricade, not to mention a reduction in the overall cycle time of the mining process.

Because it is the nature of the mining industry to constantly improve processes, it was not long before the shotcrete barricade was refined. Shotcrete soon became the material of choice and the benefits were obvious (Fig. 2):

Fig. 1: Construction of original shotcrete backfill barricades involved the use of panels constructed using two layers of welded wire reinforcement, separated with spacers to act a vehicle for the shotcrete. Fabrene was usually fastened to the back of the first layer of mesh to provide a receiving surface for the shotcrete

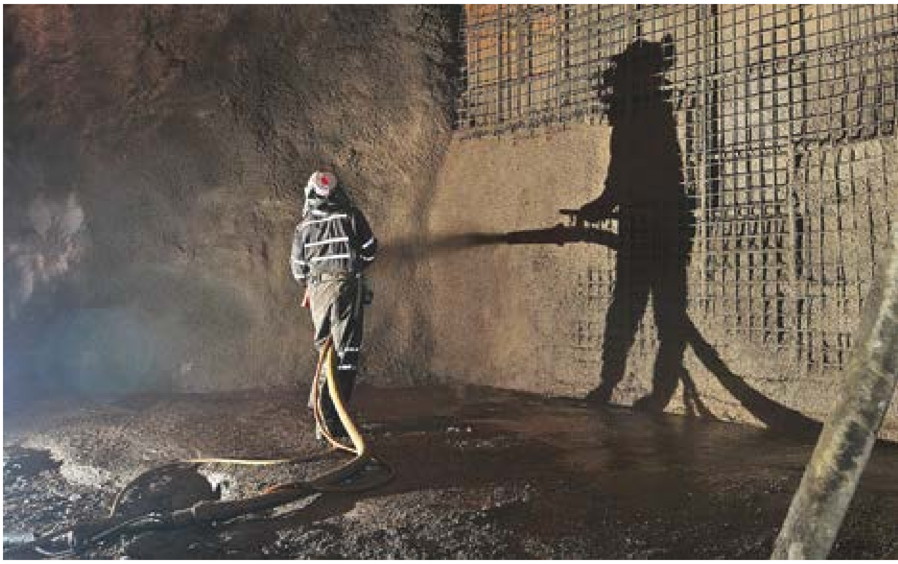


Fig. 2: Reduced manpower, reduced cycle time, and improved water retention soon made the shotcrete process the preferred method for constructing backfill barricades

- Reduced manpower;
- Reduced cycle time; and
- Improved water retention.

Process improvements led to many changes in the backfill barricade design. While some improvements were related to cost-reduction initiatives, it was recognized that a structurally sound barricade design was essential in mitigating the risk of a failure. The barricade was constructed in a section of the rock mass that allowed sufficient anchorage so that the structural integrity of the wall would not be compromised during the backfilling process. Barricades were designed with a convex curve to properly transfer and evenly disperse the load to surrounding ground. But did it have to be a solid wall?

A design concept was drafted by a mining company in the Sudbury, ON, Canada, area, using large, U-shaped troughs made with heavy-gauge sheets of wire mesh and shotcrete (Fig. 3). The perimeter of the barricade would still be mechanically anchored with reinforcing bar dowels and 24/11 weave Fabrene backed welded wire reinforcement would still be used to create a receiving surface for the shotcrete; however, the entire opening would not have to be sprayed with shotcrete. Shotcrete was placed only over the mesh troughs, which were arranged in a rectangular grid pattern. The size of the openings between the U-shaped troughs would determine if the grid arrangement would be viable. After a number of successful tests, it was determined that certain barricades could now be constructed using shotcrete in a predetermined grid pattern as opposed to a solid wall.

Fig. 3: A completed backfill barricade in a northern Ontario mine was constructed using the shotcrete process (note drainage pipes that allow water to drain from the backfill material)

Further improvements came from the development of early-age compressive strength testing equipment or end beam testers. Compressive strength of the shotcrete material was an important criterion in determining how soon the backfilling process could begin after construction of the barricade. Previous test methods for determining early-age compressive strength of shotcrete followed ASTM C1604/C1604M, which involved shooting a 2 ft x 2 ft x 4 in. (0.6 m x 0.6 m x 100 mm) wooden panel and then coring the panel to retrieve specimens for traditional compressive strength testing. The problem with this method was that the panel must remain in the position it was shot until the material had reached final set. In an underground environment, this usually meant leaving the panel underground for an extra shift before transporting it to the surface, where it was then shipped to a certified lab where the actual testing could begin. This process was time-consuming and cumbersome, resulting in the earliest available compressive strength values being 24 to 36 hours.

The end beam tester allowed a nozzleman to shoot directly into molds that were designed to be quickly and easily disassembled. After disassembling, each end of the beam could be broken on-site, using a hydraulic hand pump so that a compressive strength value could be determined at almost any stage of the hydration process.

One company's barricade and backfill procedures specified that the empty stope could not be backfilled until the shotcrete reached a minimum compressive strength of 2900 psi (20 MPa) which, based on the available test methods, meant 48 hours after the shotcrete was placed. Using the early-age compressive strength testing equipment, the company was able to determine that the shotcrete material reached the minimum 2900 psi (20 MPa) value only 24 hours after placement. This information allowed the mine to change their procedures so that the stope could be filled just 24 hours after placement, translating into a full day's reduction in cycle time (Fig. 4). Although this decision was based on the use of a special shotcrete mixture that provided high-early-strength gain, the early-age compressive strength of the in-place shotcrete could only be properly assessed through the use of the end beam testing apparatus, which allowed the engineers to properly quantify the results.

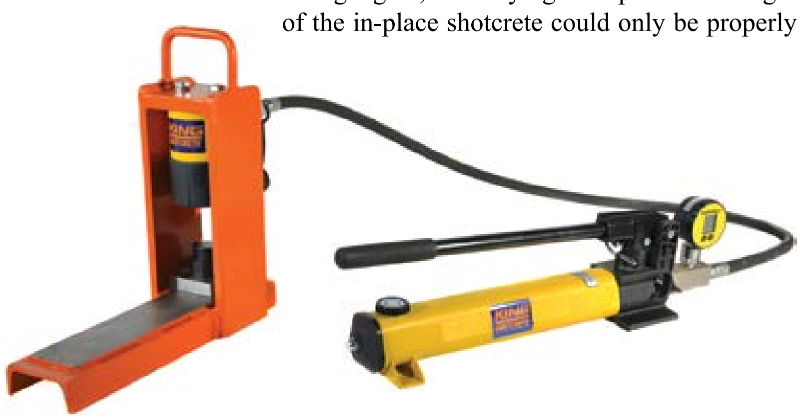


Fig. 4: The end beam tester provided one mine with the information required to change their procedures so that the stope could be filled just 24 hours after placement, translating into a full day's reduction in cycle time

Because there are many factors that can affect set time and rate of strength gain, including water-cement ratio, water temperature, air temperature, and product temperature, the company, to maintain their due diligence, completes frequent testing of their backfill barricades with the end beam testing apparatus.

Within the mining and tunneling industries, the popularity and diversity of shotcrete continues to grow. Engineers understand that the shotcrete process allows for the elimination of labor-intensive forming activities and the costly transportation of forming materials underground. The use of the welded wire reinforcement panels as a receiving surface for shotcrete has dramatically reduced the labor content and cost of projects, such as the construction of backfill barricades. Ventilation bulkheads, garage doors, refuge station walls, and many other projects that require concrete placement are now also completed using the shotcrete process. It is now understood that the shotcrete process is merely an alternative method for placing concrete, so with proper design and engineering, the use of shotcrete underground is only limited by the imagination of the design engineer.

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Joe Hutter *is the Vice President, Sales, for King Packaged Materials Company, Burlington, ON, Canada. He has more than 25 years of experience in the cement/shotcrete industry. He is a former President and an active member of ASA and has been Chair of the ASA Marketing/Membership Committee since its inception. Hutter is also a member of the American Concrete Institute.*

Shotcreting on Frozen Ground

By Paul H. Madsen

The Northern Boulevard Crossing (NBX) is the keystone portion of the massive multi-billion-dollar East Side Access (ESA) Program by the Metropolitan Transit Authority Capital Construction (MTACC) to bring Long Island Railroad trains into and out of New York City's Grand Central Terminal. NBX constitutes the link between the Queens Tunnels and Manhattan Tunnels portions of ESA. The crossing consists of 120 ft (37 m) of 2000 ft^2 (186 m^2) cross-sectional area tunnel through soft ground, constructed using the sequential excavation method (SEM) under the protection of a structural frozen arch (Fig. 1).

NBX extends under an active five-track-wide subway box, a major six-lane highway, as well as through the foundation piles of operating elevated subway line structure. All of the above presented a unique challenge to the owner and contractor. NBX is the first and only soft-ground SEM tunnel project within the five Boroughs of New York and was constructed by a joint venture of Schiavone Construction Co., LLC, and Kiewit Infrastructure Co. (S/K).

Construction on NBX started in February 2010 with the SEM excavation starting in April 2012 following access chamber excavation, grouting, and ground freeze. Excavation was completed in

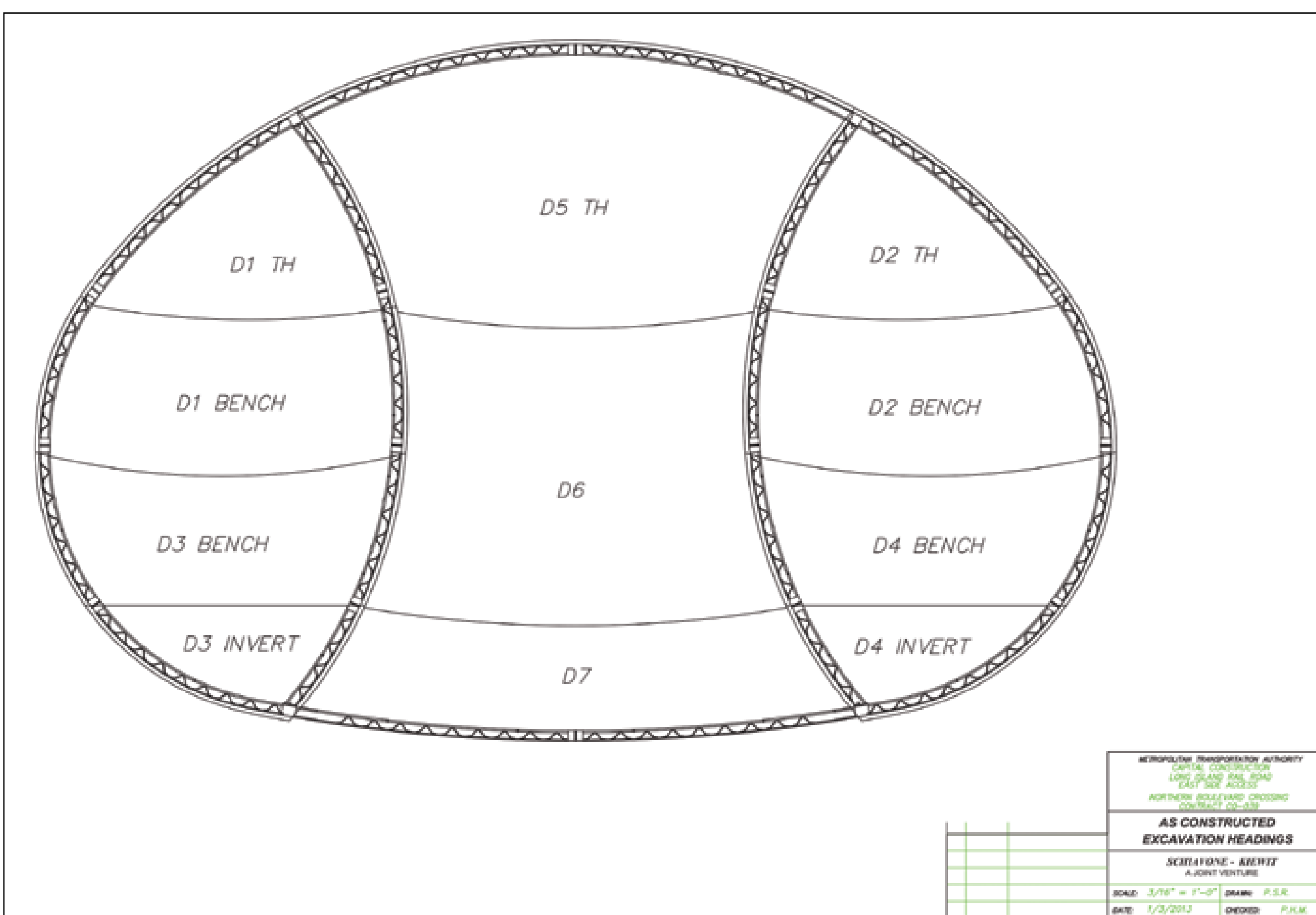


Fig: 1: Drift layout

November 2012 and was followed by PVC waterproofing installation and final lining.

This article describes lessons learned from the shotcreting on frozen ground during the SEM excavation and support.

Subsurface Conditions

The tunnel envelope of the NBX tunnel is predominantly within mixed glacial deposits that consist of brown-gray to olive-brown medium-stiff to hard non-plastic to low-plasticity silts and clays. The stratum was predominantly varved with fine micaceous sands and fine gravel. Gravel, cobbles, and boulders were also observed. The Unified Soil Classification System (USCS) group symbols are generally ML to CL. Parts of the crown encountered very loose to very dense coarse to fine micaceous sands and silts with gravels.

Tunnel Design

The tunnel was designed by the General Engineering Consultant (GEC) for MTACC. The design incorporated a frozen soil arch that served as pre-support and water cutoff. The frozen arch had to span the entire 120 ft (37 m) length of the tunnel from the slurry wall on the east side of Northern Boulevard to the slurry wall on the west. The frozen arch had to be socketed into the bedrock at the invert level of the tunnel to isolate the soils below the frozen arch from any water infiltration and allowing for drainage of the soils inside the arch.

Full drainage of the soils under the frozen arch were required prior to removal of the slurry walls' temporary bracing in front of the tunnel portal, and to ensure stand-up time of the soils during tunnel excavation.

The initial tunnel lining consisted of a 3 in. (75 mm) insulating shotcrete layer and 12 in. (300 mm) structural shotcrete reinforced with two layers of 4x4-D4xD4 welded wire reinforcement (WWR). Lattice girders were required at 4 ft (1.2 m) centers, equal to the excavation round length. The temporary sidewalls had the same reinforcement with a 12 in. (300 mm) total shot-

Fig. 2: Mockup of Drift 1

crete thickness. Temporary inverts between the upper and lower sidewall drifts were 9 in. (225 mm) of shotcrete reinforced with one layer of WWR. Specified shotcrete strength was 100 psi (0.7 MPa) in 1 hour, 500 psi (3.5 MPa) at 6 hours, 1800 psi (12 MPa) at 24 hours, 3500 psi (24 MPa) at 7 days, and 5000 psi (34 MPa) at 28 days.

Lessons Learned

Compatibility testing and early set tests were conducted on several accelerator sources prior to selecting a supplier. This was followed by yield tests and strength testing in the lab.

Because shooting shotcrete panels has little in common with applying shotcrete in a tunnel environment around lattice girders and WWR, it was agreed with the owner to eliminate shotcrete panels as the method of verifying the nozzlemen's skills and instead construct a full-size mockup section of an upper sidewall drift, Drift 1 (Fig. 2).

This allowed S/K to evaluate the nozzlemen's capabilities to maneuver the robot and the nozzle around the girders and see if they understood the sequence of application. One primary and one backup nozzleman were approved for each shift.

Shotcrete panels were shot for verification of the mixture performance both before and during construction. Early-strength testing was done using penetration needle and the powder-actuated nail pullout test.

All shotcrete was delivered by a ready mix supplier because it was not possible to set up an on-site batching facility due to site restrictions. A retarding admixture was added to the shotcrete mixture because the trucking time from the batch plant to the site varied from 20 minutes to over an hour, depending on traffic.

Shooting shotcrete on frozen soil, especially overhead, creates certain challenges that had to be solved. The design required a 3 in. (75 mm) insulating layer to be applied to the frozen ground as flashcrete prior to lattice girder installation.

After application of the 3 in. (75 mm) flashcrete, the heat of hydration from the flashcrete thawed the first inches of frozen soil, causing the unfrozen soil and the flashcrete to delaminate from the frozen soil and causing fallout from the crown. Additionally, on vertical walls where the flashcrete did not fall off, the freezing energy from the ground would refreeze the thawed soil and the flashcrete during lattice girder installation, hence resulting in the structural shotcrete being applied on a frozen surface and defeating the intent of having the flashcrete insulate the structural shotcrete.

Because there were no stability issues with the frozen soil requiring flashcrete, it was decided with the acceptance of the owner's design representative to apply the flashcrete/insulating layer together with the initial structural shotcrete layer. Additionally, the outside layer of wire mesh was stiffened with No. 7 (No. 22M) reinforcing bars to allow the shotcrete to build up without sagging due to deflection of the mesh.

Fig. 3: Drift 1 top heading

Due to safety concerns over having crews working directly below freshly applied shotcrete while installing the inside layer of WWR, it was decided to apply all overhead shotcrete in two passes. Using this approach, the inside WWR of a round was installed during the outside mesh and girder installation of the following round. Identically, the second shotcrete pass of a round was applied immediately after placing the initial pass on the following round. Using this approach, the next operation following shotcreting was excavation and no personnel—only the stick of the excavator—was exposed to potential shotcrete fallout (Fig. 3).

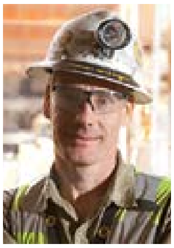
Shotcrete was applied using a small track-mounted robot, except for the invert shotcrete in the center drift, which was applied using a 2 in. (50 mm) hand nozzle suspended from the stick of the excavator. This solution was required to properly shoot the tight areas at the connection points to the lower sidewall drifts below the temporary sidewalls.

The shotcrete was pumped from the surface to the headings through a 4 in. (100 mm) slick line using shotcrete pumps with an integrated accelerator dosing system. This setup allows for proper quality control of the accelerator dosing and ultimately the strength performance of the mixture.

A dry-mix shotcrete setup using bagged materials was kept as backup for the two wet-mix shotcrete pumps and in the event that there was an issue with the wet-mix material supply.

Summary

The project provided an opportunity to learn about the challenges of applying shotcrete on frozen ground. Using WWR, No. 7 (No. 22M) reinforcing bar, and lattice girders, it was possible to shotcrete an initial self-supporting shell that could support the structural shotcrete thickness and prevent any loss of ground (Fig. 4).



***Paul H. Madsen** received his BSc in civil and construction engineering at the Engineering College of Copenhagen, Copenhagen, Denmark, and his MSc in soil and rock mechanics at Heriot Watt University, Edinburgh, Scotland. He has over 20 years of underground experience as a contractor's Geotechnical and Tunnel Engineer as well as Tunnel Superintendent and Project Manager with Kiewit Infrastructure Co. Projects include Storebaelt Tunnel in Denmark, Devil's Slide in California, and recently the Northern Boulevard Crossing in New York.*

Fig. 4: Completed tunnel

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2005 Outstanding Repair and Rehabilitation Project:

Pointe de la Prairie Lighthouse

By Patrick Giroux and Simon Reny

The Pointe de la Prairie Lighthouse is located on the north shore of the Île-aux-Coudres Island across from Baie-Saint-Paul in the St. Lawrence River. Since its construction in 1972, the lighthouse has been exposed to extremely severe environmental conditions. Exposure to salt water, continuous freezing-and-thawing cycles, and impact from ice flows have contributed over the years to severe deterioration of the concrete that makes up the base of the lighthouse. A 1/4 in. (6 mm) thick steel plate surrounding the concrete base was designed to provide added protection against impact from ice flows. In several areas, these plates were completely destroyed. The extent of the concrete deterioration behind these plates was so severe that in some areas it reached nearly 3 ft (915 mm) in depth.

Pointe de la Prairie Lighthouse before reconstruction

Nozzlemen shooting the base of the lighthouse

In the summer of 2004, Public Works and Government Services Canada elected to tender a project to conduct a much needed, major rehabilitation of the lighthouse. The consulting engineers at BPR Inc. recognized the need to come up with a system that would meet the challenges associated with the difficult access while providing protection against the severe environmental conditions.

Working with engineers from King Packaged Materials Company, BPR Inc. specified a dry-mix shotcrete mixture containing silica fume, steel fibers, a granite-based coarse aggregate, air-entraining admixture, and a set accelerator. The air-entraining admixture was specified to provide improved durability, the steel fiber and granite stone were incorporated to provide resistance to impact and abrasion from ice, and the set accelerator and the silica fume were specified to reduce the risk of washout created by the rapidly moving tides and waves. The new structural design of the base of the lighthouse did not include the use of steel plate to guard against impact and abrasion damage. It was agreed that this protection would be offered by the impact and abrasion-resistance properties of the shotcrete.

In July of 2004, Public Works and Government Services Canada awarded the contract to complete the rehabilitation of the lighthouse to Yves Germain Construction of Québec City, QC, Canada, and the shotcrete portion of the contract was sub-contracted to Cimota Inc., also of Quebec City. Cimota elected to have the preblended shotcrete mixture supplied in 2200 lb (1000 kg) reusable bulk bags and worked with personnel from Yves Germain Construction to schedule the shipment of the material to the work site by barge. As in all dry-mix

Shotcrete was supplied in 2200 lb (1000 kg) reusable, bulk tote bags

Pointe de la Prairie Lighthouse

Test panels were shot to evaluate the competence of the nozzlemen and to confirm hardened properties of the mixture

shotcrete applications, potable water was added at the nozzle. Cimota Inc. elected to use a hydromix nozzle to predampen the dried shotcrete material.

Before beginning the shotcrete portion of the project, test panels were shot and mechanically finished to provide a representative sample of the finished product. The panels were left on site for 24 hours, after which time cores were taken to evaluate the compressive strength and quality of the shotcrete placement.

Completed shotcrete application at low tide

The concrete base of the lighthouse was divided into 14 triangular sections, each separated by a vertical construction joint. Each section was shot from the bottom of the section (at the base of the lighthouse) to the top to maximize the amount of material that could be applied before the action of the rising tides threatened to wash out the applied shotcrete. As the tide retreated, cleaning and preparation work was completed on the next section and the next shooting session began.

To ensure the project would be finished in time to meet the fall 2004 deadline, Cimota Inc. elected to use two Aliva AL 246 shotcrete machines, supplied by King Packaged Materials' Minequip division. Cimota Inc. also used two ACI certified nozzlemen. This challenging shotcrete rehabilitation project was successfully completed on time despite the difficult weather conditions that constantly disrupted shooting schedules. The skill of the Cimota Inc. certified nozzlemen and the quality of the specially designed King shotcrete mixture were evident by the overall quality of the completed project. After 2 years, the performance of the shotcrete has met all expectations and Public Works and Government Services Canada has expressed complete satisfaction with the performance of the product and the installation.

Pointe de la Prairie Lighthouse

Project Name
Rehabilitation of the
Pointe de la Prairie Lighthouse

Project Location
L'Ile-aux-Coudres, QC, Canada

Shotcrete Contractor
Cimota Inc.

General Contractor
Yves Germain Construction

Project Owner
Canadian Coast Guard

Architect/Engineer
BPR Inc.

Material Supplier
King Packaged Materials Company

***Patrick Giroux** is President of Cimota Inc., a Quebec, Canada-based civil contractor specializing in shotcrete and concrete repair, rock protection and stabilization, drilling, and grouting. He is a graduate civil engineer from Sherbrooke University, Sherbrooke, QC, Canada. Giroux has over 15 years of experience in shotcrete and concrete repairs.*

***Simon Reny**, Eng., is Manager of the Technical Services for King Packaged Materials Company (an ASA Corporate Member), where he is responsible for all mixture design development, quality control, and technical support. He received his degree in civil engineering from Laval University in 2004. He is a member of the American Concrete Institute; a member of ACI Committee 506, Shotcreting; and a member of the Shotcreting-Guide Subcommittee and the Shotcreting-Underground Subcommittee. He is also Past President of the International Concrete Repair Institute's Quebec Chapter.*

Retarders versus Set Stabilizers

By Dan Millette

When concrete is cast, a retarding admixture is often used to keep the mixture workable until finishing is completed. This seems most common with concrete used in flooring applications where more finishing time is required. If concrete is being used a considerable distance from the ready mix plant, or the ambient temperature at the construction site is very warm, these are good reasons to use a retarder. Even at normal or lower temperatures, concrete loses its workability with time. A retarder can be dosed at a specific amount depending on the extended time of setting that is required to give some flexibility to the operation. As seen in Fig. 1, temperature has a very significant effect on the rate of cement hydration.

Then why can we not use retarders for shotcrete? But we can and do. Retarders are great for shotcrete for many of the same reasons as for concrete, because shotcrete is concrete: extended travel distances; time required for placement, especially if you need to move a pump during placement; hot weather at the job site, and so on.

But what must be considered is if we are using an accelerator at the nozzle for any particular reason—are retarders still suitable? It seems counterintuitive to use both a retarder and an accelerator for the same mixture, but many situations can arise, such as in mining or tunneling, where a mixture is batched, travels over an hour to the work site, is then sent underground, and must be transported from the point of underground delivery to the work area. I have seen this take up to 5 hours in many cases. And what if, for example, there is a further delay while the sprayer is being repaired? And when you are finally ready to use the mixture, you need to accelerate it at the nozzle. This is fine if the retarder is wearing off, but if the retarder was dosed to hold off the set time for 6 hours and you are ready to use the mixture in 2 hours, it would be correct to assume you would need a lot more accelerator to overcome the effect of the retarder. That is why set stabilizing admixtures or set stabilizers are used in many shotcrete mixtures.

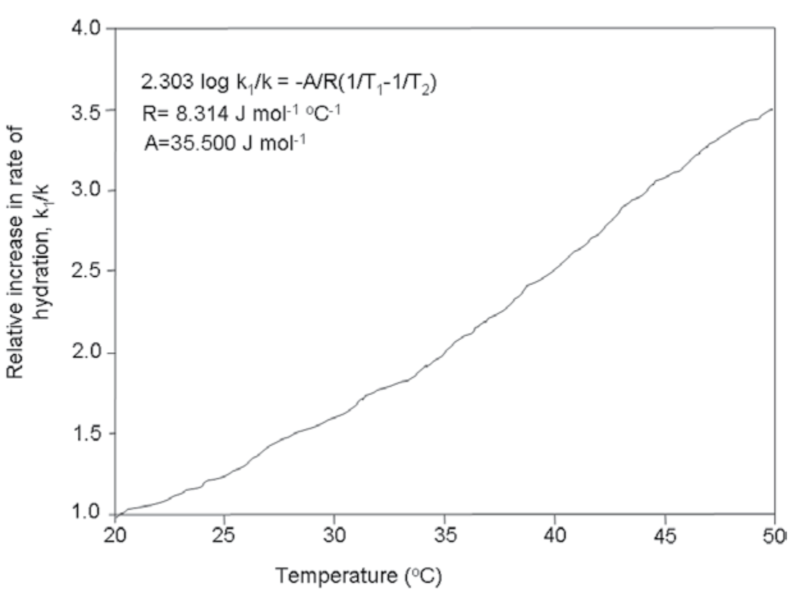


Fig. 1: Effect of temperature on the rate of hydration (Rixom and Mailvaganam 1999)

First, let's take a look at how retarders work. The purpose of the retarder is to delay the setting time of the cement paste in the mixture. When water is added to cement, there is a rapid initial reaction (hydration) that occurs, after which there is very little formation of further hydrates for approximately 2 to 3 hours. This is called the dormant period but can be significantly shortened due to cement type and/or temperature. The hydration rate increases at the end of the dormant period and a lot of calcium silicate hydrate and calcium hydroxide forms relatively quickly, which is what corresponds to the setting time of the mixture.

A retarder added to the mixture will delay the end of the dormant period and therefore the start of setting and hardening. This is done by a mechanism based on absorption. The larger admixture anions and molecules are absorbed by the surface of the cement particles to hinder reactions between cement and water. In other words, the retarding admixture coats the cement particles. Most retarding admixtures are made with sugars or sugar derivatives while others contain lignosulfonate, which is a waste product from the pulp and paper industry. Many retarders are also water reducers. ASTM C494 Type B designates that the admixture is a retarder only. Sugars retard the formation of silicates, thereby getting rid of calcium molecules and putting them into solution; and this, along with the coating on the cement particle, keeps the nozzle accelerator from being able to reactivate the mixture.

Retarders are normally added to the initial mix water in the mixer. One must be careful when using retarders for applications in hot temperatures. Depending on the cement and the admixture used, there have been instances of excessive retardation or flash setting.

Unlike retarders, it is not known exactly how set stabilizers work but there is a lot that is known about their application. Stabilizers can be used at high dosages without the adverse effects such as flash set and poor strength development characteristics that can occur when using conventional retarders. Stabilizers are commonly made from carboxylic acids and/or phosphorous-containing organic acid salts, and as a result, often have a low pH in the 2 to 3 range.

The way a stabilizer works is thought to be related to the inhibition of calcium silicate hydrate and calcium hydroxide nucleation. Many will claim that the stabilizer will do a much better job of controlling the nucleation process than retarders. This claim has been supported in laboratory trials using calorimetric data and by viewing under a scanning electron microscope the surfaces of both stabilized and activated alites. As mentioned earlier, retarders will retard the formation of silicates, which is just one phase of cement hydration, while a stabilizer will act on all phases of cement hydration, including the C3A fraction.

Stabilizers also coat the cement particles but it is thought that they can be penetrated by shotcrete accelerators to restart the hydration process. The addition of a stabilizer is different than that of a retarder. To be completely effective, a stabilizer should be added to the mixture only after the cement has had a chance to completely wet out with the water in the mixture, thereby starting the hydration process. If a stabilizer is added to the mixture water up front, before the cement is added, it will only have approximately half the effectiveness of adding it after the cement has wetted out. Another advantage to using a stabilizer is that it can be added again to the same mixture if the job is further delayed and a longer retardation of the set time is required.

When using either retarders or stabilizers, it must be realized that the purpose of these admixtures is to hold off the setting time of cement, or more specifically to extend the dormant period of the cement hydration process. They are also often mistakenly used in an attempt to decrease slump loss. This was never the intended purpose of these admixtures. In hot temperatures, extending the set time can in some applications give the mixture more time to lose water due to evaporation, causing slump loss.

If there is a need to hold off the setting time of your shotcrete mixture, make sure that you do some initial investigation or trials to make sure that you are using the proper admixture or combination of admixtures to attain the objective required for the project.

References

Rixom, R., and Mailvaganam, N., 1999, *Chemical Admixtures for Concrete*, third edition, Taylor and Francis Group Publishing, 456 pp.

Whiting, D., and Dziedzic, W., 1992, "Effects of Conventional and High-Range Water Reducers on Concrete Properties," *Research and Development Bulletin RD107*, Portland Cement Association, Skokie, IL.

***Dan Millette**, a Mining Engineer, is the Director of the Mining and Tunneling Division of The Euclid Chemical Company. Millette has over 30 years of experience in the shotcrete industry and is a certified EFNARC Nozzleman Examiner. He is a member of ACI Subcommittee 506-F, Shotcreting-Underground, as well as a member of the Society for Mining, Metallurgy and Exploration (SME); the Canadian Institute for Mining, Metallurgy and Petroleum; and the Tunneling Association of Canada.*

Fallouts Can Be Deadly!

By Joe Hutter

Many years ago, when the use of shotcrete in an underground support system was not as popular as it is today, I witnessed a mine foreman walk into an underground opening to admire the job his shotcrete crew had done placing shotcrete only an hour or two earlier. He knew that the area had already been supported with screen and bolts (the shotcrete was placed over the screen as part of the ground control engineer's design) so he felt safe knowing that he was not entering an area of unsupported ground. Just as a member of the shotcrete crew warned him to step back from the area, a small section of shotcrete fell from above and landed about 15 ft (5 m) from where he was standing. This incident was a serious reminder that even though a shotcreted area may appear safe, there are many variables that impact the time required (after overhead placement) before shotcrete can be considered structurally sound.

To illustrate the danger posed by unexpected fallouts, it is important to understand the mass associated with even a small section of shotcrete. A 2 ft x 2 ft x 4 in. (0.6 m x 0.6 m x 100 mm) area of in-place shotcrete will weigh approximately 175 lb (80 kg). To drop a 175 lb (80 kg) slab of concrete from even a moderate height would most likely have fatal consequences if it directly impacted someone. No experienced miner would ever consider standing beneath freshly excavated and unsupported ground. For the same reason, no one should ever consider walking into an area of freshly placed, nonsupported shotcrete.

At the time when the fallout incident occurred, there was no way of knowing the value of the compressive strength of the shotcrete at an early age. There was an easy test method for determining final set time but to accurately measure early-age compressive strength, engineers would require that a test panel be shot, cored a minimum of 8 hours later, and the core broken to determine the compressive strength value. Although this test procedure provided accurate results, the time lapse before coring meant the earliest age result was 8 to 12 hours. Today, early-age compressive strength can be obtained using specialized equipment (end-beam testers) (Fig. 1) that allow compressive strength to be measured as early as 1 or 2 hours after placement. These results provide the ground control engineer with confidence that the in-place shotcrete has gained sufficient strength

Fig. 1: Today, early-age compressive strength can be obtained using specialized equipment (end-beam testers) that allow compressive strength to be measured as early as at 1 or 2 hours after placement

to do the job for which it was intended and will remain in place.

When measuring the risk of a fallout, consideration should also be given to other factors that can influence the early-age strength of recently placed shotcrete—one of the most important being temperature. The temperature conditions under which initial compressive strength values were obtained may be much different than those where the shotcrete is actually being placed. Cold ambient temperatures will always increase the final set time and reduce the rate of strength gain, as will the temperature of the material and the mix water.

Other factors that can influence the potential for a fallout are: surface preparation, nozzleman skill, application thickness, vibration, seismic activity, the presence of welded wire reinforcement, the process (wet- versus dry-mix), and of course the shotcrete mixture design. If changes are made to the shotcrete mixture design or there are changes in shotcrete supplier, early-age testing should be repeated to verify that the set times and early compressive strength results are meeting expectations.

Shotcrete mixtures using new cement technology that achieve compressive strengths as high as 2900 psi (20 MPa) after only 2 hours have recently been introduced to the mining and tunneling industries. Vale's Coleman Mine, located in Sudbury, ON, Canada, has used this technology in its underhand cut-and-fill mining process to accelerate the mining cycle and increase productivity (Fig. 2). As a safety precaution, Vale's shotcrete supplier offered to pigment the shotcrete mixture red so that shotcrete crews and other underground personnel could easily differentiate between this high-performance mixture and the conventional shotcrete used in other areas of the mine. Fallouts would be an obvious hazard if shotcrete crews were unable to easily distinguish if the material placed reached 2900 psi (20 MPa) at 2 hours or 24 hours.

We are all ultimately responsible for our own safety and understanding when a shotcreted area is safe to enter is an important part of that responsibility. The information needed to understand safe re-entry times, however, must come from a number of sources. The shotcrete material suppliers should be able to provide set times and early-age strength results for any mixture that is supplied to the shotcrete crew. In the case of mine and tunnel excavations, ground control engineers should establish guidelines for minimum compressive strength and correlate those strength values to minimum re-entry times. A safe re-entry time will depend on a number of previously mentioned factors. Ignoring those minimum re-entry times is a risk that can cause serious injury and, in some documented cases, cause workplace fatalities.

Fig. 2: Shotcrete mixtures using new cement technology that achieve compressive strengths as high as 2900 psi (20 MPa) after only 2 hours have recently been introduced to the mining and tunneling industries

***Joe Hutter** is the Vice President, Sales, for King Packaged Materials Company, Burlington, ON, Canada. He has more than 25 years of experience in the cement/shotcrete industry. He is a former President and an active member of ASA and has been Chair of the ASA Marketing/Membership Committee since its inception. Hutter is also a member of the American Concrete Institute.*

Construction Forms, Inc.

Since 1969, Construction Forms, Inc., has been a leader in the development, manufacture, and distribution of concrete pumping systems and accessories. The company was founded with the goal of engineering and producing a complete line of concrete pumping systems and accessories for the rapidly growing concrete pumping market.

As pump manufacturers improved the performance and reliability of pump trucks, a small group of entrepreneurs came together in Cedarburg, WI, to found Construction Forms, Inc. (Con Forms). The team quickly set out to refine delivery placing systems used to convey concrete from the pump to the point of placement. The company addressed the needs of standard placing applications as well as more specialized applications, such as high-rise, tunnels, bridges, large deck placings, and shotcrete.

A dedication to excellence in product performance and customer service has positioned Con Forms as an industry leader in the United States and around the world. Headquartered in Port Washington, WI, Construction Forms has additional locations in California, the United Kingdom, Germany, and Asia.

Product Solutions

Con Forms produces a wide variety of concrete pumping products, designed specifically for the customers' application needs.

Boom Systems

Con Forms provides all the needed pipe, elbows, and accessories to re-boom your concrete pump truck. We support all manufacturers of pump trucks, focusing on total customer satisfaction by providing a complete, high-quality, custom-painted system. System pipe is available in twin- or single-wall, induction-hardened, or non-heat-treated.

Backend Kits

Chrome carbide insert-lined components create a pre-engineered, wear-resistant package, designed to lower operating costs by reducing changeover-related downtime. Our kits are engineered to fit standard Schwing or Putzmeister pumps.

Lay-Down Systems

Fully engineered and supported systems are designed to provide the safety and quality demanded

on today's modern job sites. Con Forms' pipe supports everyone from single-trailer pump customers to the largest contractors in the concrete pumping industry.

Custom-Engineered Placing Devices

Con Forms' placing systems provide greater control over concrete flow and material use; improve quality; and streamline major bridge, deck, and tunnel projects. Placers are professionally designed and custom-built for each project.

Hose

Con Forms' hose is fabricated to customer specifications and pumping requirements. Choose high-pressure, wire-reinforced hose for boom or discharge use, or textile hose for shotcrete and other lower-pressure applications.

Small Line and Shotcrete

Con Forms offers the most complete selection of top-performing shotcrete components, including nozzles, hose, pipe, couplings, ends, reducers, and cleanout accessories.

Peace-of-Mind Quality and Support

Every Con Forms product is backed by over 40 years of worldwide application experience, quality application engineers, innovative product engineering, and global product support. Con Forms' experienced engineering staff is here to assist you in all aspects of your concrete pumping system—from design and layout to product recommendations and custom modifications.

Con Forms' products will lower your maintenance repair costs, lengthen replacement intervals, and reduce total life-cycle costs. All products meet international standards and are CPMA-certified for quality and safety.

Construction Forms, Inc.
777 Maritime Drive
Port Washington, WI 53074
Toll-Free: (800) 223-3676
E-mail: cf-sales@conforms.com
Website: www.conforms.com

Get Out Your Cameras and Submit Your Outstanding Shotcrete Projects

ASA is now accepting entries for its 10th Annual Outstanding Shotcrete Project Awards. Entries are due by October 1, 2014. These annual project awards recognize excellence and innovation in projects in which the application of shotcrete has played a significant role.

The ASA award program offers you and your organization unique and distinguished exposure within the shotcrete industry. In addition, the awards program and the annual awards issue of *Shotcrete* magazine are important tools used to inform and educate the construction world, providing an exciting real-world demonstration of the many benefits and advantages of placing concrete via the shotcrete process.

Use the streamlined and simple online application form to submit your project today at **http://shotcrete.org/pages/membership/project-awards.htm**.

Now Accepting ASA Graduate Scholarship Applications

ASA is now accepting applications for Graduate Scholarships for the 2014-2015 academic year. Up to three $3000 (USD) awards are available for the 2014-2015 academic year to those pursuing a graduate degree in an accredited college or university within either the United States or Canada.

The purpose of the ASA Graduate Scholarship Program is to attract, identify, and assist outstanding graduate students pursuing careers in the concrete industry with a significant interest in the shotcrete process. Based on essays, submitted data, and references, the ASA Scholarship Committee will select scholarship recipients who appear to have the strongest combination of interest and potential for professional success in the shotcrete industry.

Winners will be asked to submit a brief summary of their concrete-related research for publication in ASA's *Shotcrete* magazine. Each ASA Graduate Scholarship Award is paid in one installment of $3000 USD directly to the student's educational institution.

Applications and all required documents must be received by 5:00 p.m. EST on Monday, **November 3, 2014**. All application information and requirements can be found at **http://shotcrete.org/pages/education-certification/grad-scholarships.htm**.

ASA Sponsors Research on the Durability and Service Life of Shotcrete

ASA has generously contributed $20,000 to LZhang Consulting & Testing Ltd. in support of a research project comparing the transport properties—and, by inference, the inherent durability and service life prediction characteristics—of cast concrete and cast wet-mix concrete compared to companion shot wet-mix shotcrete and shot dry-mix shotcrete. This research was proposed to specifically address one of the most difficult challenges currently facing the shotcrete industry: How does the durability of shotcrete (both wet- and dry-mix) compare with the durability of an equivalent cast-in-place concrete mixture?

Shotcrete is a method of placing concrete. The question still arises, however, whether the placement method affects the transport properties in shotcrete. Such questions are frequently asked by DOT/MOTs, structural engineers, architects, owners, as well as materials suppliers. Meanwhile, the challenges in proving the durability of shotcrete compared to cast concrete have become more difficult. The shotcrete industry has even encountered DOT specifications containing specific provisions against the use of shotcrete and highlighted their opinion that shotcrete is not as durable as cast-in-place (CIP) concrete. This research aims to directly address such claims.

Research Program

Transport properties in concrete are fundamental in understanding the durability and expected service life of concrete and shotcrete and include:

- Absorption;
- Diffusion;
- Permeability;
- Sorptivity; and
- Wicking.

This study should provide a quantifiable statement as to how the quality of cast concrete and cast wet-mix shotcrete compares to shot wet- and dry-mix shotcrete and how this should affect durability and predicted service life.

The testing program includes the following mixture types: cast concrete, cast wet-mix, shot wet-mix, and shot dry-mix. The concrete and shotcrete mixtures were all designed to meet ACI and Canadian Standards Association (CSA) requirements for chloride and freezing-and-thawing exposure (that is, minimum compressive strength of 5075 psi [35 MPa] at 28 days, 0.45 maximum water-cementitious material ratio [*w/cm*] and suitable air entrainment).

The current state-of-the-art for evaluating and modeling the durability and service life prediction of shotcrete/concrete, as adopted by the U.S. Navy and other agencies, involves the use of STADIUM software for service life modeling. STADIUM is proprietary software that models the durability of shotcrete/concrete based on the time to initiation of corrosion in reinforcing steel considering the shotcrete/concrete cover. Tests required to provide input information for STADIUM modeling and these tests are typically performed on test samples at 90 days:

- Porosity (modified ASTM Test Method C642);
- Ionic Migration Test (modified ASTM Test Method C1202); and
- Drying Test (moisture migration assessment).

Preliminary Results and Deliverables

At the time of this writing, most of the sample types have been cast or shot. Over 40 shotcrete test panels were produced and over 600 shotcrete cores were extracted and tested for compressive strength, and boiled absorption and volume of permeable voids. The test results show very promising data for shot wet- and dry-mix shotcrete. All mixtures meet the specified performance requirements, with the shot mixtures typically outperforming the companion cast mixtures.

Stay tuned for future updates and results from this highly important research venture for the entire shotcrete industry.

ASA Fall Committee Meetings in Washington, DC, October 25, 2014

The ASA Fall 2014 Committee Meetings in Washington, DC, will be held at the Hilton Washington on Saturday, October 25, 2014.

The following committees have scheduled working meetings: ASA Executive Committee, Education Committee, Pool & Recreational Shotcrete Committee, Safety Committee, Publications Committee, Marketing Committee, Membership Committee, and the ASA Board of Direction. These meetings offer participants the opportunity to network with colleagues, provide input on shotcrete materials and publications, and take part in ASA's overall mission.

The ASA committee meetings are held in conjunction with the ACI Fall 2014 Convention but do not require ACI convention registration. ASA meetings are open and free to anyone with an interest in the shotcrete process.

Scheduled times for all meetings can be found at **www.shotcrete.org/pages/news-events/calendar.htm**.

ASA Sponsors SPACE Shotcrete Course

COLORADOSCHOOLOFMINES.
EARTH • ENERGY • ENVIRONMENT

ASA is proud to announce its sponsorship of a shotcrete short course administered by the Office of Special Programs and Continuing Education (SPACE) at the Colorado School of Mines. This comprehensive 3-day course will explore effective and sustainable uses of shotcrete as well as its cost- and time-savings benefits. The course is intended for owners, engineers, contractors, consultants, and equipment suppliers involved in the design and implementation of above-ground structures, support of excavation, tunneling, mining, shaft construction, and heavy civil and architectural projects.

Under the instruction of industry experts—over a dozen of whom are ASA committee members—attendees will gain knowledge to specify, design, and provide quality assurance of reinforced concrete construction using shotcrete complemented with ACI specifications, guide and underground guide specification, and proper use of nozzleman certification. This course further provides an excellent opportunity for meeting and networking with shotcrete industry professionals. Attendees will receive 2 continuing education units (CEUs).

The course will be held on September 3-5, 2014, on the campus of the Colorado School of Mines in Golden, CO. Registration is now open—however, enrollment is limited; therefore, applications will be accepted in the order received.

For more information about the course or to register as an attendee, please contact course director Dr. Raymond Henn, PG., Senior Consultant, Brierley Associates and Adjunct Professor, Colorado School of Mines at: rhenn@brierleyassociates.com or visit **http://csmspace.com/events/shotcrete/**.

Shotcrete Courses at This Year's Pool | Spa | Patio Expo

Two shotcrete courses will be offered at the 2014 International Pool | Spa | Patio Expo this fall in Orlando, FL. The courses will be instructed by William Drakeley, ASA Board member, ASA Pool & Recreational Shotcrete Committee Chair, ACI examiner, and certified nozzleman.

ASA Shotcrete Nozzleman Education

An ASA Shotcrete Nozzleman Education Session will be offered November 5-6, 2014. Nozzleman Education Sessions are designed for shotcrete nozzlemen, individuals involved with shotcrete inspection, and anyone interested in learning the principles and practices that a nozzleman must employ to successfully use the shotcrete process.

ASA Nozzleman Education Sessions present an overview on placement technique, finishing, curing, testing, equipment, and safety as it relates to the nozzleman and the shotcrete process. ASA Education sessions also prepare individuals for participation in the ACI Nozzleman Certification program.

Please note:

- Session attendance alone will not result in ACI Shotcrete Nozzleman certification.
- This session will satisfy the education session requirement for a nozzleman wishing to pursue certification as an ACI Shotcrete Nozzleman through ASA.
- Attendees who wish to pursue ACI Certification will need to arrange for a separate certification session through ASA, which includes the ACI written and performance examinations.
- Attendees will qualify for and receive a complimentary 1-year ASA Nozzleman Membership.
- The ACI CP-60 (09): Shotcrete Nozzleman Craftsman Workbook for ACI Certification is included with the session registration fee.
- Supervisors, Project Managers, and Foremen who do not intend to pursue certification are also encouraged to attend for background to better understand the process and guide your crew.

This is a Level 300 course that offers 7 Technical Credit Hours. The individual registration fee is $295 (USD) until September 16, 2014; the registration fee after September 16, 2014, is $345 (USD). Registration fees include study materials provided by ASA.

For more information and to register, visit **http://poolspapatio.com/Attendee/Schedule/SessionDetails/12932**.

Construction Techniques for a Vanishing-Edge Pool

One of the most distinctive features in modern swimming pool design and construction is the vanishing edge. The visual phenomenon of water perpetually in transit is a tribute to quality engineering and execution. Using real case studies of what will and will not work, this module describes the steps necessary to successfully construct a vanishing-edge swimming pool. The class will focus on quality plans and good engineering, soil analysis and site preparation, forming, plumbing, shotcrete application, and proper finishes.

This course will be offered on Friday, November 7, 2014, from 8:00 a.m. to 9:45 a.m. Attendees can expect to learn about the following aspects of pool construction:

- Review excavation and drainage underneath common wall(s);
- Identify proper forming and load resistance;
- Review proper and improper plumbing installations;
- Show shotcrete applications do's and don'ts;
- The effect of construction techniques on finished materials; and
- The effect of construction techniques on water flow and/or water in transit.

This 1.75-hour course offers 0.2 IACET CEUs. For registration information, pricing, and additional information, visit **http://poolspapatio.com/Attendee/Schedule/SessionDetails/12935**.

Errata

In the Spring 2014 issue of *Shotcrete* magazine, in the article "Briardale Gardens," a correction to the author's name should read **Andersen** rather than Anderson. In addition, the contact phone number should be **604-324-8280** rather than 603-324-8280.

New ASA Members

CORPORATE MEMBERS

Cemen Tech Inc.
www.cementech.com
Indianola, IA
Primary contact: Connor Deering
cdeering@cementech.com

Oscar Orduno, Inc.
www.oscarordunoinc.com
Dallas, TX
Primary contact: Oscar Orduno
oorduno@oscarordunoinc.com

Precon Marine Inc.
www.preconmarine.com
Chesapeake, VA
Primary contact: Matthew Miller
agemmell@preconmarine.com

South Industries
www.southindustries.com
Menan, ID
Primary contact: Josh South
traci@southindustries.com

CORPORATE ADDITIONAL INDIVIDUALS

Tim Badilla
Restek Inc.
Manchaca, TX

INDIVIDUALS

Warren Harrison
WLH Construction Company
Centennial, CO

Jeff Lea
Harris Rebar
Delta, BC, Canada

Dominic Petrella
Petrella Concrete
San Mateo, CA

INTERESTED IN BECOMING A MEMBER OF ASA?

Read about the benefits of ASA Membership and apply online at **https://www.shotcrete.org/membership/index.htm**.

Shotcrete Technologies Receives Presidential Award for Exports

U.S. Secretary of Commerce Penny Pritzker presented Shotcrete Technologies, Inc., with the President's "E" Award for Exports at a ceremony in Washington, DC, on May 28, 2014. The "E" Awards are the highest recognition any U.S. entity may receive for making a significant contribution to the expansion of U.S. exports.

"Exporting, especially to developing countries, is a foundation of our sales growth, and we are honored to receive the 'E' Award," said Mary Jane Loevlie, CEO of Shotcrete Technologies. "In this challenging international environment, we are a small company able to compete with the large multinationals due to our nimbleness in the marketplace, and ability to 'customize' for each application. In the early 90s, exports made up less than 15% of our sales, but due to international demand for quality and service, our exports have grown dramatically to nearly 50% of our total revenues. Our manufacturing and technical training enable several U.S. businesses and contractors to thrive."

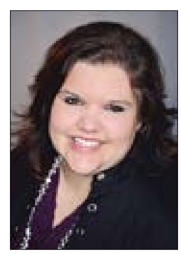
"Shotcrete Technologies has demonstrated a sustained commitment to export expansion. The 'E' Awards Committee was very impressed with Shotcrete Technologies innovation in developing products for the infrastructure repair industry. The company's customization of products for export markets was also particularly impressive. Shotcrete Technologies' achievements have undoubtedly contributed to national export expansion efforts that support the U.S. economy and create American jobs," said Secretary Pritzker in her congratulatory letter to the company announcing its selection as an award recipient.

Shotcrete Technologies has been a leader in shotcreting for underground projects, infrastructures, and new construction since 1979.

A total of 66 U.S. companies were presented with the President's "E" Award this year. President Kennedy revived the World War II "E" symbol of excellence to honor and provide recognition to America's exporters. The "E" Award Program was established by Executive Order 10978 on December 5, 1961. U.S. companies are nominated for the "E" Award for Exports through the Department of Commerce's U.S. and Foreign Commercial Service office network, located within the Department's International Trade Administration, which has offices in 108 U.S. cities and more than 70 countries to help U.S. exporters.

Industry Personnel

Genesis 3 Hires Education Coordinator



Katie Wilke Junkers

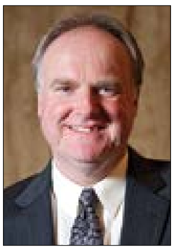
Genesis 3 has added **Katie Wilke Junkers** to its growing team to help handle their increasing number of students and members. Wilke Junkers will work with Director of Operations Lisa Bouton, Chair of the Education Council David Peterson, and volunteers to assist and manage the many facets of continuing education, social media, and database management. Genesis 3 has experienced substantial growth in the number of courses and range of topics offered, particularly in the last 3 years, and maintaining the all-important IACET certification has been handled by Wilke Junkers on a limited basis. She will now have more time to spend in this area as well as expanding her responsibilities in other areas.

Her current duties include full database management of student education and CEU accreditation as well as maintain the Constant Contact e-blast software of contact data. Wilke Junkers will handle the creation of annual transcripts, CEU Affiliations with ASLA and APLD, and maintain the IACET certification, including attending webinars in guidelines and updates when necessary and maintaining IACET policies and procedures. She will also take on the role, alongside Dave Peterson, of developing and designing updates for the University Catalog and support solicitation of Genesis 3's sponsors with underwriting costs in exchange for advertising.

Since 1998, Genesis 3 has grown to become a major international offering with themed educational schools that feature international experts in various design and construction fields. Inspired by Skip Phillips and Brian Van Bower, Genesis 3 is committed to raising standards in the industry by providing continuing education for quality-oriented professionals.

King Shotcrete Announces New Appointments

King Packaged Materials Company is pleased to announce the following appointments:


Scott Rand

Scott Rand—to the position of Vice President Sales, Construction Products Group. Rand will be responsible for the sales activities involving all King Shotcrete materials and equipment throughout North America.

Since he started his career with King over 17 years ago, Rand has played a major role in the growth of its U.S. markets and has led the sales team that has grown the King Shotcrete brand to become a leading brand in the North American shotcrete industry. His involvement in major award-winning projects such as the construction of New York's East Side Access Tunnel and the rehabilitation of Detroit's Lodge M-10 Freeway also helped strengthen King's reputation as an industry leader.

Rand has served on several committees of ASA and is a current member of the ASA Board of Directors.


Patrick Bridger

Patrick Bridger—to the position of Sales Manager, U.S. Markets. Bridger joins King with over 30 years of experience in the shotcrete industry. He will be responsible for overseeing the continued growth of King Shotcrete materials and related shotcrete equipment throughout the United States.

Bridger began his career at Shotcrete Plus in San Antonio, TX, under the leadership and mentoring of George Yoggy. He then spent 10 years working as a refractory shotcrete contractor in Texas, where he gained valuable field experience. For the past 17 years, Bridger has worked continuously in the field of sales and most recently in a senior management position with Putzmeister America.

He has been an active member of ASA since its inception and has served on several ASA committees. He is also a Past President of ASA.

Nicolas Ginouse—to the position of Research and Development Leader. Ginouse received his degree in mechanical and industrial engineering from Art et Métiers Paristech (Paris, France) in 2010 and his master's degree (MSc) in civil engineering in 2013 at Laval University, where he is currently a PhD candidate. His research deals with all aspects of the shotcrete process (equipment, placement, mixture design, material properties, and testing).


Nicolas Ginouse

Ginouse will be responsible for many research and development testing initiatives and will also perform other technical functions involving King Shotcrete materials and equipment. Ginouse joined King 2 years ago as a work term student, through a fellowship industrial work term program. This program allowed him to pursue his doctorate while gaining valuable industry experience.

King Packaged Materials Company is a leading supplier of shotcrete materials and equipment for the North American mining, tunneling, and construction markets. The company has three manufacturing facilities from which shotcrete materials can be produced for shipment to markets across North America and around the world. These appointments will strengthen King's position as a full-service provider to the shotcrete industry.

Shotcrete Calendar

SEPTEMBER 3-5, 2014
Shotcrete Course
Colorado School of Mines
Golden, CO
www.csmspace.com

SEPTEMBER 16-18, 2014
Seventh International Conference on Deep and High Stress Mining
Radisson Hotel
Sudbury, ON, Canada
deepmining2014.com

OCTOBER 25, 2014
ASA Fall 2014 Committee Meetings
Washington Hilton
Washington, DC
www.shotcrete.org

OCTOBER 26-30, 2014
ACI Fall 2014 Convention
Theme: "Spanning the Globe"
Washington Hilton
Washington, DC
www.concrete.org

NOVEMBER 2-7, 2014
2014 International Pool | Spa | Patio Expo
Orange County Convention Center
Orlando, FL
www.PoolSpaPatio.com

NOVEMBER 5-6, 2014
ASA Shotcrete Nozzleman Education
Presenter: Bill Drakeley
Registration Code: **ASA**
Use Promotional Code: **AS03** for a **10% discount** until September 16, 2014
Orange County Convention Center
Orlando, FL
www.PoolSpaPatio.com/Attendee/Schedule/SessionDetails/12932

NOVEMBER 7, 2014
CONSTRUCTION 408: Construction Techniques for a Vanishing Edge Pool
Presenter: Bill Drakeley
Registration Code: **FR01**
Orange County Convention Center
Orlando, FL
www.PoolSpaPatio.com/Attendee/Schedule/SessionDetails/12935

DECEMBER 7-10, 2014
ASTM International Committee C09, Concrete and Concrete Aggregates
Sheraton New Orleans
New Orleans, LA
www.astm.org

JANUARY 29-30, 2015
Conference & Exhibition Shotcrete 2015
Alpbach Conference Centre
Tyrol, Austria
www.spritzbeton-tagung.com

FEBRUARY 2, 2015
ASA Committee Meetings at World of Concrete
Las Vegas Convention Center
Las Vegas, NV
www.shotcrete.org

FEBRUARY 3, 2015
ASA Shotcrete Nozzleman Education
Presenters: Oscar Duckworth and Marc Jolin
Las Vegas Convention Center
Las Vegas, NV
www.shotcrete.org

FEBRUARY 3, 2015
ASA 10th Annual Outstanding Shotcrete Project Awards Banquet
6:30 pm Reception | 7:30 pm Dinner
Staten Island Ballroom
New York, New York Las Vegas Hotel & Casino
Las Vegas, NV
www.shotcrete.org

FEBRUARY 3-6, 2015
World of Concrete 2015
Visit ASA's booth: S10839
Register using ASA's source code: **A17** for reduced exhibit-only passes!
Las Vegas Convention Center
Las Vegas, NV
www.worldofconcrete.com

FEBRUARY 4, 2015
Advanced Shotcrete for Infrastructure, Rehab, and Recreational Construction
Presenters: Bill Drakeley and Lihe (John) Zhang
Las Vegas Convention Center
Las Vegas, NV
www.shotcrete.org

Shotcrete Calendar

FEBRUARY 5, 2015
ASA Shotcrete Inspector Education
Presenter: Oscar Duckworth
Las Vegas Convention Center
Las Vegas, NV
www.shotcrete.org

APRIL 11, 2015
ASA Spring 2015 Committee Meetings
Marriott & Kansas City Convention Center
Kansas City, MO
www.shotcrete.org

APRIL 12-16, 2015
ACI Spring 2015 Convention
Theme: "Fountains of Concrete Knowledge"
Marriott & Kansas City Convention Center
Kansas City, MO
www.concrete.org

JUNE 14-17, 2015
ASTM International Committee C09, Concrete and Concrete Aggregates
Marriott Anaheim
Anaheim, CA
www.astm.org

NOVEMBER 7, 2015
ASA Fall 2015 Committee Meetings
Sheraton
Denver, CO
www.shotcrete.org

NOVEMBER 8-12, 2015
ACI Fall 2015 Convention
Theme: "Constructability"
Sheraton
Denver, CO
www.concrete.org

All ASA members and subscribers now have access to the electronic version of *Shotcrete* magazine. A link to this e-magazine is sent as an item in the "What's in the Mix" e-newsletter. To ensure that you receive access to all future issues of the electronic version of the magazine, send your e-mail information to info@shotcrete.org.

REED Introduces B50HPS Concrete Pump

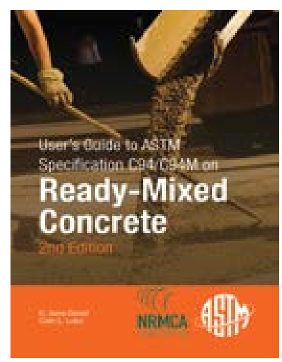
REED has just added a new model to its B-Series lineup—the B50HPS model concrete pump, an extremely high-performance pump at an economical price. The B50HPS offers the highest concrete pressure in its class (1778 psi [12 MPa]), with an 11 in.^{3} (180 cm^3) hydraulic pump and a 42 in. (1067 mm) pumping stroke. Powered by a 130 hp (97 kW) Cummins diesel, it is both reliable and quiet. The low hopper height allows for fast cleanup, and the standard 9000 lb (4082 kg) axle, frame, and reinforced hopper are all heavy duty.

For more information on the new B50HPS, visit **www.REEDpumps.com** or call (909) 287-2100.

ASTM International and NRMCA Publish New Edition of Manual 49

Now available is the second edition of Manual 49, "User's Guide to ASTM Specification C94/C94M on Ready Mixed Concrete," co-published by ASTM International and the National Ready Mixed Concrete Association.

"This manual is unique in that it takes an existing material specification and discusses the intent and purpose of each clause in it," says Colin Lobo, PhD, PE, Senior Vice President of the Engineering Division of the Ready Mixed Concrete Association, who wrote the manual with D. Gene Daniel, a ready mixed concrete industry veteran and 50-year ASTM International member. While the primary audience for the manual might be ready mixed concrete producers, the book can also assist purchasers and specifiers in understanding what is involved when the specification is cited in contract documents.



Manual 49's chapters correspond to the sections of the standard, featuring discussion of the section and accompanying images, photos, and numerical examples. The book has been updated to reflect changes in ASTM C94/C94M and the standards cited in it since the first edition of the manual.

For more information, visit **www.astm.org**.

Shotcrete FAQs

As a service to our readers, each issue of *Shotcrete* 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, **http://shotcrete.org/pages/products-services/technical-questions.htm**.

Question: *I am interested in any information or suggestions you may have regarding practical working space requirements for shotcrete applications. Shotcrete is a common approach for sewer pipeline and storm-water culvert rehabilitation projects. My concern relates to the space requirements necessary to best ensure a quality installation—for pipelines, this boils down to the question: What is the smallest diameter pipe that can be used for this method? Technical specifications that I have come across call for a minimum of 3 ft (1 m) between the surface being covered and the application nozzle. To me, this means that pipes that are much smaller than 6 ft (1.8 m) would create some difficulty. Similarly, for applications between vertical walls, how much room does a nozzleman need between the wall receiving the shotcrete and the wall at his/her back?*

Are there robotic means or other methods in use that would allow shotcrete applications without a hands-on nozzleman? Are there any other workspace limitations or controls that should be considered when determining feasibility of shotcrete application methods?

Answer: In the case of installing a lining inside of an existing pipe, there are robotic methods available, such as spin lining, where the cementitious material is cast from a rotating head as the carrier is moved along the pipe. For pipe smaller than 42 in. (1067 mm) diameter, the spin lining is likely the best method.

For pipe larger than 42 in. (1067 mm) and up to 6 or 8 ft (1.8 or 2.4 m) diameter, either hand shotcrete nozzling or spin lining are applicable. For pipes much larger than 6 to 8 ft (1.8 to 2.4 m), hand nozzling is likely the best solution.

In the case of clearance between a wall to be shotcreted and an obstruction, 3 ft (1 m) is a good rule of thumb, but a qualified and experienced shotcrete contractor can use modified equipment to place quality shotcrete in tighter spaces. A recent article on shotcreting in confined spaces can be found here: **http://shotcrete.org/media/Archive/2013Sum_Sustainability.pdf**.

Question: *We have a vertical shaft that is (right now) 70 ft (21.3 m) deep and we do blasting every 5 ft (1.5 m) after applying shotcrete to the vertical surface for protection. My concern is that if we have less than 48 hours between successive blasting, is it allowable? How does one measure if the shotcrete reaches the required percentage of strength?*

Answer: The best guidance on this subject can be found in ACI 506.5, "Guide for Specifying Underground Shotcrete" (available through the ASA Bookstore), and some articles from past issues of *Shotcrete* magazine might be of interest:

- **http://shotcrete.org/media/Archive/2006Spr_Keienburg.pdf** (support in tunnels)
- **http://shotcrete.org/media/Archive/2006Sum_Keienburg.pdf** (slope stabilization)
- **http://shotcrete.org/media/Archive/2013Fal_GoinUnderground.pdf** (concrete lining in tunnels)
- **http://shotcrete.org/media/Archive/2012Spr_SafetyShooter.pdf** (fallouts)
- **http://shotcrete.org/media/Archive/2012Spr_UndergroundProject.pdf** (incline tunnel)
- **http://shotcrete.org/media/Archive/2013Fal_ShotcreteCorner.pdf** (reaching 20 MPa in 2 hours)
- **http://shotcrete.org/media/Archive/2013Spr_GoinUnderground.pdf** (rapid-setting cement)

With properly qualified nozzlemen, a good shotcrete mixture, and high-quality accelerator added at the nozzle, the re-entry time can be minimal—normally 24 hours.

Question: *I know that there are many factors that affect the distance that shotcrete can be pumped. For a dry-mix process, is there a rule of thumb for a maximum recommended horizontal pumping distance?*

Answer: The best information on this subject can be found in ACI 506R-05, "Guide to Shotcrete," and likely in past articles in *Shotcrete* magazine. The distance that can be pumped is a function of too many parameters to fit a rule of thumb. The distance that can be pumped is influenced by the equipment being used, the vertical lift, the available compressed air, and other factors. We would suggest that you consult with one of our corporate members (**http://shotcrete.org/pages/products-services/Buyers-Guide/index.asp**) in the area of the project and get their input.

Question: *We would like to place 4 in. (100 mm) thick shotcrete reinforced with welded wire reinforcement and anchoring bolts in a water pressure tunnel. The water velocity would be between 10 and 16.4 ft/s (3 and 5 m/s). We would like to know if there is a possibility of erosion or cavitation of the shotcrete at this range of velocity.*

It is mentioned in our concrete manual that cavitation and destructive erosion begin when water velocities reach about 40 ft/s (12 m/s). Because the roughness of the shotcrete surface is higher than the concrete surface, is erosion more likely to occur? Do you know what may be the maximum water velocity acceptable for reinforced shotcrete?

Answer: Shotcrete is a method of placing concrete and the surface finish can be as smooth as that of cast concrete. Even with a nozzle finish, shotcrete erosion or cavitation should not be an issue at the stated velocities. Examples of smooth shotcrete surfaces can be found in many *Shotcrete* magazine articles (**http://www.shotcrete.org/media/archive/2004Sum_Town.pdf**) and in particular the article on the Wachusett Aqueduct.

Shotcrete FAQs

Question: *We are shooting 5000 psi (34.5 MPa) shotcrete. Because of rising temperatures, the mixture is getting too stiff to pump, and the inspector will not let us add water. What should be done in this situation?*

Answer: At the point at which concrete/shotcrete temperature is starting to rise and the mixture is stiffening up, adding water should not be allowed. Water should only be added when the mixture is stable and only up to the water specified in the approved mixture design. In warm or hot conditions, retarders, set stabilizing admixtures, or ice may be needed to keep the mixture stable for the period of time to transport and pump the load.

Question: *Is there any documentation showing that it is okay to tie off to a man-lift basket? I have never found any.*

How do other contractors deal with ACI requirements of an air lance, knowing that OSHA has contradicting standards of air wand pressure?

Answer: OSHA requires that the personnel in aerial man baskets be tied off with the appropriate harness and lanyard. When you are in a JLG or other type of man lift, the only place to tie off to is to the basket or boom bracket. This question may be better answered by studying current OSHA documents.

We cannot recall any of our members being cited for using an air lance or blow pipe.

Question: *Can you refer me to the standards for adding water to ready mixed shotcrete?*

Answer: Wet-mix shotcrete is a placement method for concrete. Ready mixed concrete used for wet-mix shotcrete needs to meet the requirements of ACI 506.2-13, "Specification for Shotcrete." ACI 506.2 specifies concrete materials shall meet ASTM C94/C94M, "Standard Specification for Ready-Mixed Concrete." ACI 506.2 also requires you shall batch, mix, and deliver wet-mixture shotcrete in accordance with Specification C94/C94M, or Specification C1116/C1116M if fiber-reinforced. Further guidance may be found in ACI 506R-05, "Guide to Shotcrete," and ACI 304R-00, "Guide for Measuring, Mixing, Transporting, and Placing Concrete."

Question: *Could you provide information regarding the appearance of efflorescence on a newly constructed 2 million gal. (7.57 million L) holding tank? The tank was constructed correctly and has held water for over 6 months. A leak test shows no water loss over a 72-hour period, and no moisture has been seen on the surface, but efflorescence has been noted.*

The tank was painted after the shotcrete was properly cured. (The applied paint was inspected by a NACE inspector and found to be approximately 7 mils [0.2 mm] and meets the specification.) At what point will this stop and what is the best practice to prevent it from happening again? Would covering the areas where it has occurred with additional paint seal the cracks?

Answer: Efflorescence is common on many exposed concrete and cement mortar applications. Generally it is seen when cracks in concrete or mortar are exposed to water rather than accumulating within the crack. The basic mechanism creating efflorescence is when concrete is exposed to water for a long time; excess free lime (calcium hydroxide) in the cement paste goes into solution with water (leaches). Then when that water eventually leaves the crack and dries on the surface, the white residue of calcium hydroxide creates what is termed "efflorescence."

It is very common to see efflorescence on brick structures where the mortar joints are exposed to rainwater that leaches out the calcium hydroxide and the resulting white efflorescence is highlighted on the dark-colored face of the brick. In concrete tanks, it is often found in cracks that can accumulate water for a sufficient time to leach the calcium hydroxide. The bottoms of vertical cracks or low areas in horizontally oriented cracks often show the greatest buildup of efflorescence. These can be surface cracks that are exposed to rainwater or through wall cracks that are exposed to water contained within the tank.

Although the tank was cured properly to help deal with long-term drying shrinkage, surface cracking on shotcrete often results from early-age plastic shrinkage cracks. These are shallow cracks that form within hours (or minutes, in extreme conditions) of placement due to rapid evaporation of water from the exposed surface of fresh concrete (common in exposed floor slabs or in your case the fresh shotcrete wall surface).

To answer your question regarding when it will stop, the answer is it won't unless the cracks are sealed, or water is prevented from getting into the cracks. Cement-rich shotcrete has more than enough free lime to continue the leaching for decades. Although surface-applied coatings may initially span small cracks, as the walls of tanks expand and contract due to filling and emptying, and undergoing daily and seasonal thermal changes, the surface cracks will open and close slightly and eventually mirror through the coating. Coatings designed to tolerate moving cracks would likely be much thicker than the 7 mils used on your project. If the cracks are through-wall cracks that are seeping from the contained water, the crack will need to be sealed, most commonly by injection of polyurethane grout or interior surface coatings.

To answer your question on how to prevent this in the future, early-age plastic shrinkage cracks can be reduced by fogging the fresh shotcrete surface to keep the surface humidity high and reduce evaporation of the water at the surface of the concrete. Also, using fibers in the shotcrete can help reduce plastic shrinkage cracking. In hot or windy climates, placing the final layer of shotcrete during the coolest or calmest time of the day may help, too.

To answer the question if additional paint would seal the cracks, simply coating with an additional 7 mil (0.2 mm) coating would provide a temporary seal, but more than likely the crack will mirror through after some period of exposure. A coating designer would need to evaluate the crack widths and potential movement to design a coating system that would provide a long-term seal.

Finally, the efflorescence caused by exposure to rainwater is generally only a visual defect and doesn't affect the long-term structural integrity or durability of the tank. Many owners tolerate efflorescence on the tanks and simply clean it off when it becomes objectionable.

Question: *We have a large project involving shotcreting soffits in an underground parking garage. The shotcreting overhead is not the problem; the problem is properly screeding the excess shotcrete from the ceiling leaving a semi-smooth finish.*

Answer: Properly screeding and finishing overhead shotcrete is very challenging. The contractors who do this type of work properly have very well-trained and skilled tradesmen throughout the crew, including the nozzlemen, rodman, and finishers. Shotcrete that is not screeded and finished properly will likely suffer bonding and other issues.

Question: *We are involved in the design of a hydro project in a section of a water-conveyance power tunnel; we are considering using shotcrete reinforced with welded wire reinforcement as a final liner. In this particular section, the tunnel is under an internal water pressure of 189 psi (1.3 MPa) and water velocities in the range of 16.4 ft/s (5 m/s) can be expected. We have not found any examples of such a design/use at this water velocity and are concerned about long-term durability and potential erosion of the shotcrete and entrainment of fragments into the turbine/powerhouse.*

Would you have any information regarding the ability of shotcrete to resist water erosion, particularly at 16.4 ft/s (5 m/s)? (Any examples would be appreciated.) What additive can be used to reduce the porosity of the projected mixture?

Answer: Shotcrete is simply a placement method for concrete, so characteristics of concrete that are resistant to erosion are equally applicable to shotcrete. ACI 210R-93, "Erosion of Concrete in Hydraulic Structures," has guidance on flow characteristics that lead to erosion of concrete. Also, ACI 350-06, "Code Requirements for Environmental Engineering Concrete Structures and Commentary," Sections 4.6.2 and 4.6.3, also provide guidance on concrete mixture characteristics helpful for protecting against cavitation erosion. Properly designed shotcrete mixtures can easily meet the ACI 350 4.6.3 concrete requirements.

In 2000, Rusty Morgan compiled a list of some 37 water supply tunnels that had been lined with shotcrete (a copy of the data sheet can be supplied upon request). Shotcrete was not the final lining in all of these tunnels and not all the inverts were lined with shotcrete. The evaluation does not document the water velocity in these tunnels, but could be ascertained by contacting the project owners.

It should be noted, however, that the 16.4 ft/s (5 m/s) water flow rate is not particularly fast. The water velocity needs to be in excess of 39.3 ft/s (12 m/s) before cavitation erosion can be expected (refer to A. M. Neville, *Properties of Concrete*) and cavitation would be the most likely cause of erosion of the concrete surface.

Supplemental cementitious materials including microsilica, fly ash, and slag will generally reduce the porosity of the hardened concrete. Microsilica is used in many shotcrete mixtures, as it helps to reduce rebound, as well as gives the fresh concrete better adhesion and cohesion that can allow for thicker or overhead placements.

Question: *I have a client with an old, soft-stone masonry building of approximately 150 years of age. The mortar is badly deteriorated and the stone is quite friable. I am advocating the use of shotcrete as an application to the interior face of the walls that will restore both in-plane and out-of-plane strength to the building walls.*

My client has expressed concern that there may be incompatibility issues between the stone masonry and the shotcrete both from a structural stiffness perspective as well as from a moisture intrusion perspective. (We have successfully used shotcrete over stone masonry in the past.)

Do you have any information you can share with me on this topic? Do you have either examples of incompatibility or successful use of shotcrete over stone masonry?

Answer: As you have noted, shotcrete has been used extensively to reinforce unreinforced or under-reinforced masonry walls and rock walls. It has been used on the Crater Lake Lodge to strengthen and stabilize a rock wall foundation and any number of other projects. In California, shotcrete has been used to strengthen or repair walls since the 1933 Long Beach Earthquake. It was used to strengthen the California State Capitol (3 ft [0.9 m] thick brick walls) in the late 1970s and all of the older unreinforced masonry walls for the San Francisco School District. To the best of our knowledge, there have been no failures of shotcrete strengthening on the West Coast in the past 80 years.

Question: *Why is there not more extensive use of fiberglass reinforcing bars? It seems like it would be a natural choice for most projects involving shotcrete in wet applications, as well as conventionally placed concrete, especially in the types of jobs we do, such as the rehabilitation of existing concrete channels that usually contain acidic waters. I understand that anything other than steel is more expensive, but isn't prevention now cheaper than remediation later?*

Answer: Although similar in dimensions, fiberglass reinforcing has distinctly different structural properties when compared to conventional steel reinforcement. This is a question better answered by the fiberglass reinforcing industry or the structural engineering community. As the American Shotcrete Association, we do not get involved in the engineering design of structural sections. However, it should be pointed out that properly designed and applied shotcrete provides a very corrosion-resistant environment around embedded steel reinforcement, providing excellent long-term durability in normal exposure conditions.

Shotcrete

2014 MEDIA KIT

A quarterly publication of the American Shotcrete Association

MAGAZINE

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- **PROMOTE** the benefits of shotcrete at national trade shows
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