shotcrete MAGAZINE
A quarterly publication of the American Shotcrete Association
VOLUME 23, NUMBER 3 • SUMMER/FALL 2021
www.shotcrete.org

Creativity in Shotcrete

american shotcrete association

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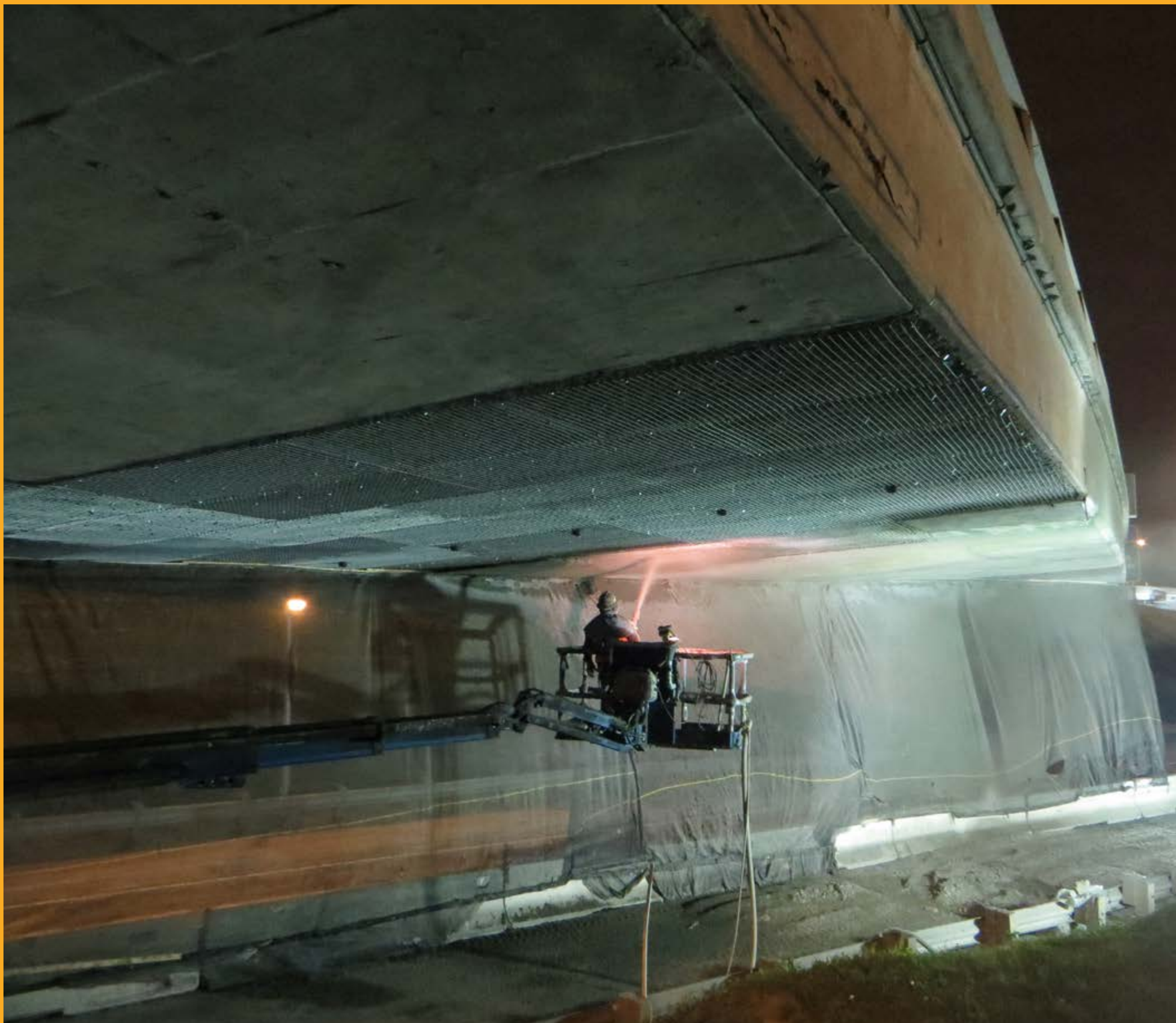

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Volume 23, Number 3 • Summer/Fall 2021

FEATURES

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

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

Please note that this issue is a combined Summer/Fall 2021 issue. In an effort to close out the 2021 Volume and fit our regular four issues into 2022, we've made the tough decision to combine Summer and Fall into one issue. Thank you for your understanding.

DEPARTMENTS

South America's Pantanal, Houston Zoo in Houston, TX featured in Artistic Shotcrete use in Exhibit Fabrication by Christopher Foster.

Perseverance Through Questionable Times

By Lars Balck

For nearly two years the country has suffered under the COVID-19 pandemic. As of December 2021, we have lost over 800,000 lives in the United States. You probably know someone who has had the coronavirus or unfortunately even succumbed to the disease.

Fortunately, for the shotcrete community business has been good. Shotcrete work has never been more in demand. Many contractors are booked out 12 months. Craftsmen are difficult to find. Shotcrete contractors are taking on larger and more complex projects. In 2021, ASA has performed more ACI shotcrete nozzleman and inspector certifications than ever before.

For two years we have been unable to have our regular in person meetings. Yes, we have had Zoom or Teams meetings online, but it is definitely not the same. We were hoping to have a strategic planning meeting in 2021 with current and past association leaders. However, we were forced to move the strategic planning meeting to 2022 because of the continued impact of Covid on holding a face-to-face meeting. A successful strategic planning meeting is only effective in person.

Since early 2020, the full-time ASA staff comprised of Charles Hanskat (Executive/Technical Director), Alice McComas (Assistant Director), and Tosha Holden (Editorial and Marketing Manager). Have kept ASA running smoothly during these trying times.

At the beginning of 2020, the Association began working with a new association management team, Virtual, which required moving files from one data base to another, relocating our inventory and shipping resources, establishing a new accounting and customer service team, working with a new graphics team and magazine publisher, and creating an entirely new website among the many challenges aspects of the move. As was expected there were some snags and delays in working with the new Virtual team. On top of the transition Covid hit in the spring, restricting travel, and forcing most interactions online. Nozzleman certification, a core activity of our Association, was hit hard forcing Alice, who is the primary program administrator, to deal with many delays and rescheduling of sessions. Though we have a good-sized pool of nozzleman certification session examiners several of our older examiners (like me) were not comfortable traveling during the height of the pandemic. Frankly, I was most concerned about bringing Covid home. Unfortunately, some of our examiners did contract Covid during their travels and were unavailable for sessions. There were also travel restrictions between Canada and the US that closed cross border travel. In addition to those restrictions, Canada also restricted air travel between provinces. As a result of the restrictions, our US-based examiners were prevented from crossing the border and some of our Canadian examiners had to drive 12 hours one way to get to sessions. In spite of all the restrictions, Alice guided 66 nozzleman certifications and 452 nozzlemen were educated and attempted certification.

2021 started off with the same problems as 2020 yet Alice and the examiners conducted 96 sessions in 2021, an all-time record. During 2020 and 2021, Charles Hanskat and Frank Townsend presented shotcrete education seminars to 927 engineers, architects, students and owners. We also conducted eight "Shotcrete Inspector" education programs for 66 attendees. Many of the inspector education attendees also took the ACI Shotcrete Inspector certification exam. Tosha Holden, our editorial manager and marketing specialist, who joined us just when the world went virtual, guided us through virtual meetings and presentations. She also initiated a "The Art of Shotcrete" program to encourage submission of photos of shotcrete. The top three best photos of each quarter are published in the *Shotcrete* magazine bringing more awareness of shotcrete. Tosha and Alice were also essential in putting together our virtual ASA Outstanding Projects Awards program in 2021. The level of effort required to pull together all the award winner videos and have a "live" awards ceremony was far above the normal requirements when we have an in-person awards program.

Several years ago, Michael Cotter pointed out that it is the shotcrete contractor, not the nozzleman, that is held responsible for a project's quality and ultimately the overall success. He recommended to the Board that we develop a program to qualify shotcrete contractors. The ASA Board approved development of a Contractor Qualification Program and over the course of several years developed our Contractor's Qualification (CQ) program. Marcus von der Hofen and his CQ committee spent a lot of time in 2020 and 2021 to fine tune the program. ASA developed a new online submittal process for the CQ program. Once an application is submitted, ASA staff reviews for completeness and then Marcus assigns a review group. The review group of three experienced shotcrete industry professionals then spends hours thoroughly evaluating and discussing the applications. ASA's qualification process of shotcrete contractors allows specifiers a measure of confidence in an ASA qualified contractors' knowledge, resources, and experience to successfully complete a shotcrete project of similar size and scope. To date eight firms have been qualified with several applications in progress.

In 2022, we will hold our Annual ASA Shotcrete Convention and Technology Conference from Sunday, February 27 through Tuesday, March 1, at the Sonesta Hilton Head Resort in Hilton Head, SC. It will be the first time in two years that we had a chance to have face-to-face meetings. There will be 12 technical presentations, the Outstanding Shotcrete Projects Awards Celebration, exhibits and networking. ASA staff have put in a lot of time and effort into making this meeting a success. Our community will be finally able to get together.

ASA staff for the past two years has gone above and beyond under difficult conditions. Please take the time to thank them at the upcoming convention.

Oh, please visit www.shotcrete.org to register and attend this year's convention!

Membership Committee

By Jason Myers

As we are hopefully emerging from this Covid Era, many of us are looking at our lives and lifestyles and making adjustments to figuring out what the new "normal" is going to look like. This applies not only to our personal lives but also to our work and professional lives. All of us are getting tired of having endless Zoom Meetings and are looking forward to a time of not worrying about facemasks, figuring out who might or might not have the shot, and just having a time to get together and hanging out without any concerns. I think that all of us are tired of telling that to our children, but it is time that we practice what we have been preaching and put down our screens and get back to face to face ASA Meetings.

As we are getting ready to have the next ASA Convention and starting to have face to face meetings again, we all have to see what the new normal is going to be like. We're all looking forward to renewing friendships, having a good laugh, and having a meal together. During this Covid Era membership has remained strong and participation in ASA meetings has grown, which makes now a great time for us to get off of the screens and start to work together again face to face.

ASA is presently working on numerous areas of the shotcrete industry that will make the industry better. From working through the OSHA Silica regulations, Qualifications for being a Shotcrete Contractor, a Safety program that is specific to the shotcrete industry, and guidelines for shotcreting a structurally reliable pool, to name a few. These are some of the areas that our ASA committees are working through. By relying on the experiences and knowledge that each of us possess, we wrestle with issues and find ways to raise the quality bar for the entire industry. It is one thing to read the articles and try to learn from the position papers that are governing the industry by yourself, and another to work as a team and participate in all of the discussions that have gone into getting a position paper written. In addition, it is more effective to work in a committee, find out how others are dealing with a situation and also gives you the opportunity to influence new industry standards. I have had many a meal, and even a greater number of drinks, with other ASA members from which we have each shared information of how we go about our business and have solved the problems that we are facing or could in the near future.

Over the past couple of years, parts of our lives have been on automatic. However, as the new normal emerges it is time to start getting back in motion and being proactive in our industry. There is only one way to be influential in that future, and that is to be an active member. Like many tasks, a single set of hands leads to an impossible task, but many hands can make anything possible. It is by discussions and conversations that we figure out where the weak points of our industry exist and where the hot buttons of the future lie. The world is getting increasingly more complex and global, and the competitive edges are getting slimmer and slimmer. You can face this slim margin by yourself or by being an active ASA member and work together to solve the problems of the future and define the competitive margin rather than being defined by it. All of the ASA committees are always looking for new active members, lend a hand and help us make anything possible.

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

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Steps to Becoming a Certified Shotcrete Nozzleman

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

First, on a sad note we learned that Axel Nitschke, ASA's Vice President, passed away on Sunday, December 26, 2021.

Though only 53 years old he had accomplished much in his career in the underground world, and with us at ASA. Axel revigorated our Underground Committee, and further accepted the challenges of becoming a Board member and moving through the officer roles of ASA. As Vice President this year he would have moved into the President's role next year. Axel always paid close attention to detail and provided comprehensive and through reviews of all ASA activities that he was involved with. His opinions were insightful and helped us move several programs forward at ASA. Axel was always willing to help where he felt he could make contributions to the effort and gave freely of his time and energy.

You can find a remembrance of Axel with input from several of our members who worked with him professionally and in ASA activities in our Association News section. We will all miss his enthusiasm and commitment to ASA and the shotcrete world.

In fielding questions about ASA's shotcrete certification, I often get the question "Does ASA provide nozzleman training?". The short answer is "No". However, we do provide comprehensive nozzleman "Education" and conduct the large majority of ACI's shotcrete nozzleman certifications for shotcrete contractors around the world.

Training

So why is training different from education? A definition for training from the American Heritage® Dictionary of the English Language, 5th Edition includes:

"Practical education in some profession, art, handicraft, or the like; instruction coupled with practice in the use of one's powers: as, manual training."

Shotcrete nozzling is a physically demanding trade skill. Note in the definition "practical education", "instruction coupled with practice", "manual training". In shotcrete, training requires hands on work with the nozzle. Full ACI nozzleman certification requires a minimum of 500 hours of hands-on shotcrete nozzling experience. Even a Nozzleman-in-Training requires a minimum of 25 hours of hands-on shotcrete nozzling experience.

Thus, "training" in our shotcrete world is the experience a nozzleman gains by physically manipulating the nozzle, evaluating the consistency of the concrete mixture, and constantly monitoring the quality of placement.

So how does a new nozzleman gain proper training? We recommend that new nozzlemen train under the direct supervision of an ACI-certified shotcrete nozzleman. The ACI-certified nozzleman has been given the basic knowledge of concrete and shotcrete placement through ASA's education seminar and direct interaction with one of our experienced examiners. We trust they will convey their knowledge about quality shotcrete placement to the junior nozzleman. If there are no ACI-certified nozzleman on the crew to help mentor a new nozzlemen, we would recommend reaching out to one of our ASA members who can assist in teaching the new nozzlemen the proper methods of quality shotcrete placement.

Education

When ASA first started conducting the nozzleman certifications we realized that nozzlemen may have nozzling experience but may lack full and accurate knowledge of concrete properties, equipment needs, proper placement techniques, curing and protection. All these contribute to the nozzleman's ability to recognize quality shotcrete placement.

Thus, ASA developed a full-day education session specifically for nozzleman and requires all new nozzlemen pursuing ACI certification to attend our nozzleman education course. The ASA education builds on the ACI CP-60(15) *Craftsman Workbook for ACI Certification of Shotcrete Nozzleman* and provides many more images and examples to support the CP-60 book. Most nozzlemen find our comprehensive education seminar and interaction with the experienced examiner helpful in passing the ACI written exam based on CP-60, required for certification.

The education course is usually offered during a certification session conducted for a host company. However, we also provide the education course as a standalone seminar. We usually conduct the standalone education course at the annual World of Concrete exhibition or the International Pool Spa Patio show. It can also be offered on-site if a company wants to give their new nozzlemen trainees a great start on learning the basics of quality shotcrete placement before gaining their full work experience hours.

CERTIFICATION

So how is certification different from training or education? From the Cambridge Academic Content Dictionary certification is defined as:

"proof or a document proving that someone is qualified for a particular job, or that something is of good quality"

Thus, certification is the process of proving that a nozzleman has the ability to place quality shotcrete. This must follow proper education and training.

The American Shotcrete Association is the primary sponsoring group for the ACI Shotcrete Nozzleman Certification program. Alice McComas, our Assistant Director, spends innumerable hours fielding inquiries from potential sessions hosts, arranging sessions, securing documentation from the host and nozzlemen, ordering exams, assigning examiners, collecting and submitting the final exam results. ACI's certification policy for the Shotcrete Nozzleman Certification (ACI CPP 660.1-21) is likely the most complicated certification program ACI offers.

Sometimes we are asked, "Why can't the ASA/ACI examiner for our certification provide hand-on training before the certification?" Though this may be possible, ACI's and ASA's position is that the examiner conducting the certification should not have any conflict of interest with the company or nozzlemen being evaluated for certification. If the examiner was working with nozzlemen for days (or weeks) to train them in shotcrete placement there may be the impression that the examiner would be predisposed to pass the nozzlemen in their performance exams. Thus, both ACI and ASA policies directly address what constitutes a potential conflict of interest.

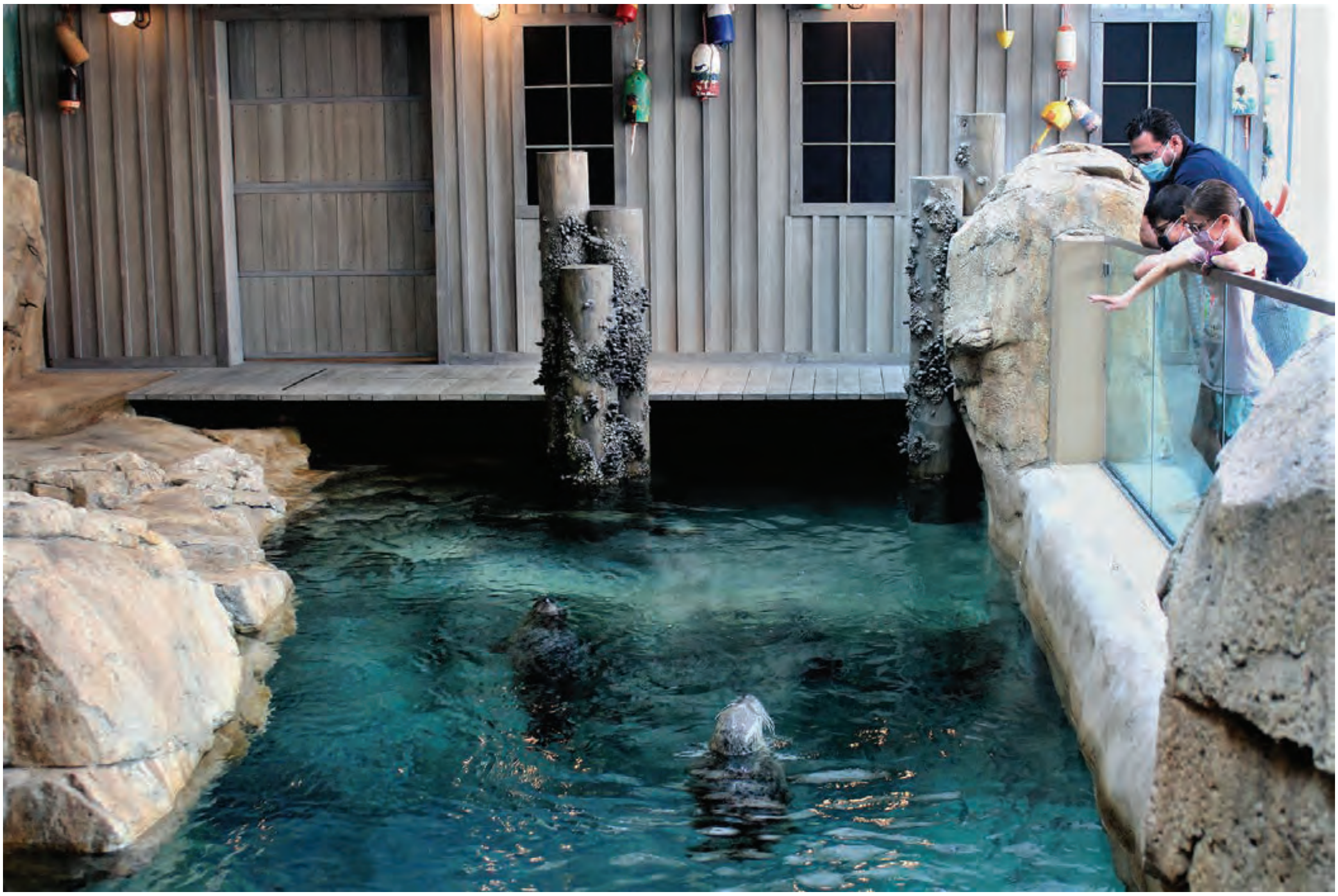
ASA is continually working to improve the consistency and quality of the nozzleman certification sessions. We conduct annual workshops for our 16 examiners where we address updates in the policies and refinements in our processes, including an open roundtable discussion on how to improve our sessions for both hosts and nozzlemen. We also work closely with ACI certification to assist in refining the policies and helping to ensure they meet the needs of our shotcrete industry.

Training and Education need to occur before Certification. Successfully completing Certification is the proof that shotcrete nozzlemen have the basic skills and knowledge for shotcrete placement. Most nozzlemen progress from trainee to certified by Training, then Education at one of our ASA sessions and finally Certification. However, there is value in trainees securing ASA Education early in their shotcrete career before completing hands-on Training. In fact, we do encourage new nozzlemen to take the Education, if an opportunity presents itself, sooner rather than later in their development. The Nozzleman-in-Training (NIT) option of ACI certification supports this approach.

In summary, Training, Education and Certification are distinctly different but interrelated processes that lead to the ultimate goal of having shotcrete nozzlemen in the workforce who will have the skill and knowledge to consistently place quality shotcrete. This has been ASA's goal in working with ACI to develop and refine the ACI Shotcrete Nozzlemen Certification program. Quality shotcrete placement is essential to broad acceptance and adoption of shotcrete in the concrete construction market.

Artistic Shotcrete Use in Exhibit Fabrication

By Christopher Foster



The zoological and aquarium industry has been successfully using shotcrete placement within animal habitats for several decades. The flexibility and durability of shotcrete provides natural settings that allow for better animal enrichment over caged habitats. Zoo guests also benefit from viewing animals in a more organic habitat where the animals exhibit their natural behaviors.

There are numerous uses for shotcrete work in exhibit applications including:

- Shotcrete provides naturalistic animal barriers, artistically finished to blend with other naturally landscaped surroundings.
- When properly designed, shotcrete can be used to hide unsightly objects or architectural elements within exhibits.
- Pools, ponds, streams, and other water containment vessels, vital to specific animal habitats, can be built with artistically finished shotcrete.

PROVIDING NATURALISTIC BARRIERS

The long-term durability of shotcrete coupled with the flexibility of artistic finishes provide excellent animal containment in zoo and aquarium exhibits. Containment barriers that house large and potentially dangerous animals need to be structurally sound and escape proof. Shotcrete, along

theme matching shotcrete finishes. This provides a more consistent thematic or exhibit experience. For example, an animal holding building can resemble a rustic field stone cabin that aligns with the habitat's thematic direction. Foundations or other structures can be theme finished with a shotcrete rockwork texture that blends with natural stone placed in the exhibit. In any case, disguising architecture to blend more with natural surroundings has been a key exhibit strategy for decades.

with proper embedded steel reinforcement, provides the containment barriers necessary for safely housing animals within zoos, animal sanctuaries, and aquariums, while also enhancing the visitor experience. Shotcrete placement allows creative opportunities for aesthetically pleasing barrier walls that resemble earthen embankments, rock cliffs, or even themed ruin walls. Likewise, faux shotcrete trees and thematic walls can be used as structural connections for mesh and other fencing used in habitats.

HIDING UNSIGHTLY OBJECTS

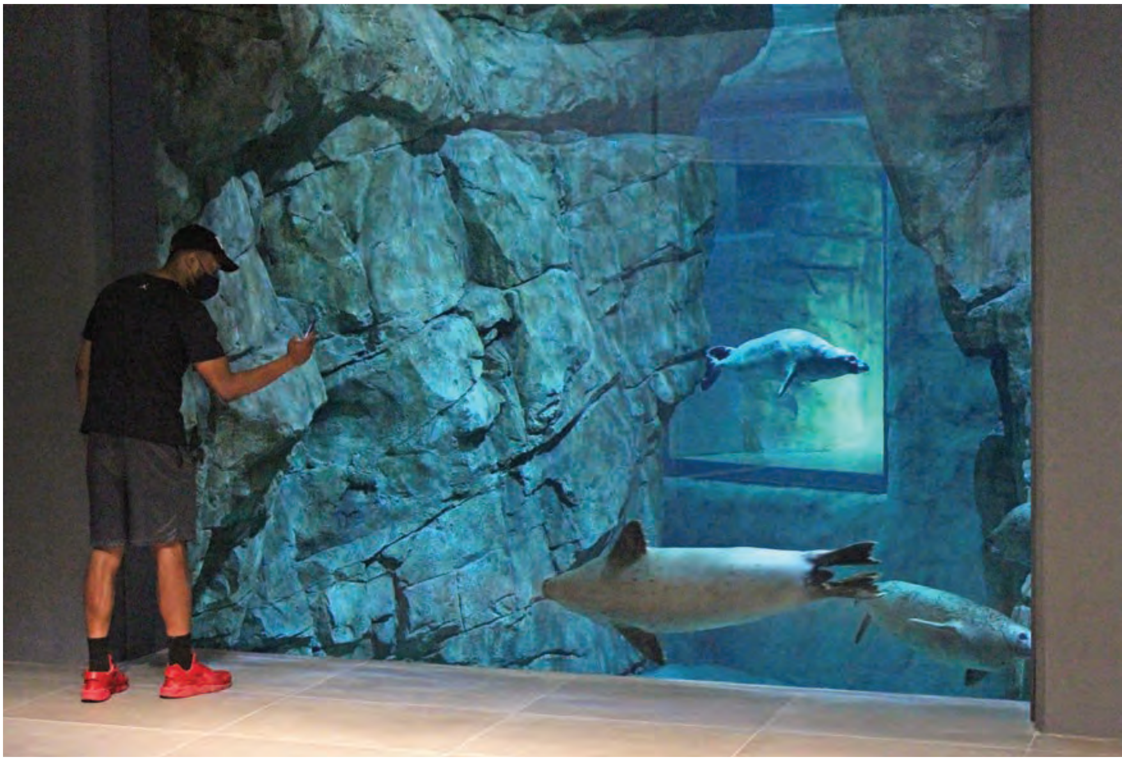
The flexibility of shotcrete applications along with artistic integration provides naturalistic screen walls and structures that can disguise line-of-sight architectural elements. These strategies can be as simple as hiding access doors, piping penetrations, life support systems and pump houses, to concealing back of house walls. Themed shotcrete screen walls are often used to separate view windows from other vantage points to allow for a better guest experience and enhance the "around every corner discovery," critical to design strategies for immersive experiences.

BLENDING WITH NATURAL SURROUNDINGS

Architectural elements within exhibit spaces can be camouflaged with

WATER ELEMENTS

Artistic shotcrete allows for pond and stream construction that simulates natural waterways. Edging treatments that resemble mud or sand textures create realistic water sources for animal habitats and allow for animal enrichment opportunities, such as foraging within the irregular textures. When coupled with waterproofing and structural details, shotcrete ponds provide a long-term water containment vessel requiring little maintenance over time. Adding more robust structural steel to thickened shotcrete pond features provides support for even the largest animals such as elephants, hippos, and rhinos.



THE PROCESS

Preconstruction/Shop Drawings

Exhibit contractors, like COST, consult with owners, architects, engineers, and contractors during preconstruction phases. These meetings are beneficial for project scoping, pricing, and scheduling. The project stakeholders weigh and critique approaches, materials, and other aspects of specialty exhibit construction to determine the best fabrication and construction methods.

Preconstruction assistance in exhibit projects typically saves time and reduces costs as many of the challenges that occur in developing exhibits are clearly identified early in the project life cycle. Early exploration is even more critical when the design integrates exhibit components with other building structures and trades (for example rockwork attached to walls or water features adjacent to building foundations).

In many cases, shop drawings are required to successfully execute exhibit projects. Shop drawing packages can be as simple as connection details or as complicated as complete water feature mechanical design. Likewise, sealed drawings by a professional engineer for structural assemblies are often required to compliment the shop drawing package. Engineered drawings are typically needed for permitting when theme finishes are attached to retaining walls or to building walls.

Modeling

Oftentimes highly detailed scale models, generally composed of wood, foam, and clay, are built during the preconstruction phase. Physical models are a meticulously detailed, scaled representation of the finished project. In exhibit fabrication, a scale model is generally considered a better reference tool for architects, designers, contractors, and owners over both 2D and 3D drawings. The physical model allows the project team to make minor and even major adjustments, ensuring the project meets the design intent before exhibit fabrication and construction commences. Preconstruction modeling saves valuable time and dollars over making in-field changes.

Three-dimensional modeling, using software such as Autodesk Revit, is becoming more prevalent in exhibit fabrication projects. Builders often integrate these files within the entire site model. However, there are limitations with 3D models, particularly when presenting organic finishes. Typically, 3D models only enhance, but do not replace the physical model in the zoo and aquarium exhibit fabrication industry.

Fabrication

Prior to shotcrete work commencing on-site, preconstruction work, like steel fabrications, can be built in factory environments. Firms such as COST have used off-site fabrication of steel assemblies and armatures for decades. There are numerous advantages to shop fabrication. Technological improvements such as water jet equipment, bar bending machinery, and CNC equipment offer efficiencies. These advanced systems are revolutionizing the way that highly detailed thematic finishes are constructed for several reasons:

- Provide more accurate feature replications based on computer-generated modeling.
- Off-site fabricated features decrease on-site construction timelines.
- Allow for Just in Time (JIT) deliveries of fabricated panels and pieces.

- Provide quality control checks and balances.
- Increase efficiencies within controlled conditions.

SHOTCRETE SITE CONSTRUCTION

While all the best planning and fabrication technologies aid in a project's success, highly trained artisans and technicians will be the real difference-makers. This is especially true in artistic shotcrete applications. Exhibit projects require more than experienced construction tradesman.

Blending artistry with sound construction methods require passionate and highly capable artists. Educated and trained artisans use their skillsets to deliver realistic and natural theme finishes. Their handwork, sculpting, painting, and aging techniques will be the true test of a project's success.

We often dispatch art teams to the project site during steel erection because the articulation of the steel and backing material dictate the overall shaping of the theme features. The artistic team typically oversees steel armature

setting and they are involved in the shotcrete structural placement. To meet structural requirements, the steel reinforcing bars must be completely encapsulated. Once the structural concrete cures, the artistic team is responsible for applying, carving, and stamping the finish shotcrete layer. Artisans use the approved models, samples, and photographic imagery to capture the texture of the landform they are replicating. Our shotcrete artists use a variety of hand carving tools, but each applies unique skills and techniques to achieve the desired finish.

While carving and finishing is paramount to achieving realistic finishes, paints and other topical applications further enhance the exhibit work. Artists use multiple paints and stains to match colorations found in nature and align with the approved model and samples.

RECENT REFERENCE PROJECTS

COST recently completed the following exhibit projects using artistic shotcrete placement. These overviews on exhibit specifics exemplify how shotcrete delivers superior zoological and aquarium exhibits.

PINNIPED COVE, MARITIME AQUARIUM OF NORWALK

Pinniped Cove is a 160,000-gal (730,000 l) exhibit for Maritime Aquarium's five female harbor seals. The L- shaped exhibit is seven times larger than their previous tank and is the aquarium's largest exhibit project completed in its 33-year history. The exhibit encompasses two levels of the building and allows guests to view the habitat from three sides. The second floor includes above water views that put patrons at eye level with a rustic "fishing shanty" and a seal demonstration space. The ground floor has under water viewing from floor to ceiling. During three daily educational demonstrations, guests watch the seals plunge 22 ft (6.7 m) deep to the tank bottom. The underwater rockwork provides areas for seals to explore and play.

As the exhibit contractor, COST provided engineered shop-drawings, models, and mockups ensuring artistic consistency throughout the project. Both the institution and Seattle-based MIG/Portico reviewed and approved the project tools prior to construction. Once shops, models and samples were approved, the COST team mobilized and installed secondary steel and structural shotcrete based on the engineered drawings. The team carved, colored, and aged finish layers of shotcrete to replicate coastal rock and earthen embankment textures. The artistic package also included a shotcrete deadfall tree and a fishing shack with cedar shingles and Ipe wood decking. Two themed decorative wood pilings with faux barnacles were within the exhibit scope.

SOUTH AMERICA'S PANTANAL, HOUSTON ZOO

Houston Zoo's new South America's Pantanal allows patrons to explore regions of Brazil, Paraguay, and Bolivia, without leaving Texas. The exhibit focuses on wetland areas that are home to piranha, giant anaconda, and river otters. Studio Hanson|Roberts designed a unique underwater view space to allow patrons to come face-to-face with the playful and inquisitive otters. Other dry grassland and forest habitats for jaguars, howler monkeys, macaws, and golden lion tamarins were created for the project.

The area covers just over four acres within the zoo and provides numerous vantage points to view the animals in naturalistic environments. The elevated platforms and view structures provide the visitors with the experience of walking amongst the wetlands and within the eco-lodges found in the Pantanal region.

The project was a collaborative process where the exhibit contractor's artistic team worked alongside the Houston Zoo's team of artisans. Exhibits were developed to maximize construction efficiencies during a condensed project schedule. Both teams of artisans were responsible for specific rockwork and earthen/mud bank finishes, but all worked together to ensure continuity, and a high degree of artistry and authenticity.

COST worked closely with the zoo staff, exhibit designer Studio Hanson|Roberts, and Tellepsen Builders to provide shop drawings and detailed scale models. These models were effective tools to ensure artistic consistency throughout the Pantanal, especially across the multiple art teams. Once approved, COST crews were dispatched to provide secondary steel and structural shotcrete throughout the exhibits. They were also responsible for simulated rockwork and earthen texture finishes in the otter, macaw, and jaguar exhibits, as well as in some common areas.

The same project team is deployed on the new Galapagos zoological exhibit, future home of sea lions, sharks, giant tortoises, and more. This exhibit is scheduled to open in Spring of 2022.

For more information on these projects or using shotcrete in artistic applications, you may visit www.cost-inc.com. ASA is also a great resource for information on the uses and benefits of shotcrete.

BIO

COST has actively used shotcrete placement in zoo and aquarium exhibit fabrication projects since 1957. Our exhibit projects have received numerous awards from the Association of Zoos and Aquariums in addition to a 2020 American Shotcrete Association award in the New Construction Category.

***Christopher Foster**, VP of Sales and Marketing, and COST's executive and project management teams contributed to this article.*

UMA Corrects Shotcrete Pool Settlement Issues with HDPR Injection

By Brian M. Fraley

The engineer chose UMA's High-Density Polyurethane Resin (HDPR) Injection to remediate the voiding below the shotcrete surface of a pool that was experiencing settlement issues.

UMA was contacted in January 2021 regarding a residential pool in Winston-Salem, North Carolina that was experiencing settlement issues in the shallow end. Prior to UMA's involvement, Catawba Valley Engineering & Testing (CVET) conducted soil test borings at the property to determine the in-situ soil conditions.

Drilled soil test borings, hand auger borings, and dynamic cone penetrometer (DCP) tests in the settlement area revealed existing fill, alluvial, and residual soils. The fill and alluvial soils consisted mainly of sandy clay with very soft to stiff cohesive soil consistencies. There was also a review of aerial photos that revealed an apparent open ditch excavation for a storm drainage pipe that had been installed in February of 2005. The pipe appeared to be directly under the existing pool. All of these factors contributed to the observed settlement and distresses in the shotcrete lining.

HDPR was injected by performing a series of Deep Injections (DIs) at increments of 3 ft below the bottom of the pool to a final depth of 9 ft.

The settlement was easily corrected, and voids were filled without the need to rip out and replace the valuable shotcrete.

Based on the findings, CVET recommended UMA's High-Density Polyurethane Resin (HDPR) Injection to remediate the voiding below the shotcrete surface. UMA's approach was to eliminate future settlement by densifying the low consistency soils and filling the void space without lifting the pool and causing potential damage to the reinforced shotcrete structure.

UMA determined that injecting HDPR by performing Deep injections (DIs) was the best method to solve this problem. The plan was to perform a series of DIs at increments of 3 ft (0.9 m) below the bottom of the pool to a final depth of 9 ft. (2.7 m) The pool treatment area consisted of approximately 640 ft^2 (60 m^2) with DIs placed on approximate 3 ft centers.

Extreme caution had to be exercised, because if the structure was lifted, even the slightest cracking in the shotcrete surface could cause more damage. UMA deployed laser measuring devices capable of measuring tolerances within 1/16 in. (1.6 mm). In addition to monitoring elevations, avoiding further damage, and alleviating pore pressure increases from excess water, crews had to methodically inject material by periodically "jumping" back and forth between the shallow and deep ends. This made the process slower than working in a single area because equipment had to be constantly moved and re-calibrated. Despite the additional time required, the work was done effectively and damage-free. The client's pool technician repaired the surface of the pool following UMA's injections.

Injections, like the type performed by UMA, can salvage quality work performed by pool shotcrete contractors. Having geotechnical information is a luxury that not every homeowner or shotcrete pool enthusiast can afford or even knows that they need. The damage caused at the Winston-Salem pool was due to subsurface construction of the site

UMA deployed laser measuring devices capable of measuring tolerances within 1/16 of an inch to ensure that no lifting or shotcrete damage occurred.

developer and was unknown to the homeowner or pool contractor. Due to the resilient nature of reinforced shotcrete construction, the settlement was easily corrected, and voids were filled without the need to rip out and replace the structural shotcrete.

It is important to consider all factors when deciding if a rip out and replace option is even possible. Cost is the first that comes to mind. Intricate shotcrete pools require precise excavation and a qualified nozzleman to construct.

Pools constructed in an elevated water table require significant and costly dewatering to complete. These dewatering methods must be performed prior to emptying the pool for repairs because of buoyancy and a risk of the pool lifting out of the ground when emptied. With injections, technicians using waders can inject the polymer while the pool is still partially filled to counteract the buoyancy.

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Definitions of Key Shotcrete Terminology

Shotcrete specifications—from mixture design through application—hold pool contractors responsible for shotcrete performance. Engineering plans, architectural renderings, or referenced concrete standards applied to pool construction use a variety of shotcrete terminology—both correctly and incorrectly. Understanding the meaning of the terminology is paramount to understanding the entire process as it relates to the pool construction industry. These key shotcrete terminology definitions are a starting point for any contractor building concrete swimming pools using the shotcrete process.

Shotcrete as a technology is not industry-specific. ASA and its Pool & Recreational Shotcrete Committee, however, are currently narrowing the focus on some key phrases or definitions that are used consistently in their practice area. These are steps to increase the cohesiveness and the uniformity of the shotcrete industry. Having contractors understand and use the same terminology for both the dry- and wet-mix processes immediately improves communication and understanding of all involved in the shooting applications. This understanding is the first step toward the universal acceptance of the shotcrete process by the entire pool industry.

TERMINOLOGY AND DEFINITIONS

Shotcrete	A concrete-placing process where concrete mixtures are conveyed through a hose and then pneumatically projected at a high velocity onto a surface to achieve high-quality, in-place compaction. It produces high-quality dense concrete with a low water-cementitious material ratio (w/cm), low permeability, and a high cementitious material content.
ACI	The American Concrete Institute (ACI) develops and publishes consensus documents (codes, specifications, and guides) for the shotcrete process through ACI Committee 506, Shotcreting. ACI also maintains the ACI Shotcrete Nozzleman Certification program under the guidance of ACI Committee C660.
ASA	ASA is a nonprofit organization of contractors, suppliers, manufacturers, designers, and engineers that encourages and promotes the safe and beneficial use of the shotcrete process. ASA is the primary sponsoring group for administering the ACI Shotcrete Nozzleman Certification program.
Admixture	Any material deliberately added to concrete before or during mixing, other than cementitious material, water, aggregates, and fiber reinforcement.*
Blowpipe	Air jet operated by a nozzleman's helper in shotcrete shooting to assist in keeping rebound or other loose material out of the work. Also known as an air lance.†
Brooming	A finishing procedure in which a broom is pulled across the shotcrete surface to roughen the surface.†
Cementitious paste	Mixture of cementitious material and water that is part of concrete.*
Compressive strength	Measured maximum resistance of a concrete or mortar specimen to axial compressive loading, expressed as a force per unit cross-sectional area (for example, lb/in.2).*
Concrete	A mixture of two components: aggregate and paste. The paste is made of cementitious materials and water and acts as the glue that binds the aggregates (sand and/or ground or crushed stone) into a hardened mass due to the chemical reaction of the cement and water (hydration).*†
Consistency	The relative mobility or ability of freshly mixed concrete or mortar to flow.*
Cracking	It occurs when the rate of evaporation exceeds the rate of bleeding.*
Curing	Action taken to maintain moisture and temperature conditions in a freshly placed mixture to allow cementitious material hydration to occur so that the potential properties of the mixture may develop.

Cuttings — Shotcrete material that has been applied beyond the finish face and is cut off in the trimming or rodding process.†

Delivery equipment — Equipment that introduces and conveys shotcrete material into the delivery hose.

Delivery hose — Hose through which shotcrete materials pass on their way to the nozzle; also known as the material hose or conveying hose.†

Dry-mix shotcrete — Shotcrete in which most of the mixing water is added at the nozzle.†

Earth surface — When used as forms, must be firm, stable, and trimmed to the desired lines of the finished concrete.

Entrained air — Microscopic air bubbles intentionally incorporated in mortar or concrete during mixing, usually by use of a surface-active agent; typically between 0.0004 in. (10 μm) and 0.04 in. (1 mm) in diameter and spherical, or nearly so.†

Finish — The texture of a surface after consolidating and finishing operations have been performed.‡

Finisher — Craftsman who trims and finishes the surface of the shotcrete (also refer to Rodman).†

Fly ash — The finely divided pozzolanic residue resulting from the combustion of ground or powdered coal, which is transported from the firebox through the boiler by flue gases.*

Forms — A system for the in-place support of fresh shotcrete, which is rigid enough to resist the impact force of shotcrete while maintaining the intended shape and preventing excessive vibration.

Ground wire — Small-gauge, high-strength steel wire used to establish line and grade for shotcrete work; also called alignment wire, screed wire, or shooting wire.†

Gun — Dry-mix shotcrete delivery equipment.†

Gun finish — Undisturbed final layer of shotcrete as applied from a nozzle without hand finishing. Sometimes referred to as a natural finish.†

Gun operator — Craftsman on dry-mix shotcreting crew who operates delivery equipment. Sometimes referred to as "gunman."†

Gunite — Trade name originally used for dry-mix shotcrete.†

Hose tender — Crew member responsible for moving and/or adjusting delivery hose to aid nozzleman; also responsible for delivery hose connections.

Hydration — The chemical reaction between hydraulic cementitious material and water.*

Impact velocity — The velocity of the material particles at impact on the receiving surface.† (Ideal at 60 to 80 mi/hr [100 to 130 km/hr].)

Mortar — A mixture of cementitous paste, fine aggregate, water, and admixtures. In fresh concrete, this is the material that occupies the spaces between the particles of coarse aggregate.*

Nozzle — Attachment at end of delivery hose where shotcrete is projected at high velocity.†

Nozzleman — Craftsman on a shotcrete crew who manipulates the shotcrete nozzle, controls material consistency (dry process), and controls the final placement of the material.

Overspray — Shotcrete material deposited away from intended receiving surface.†

Plastic shrinkage — Cracking that occurs in the surface of fresh concrete soon after it is placed and before initial set.

Pneumatic feed — Shotcrete delivery equipment in which a pressurized air stream conveys material.†

Positive displacement — Wet-mix shotcrete delivery equipment in which a pump or other non-pneumatic means pumps the material through the delivery hose in a solid mass.†

Porosity — The ratio of the volume of voids in a material to the total volume of the material.

Permeability	The rate of flow of water through a cross-sectional area of a porous medium under a given hydraulic gradient and temperature condition.
Pozzolan	A siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.*
Predampening	In the dry-mix process, adding water to the aggregate before mixing to bring its moisture content to a specified amount, usually 3 to 6%.†
Pump	Wet-mix delivery equipment.†
Pump operator	Craftsman on wet-mix shotcreting crew who operates the shotcrete pump.†
Rebound	Shotcrete material that bounces away from the surface against which the shotcrete is being projected.† Rebound has inadequate cementitious content as compared to the original shotcrete.
Rod	Sharp-edged cutting screed used to trim shotcrete to forms or ground wires.†
Rodman	Craftsman on the shotcrete crew who uses a rod or other tools to trim and finish the shotcrete.†
Rolling	The result of applying shotcrete at angles less than 90 degrees to the receiving surface, resulting in an uneven, wavy, textured surface at the outer edge of the spray pattern.†
Saturated surface-dry (SSD)	The moisture condition of the substrate so that it does not absorb water from the placed shotcrete.
Sand pocket	A zone in the shotcrete containing fine aggregate with little to no cement† (sand lens).
Shadow	Area behind an obstacle that is not adequately impacted and compacted by the shotcrete stream. In hardened shotcrete, shadow refers to any porous area behind an obstacle, such as reinforcement.†
Sloughing	Subsidence or sliding of shotcrete, generally due to excessive water in the mixture, also called sagging.†
Slump	A measure of the consistency of fresh concrete equal to the subsidence of a molded specimen immediately after removal of the slump cone.*
Substrate	Any material surface onto which shotcrete is applied.
Waterproof	Completely impervious to water in either liquid or vapor state. (Because nothing can be completely “impervious” to water under infinite pressure over infinite time, this term should not be used.‡)
Watertight	Impermeable to water except when under hydrostatic pressure sufficient to produce structural failure.
w/cm	The ratio of the total weight of water (including water in high-range water-reducing admixtures [HRWRA]) to the amount of cementitious material (portland cement, fly ash, silica fume, slag, or other supplemental cementitious materials) in a concrete mixture, stated on the basis of weight or mass; frequently abbreviated w/cm.*
Wet-mix shotcrete	Shotcrete where the concrete, including water, is completely mixed prior to introduction into the delivery hose; compressed air is introduced to the material flow at the nozzle.

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†ACI Committee 506, “Guide to Shotcrete (ACI PRC-506-16),” American Concrete Institute, Farmington Hills, MI, 2016, 52 pp.
‡ACI CT-21, ACI Concrete Terminology, American Concrete Institute, Farmington Hills, MI, 2021, 76 pp.

Position Statements

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Monolithic Shotcrete for Swimming Pools (No Cold Joints)

Shotcrete is the preferred construction method and concrete placement process for structural swimming pool installations. The versatility of shotcrete placement allows for a wide variety of sizes or shapes. Applicable stan dards for shotcrete design, specifications, and application can be found in American Concrete Institute (ACI) Committee 506 Guides, Specifications, and Technical Notes. Proper shooting technique and nozzle operation are well-covered in CCS- 04(20), "Shotcrete for the Craftsman." Specific pool shotcrete applications are described by the American Shotcrete Association (ASA) Pool and Recreational Shotcrete Committee Position Statements (currently numbered #1-7: "Compressive Strength Values of Pool Shotcrete," "Shotcrete Terminology," "Sustainability of Shotcrete in the Pool Industry," and "Water-tight Shotcrete for Swimming Pools", "Monolithic Shotcrete for Swimming Pools", "Forming and Substrates in Pool Shotcrete", and "Curing of Shotcrete from Swimming Pools").

Shotcrete contractors and applicators specializing in swimming pool construction are responsible and liable to observe appropriate design standards, use quality materials, establish appropriate quality control testing, and employ application techniques to build a fully functional pool with long-term serviceability and durability. Two important criteria in a pool shell are the concrete must meet the ASA's minimum 28-day compressive strength of 4000 psi (28 MPa) (ASA Pool Position Statement #1) and be essentially watertight prior to final surface applications (paint or plaster). These performance criteria assume a monolithic shotcrete pool shell without any cold joints. With shotcrete, the construction of a monolithic shotcrete pool shell is not constrained by time limits as long as proper techniques are observed from surface preparation to mixture design to the shooting velocity of the concrete itself. Shotcrete can be applied in multiple layers, sections, or phases without producing a single cold joint.

The American Concrete Institute's (ACI's) Concrete Ter- minology defines "cold joint" as "a joint or discontinuity resulting from a delay in placement of sufficient duration to preclude intermingling and bonding of the material, or where mortar or plaster rejoin or meet."

In cast-in-place concrete construction, internal vibration is the most common method for providing adequate consolidation of the placed concrete. In cast-in-place work, a cold joint is formed when an initial lift of concrete becomes too stiff for penetration by the vibrator used to consolidate a subsequent lift. This thus precludes the "intermingling" of material in the definition. However, ACI PRC-309-05, "Guide for Consolidation of Concrete," indicates that if bond is obtained between cast sections, a cold joint is avoided. ACI PRC-309-05, Section 7.2, states: "When the placement consists of several layers, concrete delivery should be scheduled so that each layer is placed while the preceding one is still plastic to avoid cold joints. If the underlying layer has stiffened just beyond the point where it can be penetrated by the vibrator, bond can still be obtained by thoroughly and systematically vibrating the new concrete into contact with the previously placed concrete; however, an unavoidable layer line will show on the surface when the form is removed."

Shotcrete does not require internal vibration for consolidation of concrete. Instead, shotcrete provides thorough consolidation and densification by high-velocity impact of fresh concrete material on the receiving surface. Laboratory testing proves that properly placed shotcrete is very well-consolidated, and provides excellent bond strength and durability (Zhang et al. 2016). The high-velocity impact of shotcrete on a hardened, previously shot layer (or existing concrete surface) provides a strong, abrasive blast to open up the surface, and then provides immediate exposure of that hardened surface to fresh cement paste. As a result, properly placed shotcrete exhibits excellent bond to concrete and previously shot surfaces.

TABLE 1: MULTI-LAYER BOND STRENGTH IN PSI (MPA) (BEAUPRÉ 1999)

	Type of finish between layers (results with no curing compound)			
Time	None	Scratch	Scratch + wood	Roughen with broom
4 hours	300 (2.1)	260 (1.8)	300 (2.1)	275 (1.9)
1 day	NA	300 (2.1)	300 (2.1)	NA
28 days	NA	260 (1.8)	NA	290 (2.0)

Notes: One-layer full thickness used in this project had a bond (tensile) strength of 350 psi (2.4 MPa); NA is not available

Fig. 1: Floor cast with installed keyway

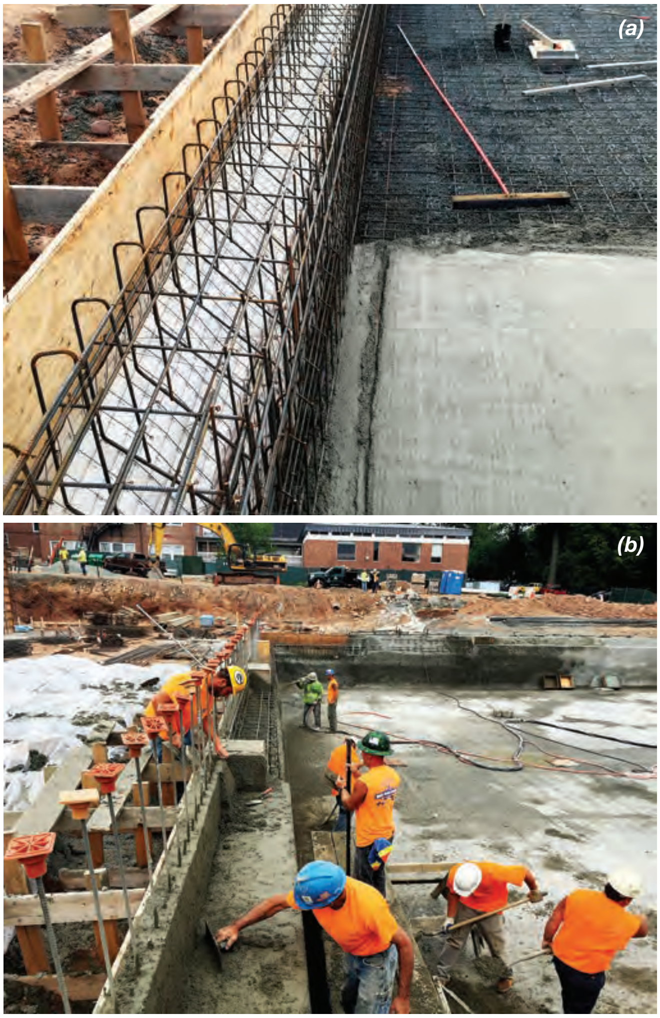

Fig. 2(a) and (b): Shotcrete on top of cast floor

A study on shotcrete bond to concrete repair surfaces that included work on multi-layer shotcrete bond was conducted at Laval University (Beaupré 1999). The study looked at bond with multiple layers of shotcrete shot 4 hours, 1 day, and 28 days apart with four levels of surface finishing (no surface finishing, scratched with steel trowel, scratched and finished with wood trowel, and rough broom finish). Table 1 shows the results from Beaupré's report. The report concluded that "for the waiting period and the types of finish studied, there is no significant influence of these parameters on bond strength" and "With respect to the multi-layer bond strength of shotcrete, the presence of shotcrete/shotcrete interfaces does not seem to create a large reduction in shotcrete quality in terms of mechanical bond if no curing compound is used." Specified shotcrete bond strength for shotcrete to properly prepared concrete substrates generally range from 100 to 150 psi (0.69 to 1.00 MPa). These levels of bond strength were easily reached by any of the combinations found in Table 1. If a curing compound is used on a layer, it should be completely removed before shooting subsequent layers of shotcrete. In shotcrete construction, surface preparation between layers to provide adequate bond is important. ACI SPEC-506.2-13 (18), "Specification for Shotcrete," specifically addresses this in the requirements of Sections 3.4.2.1 and 3.4.2.2 that:

"3.4.2.1 When applying more than one layer of shotcrete, use a cutting rod, brush with a stiff bristle, or other suitable equipment to remove all loose material, overspray, laitance, or other material that may compromise the bond of the subsequent layer of shotcrete.

Conduct removal immediately after shotcrete reaches initial set."

"3.4.2.2 Allow shotcrete to stiffen sufficiently before applying subsequent layers. If shotcrete has hardened,

Fig. 3: Watertight tank test

clean the surface of all loose material, laitance, overspray, or other material that may compromise the bond of subsequent layers. Bring the surface to a saturated surface-dry (SSD) condition at the time of application of the next layer of shotcrete."

The shotcrete specification requires removal of all potential bond-breaking materials immediately after initial set, as well as the cleaning and SSD conditions provided for in 3.4.2.2. Thus, shotcrete placed in layers does not produce a "cold joint" as defined by ACI because it produces excellent bond between the layers. This has been confirmed by visual inspection of numerous cores taken through multiple layers of shotcrete, where it is often impossible to identify where one layer stops and the other starts, unlike cold joints in form-and-pour work where the difference between lifts is readily apparent.

The connection point between two or more layers of shotcrete or between days of placement is considered to be a "construction joint." This joint is still considered to be monolithic based on the shotcrete application methods. Swimming pool shotcrete performance, durability, watertightness, and compressive values depend greatly on the proper application and preparation of the construction joint. Preparation includes shaping the joint to a 45-degree angle, cleaning overspray from adjacent reinforcement not yet embedded, and roughening the surface of the joint with a stiff broom, brush, or tool. The joint can then stand for as long as needed before the next placement. When it is time to complete the area, the joint must be cleaned and predampened to a saturated surface-dry damp condition. When properly shooting and curing the subsequently placed shotcrete, the concrete will act as a monolithic section, just as if there were never a joint there to begin with. The secret in making this a joint that acts monolithically with perfect bond is the combination of the proper surface preparation of the joint and high-impact velocity of the shotcrete stream. Shotcrete is a paste-rich concrete that is pneumatically driven by impact into the rough surface left by the joint preparation. No bonding agents are needed, and indeed no bonding agents should be used because they may interfere with the bond of the fresh paste to the rough substrate.

To reiterate, shotcrete swimming pool construction using quality materials, proper equipment, surface preparation, and placement techniques will not have cold joints and will behave monolithically. Also, with high-velocity impact on a receiving surface, the cement paste penetrates the existing three-dimensional bond plane and requires no bonding agents for proper adhesion between shotcrete layers or applications.

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Position Statements

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Position Statement #7
ASA Pool and Recreational Shotcrete Committee

Curing of Shotcrete for Swimming Pools

Shotcrete for swimming pools and other water containment structures such as aquatic parks and lazy rivers present unique complexities in curing and protection. As with all concrete, proper curing improves the overall gain of strength-related properties and reduces the overall amount and size of concrete cracking near the surface. However, for swimming pools, proper curing influences watertightness, long-term durability, and facilitates the bond and finishing ability of subsequent-applied cementitious finish coatings.

'Curing' is a method of maintaining adequate moisture within the concrete material nearest to the surface to ensure ongoing hydration of the cementitious binder. ACI PRC-308-16, "Guide to External Curing of Concrete," notes that surface exposure to 90% or less relative humidity can suspend hydration of cement at early ages. Thus, unless relative humidity is maintained above 90%, deliberate action must be taken, such as misting, soaking, or covering of the surface to maintain high humidity levels and conditions that allow the surface to hydrate at a similar rate to that of the inner matrix of the shotcrete.

Refer to ACI PRC-506, "Guide to Shotcrete," for additional curing methods. Typically, the effective zone for curing of concrete can reach depths between 1/4 and 3/4 in. (6 and 19 mm) from the outer surface depending on the finish texture and the permeability of the material. Although external curing does not penetrate deep enough to supply moisture to the inner matrix, maintaining a high humidity at the surface reduces the rate at which the inner-matrix water exits the system. Maintaining a similar moisture content and temperature between the outer surface and the inner matrix of the material promotes uniform hydration and lessens cracking associated with moisture and temperature gradients.

'Hydration' is the chemical reaction that converts the cementitious powder materials and water into a rigid structural material, or binder. In general, with sufficient moisture present, approximately 70% of cement hydration takes place in the first 7 days, and approximately 85% of cement hydration takes place in the first 28 days. The remaining unhydrated cement will continue to hydrate for many years after placement if moisture is present.

MINIMIZING MOISTURE AND TEMPERATURE GRADIENTS

The primary goal of curing is to maintain the moisture and temperature of the surface to levels that are similar to the interior of the shotcrete. Significant temperature or moisture gradients between the outer surface and the interior of shotcrete can result in cracking and a weaker, less-durable surface. Maintaining the temperature and sufficient moisture at the surface allows for a similar development of hydration and strength-gain properties to that of the interior of the shotcrete. A unique aspect of shotcrete in a water-submersion environment is that often, any shortfall in physical strength is quickly recovered subsequent to submersion, assuming sufficient cementitious material is present.

When a shotcrete cylinder or core meets or exceeds its required compressive strength (f_c'), a sufficient amount of cement has hydrated to achieve this strength. However, such testing may not adequately qualify the condition, strength, or durability of the outer surface. The quality of the outer surface can be weak or compromised, yet have little effect on strength test results based on cylinders or cores. Adherence to a proven curing method ensures the development of necessary outer-surface properties that directly impact the overall watertightness of shotcrete and the application and performance of a subsequently-applied cementitious finish coating.

CURING CONSIDERATIONS

ACI and ASA typically require that curing remains in place for a minimum of 7 days, or until at least 70% of the specified 28-day compressive strength (f_c') is achieved. It has been shown that extending wet curing from 3 days to 7 days can result in a 10 to 20% reduction in shrinkage cracking at the outer surface (the curing-affected zone). Prolonged wet curing significantly increases abrasion resistance (increases upper-surface strength) and significantly reduces surface permeability and absorption capacity.

For shotcrete swimming pool structures that are to receive a cementitious finish coating, ACI Committee 524, Plastering, and the National Plasterers Council (NPC) recommend that moist curing be continued for 28 days.

Ideally, the first 7 days should be soaked more frequently. It is recommended to soak the surface from three to five times per day (the more the better) initially, dependent upon the climate or region of the country. This is typically done by spraying water onto the shotcrete surface with a garden hose. Thereafter, it is recommended to wet all exposed surfaces at least once per day.

Wet curing for 28 days drastically reduces shotcrete's absorptive capacity. This is due to discontinued capillaries and carbonation of the surface. In some cases, well over a 50% reduction in absorptive capacity of the substrate is reported. Reducing shotcrete-absorptive capacity (capillary suction) also reduces shrinkage cracking. Reducing absorptive capacity also allows increased control of the subsequently-applied finish coating application by: creating a more uniform absorption rate across the surface of the shotcrete; extending the period of time available to physically force the finish coating material into the rough darby-cut shotcrete with minor surface depressions to achieve a good bond; and extending the time that mix water remains within the coating, enhancing overall finishability.

RECOMMENDED CURING

Immediately after finishing, keep shotcrete continuously moist for at least 7 days by soaking the surface three to five times daily or more. Thereafter, continue water curing at least once a day from day 7 to day 28. Wet periodically thereafter, one to two times per week, until the interior finish coating has been applied, and the swimming pool is filled with water.

Alternative curing methods have been employed to main- tain surface moisture, such as covering the shotcrete with absorptive mat or fabric, sand or other covering, and keep- ing continuously wet; or covering the shotcrete with polyeth- ylene sheeting of at least 4 mil thickness to prevent moisture loss. Curing compounds, if used, must be removed prior to applying subsequent coatings to ensure that an adequate bond can be achieved between the coating and the shotcrete.

The shotcrete should not be allowed to freeze until it has reached a minimum compressive strength. Generally, shotcrete that has reached 500 psi (3.5 MPa) before freezing takes place will not be damaged by freezing. When the temperature of shotcrete rises above 40°F (4°C), the hydration reaction will resume, and further develop strength. In general, shotcreting operations should be stopped when the anticipated 24-hour (daily) average ambient temperature falls below 40°F unless cold weather concrete measures are taken such as those mentioned in ACI PRC-306-16. In a hot-weather environment, the problems encountered with wet-mix shotcrete are the same as for form-and-pour concrete: increased water demand, increased rate of slump loss, rapid setting, and difficulty in regulating the entrained air content. For dry-mix and wet-mix shotcrete, the finishing operations, if any, should proceed as rapidly as the shotcrete condition allows. Curing should also start as soon as possible.

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UMA to Break NCDOT Record for Largest Square Footage of Soil Nail Wall

By Brian DeSpain, President, UMA Geotechnical Construction

UMA Geotechnical Construction's work on the NCDOT I-26 Exit 40 to I-40 Interstate Expansion Project is on track to become the largest square footage of soil nail walls done under a single contract in NCDOT history.

Colfax, N.C., February 9, 2021: UMA Geotechnical Construction, a North Carolina-based geotechnical contractor serving the Mid-Atlantic Region, is working on a project that will become the largest square footage of soil nail walls done under a single contract in North Carolina Department of Transportation (NCDOT) history. The contractor is on track to construct roughly 115,610 ft^2 (10,740 m^2) of wall along Interstate 26 by April of 2022.

UMA is working as a geotechnical subcontractor to a Fluor-led joint venture (JV) with United Infrastructure Group, Inc. The project, formally known as NCDOT I-26 Exit 40 to I-40 Interstate Expansion Project, will help to alleviate traffic congestion and improve the safety and operational efficiency of this vital stretch of interstate in the Asheville area.

UMA commenced work in September 2020, and will ultimately construct 15 soil nail walls of varying heights, ranging in square footage from less than 1,000 to more than 25,000 (300 to 7600 m^2). All are permanent walls consisting of epoxy-coated soil nails, bearing plates, and a decorative cast-in-place concrete finish.

The magnitude of the project required UMA to rely on several local material suppliers. The I-26 project was subject to the Federal Highway Administration's (FHWA) Buy America policy, so UMA secured nearly 500,000 lbs (230,000 kg) of domestic structural steel for the epoxy-coated soil nail bars from Skyline Steel. Reinforcing steel is being sourced from Guaranteed Supply Company. Roanoke Cement is supplying nearly 2,000,000 lbs (910,000 kg) of portland cement required to bond the reinforcing tendons to the surrounding soil and rock, and enough shotcrete to cover a football field with an 8 in. (200 mm) layer.

The widening project also required a wider, taller, and more aesthetically pleasing Blue Ridge Parkway Bridge over I-26. UMA was tapped to install 35 rock anchors for the new three-span precast segmental bridge.

"UMA is proud to play an integral part on the Fluor-United JV for the I-26 project," says President Brian DeSpain. "Our combined efforts will help to improve traffic flow in the area while also retaining the natural beauty of Asheville."

An industry leader in the development and refinement of innovative polymer grouting techniques, UMA Geotechnical Construction, Inc. creates specialized solutions to assist clients with ground engineering needs that save money and minimize downtime. As one of the first to use lightweight structural polymers to improve subsurface soils at depths greater than 40 feet, UMA is uniquely equipped to deliver safe, predictable, and effective results. The team includes industry experts in structural support, earth retention, and soil stabilization with decades of experience, and is dedicated to ongoing advancement in the field.

"UMA IS PROUD TO PLAY AN INTEGRAL PART ON THE FLUOR-UNITED JV FOR THE I-26 PROJECT," SAYS PRESIDENT BRIAN DESPAIN. "OUR COMBINED EFFORTS WILL HELP TO IMPROVE TRAFFIC FLOW IN THE AREA WHILE ALSO RETAINING THE NATURAL BEAUTY OF ASHEVILLE."

Brian DeSpain *is the president of UMA Geotechnical Construction and has been part of the geotechnical construction community since 2003. With a background in construction management, geotechnical engineering management, and strategic planning, he brings wide-ranging experience in the sales, field operations, and management of deep foundation and geotechnical grouting operations. Brian also has extensive experience with grouting equipment, hydraulic equipment, hydraulic equipment design, drilling equipment, polyurethanes, deep soil stabilization and foundation stabilizations of large commercial buildings, tunnels, and highways.*

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Mass Shotcrete Wall Construction and Thermal Control Plan

By Lihe Zhang, Dudley R. Morgan, Iain Kirk, Anastasia Rolland, and Robert Karchewski

Authorized reprint from *ACI Materials Journal,* May 2021

Wet-mix shotcrete has been used more and more for structural applications in the past few decades. Recently, wet-mix shotcrete was successfully used to construct a mass structural wall with congested reinforcement and minimum dimensions of 1. 0 m in a sewage treatment plant. A low-heat shotcrete mixture that included up to 40% slag was proposed for shotcrete application. A preconstruction mockup was shot to established proper work procedures for shotcrete application and qualify the shotcrete mixture and shotcrete nozzlemen. Extraction of cores and cut windows from the mockup confirmed proper consolidation around the congested reinforcement. A thermal control plan was developed, which included laboratory and field testing requirements, thermal analysis modeling with a three-dimensional (3-D) finite element program, and thermal control requirements, including installation of cooling pipes and thermal blankets.

Shotcrete proved to be an efficient means for mass concrete structural construction. Thermal control for mass shotcrete construction was studied, and the proposed thermal control plan was proved to function properly. The general guidance for mass shotcrete construction is provided.

Keywords: compaction; consolidation; encapsulation; mass concrete; mass shotcrete; nozzleman; shotcrete; temperature differential; thermal control plan.

INTRODUCTION

Shotcrete is the pneumatic conveyance of concrete materials at high velocity to a receiving surface to achieve in-place compaction.[1] While shotcrete has been used for over a century, the use of shotcrete instead of conventional cast-in-place concrete for new construction has greatly increased in the past several decades. Structural shotcrete refers to shotcrete application for structural elements, including structural walls, pilasters, and other structural components. Structural shotcrete has many advantages over cast-in-place concrete, including reducing or even eliminating formwork requirements. More and more structural shotcrete is being applied across North America. To determine if shotcrete is suitable for structural applications, configurations of the reinforcement and structural dimensions need to be considered. Besides the reinforcement configuration, a successful structural shotcrete application requires shotcrete materials to be:

- Pumpable (that is, good workability for delivery/ transport and pumping);
- Shootable (that is, work compatibly with the shotcrete pump, hose, and nozzle, and can be efficiently managed/ controlled by the nozzleman);
- Stackable (that is, shotcrete applied to the receiving surface must display suitable adhesive and cohesive properties that it can be stacked and built up to the full thickness and height without sagging or sloughing); and
- Finishable (that is, must be suitable for cutting, screeding, and finishing properly).

With the use of proper materials, equipment, and shooting techniques as recommended by ACI 506[1] and ACI C660,[2] shotcrete is able to fully consolidate around the reinforcement and other embedments.

During the past few decades, more and more wet-mix shotcrete is being used for concrete structures with minimum dimensions increasing from 200 mm (8 in.) thick to 500 mm (20 in.) thick. Recently, structures with thicker dimensionsthat is, over 500 mm (20 in.) to as much as 1.5 m (38 in.) have been successfully built with wet-mix shotcrete.

This paper provides details regarding wet-mix shotcrete used to construct a structural wall 1.0 m (3.3 ft) thick with two layers of 25M (#8) reinforcing bar in a sewage treatment plant. Due to constrictions on the site, constructing the wall using conventional form and pour with cast concrete would have been very difficult. The shotcrete method was proposed, and the wall was successfully constructed in a practical and cost-effective manner. Features of the shotcrete construction of the mass concrete wall using this method were as follows:

First, a shotcrete mixture with 40% slag replacement for portland cement was successfully used for the shotcrete construction. This mixture proved to be able to satisfactorily meet all the pumpability, shootability, stackbility, and finishing requirements for shotcrete.

The structural wall was built by experienced ACI-certified shotcrete nozzlemen using the hand application method. A mockup with the most heavily congested section of reinforcing bar was constructed and shot to qualify the mixture, the nozzleman, and the shotcrete application.

Second, structures with minimum dimensions of more than 0.9 m (3 ft) are categorized as mass concrete and require a thermal control plan (TCP) to minimize the potential for thermal cracking. The shotcrete mixture was tested and the heat of hydration was recorded. A three-dimensional (3-D) finite element model (FEM) was used to model the heat development and thermal behavior of the structure. Based on the TCP, installation of cooling pipes was selected as an option to meet the TCP requirements. One layer of cooling pipes spaced at 1.0 m intervals was installed to meet the TCP requirements.

> *Wet-mix shotcrete was successfully used to construct a mass structural wall with congested reinforcement...*

RESEARCH SIGNIFICANCE

Although shotcrete is now being widely used for structural construction, relatively few projects have been reported to be mass concrete structures with minimum dimensions of 0.9 m. The thermal behavior for mass concrete construction needs to be controlled properly; however, there is little information in published literature regarding thermal control measures for mass shotcrete construction. This paper presents information regarding a wet-mix shotcrete mixture with 40% slag used to build a mass shotcrete wall 1.0 m (thick with two layers of 25M reinforcing bar. It also provides details regarding thermal analysis and modeling, and development of a thermal control plan for this mass shotcrete wall construction. The thermal control plan was executed by controlling the shotcrete placement temperature, installing cooling pipes to dissipate the heat generated by hydration of the shotcrete, and applying thermal blankets for thermal protection. Recorded temperatures during construction monitoring were very close to the modeled temperature development. Post-construction inspection found no thermal cracking in the structural shotcrete wall.

This paper provides general guidance for mass shotcrete construction including:

- Use of a low-heat mixture that is suitable for shotcrete batching, pumping, shooting, and finishing;
- Mass shotcrete structure construction to achieve proper consolidation around reinforcement; and
- Mass shotcrete thermal control plan to minimize the potential for thermal cracking.

FEASIBILITY STUDY

A major civil contractor in Western Canada is constructing a sewage waste treatment plant. The dimensions of the structural wall of interest are shown in Fig. 1.

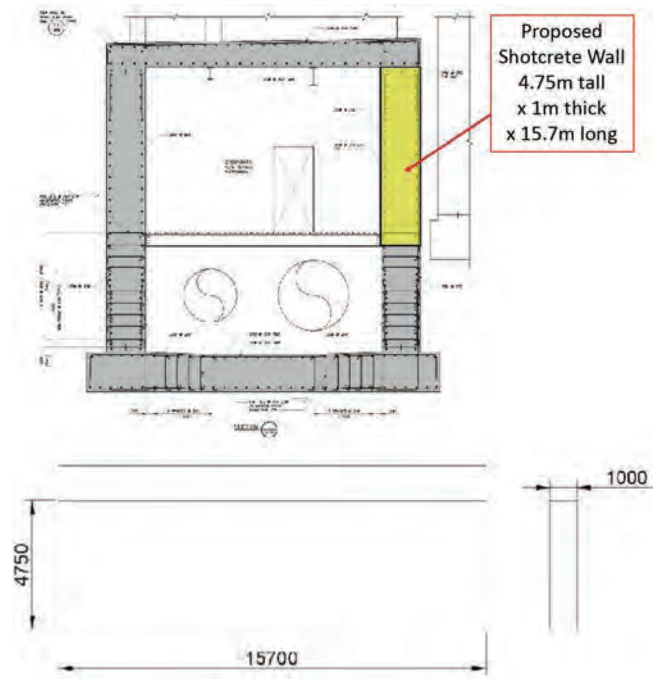

Fig. 1: Structural drawing and wall dimensions.

A method of using a shotcrete mixture with a high volume of slag and installation of cooling pipes in the structural wall was proposed. However, due to a lack of any previous project experience for mass shotcrete wall construction with proper measures to meet the thermal control requirements, questions were raised by the owner, design engineer, and contractor as follows:

1. Can shotcrete be successfully applied to a 1.0 m thick wall with two layers of 25M reinforcing bar spaced at 300 mm (12 in.)?
2. As the shotcrete process involves applying concrete at high velocity, will this process damage the cooling pipes during application?
3. Because shotcrete mixtures typically have a higher cement content than cast-in-place concrete, usually at least 400 kg/m^3 (670 lb/yd^3) cementitious material, this may result in higher temperatures. Will the heat of hydration increase the potential for thermally induced cracking?
4. What measures can be implemented to mitigate the potential for thermal cracking?

To address these questions and to prove that shotcrete was suitable to construct the 1.0 m thick structural wall with satisfactory consolidation around the multilayer reinforcement of 25M reinforcing bar and provide satisfactory thermal performance, a mockup trial shoot was proposed and conducted. The mockup panel was evaluated and the encapsulation of the reinforcing bar was visually inspected with extracted cores and cut open windows in the mockup wall. Subject to it being demonstrated that shotcrete could be applied to properly encapsulate the reinforcing bar, the contractor would then proceed with shotcrete construction of the wall. At the same time, a heat box test was conducted to obtain the adiabatic temperature rise of the mixture, based on which thermal control plan could be developed for the mass concrete structural wall.

MIXTURE DESIGN

The concrete supplier proposed a shotcrete mixture with a compressive strength of 35 MPa (5000 psi) at 28 days. This satisfied the compressive strength requirements for a structural element in this exposure environment. The mixture was designed with 60% Type GUL (Type 1L) cement and 40% slag replacement for portland limestone cement. Type GUL cement has approximately 15% limestone and has a lower heat ofhydration compared to a Type GU cement. With 40% slag replacement, heat generated during the cement hydration process is further reduced. Increasing the cement replacement with higher slags content will reduce the heat of hydration of shotcrete. However, increasing of the slag content too much can cause difficulties for the shotcrete process, which involves shotcrete pumping, shooting, and, in particular, stacking without sloughing. Prior to this project, slag was typically added at 25% replacement in the wet-mix shotcrete mixture design. Therefore, increasing the slag content to 40% was required to be tested and proven to be pumpable, shootable, and stackable.

Fig. 2: Mockup for mass concrete wall with two layers of 25M reinforcing bar and cooling pipes.

Fig. 3: Casting shotcrete into 1 x 1 x 1 m (3.3 x 3.3 x 3.3 ft) box to calibrate adiabatic temperature rise (ATR).

Fig. 4: Shotcrete construction of mockup wall.

Fig. 5: Cores extracted from mockup wall section.

Fig. 6: Cutout block showing thorough shotcrete consolidation around reinforcing bar and cooling pipes.

The combined coarse aggregate (10 mm maximum size) and fine aggregates used for the shotcrete mixture were designed to meet the ACI 506R gradation No. 2 requirements.

The water-cementitious materials ratio (w/cm) was a maximum 0.40.

The slump was designed to be 70 ± 20 mm (2.8 ± 0.8 in.) for structural shotcrete application. This has been proven to work properly with the pumping and shooting for structural shotcrete application. Slump is critical for nozzleman to successfully apply shotcrete to structural components. Lower slump helps shotcrete to stack in thick sections to greater heights without sloughing. However, if the slump is too low, the shotcrete will not properly flow around and encase reinforcing bar and embedments. With 40% slag replacement, the wet-mix shotcrete tends to slough at higher slump. Therefore, special consideration and shooting techniques are required when working with high-volume supplementary cementitious material (SCM); shotcrete and nozzlemen prefer to work with lower slump for structural application. High-range water reducer was used to reach the required slump. No hydration control admixture or retarder was required. The mixture was designed to be placed within 90 minutes, beyond which the mixture started to stiffent and could not be pumped and shot properly. Slump in the range of 70 ± 20 mm was found to be suitable for this mixture.

The shotcrete mixture was air entrained with an as-batched air content of 5 to 8% satisfying the CSA C-1 Exposure Class for freezing-and-thawing durability requirement. The addition of entrained air into shotcrete helps shotcrete to be pumpable and shootable after exiting from the nozzle. An airentrained shotcrete will have a higher as-batched air content, and reduced as-shot air content. The higher as-batched air content facilitates the pumping process while the lower as-shot air content help the stackability. This is a unique benefit of entraining air into shotcrete and is referred as the "slump killing effect".[1,3,4]

A preliminary thermal analysis based on assumed thermal values was conducted and shotcrete construction of the wall was considered to be acceptable subject to implementation of the following measures:

1. Use a 40% slag mixture, with cooling pipes and installation of thermal blankets for thermal control.
2. Use an experienced structural shotcrete contractor, with rigorous inspection and quality control testing to ensure conformance to the project specifications.

MOCKUP SHOOTING

A mockup shooting was conducted with details summarized as follows:

- Reinforcement was installed as per the structural wall drawings (Fig. 1).
- During the mockup construction, a layer of cooling pipes (polyvinyl chloride [PVC] pipe with 25 mm [1 in.] diameter) was installed at 1.0 m spacing to test if it would cause any consolidation issues (Fig. 2).
- Samples were cast to test the heat of hydration required by the 3-D FEM model.
- A block with dimensions of 1 x 1 x 1 m with 150 mm (6 in.) thick extruded polystyrene (EPS) board insulation on each of the six sides was constructed. The temperature development for both a 150 mm (6 in.) diameter cylinder and the 1 m^3 (35.3 ft^3) block was used to calculate the adiabatic temperature rise (ATR) for the shotcrete mixture (Fig. 3).

The structural wall mockup shotcrete application was conducted successfully. An experienced nozzleman (ACI certified nozzleman in wet-mix process) was able to successfully bench shoot the wall to the full height, in combination with the use of a vibrator and blow pipe (Fig. 4).

Fig. 5 shows cores extracted from the mockup wall and Fig. 6 shows the cutout block. They clearly show that both the 25M reinforcing bar and 25 mm diameter cooling pipe are properly wrapped with shotcrete and the mockup is free of voids or any other defects.

The mockup trial shoot results were considered satisfactory and met industrial best practices.[1] It was agreed by the owner and the design engineers that wet-mix shotcrete could be used to construct the structural wall with proper consolidation around reinforcement and cooling pipes.

Wet-mix shotcrete test results for the mockup were as follows:

- Slump: 55 mm (2.2 in.)
- Temperature: 17.8°C (64.0°F)
- As-batched air content: 6.2%
- As-shot air content: 2.5%

Cores were extracted from a shotcrete test panel and tested for compressive strength at 7 and 28 days, and boiled absorption and volume of permeable voids at 7 days and test results were as follows:

- Compressive strength at 7 days: 23.6 MPa (3420 psi)
- Compressive strength at 28 days: 36.1 MPa (5235 psi)
- Boiled absorption: 5.4%
- Volume of permeable voids: 12.0%

The mockup shotcrete application demonstrated that shotcrete could be successfully applied to consolidate the large-diameter reinforcing bar and multi-layer reinforcement. In particular, it was demonstrated that the most congested section of reinforcing bar could be consolidated properly with proper shooting. In addition, shotcrete could also be fully consolidated around the cooling pipes without any damage to the pipes. Compressive strength results for shotcrete cores met the specified 35 MPa (5000 psi) at 28 days. The boiled absorption was less than 8% and volume of permeable voids was less than 17%, which met the specified performance requirements and indicates a good quality of shotcrete.[3] The thermal behavior of the shotcrete mixture was obtained by both laboratory and field testing.

THERMAL MODELING AND EFFECT OF COOLING PIPES ON TEMPERATURE DEVELOPMENT

Adiabatic temperature rise (Fig. 7) was developed by laboratory testing with the 150 mm diameter cylinders and the field test with the 1 x 1 x 1 m block insulated with 150 mm EPS board (R = 15).

A 3-D finite element computer program was used to model the temperature development for the structural wall. The effect of cooling pipes was studied and the concrete block was modeled with and without cooling pipes. Results are plotted in Fig. 7. The concrete placement temperature was 15°C (59°F) for both scenarios. When cooling pipe was used, the peak temperature was reduced from 58 to 53°C (136 to 127°F). The time to reach the peak temperature was also reduced from 48 to 50 hours to 35 to 38 hours. After reaching the peak temperature, the cooling pipe was very effective in reducing the center temperature during the descendant portion of the temperature. This resulted in a lower temperature differential between the center and surface. Without cooling pipes, the temperature differential was approximately 15°C when the thermal blankets were kept in place, and then exceeded 20°C (68°F) after 168 hours or 7 days when the thermal blankets were removed. With cooling pipes, the temperature differential was 10°C (50°F) and less with the thermal blankets in place, and stayed under 10°C after 168 hours or 7 days when the thermal blankets were removed.

This demonstrates that cooling pipes can effectively reduce the peak temperature as well as the temperature differentials between the center and the surface.

Cooling pipes also provide great flexibility for the construction schedule. During construction, it is common that the construction schedule changes due to various reasons. Cooling pipes provide an alternative option for construction activities to proceed to accommodate challenges from factors, such as higher concrete placement temperatures and sudden changes in ambient temperature.

THERMAL CONTROL PLAN

A thermal control plan (TCP) was prepared for the construction of the wall to meet the specified mass concrete thermal requirements of:

1. Peak temperature to be ≤ 60°C (140°F) to avoid delayed ettringite formation (DEF)
2. Temperature differential between center and surface to be ≤ 20°C (35°F)
3. In a situation where the temperature differential exceeded 20°C, a stress analysis should be conducted and the calculated thermal stress versus tensile strength ratio should not exceed 75%.

Thermal modeling results are included in Table 1 with scenarios No. 1 and 2 as follows:

Scenario No. 1: Shotcrete placement temperature of 15°C, no cooling pipes, thermal blanket covers the finished shotcrete surface from the time of placement for 10 days. This scenario controlled the placement temperature, which may be the most effective way to reduce the peak temperature. However, this may be challenging for mass concrete batching during warm weather in the summer or early fall.

Scenario No. 2: Shotcrete placement temperature of 20°C, one layer of cooling pipes at 1.0 m spacing, with cooling water temperature of 13.7°C (56.7°F), thermal blanket covers the finished shotcrete surface from the time of placement for 7 days. This scenario requires less effort of controlling of placement temperature, but more effort on controlling temperature during construction-that is, by installing and maintain the cooling water during the curing period.

Model results from both scenarios are plotted in Fig. 8 when concrete is placed at 15°C.

Selection of the scenario is dependent on the construction schedule and effort to control the placement temperature, installation, and maintaining of the cooling pipe, which requires coordination between the design engineers and construction teams.

The construction of the shotcrete wall was scheduled to for early September, when controlling the shotcrete temperature to be 15°C and less was found to be challenging. Therefore, Scenario No. 2 was selected and cooling pipes were installed at a spacing of 1.0 m as shown in Fig. 9.

Table 1—Thermal modeling results

Maximum allowable temperature, °C	Specified, °C	Analysis (no cooling pipes), °C	Analysis (one layer cooling pipes), °C
Center temperature	60	58.7	58.5
Placement temperature	25	15.0	20.0
Differential center to surface temperature	20	14.0	11.4
Center temperature after blanket removal	60	25.3	24.0
Differential center to surface temperature (after blanket removal)	20	10.6	9.6

Table 2—QC test results summary for shotcrete construction

8 m^3 per truck	Shotcrete temperature, °C	Slump, mm	As-batched air content, %	As-shot air content, %	As-batched density, kg/m^3
Trucks 1-9, a total of 72 m^3 shotcrete was applied in 10 hours	22.6 to 25	60 to 85	7.7 to 9.0	4.8 to 5.6	2197 to 2217

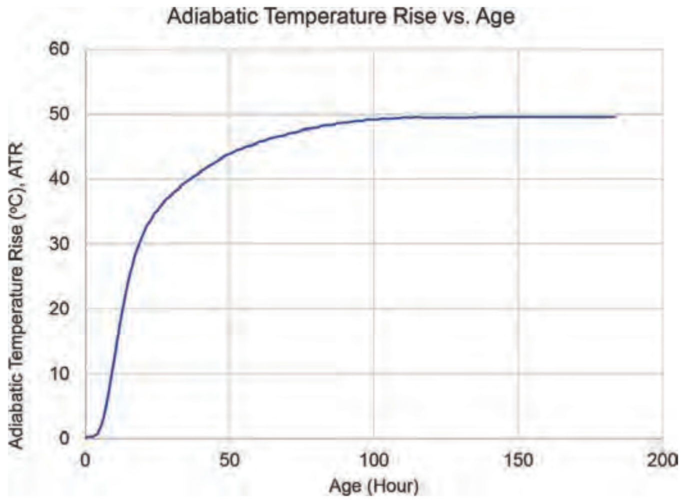

Fig. 7: ATR of shotctete mixture calculated based on results from both laboratory and field tests.

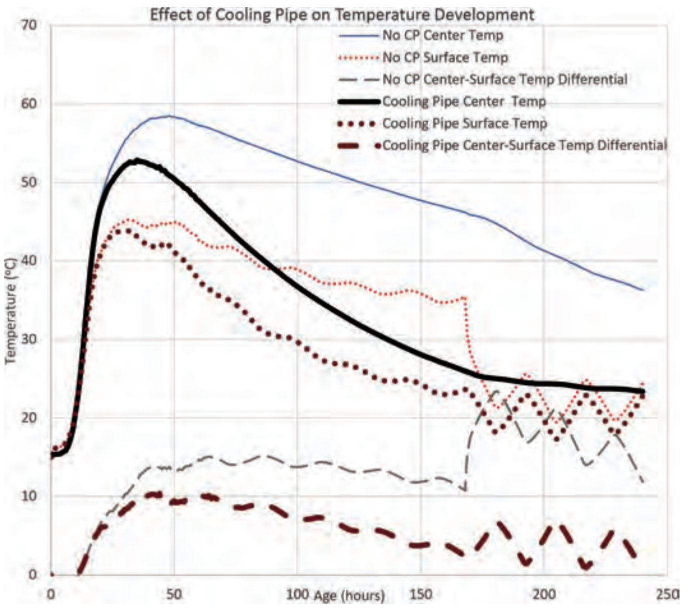

Fig. 8: Modeled temperature developments with and without cooling pipe.

STRUCTURAL WALL CONSTRUCTION

In early September, the structural wall was constructed using the wet-mix shotcrete application method. Rigorous construction monitoring and inspection and quality control testing was conducted by the author throughout the whole application process. QC test results are included in Table 2. Shotcrete application commenced at 7:00 am and finished at 4:30 pm. In brief, this large structural wall took only 9.5 hours to construct using ready-mixed supplied wet-mix shotcrete. A total of over 70 m^3 (92 yd^3) of shotcrete was applied using the bench-gun shooting method. Details of shotcrete application are included in Fig. 10 through 21.

SHOTCRETE QC TEST RESULTS

- Compressive strength at 9 days: 38.5 to 46.6 MPa; (5600 to 6800 psi) exceeds the specified 35 MPa at 28 days
- Boiled absorption: 6.5 to 7.0%, meets the specified maximum 8.0%
- Volume of permeable voids: 14.5 to 15.4%, meets the specified maximum 17.0%

PRODUCTIVITY OF MASS SHOTCRETE WALL CONSTRUCTION

Prior to construction of the wall, backside formwork and reinforcement was installed and inspected by the engineer. During the mass shotcrete wall construction, a total of nine 8 m^3 (10.5 yd^3) concrete truckloads of shotcrete, for a total of 72 m^3 (92 yd^3) shotcrete was applied. Shotcrete application started at 7:00 am with continuous shooting throughout the day. Shotcrete shooting finished at 3:55 pm, and finishing was completed by 5:30 pm. Therefore, it took a total of 9 hours to complete shooting and 10.5 hours to complete all the shotcrete work, including finishing. This resulted in a mass structural shotcrete wall construction production rate average of one truckload of 8 m^3/h for shotcrete application, with a total of over 72 m^3 being applied in a 10.5-hour shift. This production rate is typical for structural shotcrete application, with a crew of two to three nozzlemen, four finishers, and four helpers.

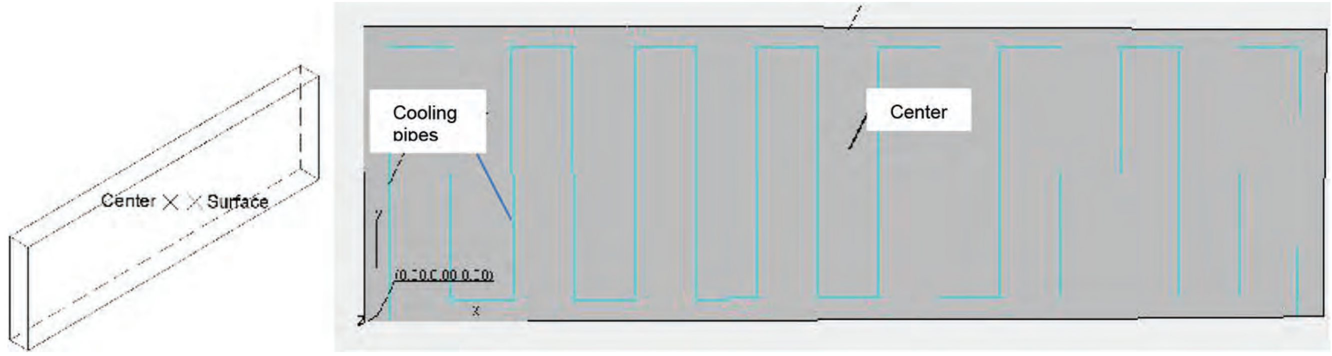

Fig. 9: Sensor locations with points of concern and cooling pipe layout (in blue).

Fig. 10: View of scaffold (three-deck platform), shotcrete crew, and finishing crew with tarp on top to protect wall from rain.

Fig. 11: Two layers of 25M reinforcement with cooling pipes (fixed using tire wire with auxiliary 10 m stirrups) erected in middle thickness of wall.

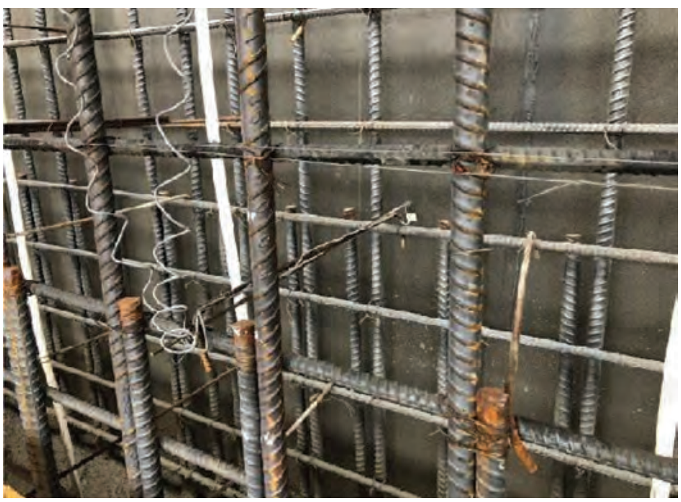

Fig. 14: Thermal sensors placed at surface of back wall (at formwork face), mid-thickness of wall, and surface of wall. All three locations are in center face of wall and at middle between cooling pipes. One additional thermal sensor was installed to measure ambient temperature.

Fig. 16: For each lift, shotcrete was applied to approximately 45-deg. slope. Prior to application of next lift, rebound and overspray were removed by blow pipe.

Fig. 15-Nozzleman moved nozzle into 300 x 300 mm reinforcing bar grid to fill up back layer of reinforcement. Note that nozzle angle was kept at approximately 90 deg. to receiving surface. Note that guide wires were used to control thickness of wall, and were cut and removed after finishing.

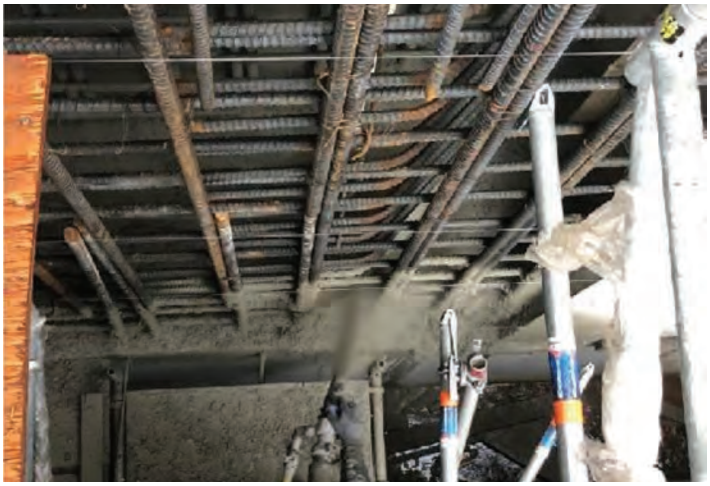

Fig. 12: Guide wires installed to control wall thickness and finishing. View from top deck. Shooting started at corner of wall.

Fig. 13: Cooling pipe installed at 1.0 m spacing with four inlets.

Fig. 17: Shooting, blow pipe operation, and light touch with pencil vibrator to enhance final consolidation.

Fig. 18: Shooting.finish coat.

Fig. 19: Screeding.finish coat to guide wires.

Fig. 20: Float finishing with darby.

Fig. 21: Final steel-trowel. finishing.

TEMPERATURE DEVELOPMENT OF MASS SHOTCRETE WALL

Right after installation of the shotcrete wall was completed, cooling water was passed through the cooling pipes for approximately 10 days. The thermal blankets were, however, not installed until 53 hours later due to site construction schedule issues. Temperature data was downloaded for approximately 4 days (90 hours), after which the temperature recording device was damaged.

Detailed temperature development data for the shotcrete wall is included in Fig. 22.

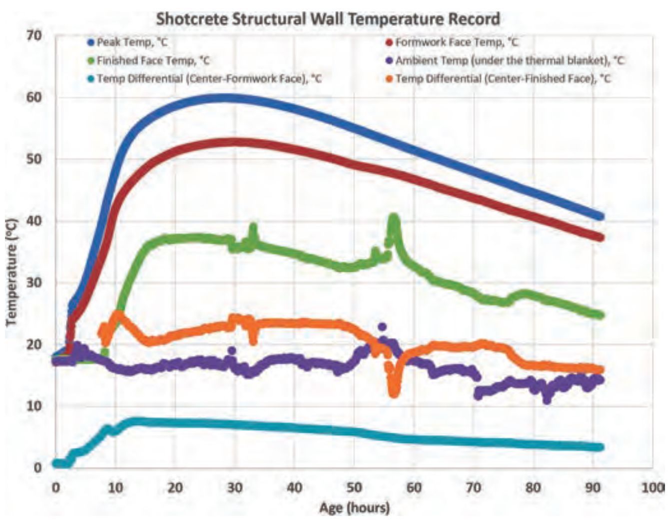

Fig. 22-Recorded temperature development.

The peak temperature at the center of the wall was 60°C and meets the specified allowable maximum temperature of 60°C. The temperature differential between the center and formwork face was less than 20°C. The ambient temperature ranged between 15 and 20°C for the first 50 hours. The temperature differential between the center and the finished face of the wall, however, was measured to range between 20 and 25°C (45°F) for the first 50 hours and then dropped back to be below 20°C (25°F). This is attributed to the fact that the thermal blankets were not installed until 53 hours in contravention of the thermal control plan. Typically, when the temperature differential exceeds 20°C (35°F), a stress analysis is required to be conducted to determine if the thermal stress exceeds 75% of the tensile strength.

Fig. 23: View of shotcrete wall surface from second deck; no thermal cracking was observed.

The post-pour remodeling and stress analysis was conducted with the 3-D FEM model and results are included in Table 3.

It should be noted that due to the construction schedule, tests for tensile strength and creep were not conducted to obtain the parameters for stress analysis. Parameters from a mixture with similar compressive strength, elastic modulus, and creep were used for thermal stress analysis. The stress analysis results show that the thermal stress versus tensile strength ratio is 59%, which is less than 75%, at which the potential for thermal cracking is considered high.

Although there was no temperature data recorded after 90 hours, the temperature trend at the peak, formwork face, and finished face are all descending to be below 20°C after 90 hours. With the ambient temperature of 10 to 25°C, the temperature differential was within 20°C until 10 days after the thermal blankets were installed, when the thermal blankets were removed and the TCP was terminated.

Table 3—Comparison of model and recorded temperatures

Maximum allowable temperature	Spec	Analysis with thermal blanket installed after completion of placement	Actual with thermal blanket installed after 53 hours	Conforms
Placement temperature, °C	25	24.5	24.5*	Yes
Maximum center temperature, °C	60	59	60	Yes, only 1°C difference
Maximum differential center to surface temperature, °C	20	11.4	24	Exceed spec, thermal stress analysis required
Thermal stress versus tensile strength ratio	<75%	Tensile strength = 1.55 MPa	Maximum tensile stress = 0.91 MPa	Yes, stress versus strength ratio = 59%

*Placement temperature was recorded as temperature when shotcrete contacted thermal sensor.

Fig. 24: View of finished wall surface from bottom deck; no thermal cracking was observed

A post-construction inspection was conducted after the thermal blankets were removed. The surface condition of the finished face is shown in Fig. 23 and 24. No thermal cracking was observed.

Conclusions

- Wet-mix shotcrete with 40% slag was successfully applied for construction of a reinforced mass shotcrete wall 1.0 m thick using the bench-gun shooting method. Proper encapsulation of the reinforcement of up to 25M in size and parallel spliced was achieved.
- Shotcrete encased the cooling pipes without any damage.
- Shotcrete was an efficient way to construct the mass structural wall.
- A thermal control plan was implemented. The peak temperature met the specified requirement for a mass concrete structure. The temperature differential between the center and the finished surface exceeded the specification requirements for up to 50 hours, but the post-pour inspection confirmed that no thermal cracking was observed.
- The recorded temperature and the modeled temperature, adjusted with the actual construction conditions, were very close, with less than 1° C (1.8°F) difference in peak temperature. This shows that the 3-D FEM model used in the project is capable of accurately modeling the temperature development of the mixture and shotcrete construction process.

In summary, shotcrete was successfully applied to the structural wall, met the specified project performance requirements of compressive strength, boiled absorption and volume of permeable voids, and the quality of mass shotcrete wall was satisfactory with no thermal cracking observed.

Recommendations

Looking forward, sophisticated complex concrete structures with complicated reinforcement details are now being constructed with shotcrete. This includes thick walls, beams, pilasters, and other structural components that can be classified as mass concrete. Most recently, ACI 308 has included shotcrete into the building code.[6] Implementation of thermal control plans for these mass shotcrete structures will be critical for meeting the structural design requirements and meeting service life requirements. This paper provides general principles and a detailed methodology for design engineers to consider for construction of mass shotcrete structural components. It involves structural design, mixture design, a thermal control plan, mockup and qualification, construction QC testing and inspection, and post-pour inspection. With appropriate efforts of the structural engineers, concrete/shotcrete engineers, contractor and supplier, mass shotcrete structural components are able to be built to properly meet the project specification and service life requirements.[5] Further research work is being carried out by the authors, including testing thermal behavior of shotcrete materials and modeling of massive shotcrete structures with optimized thermal control measures.

To design mass shotcrete structures, the following design principles are recommended:

- Specify shotcrete mechanical properties, including compressive strength, elastic modulus, flexural strength, shear strength and with fibers, residual tensile strength.
- Constructability with shotcrete. A properly designed shotcrete mixture should be trial shot and tested. The adiabatic temperature rise should be developed based on testing of the mixture.
- Thermal modeling should be conducted, based on which thermal control plan should be developed. The thermal control plan should specify the maximum allowable temperature in the structure, which is normally less than 60°C, and maximum allowable temperature differential between the center and the surface which is normally required to be less than 20°C. If the temperature differentials exceeds 20°C, a thermal stress analysis should be conducted to determine whether the stress versus strength ratio exceeds 75%. If it does, there is high potential for thermal cracking. The means and methods for proper measures to minimize the risk of thermal cracking include but are not limited to reducing the shotcrete application temperature and using thermal blankets with an extended installation period if needed. Use insulated formwork, cooling pipes, and other suitable measures if needed. The shotcrete specialist, contractor, and design engineer should work together to come up with the most efficient and cost-effective options to implement the thermal control plan.
- Pre-construction qualification for the nozzleman, shotcrete equipment, and mixture should be tested. The shotcrete nozzlemen should be ACI-certified nozzleman. During the mockup trial shoot, the structural component with the most congested section of reinforcing bar should be selected. Cores and/or cutout windows should be visually inspected by an experienced shotcrete specialist as to ACI requirements and project specification requirements. At the same time, thermal control measures should be implemented during the mockup phase. The purpose is to calibrate the thermal models and adjust the thermal control plan if necessary.

- Upon satisfactory inspection and testing of the mockup structural component, the mass shotcrete structure can then be constructed with the same materials, equipment, nozzlemen, and crew. The thermal control plan should be executed by installing sufficient thermal sensors to monitor the temperature development of the structure. Temperatures should be recorded and reviewed on a timely basis by the engineer and, if required, additional thermal control measures should be implemented, such as additional thermal blankets installation, reducing the cooling water temperature, increasing the water flow in the cooling pipes, or other suitable measures.
- Post-pour inspection should be conducted by a concrete specialist to establish whether there is any thermal cracking. Should there be any evidence of thermal cracking, the field thermal control plan should be reviewed and remodeled based on the actual curing and protection conditions of the structure. A post-pour comparison of recorded temperature versus modeled temperature is always encouraged.

ACKNOWLEDGMENTS

This research project was support by the project owner: Metro Vancouver; general contractor: Graham/ Aecon Joint Venture; shotcrete contractor: Structural Shotcrete Ltd; Shotcrete supplier: Lafarge North America; and Shotcrete Consultant and Thermal Control Plan Design, Inspection and Testing: LZhang Consulting & Testing Ltd; Shotcrete QC Testing: Metro Testing Ltd.

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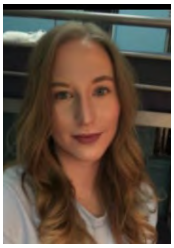

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Is your back trying to tell you something?

Mastering the correct placement posture

By Oscar Duckworth

Construction has a back problem. After the common cold, back pain is the most common reason why construction workers miss work. Worse, lower back injury is the single leading cause of long-term workplace disability. The back pain crisis plagues the construction industry. Why? It is the physical heavy work that is typical to active construction work.

Shotcrete nozzlemen are particularly at risk for certain types of back problems known as musculoskeletal disorders (MSD). These are defined as an injury or disorder that affects movement of the body's musculoskeletal system; that is, the muscles, ligaments, tendons, blood vessels, nerves, and discs of the back. MSDs are caused by constant exposure to workplace factors such as repeating the same motions, carrying high-force loads, bending, or maintaining awkward postures. All of these activities will, over time, place excessive force on the joints, muscles, and tendons associated with the spine. Nozzlemen are continuously exposed to MSD risks, however, being a nozzleman need not be a debilitating career. Since bending, twisting, and repetitive strain is a daily part of being a nozzleman, learning and utilizing certain well proven placement postures can diminish the risk of MSD injuries significantly.

It may appear to an untrained observer that shotcrete nozzling is an easy task to perform. A professional nozzleman works as if the system is practically weightless. But significant experience is required to properly handle the weight and thrust of a shotcrete nozzle for even a few minutes. Every professional nozzleman working today has one thing in common: although strength and stamina are important, they have mastered a placement posture that facilitates proper nozzle mobility while minimizing the physical effort required to offset the nozzle's weight and thrust. Though professional nozzleman may have never met, one can easily notice their nearly identical placement postures. These similar postures allow them to efficiently work the nozzle rather than allowing the nozzle to work them. Since strain, heavy objects, awkward postures, and repetitive movement is part of a nozzleman's daily work, preventing MSDs requires physical efficiency, and the knowledge of essential techniques to diminish the load that must be transferred through the nozzleman's body.

Although it has been debated for years, experts agree that for most applications, the safest placement posture is to route the hose between the legs with the hose resting on the ground directly behind the nozzleman. Only lift the amount of hose necessary to maintain the proper nozzle angle to the work. The hose should be held firmly against the body, using one hand to trap the hose against the body and bend it upward, and the other to manipulate the nozzle. This shooting position transfers much of the weight and thrust of the nozzle to the ground at the nozzleman's feet, diminishing the load that must be transferred through the nozzleman's back, arms, and legs. Place one foot well ahead of the other to counteract nozzle thrust. Keep the placement hose routed directly behind you and up, between your legs, centered within your frame. This position optimizes natural balance and provides the nozzleman with the maximum range of motion. Use your feet, legs, and arms, not your back, to manipulate the nozzle's left-right, and up-down positioning. This posture is the foundation of all effective shooting positions.

Fig. 1 Proper posture

Professional nozzlemen do not use awkward positions because they generate poor results. Using positions such as holding the hose to the side of the body or draping the hose over the shoulder dramatically increases fatigue and may

¿Esta tu espalda tratando de decirte algo?

Dominando la postura de colocación correcta

Por Oscar Duckworth

La construcción tiene un problema de espalda. Después del resfriado común, el dolor de espalda es la causa más común por qué los trabajadores de la construcción faltan al trabajo. Peor aún, la lesión en la espalda baja es la principal causa de incapacidad a largo plazo en el lugar de trabajo. La crisis del dolor de espalda afecta a la industria de la construcción. ¿Por qué? por el trabajo físico pesado que es típico de la construcción.

El lanzador de concreto está en riegos de ciertos tipos de lesiones en la espalda conocido como trastornos musculoesqueléticos. Se definen como una lesión o trastorno que afecta el movimiento del sistema musculoesquelético del cuerpo, es decir, los músculos, ligamentos, tendones, vasos sanguíneos, nervios y discos de la espalda. Los trastornos musculoesqueléticos se deben a una exposición constante a factores del lugar de trabajo, como la repetición de movimientos, la carga de objetos pesados, la flexión o el mantenimiento de posturas incómodas. Todas estas actividades, con el tiempo, colocarán una fuerza excesiva en las articulaciones, músculos y tendones asociados con la columna vertebral. El lanzador está continuamente expuesto a los riesgos de los trastornos musculoesqueléticos, sin embargo, ser un lanzador no debe ser una profesión debilitante. Debido a que doblar, torcer, y la tensión repetitiva es parte diaria de ser un lanzador, aprender y utilizar ciertas posturas de la colocación comprobadas pueden disminuir el riesgo de lesiones de espalda significativamente.

Puede parecer a un observador no entrenado que el lanzado de concreto es una tarea fácil de realizar. Un lanzador profesional hace ver como si el sistema de colocación no pesara. Pero se requiere una experiencia significativa para manejar correctamente el peso y el empuje de una boquilla de concreto, aunque sea por unos minutos. Los lanzadores profesionales de hoy tienen una cosa en común: aunque la presión y el empuje son importantes, han dominado una postura de colocación que facilita la movilidad adecuada de la boquilla al tiempo que minimiza el esfuerzo físico necesario para compensar el peso y el empuje de la boquilla. Aunque el lanzador profesional puede no haber conocido a otro lanzador anteriormente, uno puede notar fácilmente sus posturas casi idénticas de la colocación. Estas posturas similares les permiten trabajar con eficacia la boquilla en lugar de permitir que la boquilla los trabaje a ellos. Dado que la tensión, los objetos pesados, las posturas incómodas y el movimiento repetitivo forman parte del trabajo diario de un lanzador, la prevención de las lesiones de espalda requiere eficiencia física y el conocimiento de técnicas esenciales para disminuir la carga que se transfiere a través del cuerpo del lanzador.

Aunque se ha debatido durante años, los expertos coinciden en que, para la mayoría de las aplicaciones, la postura de colocación más segura es sostener la manguera entre las piernas apoyándola al suelo directamente detrás del lanzador. Elevar sólo la cantidad de manguera necesaria para mantener el ángulo de boquilla adecuado para la colocación. La manguera debe sujetarse firmemente contra el cuerpo, utilizando una mano y doblarla hacia arriba, y la otra mano para manipular la boquilla. Esta posición de lanzado transfiere gran parte del peso y empuje de la boquilla al suelo a los pies del lanzador, disminuyendo la carga que debe transferirse a través de la espalda, los brazos y las piernas. Coloca un pie delante del otro para contrarrestar el empuje de la boquilla. Mantenga la manguera de colocación directamente detrás de usted y súbela, entre sus piernas, centrada dentro de su marco. Esta posición optimiza el equilibrio natural y proporciona al lanzador el máximo rango de movimiento. Utilice los pies, piernas y brazos, no la espalda, para manipular la posición izquierda-derecha y arriba-abajo de la boquilla. Esta postura es la base de todas las posiciones de colocación efectivas.

Fig. 1 Postura correcta

lead to an MSD injury. A nozzle held from the side or over the shoulder limits the nozzle's range of movement and overall placement precision. Worse, over the shoulder and from the side shooting positions transfer the system's full weight and thrust as an off-center load through the nozzleman's spine. Pump surges produce strong twisting forces that must be continuously counteracted by muscles within the nozzleman's back, hips, and upper body. Since the hips and shoulders are not oriented squarely to the load, the body's natural leverage is diminished. In the event of an unexpected surge or blockage, these imbalanced positions increase the risk of injury to the nozzleman and other workers should the nozzleman lose control of the nozzle. Hunching must be avoided while operating the nozzle since it excessively strains the large lower back muscles. When shooting low areas, bending should occur at the knees, not the back.

Fig. 2a The hose is placed on the ground and arced upward by the nozzleman's legs. The tip hose must be sufficiently rigid to continue its upward arc

THE TIP HOSE MUST BE SUFFICIENTLY RIGID

Placement system choices matter to a professional nozzleman. The tip hose — the hose that must be held by the nozzleman, plays an important, but often overlooked role. Veteran nozzlemen know that selecting the correct tip hose dramatically impacts the load and thrust that is transferred through the nozzleman's body. Tip hoses MUST be sufficiently rigid to resist kinking or collapsing during placement. Over time, placement system hoses soften from wear and continuous bending. Older, worn hoses lose their rigidity and can kink easily. Worn, soft, "doughy" hoses should never be used as the tip hose. Many nozzlemen prefer a steel braided tip hose while others use the lighter (but similarly rated) braided fabric hoses for their flexibility or "feel."

Study the photographs in Fig.2a and 2b.

Fig. 2b Note clamping of the tip hose with arm.

The nozzleman's left hand pins the hose against his body and maintains the hose's upward curvature. The nozzleman's right hand appears to hold the entire hose up but is actually pulling downward to both bend the hose and counteract nozzle thrust. Nozzlemen working in this position are NOT actually lifting the hose. Rather, they are bending it upward against their body and manipulating a hose that is primarily supported by its own rigidity and thrust. Conversely, working with a soft hose will feel as if it is constructed from heavy chains since the hose's full weight and thrust must be supported by nozzleman's body rather than through the rigidity of the hose. To be sure, the nozzle and hose is awkward and heavy. However, utilizing well proven shooting postures can dramatically diminish the required effort for placement.

Maintaining the proper shooting posture is reliant on properly sized equipment operating at the correct speed. Placement systems and nozzles 1 ½ and 2 in. (38 and 50 mm) are correct for most wet-mix and dry-mix hand nozzle applications.

Any modern wet-mix pump can convey concrete far faster than a nozzleman can safely place it. There is a common misconception that the mark of a good nozzleman is how quickly they can place material. We have all seen social media displaying nozzlemen leaning at absurd angles to compensate for shooting too quickly.

Select a flow rate that feels right. Adjust the pump to generate a smooth, predictable nozzle stream, without excessive thrust. Excessive thrust generated from shooting too quickly diminishes accuracy and dramatically increases fatigue and the risk of an MSD injury. The mark of a master nozzleman is not how quickly he can place material—it is the precision with which the material is placed. The ideal flow rate balances placement precision with the nozzleman's safe physical capabilities.

Smooth shifts and a predictable flow of material are necessary to precisely control material placement. Slugging

Los lanzadores profesionales no utilizan posiciones incómodas porque generan resultados deficientes. El uso de posiciones tales como sujetar la manguera al costado del cuerpo o colocar la manguera sobre el hombro aumenta drásticamente la fatiga y puede provocar lesiones de espalda. Una boquilla sujetada de forma lateral o por encima del hombro limita el rango de movimiento de la boquilla y la precisión de la colocación general. Peor aún, sujetarla sobre el hombro y de forma lateral transfieren todo el peso y empuje del sistema como una carga excéntrica a través de la columna vertebral del lanzador. La presión de bombeo produce fuerzas de torsión que deben ser continuamente contrarrestadas por los músculos de la espalda, caderas y parte superior del cuerpo del lanzador. Dado que las caderas y los hombros no están alineados directamente con la carga, el apalancamiento natural del cuerpo disminuye. En el caso de una sobrecarga inesperada o un taponamiento, estas posiciones desequilibradas aumentan el riesgo de lesiones para el lanzador, y otros trabajadores en caso de que el lanzador pierda el control de la boquilla. Se debe evitar encorvarse mientras se opera la boquilla ya que tensa excesivamente los músculos grandes de la parte inferior de la espalda. Cuando se coloca el concreto en zonas bajas, se deben doblar en las rodillas, no la espalda.

La punta de la manguera DEBE ser lo suficientemente rígida

La selección del sistema de colocación importa a un lanzador profesional. La manguera de la punta — la manguera que debe ser sujetada por el lanzador, juega un papel importante, pero a menudo pasado por alto. El lanzador veterano sabe que seleccionar la manguera de punta correcta afecta dramáticamente la carga y empuje que se transfiere a través del su cuerpo. Las mangueras de punta DEBEN ser lo suficientemente rígidas para resistir dobleces o colapsos durante la colocación. Con el tiempo, las mangueras del sistema de colocación se ablandan por el desgaste y la flexión continua. Las mangueras viejas y desgastadas pierden su rigidez y pueden doblarse fácilmente. Nunca se deben usar mangueras "suaves", blandas y desgastadas como manguera de la punta. Muchos lanzadores prefieren una manguera de punta trenzada de acero, mientras que otros usan mangueras de tela trenzada más ligeras (pero con un valor similar) para su flexibilidad o "sensación".

Estudia las fotografías en la Fig.2. 2a y 2 b

Fig. 2b Nota sujeción de la manguera de la punta con brazo

Fig. 2a La manguera es colocada en el suelo y sujetada por las piernas del lanzador. La manguera de la punta debe ser lo suficientemente rígida para continuar con su arco ascendente

La mano izquierda del lanzador mantiene la manguera contra su cuerpo y mantiene la curvatura hacia arriba de la manguera. La mano derecha del lanzador parece sostener toda la manguera hacia arriba, pero en realidad está jalando hacia abajo para doblar la manguera y contrarrestar el empuje de la boquilla. Los lanzadores que usan esta posición NO están levantando realmente la manguera. Más bien, lo están doblando hacia arriba contra su cuerpo y manipulando una manguera que se apoya principalmente por su propia rigidez y empuje. Por el contrario, trabajar con una manguera suave se sentirá como si estuviera construida con pesadas cadenas, ya que el peso y empuje completos de la manguera deben estar sostenidos por el cuerpo del lanzador en lugar de por la rigidez de la manguera. Sin duda, la boquilla y la manguera son incómodas y pesadas. Sin embargo, la utilización de posturas de colocación comprobadas puede disminuir drásticamente el esfuerzo requerido durante la colocación.

El mantener la postura de lanzado adecuada depende del tamaño del equipo adecuado y de la velocidad correcta. Sistemas de colocación y boquillas de 1-1/2 y 2 pulg. (38 y 50 mm) son adecuados para la mayoría de las aplicaciones manuales de concreto lanzado vía húmeda o seca.

Cualquier bomba de concreto moderna puede bombear concreto mucho más rápido que lo que un lanzador puede colocarlo de forma segura. Hay una falsa idea que el sello de un buen lanzador es que tan rápidamente pueden colocar el material. Todos hemos visto en las redes sociales cómo los lanzadores se inclinan en ángulos absurdos para compensar el lanzar a muy alta velocidad. (insertar fig. 3)

Seleccione la velocidad de colocación que este a gusto. Ajuste la bomba para generar un flujo de boquilla suave y predecible, sin un empuje excesivo. El empuje excesivo generado por lanzar con demasiada velocidad disminuye la precisión y aumenta drásticamente la fatiga y el riesgo de lesiones en la espalda. El sello de un maestro lanzador no es la rapidez con la que puede colocar material— es la precisión con la que se coloca el material. El flujo ideal equilibra la precisión de la colocación con las capacidades físicas seguras del lanzador.

Fig. 3 nozzlemen leaning at absurd angles

or unexpected bursts of air will affect a nozzleman's balance and reduce placement precision. Uneven material flow can be caused by worn wear components, poor shift calibration, stiff mixtures, or from running the pump hopper low. Dry-mix guns and wet-mix pump hoppers must be kept full. Since allowing a pump to run low on material traps and compresses air, unpredictable bursts can unbalance, or even injure a nozzleman. If material flow is irregular, the nozzleman should stop and investigate the cause before continuing.

NOZZLEMAN CHECKLIST

- Posture, movement, and mobility strongly affect overall placement precision.
- Choose your equipment carefully. Tip hoses MUST be sufficiently rigid to resist kinking or collapsing during placement. Worn, soft, "doughy" hoses should never be used as the tip hose.
- Select a pace that feels right. Shooting too quickly diminishes accuracy and increases the risk of injury.
- Study shooting positions used by experienced nozzlemen. Practice placement postures that diminish fatigue and provide mobility and range of movement.

If scaffolding is required, it must be stable and sufficiently wide to safely work without compromising balance. Since the nozzle can produce significant and sometimes unpredictable thrust, adequate handrails are necessary when shooting from scaffolding.

It is essential that the nozzleman can signal to quickly stop the pump or gun. A nozzleman should never operate equipment that cannot be immediately stopped in the event of a blockage. A pump's nearly instantaneous buildup of pressure, if blocked, creates a serious safety risk to nozzlemen and other workers. Blockages and their related risks are a common occurrence and should be expected at any time. The best method to protect workers from blockage-related risks is to immediately recognize the signs of a blockage and stop the buildup of pressure before a potential accident.

Professionals from every craft must master specific movements or positions to diminish the risk of injury and to provide optimum efficiency. Athletes continually practice movements and refine techniques to boost leverage, reach, speed, or performance. Like athletes, mastery of the nozzle requires study, practice, and sufficient time to learn and implement safe, efficient placement postures. A highly skilled nozzleman is obvious to anyone who sees them work. The nozzle appears weightless in their hands. They have mastered efficient placement postures, and use the correct equipment to diminish the load their backs must carry.

*ACI Certified Nozzleman **Oscar Duckworth** is an ASA and American Concrete Institute (ACI) member with over 25,000 hours of nozzle time. He has worked as a nozzleman on over 2500 projects. Duckworth is currently an ACI Examiner for the wet- and dry-mix processes. He was a former member of ASA's Board and is Chair of ASA's Education & Safety Committee. He continues to work as a shotcrete consultant and certified nozzleman.*

Fig. 3 lanzadores inclinados en ángulos absurdos

Los desplazamientos suaves y un flujo predecible de material son necesarios para controlar con precisión la colocación del material. Los golpes o ráfagas de aire inesperados afectarán el equilibrio del lanzador y reducirán la precisión de la colocación. El flujo desigual de material puede deberse al desgaste de los componentes, a una calibración incorrecta del cambio, a mezclas rígidas o a un volumen bajo de concreto en la tolva de la bomba. Los equipos de vía seca y las tolvas de la bomba de mezcla húmeda deben mantenerse llenas. El permitir que baje el volumen de concreto en la tolva atrapa y comprime el aire, este aire atrapado en la línea de concreto pueden desequilibrar o incluso lesionar a un lanzador. Si el flujo de material es irregular, el lanzador debe parar e investigar la causa antes de continuar lanzando.

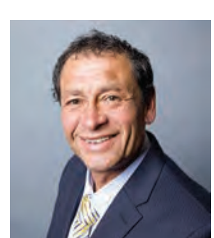
Si se requiere andamios, debe ser estable y lo suficientemente ancho para trabajar de forma segura sin comprometer el equilibrio. Dado que la boquilla puede producir empuje significativo y a veces impredecible, se necesitan barandales adecuados al lanzar desde andamios.

LISTA DE COMPROBACIÓN DEL LANZADOR

- La postura, el movimiento y la movilidad afectan considerablemente a la precisión general de la colocación.
- Elija su equipo con cuidado. Las mangueras de la punta DEBEN ser lo suficientemente rígidas para resistir dobleces o colapsos durante la colocación. Nunca se deben usar mangueras "sueves", blandas y desgastadas como manguera de la punta.
- Seleccione un ritmo que se sienta bien. El lanzado demasiado rápido disminuye la precisión y aumenta el riesgo de lesiones.
- Estudiar las posiciones de colocación utilizadas por lanzadores expertos. Practique posturas de colocación que disminuyan la fatiga y proporcionen movilidad y amplitud de movimiento.

Es esencial que el lanzador pueda hacer una señal para que detenga rápidamente la bomba o el equipo de vía seca. Un lanzador nunca debe operar un equipo que no pueda detenerse inmediatamente en caso de un taponamiento. La acumulación casi instantánea de presión de una bomba de concreto, si ocurre un taponamiento, crea un grave riesgo para la seguridad de los lanzadores y otros trabajadores. Los taponamientos y sus riesgos relacionados son una situación común y se deben esperar en cualquier momento. El mejor método para proteger a los trabajadores de los riesgos relacionados con el taponamiento es reconocer inmediatamente los signos de un bloqueo y detener la acumulación de presión antes de un posible accidente.

Los profesionales de cada cuadrilla deben dominar movimientos o posiciones específicas para disminuir el riesgo de lesiones y proporcionar una eficiencia óptima. Los atletas practican continuamente movimientos y refinan las técnicas para aumentar el apalancamiento, el alcance, la velocidad o el rendimiento. Al igual que los atletas, el dominio de la boquilla requiere estudio, práctica y tiempo suficiente para aprender e implementar posturas de colocación seguras y eficientes. Un lanzador altamente cualificado es obvio para cualquiera que los vea trabajar. La boquilla aparece sin peso en sus manos. Han dominado posturas de colocación eficientes, y utilizan el equipo correcto para disminuir la carga que sus espaldas deben llevar.



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The Gunite Supply & Equipment Company began business in 1947 and has been the premier OEM of dry-mix process shotcrete (gunite) equipment in the construction industry since the early beginnings of the gunite process. Gunite Supply & Equipment specializes in the design and manufacturing of shotcrete parts, tools, accessories, and equipment such as the C-10SL & C-10HHD gunite machines.

The C-10SL & C-10HHD gunite machines provide maximum performance and efficiency due to their heavy-duty design and powerful output. These dry-mix shotcrete machines feature a premium-life feed system, molded discharge liner and exhaust suppression chamber. A tilt-hopper provides easy access for cleaning and setup. The C-10HHD dry-mix shotcrete machine is exclusive to the shotcrete industry, offering a hydraulic motor to rotate the machine's feed system. C-10HHD gunite machines are typically used with batch plants, which provide a power-take-off (PTO) to the motor on the shotcrete machine. The hydraulic motor reduces the overall amount of air needed to power the machine.

Gunite Supply & Equipment offers a complete line of tools, parts, and accessories for shotcrete contractors, especially pool builders. Product categories include wet-mix shotcrete hose , dry-mix shotcrete hose, hose couplings (dry-mix), shotcrete clamps (wet-mix), dry-mix and wet-mix nozzles, plaster nozzles, finishing tools and more.

Other specialty accessories are available such as water booster pumps for increasing water pressure on the job site, scaffolding supports for creating an elevated work platform, shooting wire (piano wire), j-hooks, water meters, pressure gauges, cleanout accessories, air vibrators, line reducers, shotcrete additives, and primers.

Gunite Supply & Equipment allows customers to buy direct from the source with our e-commerce store (www.gunitesupply.com) that offers online ordering of shotcrete tools, nozzles, and other accessories. The website allows concrete contractors to easily search through the catalog of tools and accessories. The site is setup to offer a completely secure online environment for placing orders 24 hours a day with the convenience to accept credit cards payments and calculates shipping to anywhere in the US and Canada.

Gunite Supply & Equipment was founded by Mr. Ray Sexton and is a privately owned company, led today by Terry Sexton Segerberg. Gunite Supply & Equipment is headquartered in Cincinnati, OH with additional warehouses in Houston, TX and Pomona, CA; our quality machines are sold around the world through a network of direct sales, resellers, and distributors. Since our inception we have been proud to say that our entire product line is built in America from an American owned company—yes we are American Owned, American Built!

Gunite Supply & Equipment is a division of Mesa Industries, Inc., a family-owned corporation with diverse operating divisions across multiple industries.

GUNITE SUPPLY & EQUIPMENT

Contact Information:
888-321-5526
www.gunitesupply.com

TRIBUTE TO AXEL GUIDO NITSCHKE, PHD
APRIL 27, 1968 – DECEMBER 26, 2021

In 2015, the *Liberty Tunnel Arch Restoration with a Shotcrete Alternative* Project was celebrated with an Honorable Mention in ASA's Outstanding Shotcrete Projects Awards program. Axel Nitschke, engineer of record on that project, co-authored the resulting article and thus started Axel's affiliation with ASA. Very quickly Axel chose to actively contribute, bringing in his various employers as Corporate Members of ASA. At that time, ASA's Underground Committee had recently been decommissioned as it was in need of leadership. In October of 2015 Axel stepped up as Chair to revitalize the Committee, bringing guidance and energy to develop the AIA approved "Shotcrete for Underground Applications" seminar and the series of ASA Underground Position Statements. In 2016, Axel also accepted a spot on the ASA Board of Directors, then joined the ASA Executive Committee in 2019, rising to the Vice Presidency in 2021.

During his tenure with ASA, Axel also wrote and contributed to a number of articles for Shotcrete magazine, including "Modeling of Load-Bearing Behavior of Fiber-Reinforced Concrete Tunnel Linings" in 2017, which also won the Carl Akeley Award for best original technical article for that year. He was also an active member of the Contractors Qualifications committee, where his insights and contributions helped shaped this newly developed program at ASA.

Aside from all his professional accomplishments, Axel was kind, diligent, fair and professional in all his endeavors. He also had a great sense of humor which one enjoyed as you got to know him. Axel will indeed be greatly missed.

Born in Herten, Germany in 1968, Nitschke was to relocate with his family in 2008 to the United States. He graduated in 1993 with a master's degree in civil engineering from Ruhr University, Bochum, Germany; completing his PhD at the same University in 1998. Son of Agnes Enkel and Winfried Nitschke; survived by wife, Anke Meyer-Nitschke, and their four children: Nane, Lion, Nira and Luke.

Though only 53, Axel had accomplished much in his career in the underground world, and with us at ASA. Axel revigorated our Underground Committee, and further accepted the challenges of becoming a Board member and moving through the officer roles of ASA. As Vice President this year he would have moved into the President's role next year. Axel always paid close attention to detail and provided comprehensive and through reviews of all ASA activities that he was involved with. His opinions were insightful and helped us move several programs forward at ASA. Axel was always willing to help where he felt he could make contributions to the effort and gave freely of his time and energy.

– Charles Hanskat

Truly a sad day. When I first met Axel we had dinner at a German restaurant. What a well-rounded and experienced individual. His background and work experience was impressive. Hard working, striving gentleman. ASA and the Shotcrete industry shall miss him. Condolences and sympathy to his family.

– Michael Cotter

I am shocked and saddened to hear of Axel's passing. He was a brilliant engineer and contributed so much to ASA and the industry. Very sad to hear of the loss of someone so young and with so much more to offer. – Joe Hutter

So sad to hear the news of Axel's passing. He will be missed by us all. – Bill Geers

It was shocking news when I first read it and took me some days to digest. Condolences to his family.

Axel came to the ASA about 8-9 years ago. Prior to that, he was a lead engineer on the Devil Slides project and Caldecott Tunnel #4 project with Gall Zeidler. Since his involvement in ASA, in particular, with his leadership in the Underground Committee, He led the committee with great achievements. Some of them are:

1) *Developed a comprehensive presentation for underground shotcrete, based on ACI 506.F.*
2) *Developed three statement papers on underground shotcrete and published in Tunneling magazine and Shotcrete magazine.*
3) *Actively involved in the 506.F committee including document review.*
4) *Present in various conferences, seminars and workshops, including Deep Foundation Institute (DFI), SME UCA, etc.*
5) *Attending ACI, ASA and other conferences.*

It was a great pleasure to have worked with Axel, who had a great personality. He devoted himself to shotcrete for underground construction. As a design engineer, he had been promoting shotcrete across US and Europe on tunnel design. His Ph.D. thesis was about fiber reinforced shotcrete liner design for underground work. In the world of underground construction, experience and knowledge are equally critical. Axel is one of the few engineers that is well equipped with knowledge and field experiences. He had a very good reputation within both design engineers and large underground contractors.

This is a huge loss for the underground industry. In particular at such a young age. Axel would have led the industry, at his age, for at least another 25-30 years. Considering the fact that it took at least 10 years, if not more, to develop the experience and expertise in underground shotcrete, this is a huge impact for our industry.

I share the pain, with all of you, and other friends in the shotcrete industry. I cannot say more about my feelings for losing people like Axel, what we need to do is to educate more potential clients, recruit more young talents, work harder, and take care of our own safety and health.

– John Zhang

This is incredibly sad news.

I remember standing outside the coffee shop at Disneyland during our meetings at ACI, asking him again if he would consider joining our Board.

I'm glad that he accepted and had the opportunity to get more involved with our industry for what now seems like the short time he had left.

He was very well respected, a welcomed addition to our team and had a funny side that I admired.

I remember sitting in the meetings in Florida when he suggested to call the Scorecard the Scott-card… a nice tribute from a man who definitely deserved some himself.

We lost a true friend,

– Scott Rand

This is really sad. Axel was such a good person.

– Simon Reny, P.Eng

He was a great colleague to work with and I always looked forward to the next call or meeting with him. Huge professional and personal loss for those who knew him. God bless! – Lauro Lacerda

I am so very very sorry to hear this! We definitely lost a great one! After my initial meeting with him, I felt so much respect for his words and actions and mentioned him often! I am truly sorry and saddened. – Michele Cruz

The Art of Shotcrete WINNERS

Congratulations to our **Art of Shotcrete** winners! Thank you all for submitting photos in the 2021, 3rd & 4th Quarter judging of the Art of Shotcrete.

Project: Outdoor Pizza Oven
Ocean Rock Art
www.oceanrockart.ca
IG: @oceanrockart

Project: Private Residence, NJ
Cruz Concrete & Guniting
www.cruzshotcrete.com
IG: @cruzshotcrete

Project: Pool Project and Vanishing Edge Spa
Artisan Pools
www.myartisanpool.com
IG: @artisanpoolsnc

SUBMIT YOUR ENTRY TODAY! JUST ADD #ARTOFSHOTCRETE TO YOUR NEXT INSTAGRAM POST TO SUBMIT YOUR PHOTO. SUBMISSIONS CLOSE AT THE END OF EACH QUARTER.

ADVERTISE IN SHOTCRETE MAGAZINE

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

Themes for 2022 include:

- Winter –Award Winners
- Spring – Specifications
- Summer – Materials
- Fall – Productivity

Look for the 2022 *Shotcrete* magazine media kit online at www.shotcrete.org/mediakit. For more information, rates, and deadlines, contact Tosha Holden, ASA Editorial and Marketing Manager, at tosha.holden@shotcrete.org or 248.983.1712.

NEW ASA MEMBERS

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ThorCan Construction & Refractories
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wwebber.com
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SUSTAINING CORPORATE ADDITIONAL

Patrick Bridger
Sika STM - Shotcrete, Tunneling & Mining
Allentown, PA

Heidi Helmink
Sika STM - Shotcrete, Tunneling & Mining
Buford, GA

INDIVIDUALS

Paul Benedetti
Aquatic Technology Pool & Spa

STUDENT

Luis Mendieta
Pontificia Universidad Católica del Perú

Nirav Prajapati
CVM University

Spencer Tanner
Brigham Young University

EMPLOYEE OF PUBLIC AUTHORITIES OR AGENCIES

Peter Schubert
IUPUI

INTERESTED IN BECOMING A MEMBER OF ASA?

Find a Membership Application and list of benefits under the ASA Membership tab of www.shotcrete.org.

ACI TO DEVELOP CONCRETE POOL AND WATERSHAPE CODE

The American Concrete Institute (ACI) announced the formation of a new committee whose mission is to develop and maintain code requirements for concrete pools, spas, and other recreational watershapes. ACI Committee 322, Concrete Pool and Watershape Code, hosted its inaugural meeting Monday, October 18, 2021, from 11:30 am–3:00 pm EDT at the ACI Virtual Concrete Convention.

Under the leadership of chair Charles Hanskat, Executive Director of the American Shotcrete Association, the committee will work in direct response to an expressed industry need for code requirements that specifically address crack control, watertightness, and continuous exposure to water with wetting and drying that are essential to long term durability and serviceability of pools. Although there is an established code for concrete liquid-containing structures (ACI CODE -- 350), there has been much discussion that it is not geared towards pools and has too high a requirement for the pool industry.

> "ACI's Technical Activities Committee (TAC) created a new code committee, ACI 322, to develop codes covering pools, spas, and other recreational watershapes," said Charles Hanskat, Chair, ACI Committee 322. "Existing industry codes cover a massive scope of all liquid-containing structures in water, wastewater and industrial process applications, and this new code requirement will directly address the structural design of concrete pools."

Those with design or construction expertise in pools or other watershapes and are interested in contributing as an active voting member of ACI Committee 322, Concrete Pool and Watershape Code, please visit the ACI Join a Committee webpage and fill out the member application.

Additional information is available at concrete.org.

AMERICAN CONCRETE INSTITUTE ANNOUNCES NEW EDITOR-IN-CHIEF, MANAGING EDITOR OF *CONCRETE INTERNATIONAL*


Keith A. Tososolt


Lacey Stachel

The American Concrete Institute (ACI) is pleased to announce that Keith A. Tosolt and Lacey Stachel have been named Editor-in-Chief and Managing Editor of *Concrete International (CI)*, respectively. Tosolt takes over for Rex C. Donahey, who served as Publisher of *CI* and has transitioned into the new role of ACI's Director of Innovative Concrete Technology.

As Editor-in-Chief, Tosolt will oversee and guide the creation of content for CI, known as "the magazine of the concrete community." He has been an ACI staff member for 25+ years, serving as Associate Editor, Senior Editor, and Managing Editor during that time. Tosolt received his BA in communications, with a concentration in journalism, from the University of Michigan, Ann Arbor, MI, USA.

In her role as Managing Editor, Stachel brings 10 years of editorial and marketing experience in the concrete industry, previously serving as the Marketing Manager for the Slag Cement Association, Editorial and Marketing Manager for the American Shotcrete Association, and Editor for CI. She received her BAA in Integrative Public Relations from Central Michigan University, Mount Pleasant, MI, USA, and is a Certified Association Executive (CAE).

"The Institute is excited to have Keith and Lacey in their new roles," stated Ronald G. Burg, ACI Executive Vice President. "Both have been an integral part of Concrete International's success for more than two decades and are well-suited to lead one of the industry's most valuable publications. We are confident Keith and Lacey will guide Concrete International in the right direction as the ways in which we receive and consume information continue to change."

Concrete International is the monthly magazine of the American Concrete Institute. CI is published monthly in both printed and digital formats and is distributed to subscribers and each of the Institute's 30,000+ members. For more information or to subscribe to Concrete International, visit www.concreteinternational.org.

THE AMERICAN SOCIETY OF CONCRETE CONTRACTORS AWARDS TWO SCHOLARSHIPS

The American Society of Concrete Contractors (ASCC) Education, Research and Development Foundation has awarded two scholarships to students in the Concrete Industry Management (CIM) program. Corrina Dodd, Trafford, AL and Dixie Jane Dryden, Smyrna, TN both attend Middle Tennessee State University, Murfreesboro, TN. Each received $5,000. To qualify for the scholarship, a student must be enrolled full time in the CIM program and maintain a minimum 2.5 GPA. The ASCC Foundation was created in 1989 to fund education and research that advances the quality and productivity of concrete construction.

DFI ANNOUNCES NEW CO-CHAIR OF TUNNELING AND UNDERGROUND COMMITTEE AND BOARD OF TRUSTEE MEMBER


Robert Stier


Paul Axtell

Deep Foundations Institute (DFI) announces Robert Stier of Drill Tech Drilling & Shoring is the new co-chair of DFI's Tunneling and Underground Committee. He joins co-chair, Jim Morrison, P.E., P.Eng., COWI, and takes over for outgoing co-chair David Klug, David R. Klug & Associate.

Stier oversees the Eastern region for Drill Tech Drilling & Shoring (DTDS), a leader in the specialty geotechnical construction industry that performs tunneling operations throughout the U.S. He has over 35 years of tunneling and underground experience. Since joining DTDS in 2018, Stier has helped procure tunnel projects on both the West Coast and Eastern U.S. and has procured and managed the company's first foundation projects in the Eastern region. Under his guidance DTDS procured its largest GC design-build contract for National Parks Service, and he is currently managing the project.

Stier earned his bachelor's degree in civil engineering technology from Southern Polytechnic State University (Kennesaw State) in Marietta, Georgia.

DFI also announces that Paul Axtell, P.E., D. GE, chief operating officer and a senior principal engineer for Dan Brown and Associates, has been elected to the DFI Board of Trustees.

Axtell has over 20 years of experience in geotechnical and foundation engineering. In recent years, Axtell has primarily focused on foundations for major bridge projects across the nation, delivered under a variety of project delivery methods. He is the geotechnical engineer of record for eight Mississippi River Crossings and has acted as foundation design, construction or load test consultant on several others.

Axtell holds a B.S. degree in civil engineering from the University of Missouri and an M.S. degree in engineering from the University of Texas with a geotechnical emphasis. He is registered as a professional engineer in seven states and is a diplomate of the ASCE Academy of Geo-Professionals. Since 2013, he has served as chair of DFI's Drilled Shaft Committee. He also serves on the Board of Directors for the ASCE Academy of Geo-Professionals and was recently honored with admittance into the University of Missouri's Civil Engineering Academy of Distinguished Alumni.

SHOTCRETE CALENDAR

Please check with the meeting provider as some meetings may be postponed or cancelled after publication of this issue of Shotcrete.

MARCH 2, 2022	**Architectural Shotcrete – Creative, Sustainable and Durable Concrete Structures using Shotcrete** HALL 3A, Javits Center | New York, NY
MARCH 2 - 3, 2022	**New York Build Expo** HALL 3A, Javits Center | New York, NY
MARCH 27 - 31, 2022	**ACI Concrete Convention Spring** Caribe Royale Orlando | Orlando, FL
APRIL 4 - 6, 2022	**International Concrete Repair Institute, Inc.** Baltimore Marriott Waterfront | Baltimore, MD
APRIL 6 - 8, 2022	**Public Shotcrete Certification – Wet- & Dry-Mix** Minova | Millstadt, IL
APRIL 22 - 24, 2022	**Public Shotcrete Certification – Wet- & Dry-Mix** Valley Concrete Services | Sebastopol, CA
JUNE 12 - 15, 2022	**ASTM Summer Concrete Committee Meetings** Hyatt Regency | Seattle, WA
JUNE 19 - 22, 2022	**North American Tunneling Conference (NAT) 2022** Philadelphia, PA www.natconference.com
OCTOBER 13, 2022	**Architectural Shotcrete – Creative, Sustainable and Durable Concrete Structures using Shotcrete** McCormick Place | Chicago, IL
OCTOBER 13-14, 2022	**Chicago Build Expo** McCormick Place | Chicago, IL
OCTOBER 23-27, 2022	**ACI Concrete Convention - Fall** Hyatt Regency Dallas | Dallas, TX
MORE INFORMATION	To see a full list, current updates, and active links to each event, visit **www.shotcrete.org/calendar**.

SHOTCRETE FAQs

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

Question: *ACI 318-14 (Building Code Requirements for Structural Concrete) requires post-installed expansion anchors to meet the testing criteria of ACI 355.2-07 (Qualification of Post-installed Mechanical Anchors in Concrete). ACI 355.2 specifies certain anchor testing and evaluation requirements to verify suitable anchor performance and to determine other aspects (such as failure mode) to use in conjunction with Chapter 17 of ACI 318 when designing the post-installed expansion anchors. Anchor testing is required largely to be performed by an independent agency and normally is conducted in normal weight and/or light weight concrete that meet pertinent ACI, ASTM and other requirements.*

Some post-installed expansion anchor manufacturers (like Hilti) have not had their anchors tested per ACI 355.2 in shotcrete type concrete, only tested in normal weight and light weight concrete. As such, these anchor manufacturers typically do not publish/offer any permitted load ratings, installation torques or other design and installation requirements for their expansion bolts when used in shotcrete. Instead, they recommend site testing to determine anchor performance or that the responsible design engineer can make an engineering judgment on anchor acceptability, as appropriate, if site testing is not performed.

Do you have knowledge of any expansion bolt manufacturers that have tested their products is typical shotcrete?

If yes to #1 above, do you know if the testing was done per ACI 355.2 requirements?

Answer: Shotcrete is a placement method for concrete. With proper equipment and placement techniques, concrete shotcreted in place will have strength, unit weight, permeability, and other hardened properties equivalent or superior to cast concrete consolidated by vibration. Due to delivering concrete material through relatively small diameter lines (1.5 to 2 in.) [38 to 51 mm] concrete mixtures for shotcrete placement typically limit the maximum coarse aggregate size to a nominal 3/8 to ½ in. (9.5 - 13 mm) size. Thus, answering your specific questions:

1. We are not aware of any expansion bolt manufacturers tests that used shotcrete placement of concrete for their test samples. However, tests on cast concrete should be equivalent with a given compressive strength and aggregate size/type in the concrete mixture.
2. We expect that as answered in #1, that the tests run with ACI 355.2 requirements in cast concrete would have similar results when used with shotcrete placement of the concrete mixtures with similar hardened properties.

Also, note that ACI 318-19 directly includes shotcrete as a placement method for structural concrete.

Question: *We have a wet-mix shotcrete steel fiber overhead application progressing in our state. The question is about the use of a steel trowel finish, as opposed to say a magnesium or wood float finish.*

In the ASA Shotcrete Inspector seminar, it was stated that a steel trowel is less durable, reduces freeze-thaw resistance and shows cracking more proximately.

As this particular application is overhead and, in a tunnel, there is not as much of a concern with water infiltration and the associated freeze-thaw exposure. We usually don't allow steel trowels for flat work, due to deicing salts, but that concern wouldn't apply here.

My superintendent has asked me to reach out to you to see if you might have any further detailed advice on this type of application.

Construction is wanting a smooth finish and looks do matter here as it is a high-profile project. If the DOT were to allow the steel trowel for finishing, what would be your concerns or suggestions to this approach?

Answer: Freeze-thaw deterioration is dependent on the concrete being saturated in multiple freezing/thawing cycles. In an overhead application, where water can't stand on the surface, the concrete can't be saturated unless water permeates through from the upper surface. And with good quality concrete in the tunnel, water shouldn't permeate through, so it should be functionally watertight. As a result, freeze-thaw likely isn't a critical durability issue.

A steel trowel finish does require extra working of the surface and would require the contractor to be very attentive to the proper time to obtain the finish yet not overly disturb the fresh concrete. Gravity is working against the overhead concrete staying in place.

Having a smooth steel trowel finish would make minor shrinkage cracks more noticeable. However, in the tunnel without exposure to sunlight or much wind exposure, and with proper attention to curing, perhaps surface cracking will be minimal.

Question: *I have a question regarding shotcrete pools. Does the ASA have a position on how to detail reinforcement at bulky elements that are shot interior to the main pool shell? This would typically involve stairs or large stoops. I notice a lot of contractors shoot these as unreinforced bulk elements, but this practice appears to promote cracking at the face of the pool shell. I'm only asking because I saw a few of these this past summer.*

Answer: Shotcrete is a placement method for concrete. Thus, any concrete structure using shotcrete placement should be designed using appropriate concrete design codes and standards. ASA does not have a published position on reinforcement of these types of pool elements though we are in the midst of developing one. As most concrete experiences drying shrinkage and associated cracking, most designers would include some level of reinforcement in these types of sections to control tensile stresses from shrinkage and temperature changes creating volume change in the concrete. ACI 350 (Code Requirements for Environmental Engineeringn Concrete Structures) is the ACI Code that deals with concrete liquid-containing structures with provisions specifically for providing liquid-tightness and durability in continuously wet environments. The ACI 350 Code requires up to 0.5% reinforcement for shrinkage and temperature stresses. ACI 318 is the Concrete Code for Structures and requires 0.18% minimum reinforcement for shrinkage and temperature. Designers may choose to use the lower ACI 318 value since they consider the benches and steps not part of the water retaining pool shell. Other designers would consider the higher ACI 350 values as they are interested in better crack control. Overall, having a substantially unreinforced thickness of concrete would lead to more cracking that would be problematic in the pool.

Question: *I was taught in engineering courses that conventional concrete should not be counted on to carry tensile stress. For steel reinforced concrete, the reinforcing bar is designed to carry all tensile loads. Although concrete obviously has some tensile strength, it is too low and prone to cracking failure to consider it in design. In fact, I believe you can assume it is cracked from the shrinkage during curing. Is gunite treated the same way?*

I have a pool that is developing a crack through an elevated wall/beam and down into the plaster to the bottom floor at the sun shelf. I witnessed the plumbers cutting some rebar in the beam to allow for PVC plumbing to water sheer (up at top of beam, just under the tile topping) and I worry this is the root cause along with settlement that put the top of the beam in tension. The rebar down low should be intact and I hope the crack width may stay minor down in the plaster. On top of the tiles beam where the maximum tensile stress would have been, the crack is fairly wide. The crack movement opened up a gap in the grout line between tiles of about 0.08 to 0.10 in. (2-2.5 mm). I think it was a real sin for them to have cut the rebar. If it is necessary to reinforce the tensile side to halt future movement, I would think cutting a slot or two in the gunite across the crack (say 12 in. [300 mm] each side. Up high just under the water sheer) and epoxy a rebar in the slots.

Answer: Shotcrete, both dry-mix (gunite) and wet-mix are a placement method for concrete. Wet-mix uses premixed concrete while dry-mix simply adds water to the concrete materials at the nozzle. Both dry-mix and wet-mix with proper materials, equipment, and placement with produce quality concrete sections. The embedded reinforcement in the pool shell is designed to carry tensile loads. This may be bending stresses from structural loadings (settlement or water/backfill), or volume changes from drying shrinkage and temperature changes. Cutting a reinforcing bar would certainly negate its ability to carry loads in the vicinity of the cut and reduce the load carrying capacity until the development length allows the reinforcing bar to start carrying it full load.

The layout of your cracked section isn't clear from your description. An 8 to 10 mil (2 to 2.5 mm) crack is sizable in a water-containing structure. Fixing the existing crack with a reinforcing bar epoxied in place across the crack may be effective. However, that solution would only carry any additional load on the section (structural or volume change), as the existing loads have already created cracks. Thus, you should also address filling the crack as part of the solution. This may be with epoxy injection or swellable polyurethane grouts. You should consult with the pool design engineer for their recommendation on the best method for repair.

Question: *We are reinforcing an exterior pool wall with shotcrete, and wanted to know what preparations need to take place for the shotcrete to adhere correctly, and what the minimum thickness needs to be? We also need to level out the floor up to 5 in. (125 mm) that will gradually go to zero to meet other side. Can shotcrete be used in this application?*

Answer: When shooting onto existing concrete sections the surface must be properly prepared and then shotcreted with proper shotcrete materials, equipment, and placement techniques. This will produce a construction joint that acts monolithically and not be a "cold" joint. Shotcrete placed onto an existing concrete surface will provide an excellent bond IF the following conditions are met:

1. Make sure the surface is roughened and clean.
   a. The amplitude of roughness should be +/- 1/16th in. (1.6 mm) or more.
   b. If the surface was not roughened when it was chipped out, be sure to have the contractor roughen it.
   c. A high-pressure water blaster (5000 psi [35 MPa] or more) or abrasive blasting can help to roughen and clean the surface.
2. Bring the concrete surface to saturated surface dry (SSD) condition. This means the surface feels damp, but water is not picked up on a hand.
3. Make sure the shotcrete placement is properly executed with high velocity placement and quality materials.
   a. The shotcrete should have a minimum 28-day compressive strength of 4000 psi (28 MPa).
4. Be sure the shotcrete contractor is using an air compressor able to produce at least 185 ft^3/min (5.2 m^3/min) for wet-mix and 385 ft^3/min (11 m^3/min) for dry-mix (gunite) of air flow at 120 psi (0.8 MPa).

5. Use of an ACI-certified shotcrete nozzleman is recommended.
6. No bonding agent should be used. It will interfere with the natural bonding characteristics of shotcrete placement.
7. A minimum thickness of no less than ½ in. (13 mm) is recommended.

This article on the excellent bond between shotcrete provides more detail: shotcrete.org/wp-content/uploads/2020/05/2014Spr_TechnicalTip.pdf:

Regarding the additional floor thickness, though it may be shotcreted by an experienced nozzleman, it is difficult to properly shoot horizontal surfaces and control rebound and overspray from the shotcrete placement. We suggest that casting and vibrating for consolidation the horizontal sections is preferred to shotcreting. You should consider a bonding agent since the concrete is cast against the existing concrete floor without any impact velocity. We would also not recommend tapering down to 0 in. thickness. The feather edge will tend to be an area that may easily spall over time. Thus, we recommend cutting an ½ to ¾ in. (13 to 19 mm) deep shoulder so the concrete can have some thickness at its thinnest locations.

Question: *I'm in the market for a saltwater pool and was wondering what the ASA recommended concrete compressive strength should be. I've read California mandates a 2500 psi (17 MPa) minimum, but some construction companies use 5000 psi (35 MPa). What is the ASA standard for a saltwater pool?*

Answer: Our ASA Pool Position Statement on Compressive (Strength) Values of Pool Shotcrete states pool and shotcrete contractors have a responsibility to provide a pool structure that not only meets certain design specifications, but also meets basic durability values expected with shotcrete applications. The American Shotcrete Association's (ASA) Pool and Recreational Shotcrete Committee and ASA Board of Direction have reaffirmed a 4000-psi minimum for in-place compressive strength pool concrete.

As a saltwater pool has a higher chloride content than fresh water you may want to consider using the requirements of ACI 350 (Code Requirements for Environmental Engineering Concrete Structures) where Table 4.2.2 – Requirements for Special Exposure Conditions has this requirement:

"For corrosion protection of reinforcement in concrete exposed to chlorides in tanks containing brackish water and concrete exposed to deicing chemicals, seawater, or spray from seawater – maximum water-cementitious. Materials ratio, by weight is 0.40 with a minimum 28-day compressive strength of 5000 psi."

In summary the minimum 28-day compressive strength should be no less than 4000 psi, but for enhanced durability you may consider 5000 psi as required by ACI 350. You may find more guidance in our ASA Pool Position Statement "Watertight Shotcrete for Swimming Pools" at www.Shotcrete.org/Resources.

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