Shotcrete MAGAZINE

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DEPARTMENT OF TRANSPORTATION

american shotcrete association | asa

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

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Call to Action

By Bill Drakeley

As many of my colleagues and I enter another construction season, I pause to reflect on our industry. I believe that the American Shotcrete Association is at a crossroads. Behind us stands the legacy of a century of growth and setbacks, innovation, and prestige in concrete construction. In front of us extends the future of the shotcrete industry.

Our strategy to expand our reach is in place. Under the Strategic Plan, we have established clear and actionable targets for achievement this year. Some of these have been met. I'd like to use my first memo to call to action all sitting members of the respective ASA committees to double their efforts to meet the remaining objectives. The time is now.

Our organization offers members many opportunities to contribute. As we welcome new volunteers into the leadership of ASA, I encourage each person to enter these roles with the primary goal of advancing ASA's mission and to contribute to its growth. Recognition and credibility should be secondary goals for all of us, although there can be no doubt that adding ASA to our list of credentials inspires trust in clients and colleagues alike. Quality is more important than quantity. My hope is that every hour spent in volunteering for ASA is done with the goal of raising the bar—increasing the number of people we reach, promoting awareness of the standards and science behind good shotcrete, and enhancing the reputability of our organization.

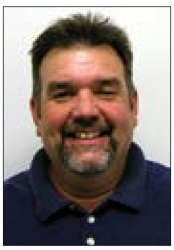
It is my privilege to call many of ASA's members my personal friends. Those who know me also know that I am inspired by those titans of our industry who have chosen to take the high road—to never cut corners in mixture design or application, to submit their work to rigorous scrutiny, and to take seriously the obligation to uphold these principles when no one is watching. I would like to recognize past ASA Presidents and influential members who carried that torch: Pete Tatnall, Curt White, George Yoggy, Patrick Bridger, Rusty Morgan, Lars Balck, Larry Totten, Michael Cotter, and Chris Zynda, among others. It is my hope that every member of ASA understands the obligation to strive for excellence—an obligation that goes hand-in-hand with claiming the credibility of membership in the organization.

Shotcrete has led me to some of the most exciting projects of my career—jobs that pushed the limits of engineering to breathtaking effect. As one of the most versatile construction methods available to us, shotcrete—done right—has the potential to carry new construction, infrastructure rehabilitation, and environmental engineering into the future. It is our job to ensure that we are there, too, with sound knowledge and excellent practices to help push the industry forward. I have every confidence that ASA will lead that advance with the help of its committed members. As part of this new generation, I am grateful for the efforts of my colleagues, among them Marcus von der Hofen, Marc Jolin, Scott Rand, Lihe John Zhang, Frank Townsend, Ezgi Yurdakul, Mason Guarino, Cathy Burkert, Randle Emmrich, and Marc Jolin.

I look forward to doing my part to see that the Strategic Plan is implemented and our established goals for the next year are reached and surpassed. As this year's President, I am honored for the opportunity to energetically represent ASA, to promote shotcrete as an advanced and sophisticated construction method, and to advocate for the highest standards in its execution.

ASA Membership Committee

By Tom Norman



First and foremost, I would like to express ASA's significant appreciation to all of the current, past, and future members who are by far the most important part of our Association. Without these individuals who have tirelessly given their time and experience, we would not be the voice in the shotcrete industry that we have become today. Formed in 1998, ASA has gone through many changes as it has grown and adjusted to accommodate the shifting demands of the market and concrete industry. Throughout our 18 years as an association, ASA has continually looked to advance and reevaluate its role in the concrete construction industry to benefit its valued members. I invite you to consider joining this organization at a time of great opportunities for you and your company. Becoming an ASA Corporate Member provides great exposure for your company within ASA's many marketing resources.

Speaking of growing, last year alone (2015-2016), 44 new Corporate Members joined ASA. They knew the value and the return on investment that membership provides on a daily benefit. Membership is the first step, but the desire to help build the industry leads to service as an active committee member, where you have a voice in steering the direction regarding important topics in the shotcrete industry. This past year, we have had several new committee members join and many who have expressed interest.

When you join ASA as a Corporate or Individual Member, your membership entitles you to join and actively participate in one or more of our committees. Our officers, Board of Directors, and committees help shape the organization's direction and grow our visibility and involvement in the concrete industry. Committee membership also allows you and your company to gain exposure among your peers and across the industry. Membership and participation in ASA committees opens many networking opportunities to interact with top professionals in the shotcrete industry. You can meet them personally and chat with them one-on-one about new shotcrete techniques, current shotcrete jobs, shotcrete issues, and troubleshooting. ASA is a community of like-industry contributors: engineers, OEM manufacturers, certified nozzlemen, project managers, superintendents, material suppliers, DOTs, educators, and students. We have a great collection of members—from new shotcrete crew laborers to the seasoned crew—all with the unified goal of advancing the shotcrete industry. Networking and information exchanges provide you the opportunity to share and learn what's going on in the industry and in your region, brainstorm over issues and solutions that could benefit you or others within the organization, and help increase awareness of shotcrete as a preferred means of concrete placement in appropriate applications. With ASA's reputation in the industry, your membership in the Association will add credibility to your operations.

ASA Corporate Membership exposes you to many opportunities to increase your customer base. Your company and specialty information will be listed in ASA's Buyers Guide, both online and in hard copy annually. Corporate Members are allowed to include the ASA logo on their business letterhead, business cards, and website. You will also have the opportunity to respond to bid requests from the ASA Online Project Bid Submittal Tool. By doing so, you have access to new customers who require your area of expertise/specialty.

As an ASA Corporate Member, you are invited to submit press release-type announcements for the Industry News and New Products & Processes sections of *Shotcrete* magazine at any time, have voting privileges at meetings and director/officer elections, submit entries for the annual Outstanding Shotcrete

ASA Membership Committee

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Randle Emmrich, Secretary | Coastal Gunite Construction Co.

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Marcus H. von der Hofen | Coastal Gunite Construction Co.
Ezgi Yurdakul | GCP Applied Technologies

Project Awards Program, and more, as outlined on ASA's website—**www.shotcrete.org**—on the ASA Membership/Benefits page.

Corporate Members may take advantage of discounts on ACI Nozzleman certifications and ASA education sessions. All members also receive discounted ASA member prices on all ASA products, discounted registration to the exhibit hall at World of Concrete, free on-site learning seminars upon request, and much more. Details are available on ASA's website. A recent addition to Corporate Member benefits includes a complimentary copy of ASA's new "Safety Guidelines for Shotcrete," a valuable resource for both contractors as well as an informational tool for equipment manufacturing firms. Corporate Members also have the opportunity to purchase long-sleeve crew t-shirts with the ASA Corporate Member logo on the back and their own company logo on the front.

These are just some of the benefits that you receive directly as a member of ASA. However, ASA's mission to inform and educate the industry is freely available to all. ASA provides a wealth of resources to help you in your business to communicate the benefits of shotcrete to your clients and project owners. You may access this information or link directly to our website, **www.whyshotcrete.org**, to help you promote shotcrete. ASA also offers FREE 1-hour-long AIA accredited seminars, either on-site or via a webinar, for engineers, architects, and specifiers you may work with to help communicate shotcrete's benefits, as well as specification resources to those in the position to specify shotcrete. ASA's many new developing programs include a Shotcrete Inspector's program to inform those whose jobs are to maintain the high quality of work that builds on the increasingly good reputation of shotcrete-specified projects. But moving our programs forward requires you—both your expertise and support. Your membership and active participation brings long-term value to your business, your customers, and ultimately the entire concrete industry.

For questions or additional information about ASA and the ways in which you can grow with us, please contact info@shotcrete.org. We look forward to welcoming you both as a member of ASA and hopefully a new member of our Membership Committee or another of our Committees.

***Editor's note:** ASA wishes to thank Tom Norman for his years of service as Chair of the ASA Membership Committee. As of the ASA Spring 2016 Committee Meetings, Cathy Burkert will assume the role of ASA Membership Chair. ASA also extends best wishes to Cathy as she continues to move ASA forward in this capacity.*

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Strategic Plan

Our Impact | ASA's Vision

Structures built or repaired with the shotcrete process are accepted as equal or superior to cast concrete.

Our Drivers | ASA's Strategic Priorities

- Professional Development
- Outreach
- Credibility
- Organization Strength

Our Business | ASA's Mission

ASA provides training, qualification, certification, education, networks, and leadership to increase the acceptance, quality, and safe practices of the shotcrete process.

Our Success | Key Performance Indicators

- Member Satisfaction
- Financial Health
- Membership Growth

Spring 2016 Update

By Scott Rand

Back in the Fall 2014 issue of *Shotcrete*, Charles Hanskat wrote an excellent piece unveiling our Strategic Plan under what was then his ASA President's Message. Charles spoke about our evolution from 1998 to present day and the need for a new vision to continue our impressive growth.

A task group was formed to meet in Detroit, MI, back in August 2014 and the results of that brainstorming session, led by Jon Hockman, a Consultant experienced in Organizational Strategy and Alignment, led to the formation of this new plan. The Vision Statement was updated; a new Mission Statement to support the vision was written; and four key priorities of Professional Development, Outreach, Credibility, and Organization Strength were adopted to accomplish the Mission. Goals and Objectives were outlined specific to each key priority and then in September 2014 the strategy was presented to the ASA Board, resulting in full approval.

Our next step was to align each of these objectives with an existing ASA committee, understanding that a second committee may be required for additional resources, especially on some of the larger tasks. We were off and running, or so we thought. While we did start to accomplish some of our initial goals, it became apparent over the next year that our meetings were falling back into the usual habits previous to the development of the plan. Entire meetings were taking place without any specific mention of the Vision.

Hanskat stated it well in his initial editorial: the Strategic Plan must not be a static document. We discussed the issues that we were experiencing at a couple of our Executive Committee monthly meetings midway through 2015, and the resulting direction was to have me dedicate effort to managing the Plan. The goal would be to bring more concentrated focus to the Plan itself, especially at our regular meetings, and to act as a liaison between the Committee Chairs and the Board/Executive Committee.

Further discussions within the Executive Committee concluded in the adoption of some of the strategies that we at King were having success with in managing our Strategic Plan. The insight to many of our thoughts and practices can be found in *The 4 Disciplines of Execution (4DX)* by McChesney, Covey, and Huling. Their insight helps focus energy on "Wildly Important Goals" (WIGs) amid the "Whirlwind" of daily activities. Agreeing that this was speaking to our experience to date, we moved to completely change the agenda for the Denver, CO, ASA committee meetings held in October 2015.

Insight from 4DX teaches us that executing a strategy like this will require lasting change in behavior. All WIGs require deadlines and committees would be best to not focus on more than two at the same time. These objectives should be placed on a scorecard, making the evolution of the plan visible, ultimately making committees accountable while recognizing at the same time that successes should be celebrated.

Discussions were held with committee Chairs and the Denver meeting started by walking through every existing goal not only to achieve consensus on which committee would actually own each objective but also in what priority they should concentrate their efforts.

The result was greater buy-in than had been experienced in the past year and a renewed dedication to completing the Strategic Plan. We understood that this exercise may challenge the focus of some existing committees and perhaps even result in the need to develop new ones. I share that both occurred. Following the decision earlier in the year by then-President von der Hofen to reestablish the Underground Committee, asking Axel Nitschke to chair, a Technical Committee was also formed to be chaired by Lihe (John) Zhang.

Specific to our Committees, Education is working on updating our Continuing Education Programs; Marketing, while just having completed our rebranding initiative, will now concentrate on implementing our Inspector Training Program; Membership will focus not only on our growth but also on our retention; Pool & Recreation is adding to their relevant Position Statements as well as following up on their numerous leads developed through this year's trade show circuit; Safety is developing a presentation to accompany their Guide; the newly revived Underground is concentrating on a presentation specific to the use of shotcrete below grade; Technical is not only wrapping up their latest research initiative but also defining future opportunities; and our Executive Director is concentrating on the heavily anticipated Contractor Qualification Program.

The summary of both the 2015 Denver and 2016 Las Vegas (World of Concrete) meetings have led to some of the most exciting initiatives and progress since adopting the plan. This new approach, together with the Strategic Plan Scorecard, will provide greater visibility for our committee's efforts for the next couple of years.

As always, if one of these initiatives interests you, please contact us (info@shotcrete.org) about how you can become involved.


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Spring Has Sprung—New Programs and Activities at ASA

By Charles Hanskat, PE, ASA Executive Director

We saw many new faces at our Spring 2016 Committee and Board meetings held in Milwaukee, WI, on April 16. Our committees have demonstrated a renewed vitality, with several exciting programs close to being finalized by our Board.

We've got a revised version of the Shotcrete Inspector education seminar ready for Board review and approval. This is a full-day seminar geared toward educating inspectors, engineers, architects, and owners on the benefits and proper application of shotcrete. Using a full-day format allows us to cover shotcrete in much more detail than afforded in our 1-hour on-site seminars. The seminar covers the history, typical applications, materials, mixture design, equipment, proper shooting techniques, curing, and the various technical documents such as ACI 506R, "Guide to Shotcrete," and ACI 506.2, "Specification for Shotcrete."

We reviewed an updated draft of a Shotcrete Contractor Qualification program. This program is a straightforward program that helps to establish a shotcrete contractor's qualifications by review of the contractor's work, by ASA experts with extensive experience in successful shotcrete work. This qualification program provides a distinct service to the industry and lets ASA do the heavy lifting for the specifier in evaluating qualifications of a contractor based on past performance. The Board established a new standing committee, the Contractors Qualification Committee, to refine the proposed program and to handle the implementation.

We've reached a point where the 1-day format for our committees has become unwieldy. Although web meetings have been ramping up with committee and task groups, it is still important to have our face-to-face meetings. With nine standing committees, plus Board and Executive Committee meetings, even starting at 7:00 a.m. and running until 6:00 p.m. doesn't allow all our committee meetings to run sequentially. As a result, a task group was assigned to review potential committee meeting formats and make recommendations to the Board for possible changes to increase our efficiency and effectiveness at the committee meetings.

Also, the Education and Safety Committees have joined together to develop a new safety-oriented education program. It's intended that this program will be directed toward our contractor members and their crews. The meetings also had discussion on some alternative delivery formats for future education modules. Options included a series of “toolbox” meetings, a DVD, or online video.

In our Strategic Plan we placed a high importance on outreach to groups outside of ASA who need to learn more about shotcrete. This year we’ve made significant inroads to working with the American Railway Engineering and Maintenance-of-Way Association (AREMA). We’ll be exhibiting at the annual AREMA Conference and Exhibition in Orlando, FL, August 28-31, 2016. Also, I’ve been meeting with the AREMA technical committee on concrete (Committee 8) at their periodic meetings to assist in updating the *Manual for Railway Engineering* to fully address shotcrete.

We’ve also had active participation with the National Concrete Consortium (NCC). Their Spring meeting was held in Columbus, OH, in late April, and we made an hour-long presentation on shotcrete. The NCC includes members from 30 DOT organizations, the FHWA, as well as major associations such as PCA and NRMCA. We had great interest in the shotcrete presentation, and now have many contacts in DOTs across the country.

Finally, we are closely evaluating our outreach to students. Traditionally, we have offered up to three $3000 scholarships to students entering graduate school with some expressed interest in shotcrete. Unfortunately, although a good program, the scholarships seem to have a very limited audience and exposure of shotcrete to the student community. As a result, we are evaluating how to best redirect our student outreach efforts.

In the last year, we’ve made many presentations to student groups about shotcrete that give us enhanced visibility to more students entering the civil engineering or construction management fields. Based on my contacts with professors at many other schools, I expect we can increase our level of presentations this year. Last summer we made a presentation to the PCA Professor’s Workshop to let the civil engineering professors, who are interested in concrete, know more about shotcrete (and in many cases give them their first exposure to shotcrete). We also worked with ACI’s Construction Liaison Committee to present a shotcrete-related problem for the student teams to research and propose a solution (see more details in our Association News section). This competition went out to nearly 30 different schools with Civil Engineering or Construction programs, and involved teams of students actively researching (and thus learning) about shotcrete as an alternative to form-and-pour construction. Each team included four to eight students advised by a faculty member. The combination of increased presentations to schools and establishing an annual shotcrete student competition would certainly give us better exposure to many more students who will be entering the concrete construction industry, which would be better than our current exposure with the scholarship program.

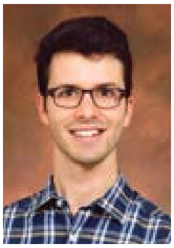
Finally, I want to thank all those ASA members who have given their time and effort to our committees and officer positions. As noted at the lead-in to this column, we’ve seen many new faces at the committee meetings and are open to anyone who has an interest in contributing to join one of our committees. With the increased focus on the Strategic Plan, we’ve certainly ramped up our activities, and active member participation is the key to getting our strategic goals realized and moving ASA forward.

2015-2016 Research Update

The following is a short update on the graduate student research being undertaken by ASA's 2015-16 Graduate Student Scholarship recipient. The 2015-16 scholarship winner was announced at the February 2016 ASA Annual Meeting, Awards Banquet, and in the Winter 2016 issue of *Shotcrete*.

Antoine Gagnon is currently pursuing his MSc in civil engineering from Laval University, Quebec City, QC, Canada.

We hope he finds the research into shotcrete-related topics rewarding and we look forward to getting future updates on the research results.



***Antoine Gagnon** received his bachelor's degree in civil engineering from Laval University, where he continues to work toward his master's degree in the same field. The focus of his graduate research is in developing shotcrete mixture designs with added environmental/sustainable value. Toward that end, Gagnon is exploring the reduction of waste associated with shotcrete rebound and inclusion of industrial waste and recycled materials to minimize the use of new resources, all with an eye toward conventional and environmental costs as well as sustainable performance.*

Research: Developing Shotcrete Mixture Designs with Environmental Added Value

Background

For decades, the concrete industry has been working on reducing its environmental footprint by optimizing working techniques, using high-performance materials, and increasing the use of alternative materials. In the shotcrete industry, this avenue also appears to be very promising, but unfortunately very few studies have been conducted regarding this subject and significant changes have yet to come.

As we know, multiple recycled products and industrial waste can be used in concrete as replacement for cement or aggregates. However, the control of the workability of the fresh concrete is often the limiting factor with such mixtures. The key to this problem is the shotcrete dry-mix process method. Indeed, this method allows the unhydrated material to easily flow with air right until it is wetted down at the nozzle, only a short moment before it reaches the spraying surface. This process opens the door for the use of multiple materials that would normally decrease the workability of cast-in-place concrete.

On the other hand, waste produced by rebound of the shotcrete causes a great deal of concern. Rebound represents wasted resources that generates direct material costs, disposal and cleaning costs, along with environmental externalities. Generally averaging from 10 to 40%, depending on various parameters, rebound is a problem in terms of economy, physical properties of concrete, and environmental footprint. Enhancing shotcrete efficiency by lowering the rebound would therefore address these compatible issues.

Objectives

In this research, the first objective is to reduce waste associated with shotcrete rebound by developing high-efficiency shotcrete mixture designs. These shotcrete mixture designs will contain supplementary cementitious materials such as modified clays and gums designed to have lower rebound. All shotcretes will be characterized both in the fresh and hardened states to better evaluate their potential.

The second objective is to minimize the need for new resources. Thus, other mixtures with substitute materials will be evaluated. These alternative ingredients are industrial waste and recycled materials such as paper sludge ashes, recycled concrete, or recycled plastic.

Finally, the third objective is to measure the potential of these mixtures in terms of conventional costs, environmental costs, and sustainable performance. If the results are promising, this research could contribute to legitimize shotcrete with environmental added value in the industry.

Research Significance

Ironically, most waste materials will keep generating costs and energy consumption as they are normally sent to landfills or treated. Alternatively, they could be used as substitute materials in shotcrete and save new resources. This situation could become a win-win strategy as the concrete producer, the waste producer, and the environment could all benefit from this collaboration. Shotcrete mixture designs have a great potential in terms of energy efficiency and sustainable development—both permanent issues of our technological challenges. It is all about managing our resources in a better way.

In a world of limited resources, adapting the shotcrete industry to sustainable development standards is essential to guarantee its prosperity. If the results of this research show potential for new shotcrete mixture designs with environmental added value, it would help enhance the environmental footprint in the shotcrete industry. As the carbon market is now a part of our economy, becoming a leader in sustainable development is one of the best ways to grow in a thriving industry.

East End Crossing

By Marcus H. von der Hofen

The East End Crossing project, currently under construction by WVB East End Partners, will connect the east end of Louisville, KY, near Prospect, KY, to southern Indiana, near Utica, IN. The Kentucky approach to the new bridge will extend I-265 (the Gene Snyder Freeway, also known as KY 841) from its current termination at U.S. 42 to the bridge, adding a new four-lane (two northbound, two southbound), 1.4 mile section. The Indiana approach will also

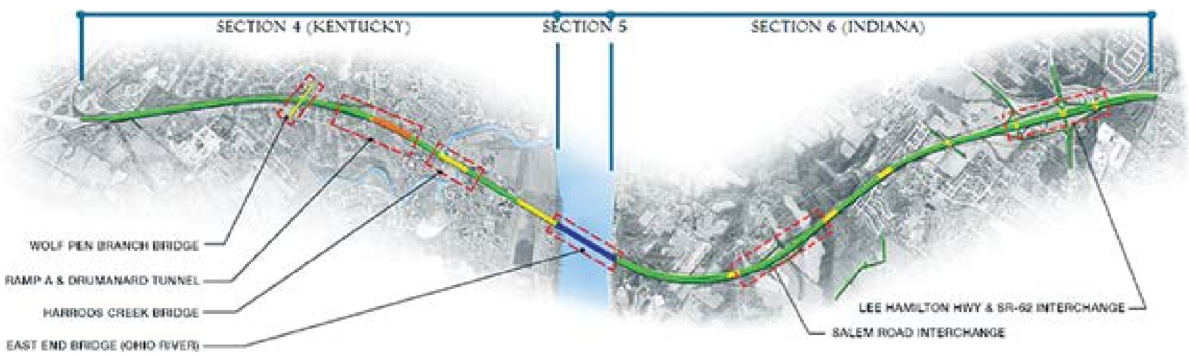


Fig. 1: Overview of project


Fig. 2: Satellite image showing proposed tunnel under Drumanard Estate


Fig. 3: Close-up satellite image of Gene Snyder Freeway entrance to the Kentucky Tunnel


Fig. 4: Gene Snyder Freeway entrance construction site


Fig. 5: 196,000 yd^3 (150,000 m^3) of rock and dirt excavated for the tunnel

Fig. 6: Construction access from the north portal also needed to be created

Fig. 7: Ventilation tubes exiting the south portal during construction

be a four-lane section, and will extend SR 265 (the Lee Hamilton Highway) 4 miles (6.4 km) from its current termination at SR 62 to the bridge.

On July 26, 2002, the two governors of Kentucky and Indiana announced that the East End Bridge would be constructed, along with a new I-65 downtown span and a reconstructed Kennedy Interchange, where three interstates connect. The cost of the three projects will total approximately $2.5 billion and will be the largest transportation project ever constructed between the two states. Construction began in 2014, with the entire project being completed by 2024.

One of the challenges was dealing with a particular property of historic value—the Drumanard Estate—that was in the direct path of the project. The answer: two 1940 ft (591 m) tunnels under an undeveloped part of the estate for the bridge approach. These tunnels will be the second longest in Kentucky and the longest that will allow hazardous materials.

The Drumanard Estate and the decision to tunnel under it is not without controversy and with proponents and detractors. In fact, this is a longstanding issue that has blocked Louisville's East End Interstate bridge for 50 years.

So, what makes the Drumanard Estate so historic? The Olmsted Brothers, world-renowned landscape architects behind New York's Central Park and many parks in Louisville, designed the layout of the grounds, gardens, landscaping, and plantings per the request of the original owner, William Strater.

Strater purchased the property around the turn of the twentieth century. Tragically, Strater drowned in Harrods Creek before he could reap the fruits of his landscaping dream. It wasn't until 1929 that Strater's wife brought her deceased husband's dream to reality and had the estate built for her son, Edward Strater, complete with the Olmsteds' plans.

The 47 acre property stretches from Wolf Pen Branch Road all the way down to Harrods Creek.

Fig. 8: Formwork for tunnel entrance

Most of the original plantings around the mansion have been taken out to prevent standing water from eroding the foundation. But inside the home, a full transformation is underway to restore and upgrade the palatial estate as required to hold the preservation easement. It will also keep a historic part of the Country Estates of River Road intact.

The tunnel was excavated using drill and blast methods. Alternative methods, including roadheaders or impact hammers coupled with line drilling of the profile, would also be considered, subject to approval by the engineer. These measures were augmented with shotcrete and invert concrete protection where the tunnel encountered poorer rock mass conditions. Portions of the entrance of the tunnel also received shotcrete and anchor solutions.

WVB East End Partners, for the most part, used robotic equipment to place wet-mix shotcrete to stabilize loose rock during the initial support. As with many of these projects, as different conditions are encountered, combinations of the various

Fig. 9: Southbound view of tunnel after initial robotic placement of shotcrete for support

Fig. 10: Smoothed finish after hand nozzling

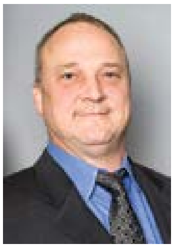
Fig. 11: Steel beam and lagging support in conjunction with lower shotcrete support

Fig. 12: Northbound view of the entire tunnel as seen from the south portal

solutions were employed. One of the issues was smoothing various areas of the extensive tunnel for waterproofing. This was accomplished by hand nozzling the shotcrete in lieu of the robotic unit, as it provided better control of the surface.

The purpose of the Louisville-Southern Indiana Ohio River Bridges Project is to increase cross-river mobility by improving safety, alleviating traffic congestion, and connecting highways. The project will stimulate the economy of the entire Louisville-Southern Indiana region. According to the Federal Highway Administration's Record of Decision, to meet these needs, two crossings are necessary—one in the downtown area and one 8 miles upstream in the metro area's growing East End.

The East End Crossing will provide several very specific benefits to the Louisville and Southern Indiana area, including convenient access for area residents commuting between eastern Jefferson County and southern Indiana. And for travelers passing through the Louisville area from the north or south, the East End Crossing is an alternate (and very accessible) route that bypasses the urban traffic of downtown Louisville. The project also keeps the Drumanard Estate intact and preserves a major piece of history for the region.



Marcus H. von der Hofen*, Vice President of Coastal Gunite Construction, has nearly two decades of experience in the shotcrete industry as both a Project and Area Manager. He is an active member of American Concrete Institute (ACI) Committees 506, Shotcreting, and C660, Shotcrete Nozzleman Certification. He is a charter member of ASA, joining in 1998, and currently serves as Past President to the ASA Executive Committee.*

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The Need for Shotcrete Provisions for State DOTs

By Dennis Bittner

Many State Departments of Transportation (DOTs) have tried shotcrete in the past and had a negative experience. That negative experience has led them to dismiss shotcrete as a viable repair method for highway applications. I've read multiple state shotcrete specifications. Unfortunately, the majority of them are outdated and don't contain language that prevents improper shotcrete techniques or materials. There have been many advances in the shotcrete industry over the past years, and many state specifications simply haven't kept up with those changes. These specifications clearly need to be updated to keep up with the times.

Fig. 1(a) and (b): Two large, round bridge piers being repaired and returned to their original contour using shotcrete

Shotcrete repairs, like all repairs, should be accompanied by a strong state provision. If a company is hired to repair a bridge deck using a rapid-set material, each state has a provision (a method of repair that must be followed). Generally, these provisions tell the contractor exactly how to perform that work. Layout of the repair, demolition, reinforcement guidelines, material requirements, and finishing techniques are included in the provision. Frequently, shotcrete provisions give much less direction to the contractor—sometimes providing no direction as to the placement of the material. Let's discuss common objections and misconceptions about the shotcrete process held by many DOTs. I'll also cover the importance of key items to include in a state provision, and how they can help guarantee a successful project.

One objection to shotcrete is a concern over quality of work. There are several elements to a well-written provision that help ensure the level of proficiency of the applicator. First, ACI Certified Nozzlemen should be required. This certification must be understood. It guarantees the nozzleman meets a basic level of shotcrete proficiency and experience. Beyond the certification requirement, language requiring an experience level possessed by the nozzleman, supervisor, crew, and the contractor commensurate to the project are advisable. Prequalification test panels should be shot and tested. The material and equipment to be used on the job should be used to produce those panels. Also, the panels should be in the same orientation as the work to be performed—vertical and overhead as applicable. All of these points should be included in a provision.

Another common objection to shotcrete is the belief that shotcrete is not structural. Oftentimes, shotcrete is referred to as a mortar. Obviously, there is a misconception about the strength of the material. Shotcrete is not a product; it is a process—a method of placing concrete. The material used in the shotcrete process is by definition and composition concrete. Shotcrete commonly reaches 28-day strengths between 6000 and 10,000 psi (41 and 69 MPa). These strengths are in excess of commonly used concretes on highway structures, which typically don't exceed 4000 psi (28 MPa). Shotcrete is the industry standard in the mining and tunneling industry. It is used to structurally support mine shafts and rail tunnels. In addition, countless highway bridge piers and decks have been repaired successfully with shotcrete, without structural failures (Fig. 1(a) and (b)). It is important that a shotcrete provision discuss materials and performance requirements to ensure the proper mixture designs are used to achieve the desired results.

Dust is a concern on shotcrete jobs. The use of a predampener greatly reduces dust in dry-process shotcrete. When using dry-process shotcrete, a predampener adds 3 to 5% of the total water to the material prior to introduction into the shotcrete machine. This allows hydration to start, improves cohesion, and increases adhesion. The addition of microsilica to shotcrete mixtures has also helped to reduce dust by increasing adhesion. Excessive dust can also be a symptom of insufficient airflow. It is important that proper equipment, specifically air compressor size, type of shotcrete machine, and the use of a predampener in dry process be addressed in a state provision. While dry-process shotcrete is not completely dust-free, generally the demolition portion of a shotcrete project creates more dust than the shotcrete process itself. One type of project where dust is a specific concern is highway tunnels. The main concern is dust getting into the fan house and damaging equipment. The Liberty Tunnels in Pittsburgh, PA, were repaired with shotcrete. Over 1000 yd^3 (914 m^3) of dry-process shotcrete were placed in the tunnels on several different phases of construction. The dry-process material was microsilica-enhanced and a predampener was used during installation. With careful attention to materials and equipment there was absolutely no damage to the fan house or any other parts of the tunnel from dust related to the shotcrete process. In the event that work needs to be performed in an extremely dust-sensitive area, wet-process shotcrete is also an option. Dust concerns can be addressed in a provision by specifying proper equipment and mixture designs (Fig. 2).

Another concern is that shotcrete can't be finished to match the existing adjacent concrete surfaces. Shotcrete has a very low water-cement ratio (*w/c*) and low slump. This means shotcrete is stiffer and slightly more difficult to finish than traditional concrete one may see in a floor pour. However, multiple finishes can be achieved on shotcrete. Depending on the project aesthetics, the fresh shotcrete can be left with the natural gun finish, screeded or cut to the proper thickness, floated with a wood or rubber float, given a broom finish, or even given a smooth steel trowel finish. When shooting preconstruction panels, an inspector can have the contractor show a variety of finishes on the panels and make the appropriate selection from those examples.

There are concerns that shotcrete can't be used to replicate complicated shapes or large, round bridge piers. This is blatantly untrue; in fact, the creation of complex, irregular shapes is a distinct advantage of using shotcrete to creatively and efficiently create these types of sections. There are several ways to restore the original shape of a structure using shotcrete. Finish surfaces can be set using pins, pencil wire, or trim. Jigs can be constructed to match an original shape. Shotcrete is commonly used to create rockscapes in zoos, water parks, or pools. It's also used to build complex, double-curved shapes to very tight tolerances for structures such as skate parks and even Olympic

Fig. 2: Shotcrete being installed in the Liberty Tunnels by ACI Certified Nozzlemen using a predampener and a sufficiently sized air compressor. No damage to the tunnel was done by dust

Fig. 3: Team Pain's Construction Superintendent, James Hedrick, testing the freshly placed "capsule" at the Kortrijk, Belgium, skatepark

Fig. 4: Artificial rock made by shotcrete in the Al Ain Wildlife Park & Resort, UAE. Winner of the 2011 ASA Outstanding International Shotcrete Project

bobsled tracks. These are all structures with difficult shapes and angles that are successfully and efficiently constructed using shotcrete (Fig. 3 and 4).

So why would a state DOT be interested in shotcrete? In short, it is an extremely efficient and cost-effective way to place vertical and overhead concrete. It often provides significant cost savings and generates superior results to traditional cast-in-place concrete. By creating the option to use shotcrete, a state DOT has another tool in their repair toolbox. It all starts with a well-written shotcrete provision. The American Shotcrete Association (ASA) has experienced staff and committee members who can assist in developing a state's provision. ASA also offers in-house education at no cost to state DOTs. If you are involved with a state agency and would like assistance in developing or updating your provisions, or seek to learn more about shotcrete through an in-house educational seminar, please feel free to contact ASA at **www.shotcrete.org**.

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Case Study

The Use of Slag Cement, Alkali-Free Accelerator, and Macro-Synthetic Fibers

in Wet-Mix Shotcrete for Tunnel Applications

By Ezgi Yurdakul, Klaus-Alexander Rieder, Niki Jackson, Mick Pawelski, Arthur Kyriazis, and Lukasz Debny

This paper presents the results of a case study conducted in a wet-mix shotcrete application of a major tunnel construction located in Sydney, Australia. The total concrete production volume of this project is estimated to be 1,300,000 yd^3 (1,000,000 m^3), of which 330,000 yd^3 (250,000 m^3) will be shotcrete. The performance specifications were developed to comply with RMS B82, "Shotcrete Works," that is set by the Roads and Maritime Services. According to these specifications, slump was targeted to be a minimum of 6.25 in. (160 mm). The compressive strength at 28 days for both cored and cylinder samples was required to be a minimum of 6000 psi (40 MPa) and a maximum of 10,000 psi (70 MPa). In addition, a compressive strength of 145 psi (1 MPa) was desired to be reached within 3 to 4 hours after spraying. The material selection was based on the cost and listed performance criteria. Macro-synthetic fibers were preferred, as they provide the desired post-crack energy absorption while eliminating the corrosion potential associated with steel fibers. In addition, the performance of slag cement was evaluated as a replacement material due to the shortage of fly ash in this region.

Materials

Aggregates

The combined particle size distribution of all coarse and fine aggregates used in this case study was within the gradation limits shown in Table 1.

Cementitious Materials

Ordinary portland cement (OPC) and various supplementary cementitious materials were used in accordance with RMS 3211[2] to compare the performance of slag cement as a replacement of fly ash.

Chemical Admixtures

The following admixtures were used:

- TYTRO® WR 172, a polycarboxylate-based high-range water reducer to maintain the target workability;

Table 1: Combined Coarse and Fine Aggregate Particle Size Distribution
(after Table B82.1 in RMS B82[1])

Sieve size	Mass of sample passing, % Specification	Mass of sample passing, % Case study
0.5 in. (13.2 mm)	100	100
3/8 in. (9.5 mm)	90 to 100	95
0.25 in. (6.7 mm)	—	76
No. 4 (4.75 mm)	70 to 85	69
No. 8 (2.36 mm)	50 to 70	56
No. 16 (1.18 mm)	35 to 55	42
No. 30 (600 µm)	20 to 40	31
No. 50 (300 µm)	8 to 20	19
No. 100 (150 µm)	2 to 10	9

- TYTRO® HC 270, a hydration control agent to provide the desired slump retention;
- TYTRO® RC 430 as a pozzolanic-based rheology control agent to reduce rebound and enhance the early-age strength development rate to reduce the re-entry time (this admixture was used in all the mixtures as a silica fume replacement to reduce the cementitious materials content);
- TYTRO® RM 471, a rheology-modifying agent to reduce rebound and increase pumpability; and
- TYTRO® SA 530, an alkali-free shotcrete accelerator.

Fibers

STRUX® BT 50 was the macro-synthetic fiber used to increase crack resistance, ductility, and toughness required for this tunnel application. The performance comparison was made using an alternative 2.1 in. (54 mm) modified olefin macro-synthetic fiber.

Mixture Design

Mixture design was prepared in accordance with the B2 exposure classification limits set by RMS B82,[1] as shown in Table 2.

A total of four mixtures were tested with various mixture proportions and mixture constituents to evaluate the impact of different supplementary cementitious materials, macro-synthetic fibers, and alkali-free accelerator dosage rate on wet-mix shotcrete performance (Table 3).

Results and Discussion

Effect of Slag Cement on Shotcrete Performance

The use of supplementary cementitious materials (SCMs) in shotcrete mixtures as a partial replacement of portland cement has several benefits, including the improved durability as a function of reduced permeability of the hydrated cementitious paste, enhanced workability due to their particle size and morphology, and increased

Table 2: Minimum Cement Content and Maximum Water-Cement Ratio
(after Table B82.4 in RMS B82[1])

Exposure classification	Minimum cement content, lb/yd³ (kg/m³)	Maximum water-cement ratio (by mass)
A	539 (320)	0.45
B1	539 (320)	0.45
B2	624 (370)	0.40
C	708 (420)	0.40
U	In accordance with Annexure B82/A Clause A1	

Table 3: Mixture Proportions

Mixtures	Mix 1	Mix 2	Mix 3	Mix 4
Ordinary portland cement, lb/yd³ (kg/m³)	570 (338)	455 (270)	759 (450)	759 (450)
Fly ash, lb/yd³ (kg/m³)	189 (112)	—	—	—
Slag cement, lb/yd³ (kg/m³)	—	303 (180)	—	—
Total binder content, lb/yd³ (kg/m³)	759 (450)	759 (450)	759 (450)	759 (450)
Water, lb/yd³ (kg/m³)	303 (180)	303 (180)	303 (180)	303 (180)
water-cementitious materials ratio	0.40	0.40	0.40	0.40
Coarse aggregate 1, lb/yd³ (kg/m³)	876 (520)	876 (520)	876 (520)	876 (520)
Coarse aggregate 2, lb/yd³ (kg/m³)	624 (370)	624 (370)	624 (370)	624 (370)
Sand, lb/yd³ (kg/m³)	1214 (720)	1214 (720)	1214 (720)	1214 (720)
Sand-to-total aggregate ratio	0.677	0.677	0.677	0.677
TYTRO® WR 172, oz/yd³ (L/m³)	80 (3.1)	85 (3.3)	88 (3.4)	88 (3.4)
TYTRO® HC 270, oz/yd³ (L/m³)	41 (1.6)	41 (1.6)	41 (1.6)	41 (1.6)
TYTRO® RC 430, oz/yd³ (L/m³)	103 (4)	103 (4)	103 (4)	103 (4)
TYTRO® RM 471, oz/yd³ (L/m³)	103 (4)	103 (4)	103 (4)	103 (4)
TYTRO® SA 530, % of total binder content	4, 7, 10	7, 10	7, 10	7
STRUX® BT 50, lb/yd³ (kg/m³)	12 (7)	12 (7)	12 (7)	—
Alternative 2.1 in. (54 mm) modified olefin macro-synthetic fiber, lb/yd³ (kg/m³)	—	—	—	8 (5)

Fig. 1: Setup for beam end test

Fig. 2: Beams prepared to test early-age strength development

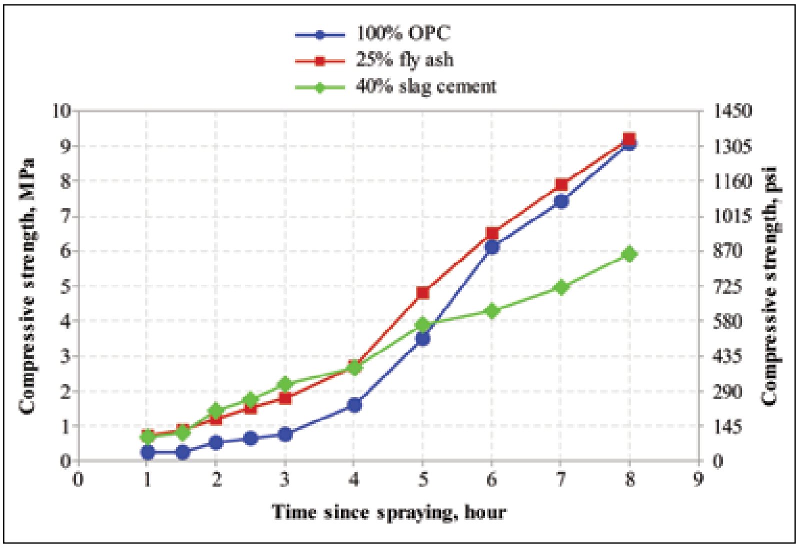

Fig. 3: Impact of cementitious materials on early-age strength development

ultimate strength as a result of their pozzolanic activity.[3] However, the percent of these contributions may vary depending on the SCM type and replacement level.

Slag cement is widely used in conventional concrete due to its advantages on long-term strength and durability. As a waste material of the iron refining industry, the contribution of slag cement as an economical and sustainable material to be used in shotcrete is well known.[4] However, as a result of its lower hydration rate, which decreases the early-age strength development, the application of shotcrete mixtures containing slag cement in tunnel projects is limited.[5] To offset this detrimental impact on early-age performance that differs from other shotcrete applications containing SCMs, mixtures tested in this case study included a pozzolanic-based rheology control agent (TYTRO RC 430), which contributes and accelerates the C-S-H gel formation leading to increased early-age strength development.

The early-age strength development is measured with beam end testing (Fig. 1). The beam end test involves the crushing of sprayed beams, which are 3 x 3 x 16 in. (75 x 75 x 400 mm) in size, by the use of a small hydraulic pump that applies direct compression until failure occurs (Fig. 2). Although the device is similar in design to other compressive testing machines, its small size makes it portable, which provides an advantage in field conditions.[6]

Figure 3 shows the comparison of early-age strength development of three different binder systems containing a plain mixture with 100% OPC (Mix 3), a binary system with 25% fly ash (Mix 1), and a binary system with 40% slag cement (Mix 2), which were tested with the beam end test. All the mixtures met or exceeded the specification requirement to reach 145 psi (1 MPa) within 3 to 4 hours. However, it should be noted that mixtures containing fly ash and slag cement had slightly higher strength than the OPC mixture up to 4 hours followed by a slower strength development for slag cement mixture between 5 and 8 hours. Considering the very early-age strength development is mainly influenced by the accelerator, these results are expected because all three mixtures have the same type and dosage rate of accelerator (TYTRO SA 530 at 10% of total cementitious weight). On the other hand, equivalent strength for fly ash and OPC mixtures, even after 5 hours, is most likely due to the synergetic impact of the SCM and pozzolanic-based rheology control agent (TYTRO RC 430 at 0.89% of total cementitious weight), which balances the early-age strength reduction associated with fly ash with strength improvement of TYTRO® RC 430.

Figure 4 shows the impact of three different binder systems on the compressive strength of cored samples at 1, 7, and 28 days. Similar to the trends shown in Fig. 3, at a very early age, such as 1 day, the mixture with 40% slag cement had lower strength than the OPC mixture and binary system with 25% fly ash. However, due to the improved pozzolanic reactivity at later ages, slag cement outperformed the other two mixtures starting from day 7.

Figure 5 shows the impact of three different binder systems on compressive strength of cast samples at 7 and 28 days. Results correlate well with the cored samples, as similar trends were observed where slag cement exhibited the highest strength. Overall, it can be concluded that, with the aid of pozzolanic-based rheology control agent, both early-age and ultimate strength on beams, cored, and cast samples met the specification as they reached 145 psi (1 MPa) in 3 hours while exhibiting strengths higher than 6000 psi (40 MPa) and lower than 10,000 psi (70 MPa) at 28 days.

Figure 6 shows the impact of OPC mixture, fly ash, and slag cement on workability. Fly ash showed the highest slump and required the lowest dosage of water reducer, which is most likely due to its particle shape and size distribution, whereas slag cement and OPC mixture had similar workability slump and water reducer dosage. This effect with slag cement is likely due to its influence on paste characteristics and absorption. Overall, all three mixtures met the requirement of having a minimum of 6.25 in. (160 mm) slump.

The Effect of Alkali-Free Accelerators on Early- and Later-Age Strength

There is a misconception in the industry that increasing the accelerator dosage reduces the later-age shotcrete strength. While this may seem to be the case for some applications, it should be clarified that such strength reduction is observed most likely when the shotcrete mixture has an inadequate rheology, resulting in poor compaction, which becomes more pronounced at higher accelerator dosage rates due to reduced set times. Therefore, for a shotcrete mixture with desired rheology allowing sufficient consolidation, accelerator amount used within the manufacturer's recommended dosage rate (for example, 4 to 10% of the total cementitious materials content) does not necessarily decrease the later-age strength.

Figure 7 shows the impact of increased dosage rate of TYTRO SA 530 accelerator on early-age strength of a binary binder system containing 25% fly ash (Mix 1). A significant strength improvement was observed, especially when the dosage was

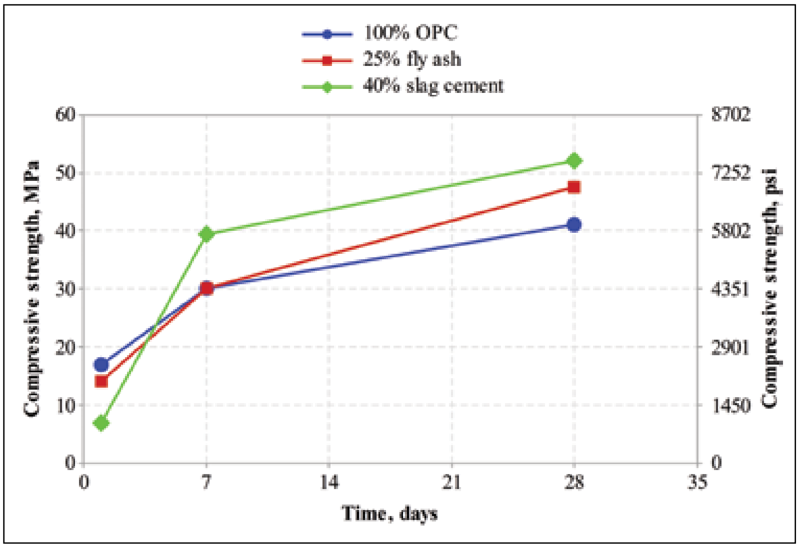

Fig. 4: Impact of cementitious materials on strength development of cored samples

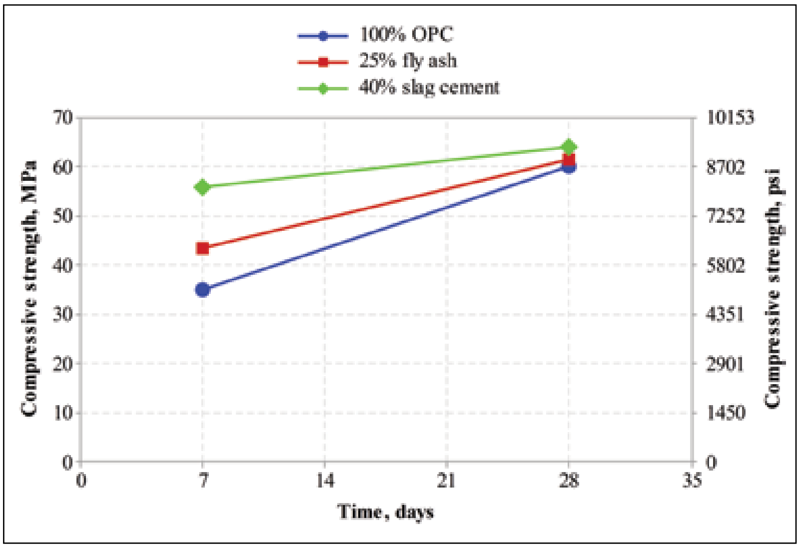

Fig. 5: Impact of cementitious materials on strength development of cast samples

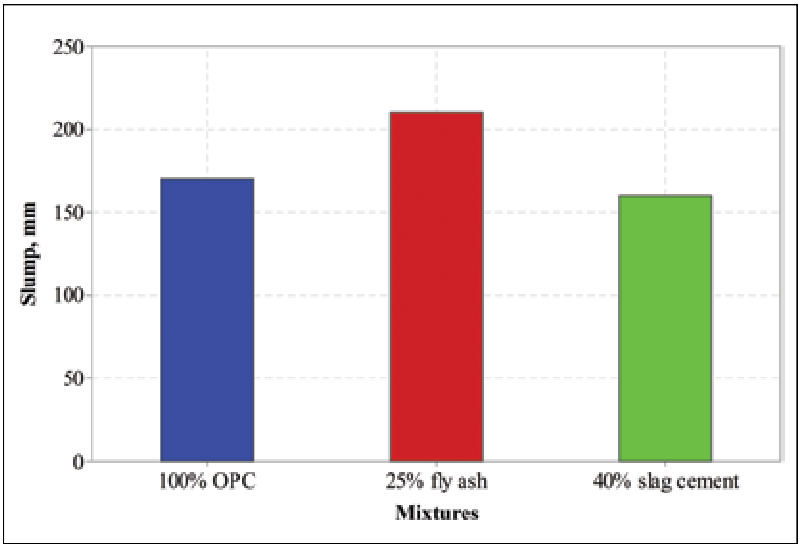

Fig. 6: Impact of cementitious materials on slump (Note: 1 mm = 0.0394 in.)

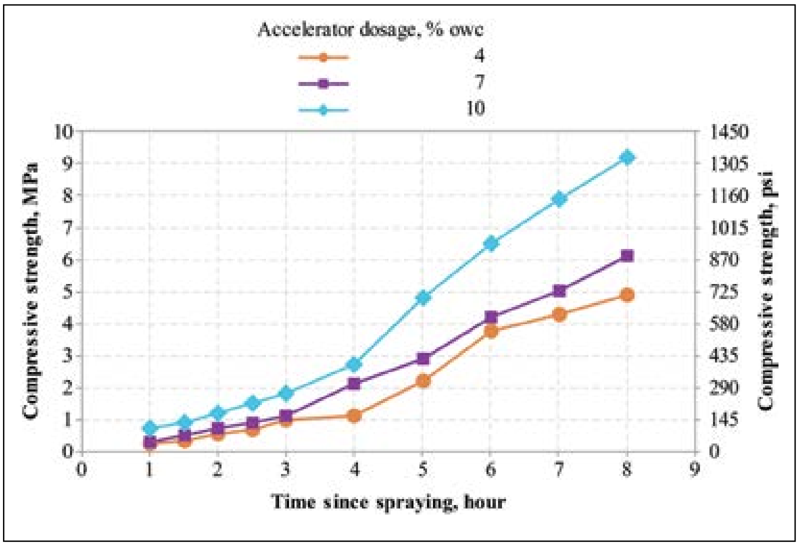

Fig. 7: Impact of TYTRO SA 530 accelerator dosage rate on early-age strength

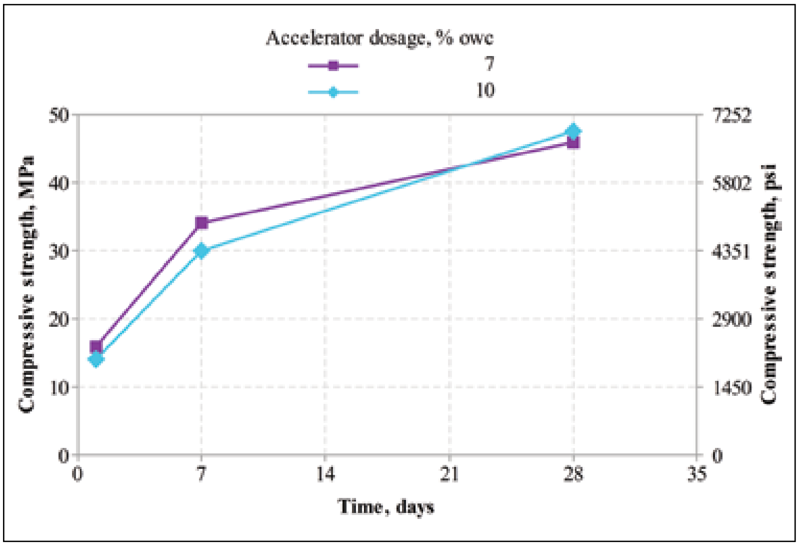

Fig. 8: Impact of TYTRO SA 530 accelerator dosage rate on ultimate strength

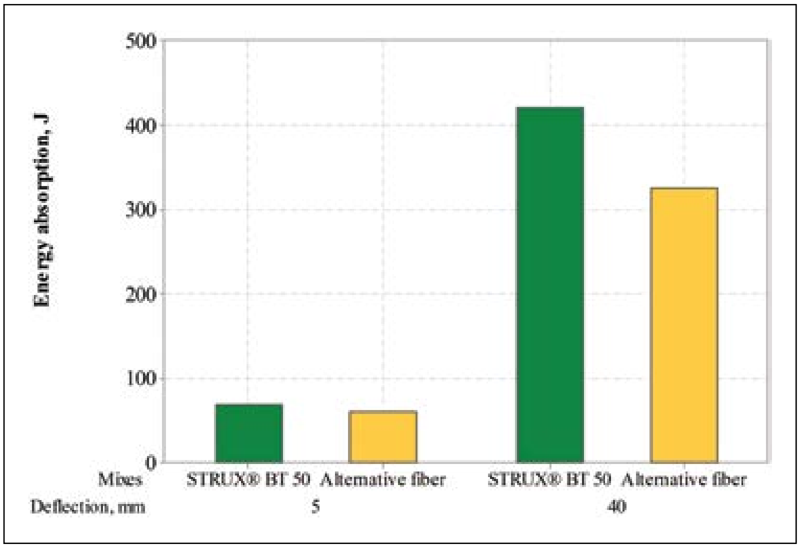

Fig. 9: Effect of STRUX BT 50 and alternative fiber on energy absorption (Note: 1 mm = 0.0394 in.)

increased from 7 to 10%. However, no strength reduction was observed on the mixture containing 10% accelerator at later ages, as shown in Fig. 8.

The Effect of Macro-Synthetic Fibers on Shotcrete Performance

Macro-synthetic fibers are commonly used in underground applications as they improve the following properties[7]:

- Post-crack energy absorption;
- Durability after cracking;
- Strain-softening behavior under deformation;
- Cost competitiveness compared to steel fibers and welded wire reinforcement; and
- Elimination of corrosion potential.

Figure 9 shows the comparison of average energy absorption measured according to ASTM C1550-12a[8] obtained from five panels for mixtures containing STRUX BT 50 and alternative 2.1 in. (54 mm) modified olefin macro-synthetic fibers. According to the round panel test, both fibers performed similar to each other at 0.2 in. (54 mm) deflection. At 1.6 in. (40 mm) panel deflection, STRUX BT 50 met the target energy absorption of 400 Joules, whereas the alternative fiber was around 325 Joules. However, when the results are evaluated considering the energy absorption and weight of fiber content at 1.6 in. (40 mm) deflection, both mixtures perform very similarly because STRUX BT 50 had 60 J/kg while the alternative fiber had 65 J/kg.

Figure 10 shows the comparison of STRUX BT 50 and the alternative fiber regarding workability. Both mixtures had comparable workability, as they had the same water reducer dosage to achieve similar slump despite the higher fiber dosage of the mixture incorporating STRUX BT 50. They both met the requirement of having a minimum of 6.25 in. (160 mm) slump. However, the aligned packaging of the STRUX BT 50 fibers (Fig. 11) helped to further reduce balling and prevented individual fibers from curling and becoming tangled prior to use, thereby enhancing placement.

Conclusions

Based on the obtained test results, the following conclusions are drawn:

- Slag cement can be used as a replacement for fly ash or ordinary portland cement as the impact of slag cement on early-age strength is offset with the presence of a pozzolanic-based rheology control agent;
- For a shotcrete mixture with desired rheology allowing sufficient consolidation, an accelerator amount used within the manufacturer's recommended dosage rate does not necessarily decrease the 28-day strength, as demonstrated in these tests;

- STRUX BT 50 is found to be a more cost-efficient option as compared to the tested alternative 2.1 in. (54 mm) modified olefin macro-synthetic-based fiber, meeting the desired energy absorption requirements; and
- With use of the full TYTRO system, all the specification requirements for this major tunnel project were met.

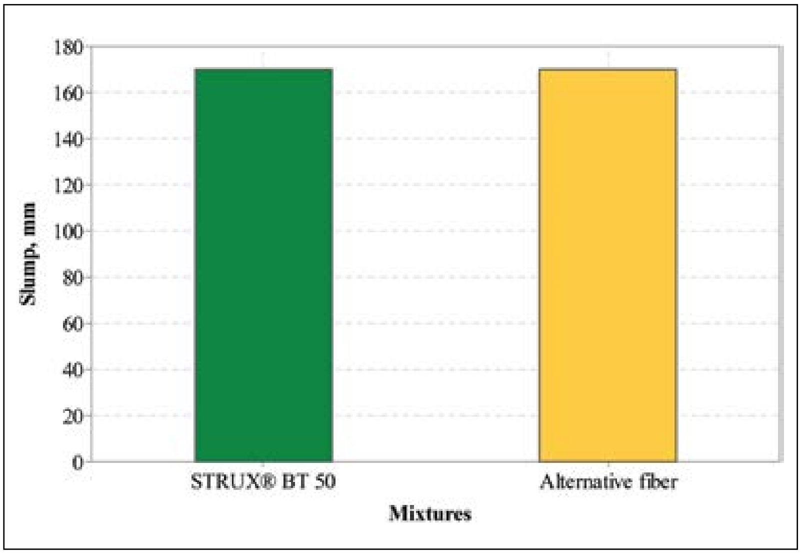

Fig. 10: Impact of macro-synthetic fibers on slump (Note: 1 mm = 0.0394 in.)

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Fig. 11: Aligned packaging of STRUX BT 50 fibers

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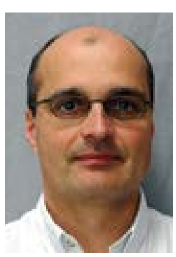

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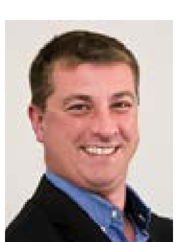

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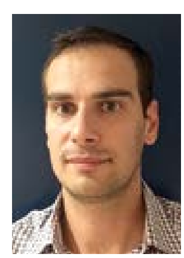

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Colorado School of Mines in Golden, Colorado is nestled in the foothills of the Rocky Mountains, just 30 minutes west of Denver international airport and next door to numerous recreational activities.

Info & Registration

More information and registration can be found at the URL below. Register early to secure your spot and receive the best rate!

csmspace.com/events/shotcrete

Changing a Culture Takes Time

By Mark Croarkin

Changing a culture takes time. Missouri's reputation as a "Show Me" state stands true as MoDOT engineers had to be shown that shotcrete is a viable solution before they opened up their specifications.

On June 1, 2011, MoDOT partnered with Concrete Strategies (a St. Louis contractor) and BASF (material supplier) to host a shotcrete demonstration on the substructure of a bridge in Chesterfield, MO. Contractors, consultants, construction inspectors, bridge engineers, and many more observed a live demonstration of shotcrete. This event kindled positive conversations on shotcrete applications, which ultimately had to overcome decades of concerns derived from observations and opinions formed during an era filled with poor quality control, little to no specifications, and no nozzleman requirements.

In November of 2011, Dan Millette with Euclid held a shotcrete class for MoDOT in Chesterfield. As a representative of the American Shotcrete Association (ASA), and a former ACI nozzleman examiner, Millette was an excellent source of information to help educate our group on the history of shotcrete, types of equipment, mixture information, safety practices, and much more. ASA has been extremely helpful and more than willing to hold education sessions like this for interested parties. I would strongly recommend that agencies interested in shotcrete take advantage of the expertise within ASA. After a demonstration, some education, and a few field trials here and there, the only thing left was to wait. It takes time to evaluate products, so time is what MoDOT needed to evaluate before allowing shotcrete placement on a more regular basis.

Shotcrete repairs are now fairly commonly allowed by Job Specific Provisions (JSP) in Missouri and many construction inspectors have become familiar with its use. While MoDOT relies heavily on ACI 506.2, "Specification for Shotcrete," each job may have additional considerations. Some portions of the job specifications tend to be enforced more strictly than others. The

Fig. 1: June 2011 Chesterfield, MO, demonstration

American Concrete Institute (ACI) or EFNARC (the European Federation of National Associations Representing producers and applicators of specialist building products for Concrete) nozzleman certification is a must. MoDOT recognizes that the experience in the art of placing shotcrete is critical to its success. While there is currently only a certified nozzleman requirement, the experience of the entire placement team contributes to the quality of the repair. If a large project was to allow the use of shotcrete, experience requirements for the contractor with similar projects would likely be required. An area not as strictly enforced has been moisture requirements of dry material, which typically require the use of a predampener or a hydro-mix nozzle. To keep costs down on small applications, MoDOT has focused more on cracking issues and has left the application up to the nozzleman. We have had good performance with a few pre-bagged products that are prequalified for use on small quantity projects without requiring additional testing, although we always reserve the right to test.

While wet-mix placement methods have been used, dry-mix shotcrete or the old tradename "gunite" is typically the method of choice due to the small quantities being placed at a time. During the learning process, some MoDOT trials were in less than ideal environments, and shrinkage cracks appeared. While shrinkage cracks are not typically a long-term issue in a material that is so dense, they definitely catch the attention of bridge inspectors. Most trials that resulted in shrinkage cracks were sealed with 100% acrylic overcoats such as BASF's Thorocoat to seal the cracks. Temperature, wind, time to finish, and curing methods are topics that are typically discussed now to avoid shrinkage issues.

The majority of shotcrete use in Missouri has been fairly small areas of substructure, deck, and superstructure repairs in locations exposed to high chlorides. The repair restores the area to protect other elements from the harmful chlorides used to melt snow. Shotcrete has the ability to produce a high-quality repair with minimal access to the location being repaired, which typically results in cost reductions. The specific characteristics that are so appealing to MoDOT engineers are cost savings, the low chloride permeability, and the high bond strength. Prepackaged products such as BASF Shotpatch 21-F, Euclid Chemical Eucoshot F, King Shotcrete MS-D1, and CTS Cement Low-P have been successful enough such that they are typically preapproved for small quantity use in Missouri. Numerous very-low, 28-day chloride permeability (around 300 coulombs) and pulloff strengths consistently exceeding hand patch or "form and pour" comparisons have made this decision easy.

While MoDOT has not had a large iconic project that makes headlines in trade magazines, they have made great strides in their knowledge and use of shotcrete over the last 5 years.

Fig. 2: Shotcrete repair under a bridge

Fig. 3: Proper curing is a critical part of shotcrete placement

***Mark Croarkin** graduated from the Missouri University of Science and Technology in 1997 and has been a licensed professional engineer since 2002. With the exception of 1 year of experience in private industry, Croarkin's career has been dedicated to MoDOT. His foundation started with Construction Inspection, but his experience includes working in six of MoDOT's seven geographically diverse districts in materials, construction, design build, bridge maintenance, and maintenance positions. Recently, Croarkin has been promoted to lead all of MoDOT's maintenance efforts as the St. Louis District Maintenance Engineer. From 2009-2016, Croarkin was responsible for the safety of all structures in the St. Louis region, as well as directing repair crews and prioritize contract repairs. His passion for finding better ways to maintain bridges earned him a reputation as a leader in innovation for the State of Missouri. This article describes his accounts of the road MoDOT took to allow shotcrete into the specifications.*

An Approach for Improving the Sustainability of Shotcrete

By Ezgi Yurdakul, Klaus-Alexander Rieder, and Diego Granell Nebot

According to the World Commission on Environment and Development,[1] sustainability is defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." Based on this definition, it is clear that the construction industry is showing weakness on sustainability because cement production is one of the most energy intensive of all manufacturing industries[2] and it contributes 5% of total global carbon dioxide (CO_2) emissions,[3] as shown in Fig. 1. These numbers are more drastic in the United States as a result of being the third largest cement producer in the world.[4]

With the increased rate of industrialization and urban development globally, construction business is significantly growing, which further increases the demand on cement production followed by higher energy consumption and CO_2 emissions. In the last decades, the cement industry has already significantly reduced the amount of CO_2 per ton of cement produced by reducing the amount of clinker while maintaining 28-day strength. Considering shotcrete applications, where a typically high amount of cementitious materials are used and often 20 to 30% of batched concrete is lost during the spraying process as a result of rebound, there is certainly a need to improve the sustainability of shotcrete. Therefore, the aim of this paper is to propose a few methods for greener shotcrete with the aid of the latest advancements in chemical admixture technology.

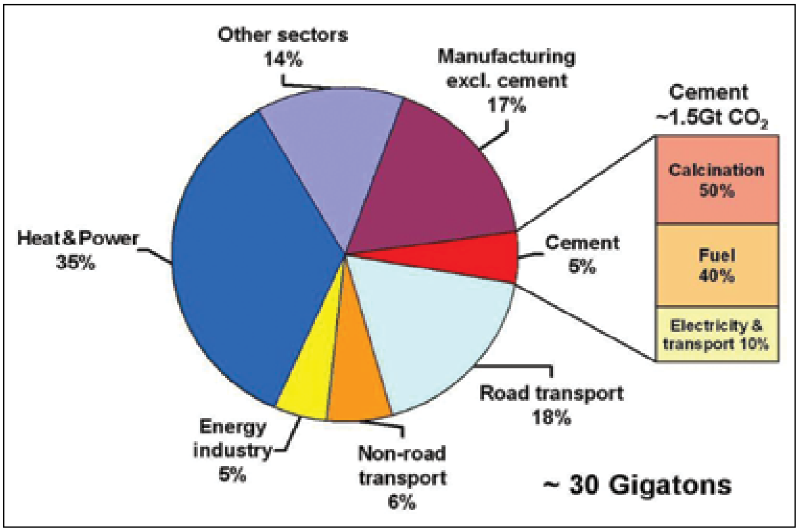

Fig. 1: Global CO_2 production[5,6]

Proposal 1—Reduction of Cementitious Materials Content

The production of each ton of portland cement clinker emits approximately 1 ton (900 kg) of carbon dioxide. Therefore, in an era of global warming and climate change, either a reduction in the production or a more efficient use of carbon-intensive materials is desirable to meet the future needs of society. Although the production of structures that are highly sustainable is still challenging to accomplish, the industry has shown progress by motivating alternative solutions such as using recycled aggregates, binary and ternary mixtures with high levels of supplementary cementitious materials, and alternative binders with different chemistries with lower carbon footprints than portland cement.[7-10] Among all these available options, a simple approach for improving sustainability of shotcrete would be to use cementitious materials more efficiently without sacrificing the shotcrete performance. Furthermore, considering that cementitious materials such as ordinary portland cement and silica fume are the most expensive mixture components in shotcrete, minimizing the cementitious content will not only lead to a more sustainable method of shotcreting but also reduce the project cost.

Researchers[11] have studied the minimum paste content requirement for optimum pumpability in shotcrete, and found out that a minimum of 34.2% of real paste content is needed to achieve the desired pumpability (10.2% of paste is required to form a lubricating layer and 24% is required to fill the voids between aggregates). However, once the paste content of a mixture reaches an optimum value (which should be determined based on the desired pumpability, sprayability, durability, and strength requirements), the use of more cementitious material does not further increase the performance.[12,13] In fact, in some cases, excessive amounts of cementitious materials may adversely affect durability and shrinkage due to the increased risk of cracking.

Outcome 1—Improved Shotcrete Performance

With the advancements in chemical admixture technology, it is now possible to replace a portion of cementitious materials with a pozzolanic-based rheology control agent (TYTRO® RC 430) to reduce the total cementitious materials content without compromising the performance. A recent study was conducted on a few shotcrete mixtures under laboratory conditions to assess the performance of mixtures containing 6 lb/yd³ (3.6 kg/m³) of TYTRO RC 430 to replace 56 lb/yd³ (33 kg/m³) of ordinary Type I portland cement in mixtures incorporating various supplementary cementitious materials, as shown in Table 1.

Early- and later-age strength results indicate that regardless of the binder type presence in a given mixture, the addition of 0.8% TYTRO RC 430 by weight of binder content was able to reduce the cementitious materials content by 7% and still achieve equivalent cylinder compressive strength at 28 days (Fig. 2). Furthermore, mixtures containing the reduced paste content supplemented with a small addition of TYTRO RC 430 pozzolanic-based rheology control agent provided higher strength at very early ages of 6 and 8 hours, which

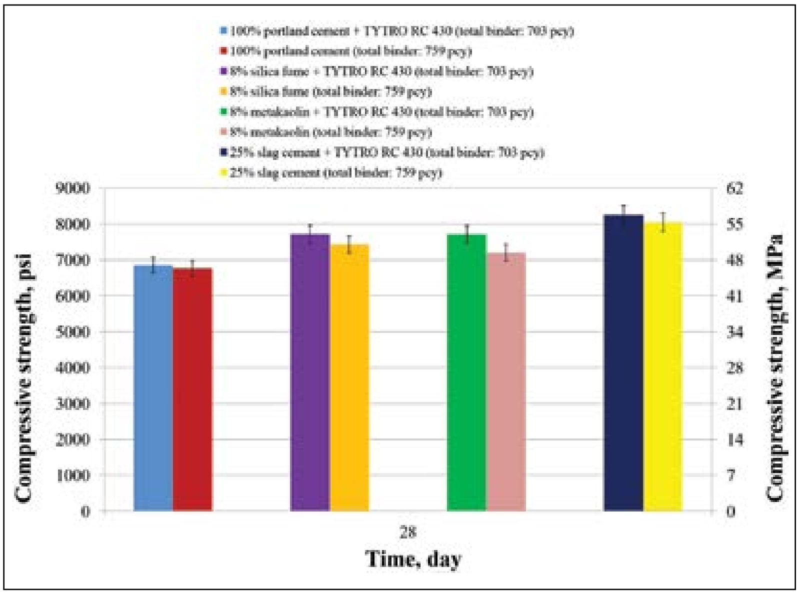

Fig. 2: Comparison of 28-day cylinder compressive strength

Table 1: Mixture Design

Mixture components	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8
ASTM C150 Type I ordinary portland cement, lb/yd³ (kg/m³)	642 (381)	698 (414)	642 (381)	698 (414)	513 (304)	569 (337)	703 (417)	759 (450)
Silica fume, lb/yd³ (kg/m³)	61 (36)	61 (36)	0	0	0	0	0	0
Metakaolin, lb/yd³ (kg/m³)	0	0	61 (36)	61 (36)	0	0	0	0
Slag cement, lb/yd³ (kg/m³)	0	0	0	0	190 (113)	190 (113)	0	0
Total binder content, lb/yd³ (kg/m³)	703 (417)	759 (450)	703 (417)	759 (450)	703 (417)	759 (450)	703 (417)	759 (450)
Water-cementitious materials content	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Sand-to-total aggregate, %	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4
High-range water-reducing admixture: TYTRO® WR 157, % of total binder	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Set-accelerator: TYTRO® SA 530, % of total binder	5	5	5	5	5	5	5	5
Pozzolanic-based rheology control agent: TYTRO® RC 430, % of total binder	0.8	0	0.8	0	0.8	0	0.8	0

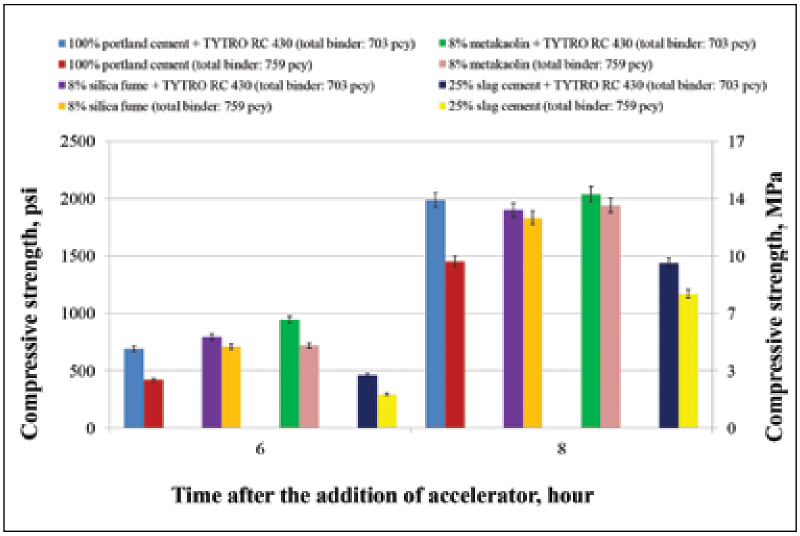

Fig. 3: Comparison of compressive strength at early ages

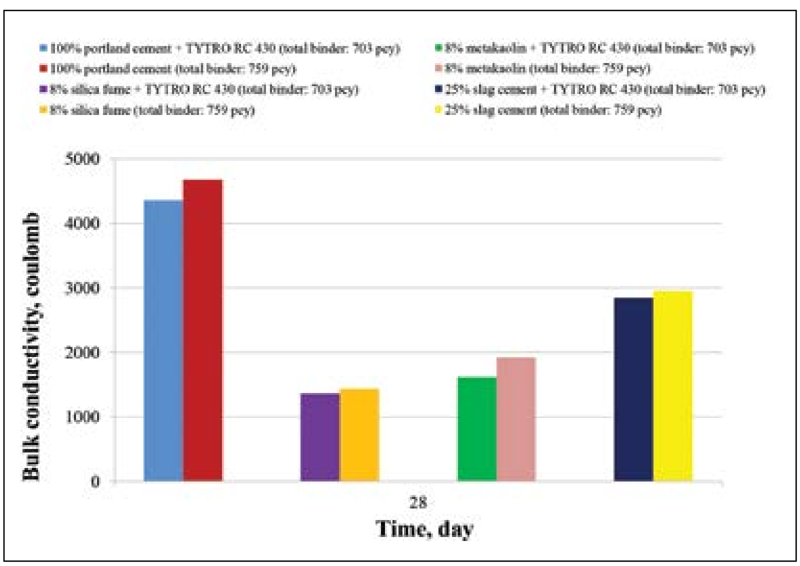

Fig. 4: Comparison of bulk conductivity at 28 days

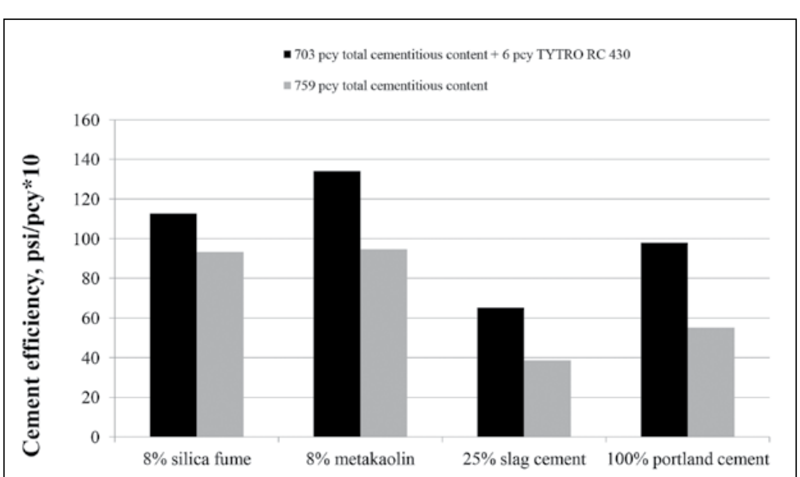

Fig. 5: Cement efficiency

is an additional benefit, as it would allow shorter cycle time for shotcrete applications (Fig. 3).

Longevity is an important parameter for sustainability, as it determines the service life of structures; therefore, durability aspects of the shotcrete mixtures were also evaluated. As shown in Fig. 4, mixtures with lower paste content (reduced by 56 lb/yd^3 [33 kg/m^3] of cementitious materials content that was supplemented with the addition of 6 lb/yd^3 [3.6 kg/m^3] of TYTRO RC 430) had slightly higher (or equal at minimum) durability compared to the mixtures having higher paste content. The improved durability of the mixtures with lower paste content is likely due to the impact of TYTRO RC 430 pozzolanic-based rheology control agent on improving the interfacial transition zone (ITZ) and reduced porosity. Furthermore, the impact of using supplementary cementitious materials such as metakaolin, slag cement, and fly ash is also significant on the reduction of the conductivity, which is consistent with what has been reported in the literature.

Outcome 2—Increased Cement Efficiency

Based on the obtained test results, cement efficiency was calculated by dividing the strength at 6 hours per unit mass of total cementitious material content in a mixture. Figure 5 supports the findings discussed previously (that the addition of 6 lb/yd^3 [3.6 kg/m^3] of TYTRO RC 430 provided 32% more efficiency for the portland cement available in these mixtures than adding 56 lb/yd^3 [33 kg/m^3] of ordinary portland cement to achieve equivalent strength at 6 hours). The most benefit was observed in the mixtures containing 8% metakaolin and 100% portland cement, as the cement efficiency was improved as much as 43% for similar strength performance.

Outcome 3—Reduced Carbon Dioxide Emissions

Because the production of each ton of portland cement clinker emits approximately 1 ton (900 kg) of carbon dioxide, reducing 56 lb/yd^3 (33 kg/m^3) of ordinary portland cement would result in a reduction of 0.033 metric ton CO_2. If this approach is applied on a middle-size project with a shotcrete production volume of 6500 yd^3 (5000 m^3), the carbon dioxide emissions of the project would be reduced by 182 tons (165 metric tons) CO_2 as a result of reducing the cement content by 7% with the addition of 0.8% of TYTRO RC 430 by total cementitious materials content.

Table 2: Cost Comparison

Mixture component	Reference mixture		Proposed mixture	
	Dosage, lb/yd^3 (kg/m^3)	Cost, $\%\$/yd^3$ ($\%\$/m^3$)	Dosage, lb/yd^3 (kg/m^3)	Cost, $\%\$/yd^3$ ($\%\$/m^3$)
Portland cement	703 (417)	45 (45)	703 (417)	45 (45)
Silica fume	56 (33)	22 (22)	0	—
Aggregates	2865 (1700)	33 (33)	2983 (1770)	34 (34)
TYTRO® RC 430	0	—	6 (3.6)	10 (10)
Total	—	100 (100)	—	89 (89)

Outcome 4—Cost Savings

Considering that an equivalent performance is obtained with the reduced binder content, the proposed approach would not only be a sustainable but also a cost-efficient solution. A simple cost analysis was done to compare a mixture containing 56 lb/yd^3 (33 kg/m^3) of silica fume that was replaced with the addition of 6 lb/yd^3 (3.6 kg/m^3) of TYTRO RC 430. Table 2 shows the cost comparison between the reference mixture containing silica fume and the mixture with the reduced binder content. Because the cost of the materials varies based on the geographical regions, a relative comparison was done based on the percentage of US$ cost per a given material to produce 1 yd^3 (0.8 m^3) of shotcrete. Based on the comparison, at least 10% less expensive shotcrete production is expected in the mixture with reduced cementitious materials content accompanied with TYTRO RC 430.

Proposal 2—Reduction of Rebound

Shotcrete has material loss due to rebound of aggregates because the concrete is pneumatically applied.[14] Although a certain percentage of rebound is inevitable and even necessary because a higher paste content is needed to create a sticky surface for subsequent shotcrete material to become compacted into the surface, it is desirable to keep the rebound to a minimum.[15] The rebound loss is affected by many factors, such as the position of the application, angle of the nozzle, skill and expertise of the nozzleman, air flow, impact velocity, thickness of layer, amount of reinforcement, and mixture design (for example, cementitious materials content, water content, size and gradation of aggregates, and type and dosage of admixtures). In many field applications, it is common to have a rebound rate of 20 to 30%. While high rebound rates are considered to be a waste of material, time, labor, material and removal cost, and a burden on environment, it should be noted that they also adversely affect shotcrete performance by increasing the tendency toward shrinkage cracking because the paste content of the in-place shotcrete is higher due to rebound, resulting in loss of aggregates.[16]

Outcome 1—Rebound Reduction

To reduce rebound, a “sticky” and cohesive shotcrete is desirable, as it will exhibit a lower tendency to bounce off the wall on impact, thus providing a mixture with a better coating of the reinforcing bar surface and fewer voids than shotcrete displaying poorer cohesive characteristics. Considering a high volume of rebound material consists of mainly aggregate particles, paste stickiness and aggregate gradation play a more important role on rebound reduction than the amount of cementitious materials content as long as a sufficient amount of paste is used that would fill the voids between the aggregate. In other words, the “quality of paste” is more important than the “quantity of paste” for evaluating rebound characteristics.

According to the previous experiments conducted in the field, plain portland cement mixtures with a high cement content of 760 lb/yd^3 (450 kg/m^3) exhibited a rebound rate of 20% on average. However, when the cement content was reduced by the addition of TYTRO RC 430, the rebound rate was decreased from 20 to 5% due to the increased cohesiveness promoted by the pozzolanic-based rheology control agent.

Outcome 2—Reduction of Carbon Dioxide Emissions

Carbon dioxide emission factors of various mixture components and construction activities are listed in Table 3.

Table 3: CO_2 Emission Factor[17]

Activity	Emission factor	Unit
Portland cement	0.8200	t CO_2/1000 kg
Coarse aggregates	0.0357	t CO_2/1000 kg
Fine aggregates	0.0139	t CO_2/1000 kg
Concrete batching	0.0033	t CO_2-e/m^3
Concrete transport	0.0094	t CO_2-e/m^3
On-site placement activities	0.0090	t CO_2-e/m^3

Table 4: Estimated CO_2 of Shotcrete Production

Activity	Dosage, lb/yd^3 (kg/m^3)	CO_2 emission, t/m^3
Portland cement	759 (450)	0.3690
Coarse aggregates	905 (537)	0.0192
Fine aggregates	1960 (1161)	0.0161
Concrete batching	—	0.0033
Concrete transport	—	0.0094
On-site placement activities	—	0.0090
Total	—	0.4260

When the listed factors are applied to calculate the carbon footprint of shotcrete production, for a mixture containing 759 lb/yd^3 (450 kg/m^3) of portland cement, a total of 0.47 tons (0.43 metric tons) CO_2 emission is expected to batch, transport, and place 1.3 yd^3 (1 m^3) of concrete, as shown in Table 4. Therefore, for a project with a shotcrete production volume of 6500 yd^3 (5000 m^3), reducing rebound by 15% (from 20 to 5%) would result in reducing CO_2 emissions by 350 tons (320 metric tons).

Outcome 3—Cost Savings

The reduction of rebound by 15% would result in providing more than 15% cost savings, as it would not only prevent 15% of the ordered concrete from being waste material but also save from efficiency of the operation and reduced labor time. Considering many shotcrete applications are composed of fibers, high-range water-reducing admixtures, and set accelerators, 15% cost savings due to rebound reduction would be significant.

Conclusions and Recommendations

Based on the obtained test results, the following conclusions can be drawn:

- Performance—When the cementitious materials content was reduced by 7% with the aid of a pozzolanic-based rheology control agent, an equivalent 28-day strength was achieved compared to the mixture containing higher cementitious materials content. Furthermore, mixtures with lower paste content supplemented with the addition of TYTRO RC 430 had slightly higher durability and 15% lower rebound compared to the mixtures having a higher paste content. The cement efficiency was improved as much as 43% for early strength performance.
- Carbon dioxide emission—When cement content was reduced by 56 lb/yd^3 (33 kg/m^3), a reduction of 0.034 tons (0.031 metric tons) CO_2 is expected; and when the rebound rate is reduced by 15%, a further reduction of 0.071 tons (0.064 metric tons) CO_2 is expected for 1.3 yd^3 (1 m^3) of shotcrete production.
- Cost savings—When 7% silica fume is replaced with the addition of 0.8% of TYTRO RC 430 by total cementitious materials content, at least 10% less expensive shotcrete is produced. Furthermore, more than 15% cost savings would be obtained with the reduction of rebound.

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Preparing for Vancouver's Growing Neighborhoods—The New Mount Pleasant Hydroelectric Substation

By Brian MacNeil

Within the ever-evolving construction industry, better products and building practices are making it easier than ever to tackle some projects once deemed impossible. Unprecedented techniques and situations are approached with valuable new research, testing, and insight, creating more durable and sustainable cutting-edge infrastructure. The increased reliability in overall project performance that these new techniques support allows developers to feel more confident in going forward with investments previously deemed too risky.

At an estimated cost of $201 million, mitigating risk was something that BC Hydro was actively conscientious of for their Vancouver City Central Transmission (VCCT) project. Part of the project included a new sub-station in the Mount Pleasant area of Vancouver, enhancing the reliability of power to the rapidly growing area. As environmental sustainability is a strong focus to new infrastructure in Vancouver, as well as for BC Hydro, the Mount Pleasant sub-station has been designed to meet strict LEED (Leadership in Energy and Environmental Design) standards.

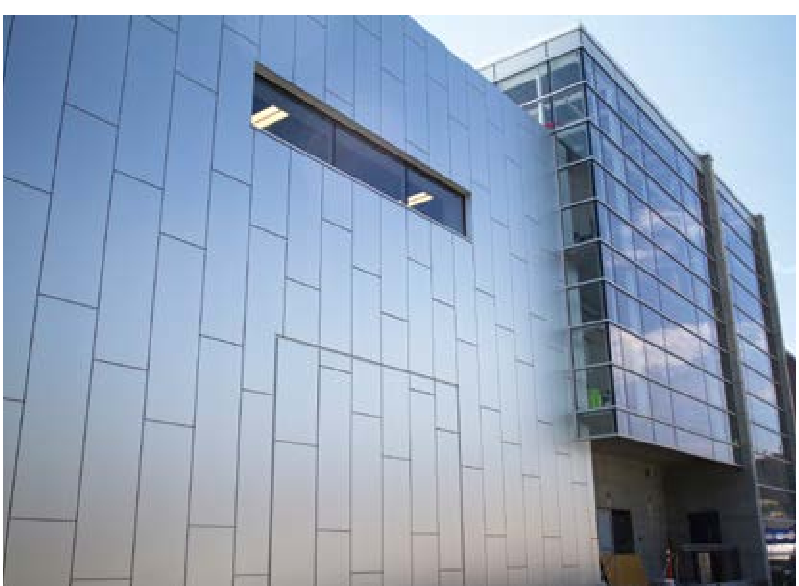

Fig. 1: The Mount Pleasant facility meets post-disaster construction requirements and is designed to achieve a LEED® Silver rating Photo courtesy BC Hydro

Not only was sustainability taken into account, but durability as well. Vancouver sits near a fault line and sits in a risk zone for a potential coastal earthquake. In an attempt to mitigate damage should such an event occur, the sub-station was designed to meet 100-year seismic standards with heavily reinforced 24 in. (600 mm) thick concrete walls.

The site itself offered particularly unique challenges to the construction. The building sits at the bottom of a slope, with the water flow rate entering the area from as much as 500 to 1500 gal. (1900 to 5700 L) of water per day. To keep the structure from floating, the engineers designed it to sit on a 3.28 ft (1 m) thick raft slab.

To assist with handling the ground water flowing below the slab, an extensive system of perforated drainage pipes was installed beneath the slab and around the perimeter of the building, called a drain mat system. The system was connected to a sump which had a three-unit pump station connecting to the city's storm sewer system.

The project's most critical construction factor was the strict requirement for the high-voltage machinery within the below-grade areas to be kept completely dry. The station cannot be shut down to repair leaks, so the waterproofing solution had to be permanent as there would be zero tolerance for leaks and moisture.

There were many factors to consider when selecting a concrete waterproofing solution that the project team could be confident in. One concern was the fact that one of the walls could not be placed using two-sided forming, therefore three walls would be built using cast-in-place (with two-sided forming), and the fourth wall with structural shotcrete by Torrent Shotcrete Structures.

Fig. 2: Preparing to shotcrete the wall. The heavily congested reinforcing bar required for seismic reinforcement made application challenging. Photo courtesy Kryton International Inc.

As the walls were to incorporate the drain mat system around their outer perimeter, close attention to joint details and placing of the four walls would be critical. The system needed to be completely sealed, which was especially challenging where the shotcrete wall met the cast-in-place walls (refer to Fig. 2).

The wall placed by shotcreting involved a number of challenges. To begin with, the wall was much larger than normal at 120 x 30 ft (36 x 9 m), needing four stories of scaffolding for the shotcrete placement. Additionally, as the structure was reinforced to seismic standards (leaving it essentially bomb-proof), the heavily congested reinforcing bar made for more difficult placement to ensure complete compaction without voids.

Commonly used sheet membranes are often problematic where cast-in-place meets shotcrete. As a sheet membrane had originally been specified for the project, the team began to search for a more compatible waterproofing solution that would provide assurance that the building would remain watertight.

After much research and consultation, the construction team selected Kryton's Krystol Internal Membrane (KIM) concrete waterproofing admixture to waterproof the below-grade areas, and the Krystol Waterstop System to fully seal the joints against water penetration. These areas would include the 3.28 ft (1 m) thick raft slab and all below-grade walls. The Kryton Waterproofing System was used to supplement an externally applied sheet membrane, as the sheet membrane could not be trusted as the only waterproofing solution for this high-risk project.

Comprehensive training on the application of the Waterstop System was provided by Kryton's Technical Team, and multiple site support visits were made. Because construction was completed in early 2014, the substation has been working as a key part of an ambitious portfolio of hydroelectric and transmission projects completed by BC Hydro to meet the projected growing energy needs of the province.

Brian MacNeil *is the North American Regional Manager for Kryton International Inc. He has worked more than 25 years in the construction industry, with the last 15 focused on mitigating the risk associated with concrete waterproofing and protection. He has worked on both cast-in-place and shotcrete waterproofing projects across Canada and the United States, from tunnels and wine caves to large foundations and water containment projects. Sea walls and marine applications are no problem.*

Reinforcing Bar Shadowing and What You Can Do

By Joey Bell

Nearly all shotcrete projects I come across in my travels consist of some form of steel reinforcement, such as reinforcing bars or welded wire reinforcement. It is sometimes overlooked how important reinforcement encapsulation can be on the job. Be it aesthetic, structural, or even safety reasons, preventing voids behind steel reinforcement is important on every job. If reinforcement is not properly encased, there are many negative effects on the structure and the potential for corrosion is increased.

When shotcrete is sprayed against reinforcing bar, a "shadow" area occurs behind the steel because the bar blocks the shotcrete material stream. The size of the shadow increases with an increase in the diameter of the bar. The shotcrete in the shadow area behind the bar is not compacted because the stream of material does not directly impact the shadow area. This shadow area is filled when using good shotcrete shooting technique to provide full encapsulation of the bar. This requires the nozzleman to keep sufficient velocity of the material stream to wrap fresh paste around the bar and fill the shadow areas. With poor velocity (too far away from the bar or too low an air flow), too dry or stiff a material, or inattention to proper shooting techniques, voids can develop.

Fig. 1: Improperly compacted concrete behind steel

Nozzle Angle and Slump

If a mixture is too stiff (wet-mix), too dry (dry-mix), or does not have sufficient impact velocity, the material will build up on the face of the reinforcing bar, creating a larger obstacle for the shotcrete spray to wrap around, thus forming a void behind the reinforcing bar. The stiff mixture, to some degree, can be overcome by using a high-impact velocity to cause the material to flow around the bar. Reducing the distance to the receiving surface will increase the velocity. In most applications, a distance of 2 to 4 ft (0.6 to 1.2 m) is advisable for adequate velocity. Also, adding more air at the gun (dry-mix) or nozzle (wet-mix) can increase impact velocity. Wet-mix shotcrete should have a slump of at least 2 to 3 in. (50 to 75 mm) to properly encase reinforcing bar.

The key to good encasement is a good paste content with proper plasticity.

When encasing bars that are larger than No. 6 (No. 19M), a higher slump is required. It requires less impact velocity to force flow of material around to the backside of a bar if a higher plasticity mixture with a 3 to 4 in. (75 to 100 mm) slump is used. On larger bars, the shadow can be reduced or eliminated by directing the shotcrete spray at a slight angle from both sides to force the material behind the bar.

Sometimes, the volume and nozzle stream should be directed to permit the material to hit more directly behind the reinforcement to reduce the size of the shadow area. It may be necessary to reduce the air volume so the nozzle can be held closer to the receiving surface.

The nozzleman can tell whether there is sufficient impact velocity and plasticity when the face of the reinforcing steel will glisten and remain clean. Reinforcing bar deformations will be visible and a ridge, rather than a valley, of material will develop behind the bar.

Mineral Additives

The use of thixotropic mineral additives in recent years has allowed suppliers and applicators to have slumps of 6 to 7 in. (150 to 175 mm) without sacrificing stability. When added to the fluid 7 in. (175 mm) slump, the additive stabilizes the mixture while at rest. But when energy is applied, the mixture becomes fluid again. The result is a 5 in. (125 mm) slump that acts like the 7 in. (175 mm) slump under shear or stress.

The additive is very effective at preventing shadowing because the nozzleman can have a very fluid mixture that will flow nicely behind the reinforcement yet remain stable enough to not sag or slough. The additive's thixotropic properties also add other benefits, such as reduced rebound, increased cohesion, and improved finishability.

There are many ways to prevent shadowing from occurring and causing headaches on the jobsite. Nozzle placement and a small dosage of a mineral additive are just a couple of easy ways to eliminate these problems and provide the industry with high-quality structural shotcrete that customers will continue to ask for.


Fig. 2: Nozzleman shooting at a proper angle

***Joey Bell**, Business Development Manager, Active Minerals International, grew up on a farm in Tennessee and received his BS in Concrete Industry Management from Middle Tennessee State University, Murfreesboro, TN. Bell travels the world developing new customers through technical support, product demonstrations, and field sales support for the Acti-Gel® 208 concrete additive. Along with shotcrete, his role at Active Minerals has furthered his knowledge in other applications, such as lightweight concrete, precast, slipform paving, RCC, and concrete block. Bell is Active Minerals' corporate member representative for ASA and also a member of the Pool and Recreational Shotcrete Committee.*

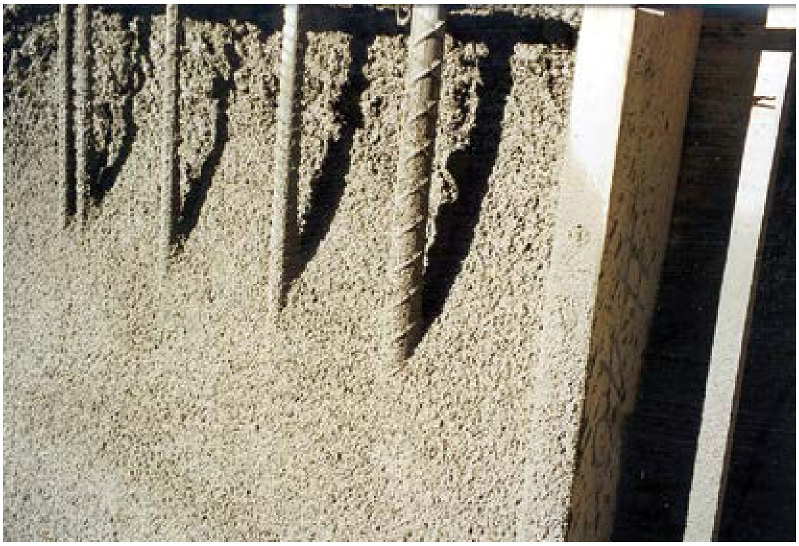
Fig. 3: Proper impact velocity and reinforcing bar encasement

Based on the article, "Shotcrete Reborn," originally published in WaterShapes*, a pool industry magazine (www.WaterShapes.com). Reprinted with permission.*

Shotcrete Reborn

(Part II of a III Part Series)

When its originators surrendered control of the shotcrete process in the 1950s, the approach fell on hard times. As the authors discuss here, however, it has since recovered and has resumed its rightful place among the world's key construction technologies

By Lily Samuels and Bill Drakeley

The years after the Second World War were times of opportunity and awkwardness in the shotcrete business.

From 1920 until the early 1950s, the Cement Gun Co. owned the trademark to "gunite" and established an aggressive licensing/franchising system to maintain as much control as it could over the process and profit from it to the greatest possible degree. By 1952, however, the Cement Gun Co. decided to release the trademark.

This enabled the American Concrete Institute (ACI) to dig in and study the process, which by that point had become extremely popular as a construction technology. From that point, the name of the process began to shift to "shotcrete," a nominal change that was most significant because it was a step away from the old "gunite" trademark.

Fig. 1: ACI Certified Nozzleman applying wet-mix shotcrete

In the first installment of this three-part series (*Shotcrete* magazine, Summer 2015, pp. 22-24), we described the genesis of the shotcrete process, starting with Carl Akeley's ingenious invention of a pressurized, double-chamber "gun," and moving on to Samuel Traylor's acquisition of both the gun's patent and of the Cement Gun Co. in Allentown, PA, near the heart of the emerging cement industry. We then described the explosive growth of the use of the company's proprietary dry-mix "gunite" and its ongoing, tight control over technologies and techniques.

The end of the Second World War was the turning point. As we'll see in this installment, changes in America and the industry had lasting effects on shotcrete—for better and worse—that continue to be played out today.

Trying Times

As it turned out, the Cement Gun Co.'s release of the trademark also facilitated the proliferation of contractors attempting the shotcrete process without any in-depth knowledge of how it should be done.

In essence, any contractor with a hose and a cement gun could market him- or herself and the product as being original "gunite," no matter how extensively they departed from the established standards for the method. The word "cowboy" was often used to describe these lone contractors, a large percentage of whom were using the method to build swimming pools.

As time passed through the 1950s and on until the ’80s, novice (but high-volume) contractors kept entering the field having little or no exposure to the original quality control guidelines enforced by the Cement Gun Co. From the early 1950s on, those rigorous procedures were effectively and increasingly watered down. By the early ’80s, the company’s standards, data, and documentation were little more than a memory among a few old-timers who had managed to stay active. It was not, in sum, a good situation.

In addition, a geographical divide soon emerged as some of the “original” gunite contractors on the East Coast became increasingly suspicious of the newcomers out West, where shotcrete was just beginning to gain traction. The perceived need to preserve a competitive edge created an environment in which knowledge sharing and discussion of best practices in the American shotcrete industry effectively ceased.

Without standards or guidance, much began to slip: Quality was sorely lacking in many installations, and the former field workers who’d risen in the business and were now owners of their own companies rarely understood what went into “good” shotcrete application.

Even today there are contractors who still have not embraced proper practices. As we’ll see in the following, a whole range of substandard methods emerged in these difficult years that threatened the reputation of the shotcrete process as the 20th century entered its last years. To this day, in fact, directly addressing and effectively contradicting poor shotcrete application is one of the primary purposes of both the American Shotcrete Association (ASA) and ACI.

Best Practices

What are those standards? Why are they so important?

Water-Cement Ratio

Let’s start with proper mixture design and its key component: the water-cement ratio. In a good mixture design, you’ll typically find a water-cement ratio of 0.35 to 0.45 (0.30 is a good lower boundary for dry-mix shotcrete). The binder in this mixture—that is, cement paste—is portland cement. If a contractor wants to cut costs and carries no claims to pursuing quality, he or she will increase the water content of the mixture while reducing the volume of portland cement. The use of this “water of convenience” and reduction in cement leads to substandard results and a cheaper product in more ways than one.

Fig. 2: Nozzleman works in tandem with other trained crewmembers to ensure a successful application

Use of Aggregate

As another example, let’s consider the ratio of aggregate (sand, gravel) to the cement paste/binder: minimally, there should be four parts of aggregate to one part cement—and, ideally, a three-to-one ratio. Cost-cutting contractors (and sometimes even engineers) will alter that ratio to five to one or even six to one, using lots of aggregate and minimal cement paste. Using this questionable cost-cutting model, the production of rebound and overspray inevitably increases—and these jobs are executed well below the specifier’s original expectation for material composition and strength.

Rebound and Overspray

Many of these substandard operators also use the rebound and overspray as “filler” in the concrete structure. Rebound and overspray are worthless—binder-free material that has bounced off the receiving substrate. Using this material in any way fundamentally weakens the concrete wherever it is used.

Fig. 3: Shotcrete sprayed at proper velocities results in compacted material with well-encapsulated steel reinforcing bar

Fig. 4: A free-form pool with a perimeter overflow edge and complex step detail is executed with the shotcrete process

When proper practices are pursued in the dry-mix process, one member of the crew will pre-dampen the dry material when using pre-bagged concrete mixtures to reduce dust and waste while another is normally stationed alongside the nozzle operator to gather and shovel away any rebound or overspray. This clears the way for application of high-quality, paste-rich concrete material to build out the structure.

The fact is, however, that the ignorant or unscrupulous contractor will save a great deal in labor and materials by skipping these crucial steps. The in-place material may incorrectly be said to conform to the norm or the standard, despite the fact that best practice would definitively classify the end product as substandard.

Curing

Another prime example of broad-scale deviation from good practice that cropped up on the 1950s (and persists in some quarters to this day) is the ill-advised tendency some contractors have to skip the curing step. Even in today's shotcrete industry, there are contractors who have apparently never been introduced to this concept or have an imperfect understanding of its importance.

Beyond question, curing is among the most important factors involved in ensuring proper strength gain in concrete. The key is maintaining an adequate level of surface moisture: This prevents evaporation of the mix water from within the hydrating concrete, allowing the chemical processes that are taking place between the water and the cement to continue and increase strength gain.

Without a wet cure or the use of a curing agent, the hydration process will halt early, and the concrete will often not reach its target strength. A properly cured structure with proper concrete mixture proportions, for example, will easily attain compressive strength values of 5000 to 6000 psi (35 to 41 MPa). The same structure, uncured, may not reach half that level.

A Troubled Process

The result of this ongoing lack of proper material selection and application standards was the development of an industry that performed poorly and had a worsening reputation into the 1970s and even into the '80s.

The strange outcome here was the creation of another subtrade of contractors who compensated for the poor performance of shotcrete crews by applying waterproofing materials to concrete pool shells. In fact, such applications became a new "norm." But those applications should be unnecessary: as we will discuss in the final part of this series, good shotcrete materials, properly mixed, placed, and cured, will be watertight on their own.

Through it all, however, those fortunate engineers who managed to have positive experiences with reputable, knowledgeable shotcrete contractors continued to specify shotcrete as a method of concrete placement and effectively kept it alive. But many more engineers had negative experiences and studiously specified other methods and materials or—and this became the rule rather than the exception—demanded provision of an encapsulating waterproofing membrane over the often-substandard shotcrete material.

Shotcrete Rebirth

Fortunately—and at the same time as the reputation of the shotcrete industry was being profoundly compromised (largely by the misdeeds of pool contractors)—key developments in other areas of the industry were paving the way for redemption.

The emergence of the wet-mix process and development of new pumps and nozzles developed to support the wet-mix approach made shotcrete the ideal method for working in underground environments. In fact, the use of shotcrete in tunnels, mines, and underground infrastructure exploded in the 1970s, giving engineers a different and beneficial set of exposures to the method and lending the process a level of credibility it hadn't seen since the early 1950s.

Test data and documentation began to emerge, and ACI, along with ASA (formed in 1998), began taking the steps needed to produce standards on what it takes to make good shotcrete. This reinvention of the process laid the foundation for the current reputable state of the shotcrete industry—and in the nick of time.

In our next and final article in this series, we'll discuss the current state of the shotcrete industry, some of the challenges it faces, and its future as one of the most versatile construction methods currently available.

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

Creating a Wine Cave

By Jason Zignego

The perfect temperature for storing wine is between 58 and 61°F (14 and 16°C). In Springfield, MO, where temperatures vary 80°F (44°C) between January and July, there's only one way to assure those ideal wine storage temperatures: go underground. For one private homeowner, the appreciation for wine extends to the construction of a wine cave under his home for storage and enjoyment of his collection. Drawing on the talents of architects, engineers, cave contractors, and a wine cave consultant from Napa Valley, this personal tribute to fermented grapes is being built with extensive use of shotcrete.

Wine caves have been constructed for more than a hundred years in northern California's Napa Valley, where land values are high and the evaporation from wine kegs can result in up to 10% product loss in 2 years if humidity isn't properly controlled. Wine makers consider humidity over 75% for reds and over 85% for whites to be ideal for wine aging and barrel storage. Humidity in wine caves ranges naturally from 70 to 90%. "Ideal wine temperature is between 58 and 60°F (14 and 16°C)," explains wine cave consultant Brady Mitchell, a hands-on cave construction specialist from Napa (refer to Fig. 1). The temperature 45 ft (14 m) under the home of the Missouri wine aficionados' new home is 60°F (16°C). "Perfect," states Mitchell.

Excavation into a hillside below the home site began in 2012. Bacchus Caves (The Woodlands, TX) dug the tunnels, including a 150 ft (46 m) long shaft that will be used for wine storage. A 2 ft (0.6 m) diameter cutting head attached to a hydraulic excavator broke up the

Fig. 1: Brady Mitchell is a modern-day cave man who specializes in wine cave construction, having built many in the Napa, CA, area

Fig. 2: Dry-mix shotcrete was used for structural support during excavation

limestone and red clay earth. A skid steer removed the spoils. Dry-mix shotcreting was used for soil stabilization. "Because they would excavate then shotcrete sporadically, they elected to use the dry-mix method because it could be applied on demand without a pump and ready mix truck standing by," Mitchell explained. The Quikrete product used for dry-mix shotcreting is a specially formulated microsilica-enhanced, portland cement-based, high-strength structural material (refer to Fig. 2).

Over the 2 years of excavation and shotcreting by Bacchus Caves, their efforts resulted in the 10 ft (3 m) diameter x 150 ft (46 m) cask storage tunnel, a 17 ft wide x 15 ft tall x 23 ft long (5.2 x 4.6 x 7 m) bottling storage room, an 18 x 15 x 40 ft (5.5 x 4.6 x 12 m) tasting room, a 17 x 15 x 48 ft (5.2 x 4.6 x 15 m) dining room with butler's pantry, and 10 x 10 x 30 ft (3 x 3 x 9 m) wine library. "The excavation and shotcreting moved pretty slowly because it is clay soil with huge suspended boulders interspersed throughout the area," Mitchell explained. "They did have a cave-in for an area we were calling the "Grotto," which was finally abandoned." The cave has two portals: the outside entrance, and an access point from the basement of the house with a spiral staircase and elevator (refer to Fig. 3). Hundreds of cubic yards of the dry-mix shotcrete were consumed during the process. "Every couple of feet, they would apply a structural coat of shotcrete and then reapply additional coats over previously applied shotcrete as they came back out," said Mitchell.

After excavating and structural shotcreting was completed, 4 x 4 in. (100 x 100 mm) welded wire reinforcement was applied to the entire interior surface and spaced off the walls. The electrical conduits were placed between the two layers of shotcrete. "We placed 6 in. (152 mm) of wet-mix shotcrete for the final tunnel liner, applied in 1.5 in. (38 mm) layers," Mitchell, who is also the nozzleman, explained. "This would result in about four passes to achieve 6 in. (150 mm) of wet shotcrete applied over as much as 14 in. (350 mm) of dry mix" (refer to Fig. 4). The wet mix sped up the process by spraying at a much higher rate than dry-mix shotcrete. Screed rakes were used to contour the larger radii such as the arches (refer to Fig. 5). Hand trowels were used to knock down any high points. Three color samples were test batched for the owner. Mitchell and co-worker Rich Lederer worked together to create the organic shapes. "Nature drives the design."

Fig. 3: Exterior portal leads to 150 ft (45 m) long tunnel and various chambers to create a wine cave 45 ft (14 m) under the owner's new home

Fig. 4: Wet-mix shotcrete was applied 6 in. (150 mm) thick over welded wire reinforcement in four passes

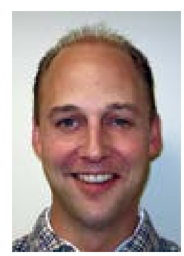
Fig. 5: Organic shape is sculpted wet shotcrete, hand-raked and troweled

Fig. 6: Schwing S17 with 180-degree discharge serves as line pump for shotcreting up to 400 ft (120 m) inside the tunnel

Wet-mix shotcrete pumping was handled by Brundage-Bone from their Springfield location. "We have pumped steadily every day in March, April, and May," Mitchell said. "The Brundage operators have been great and most of the time, the Springfield District Manager, Andy Baugh, is on-site to lend a hand." The company has been using several of their pumps on the project, including a Schwing S17 boom pump discharging directly out the back, an SP 500, and an SPT 1000 truck-mounted pump (refer to Fig. 6). All pumps are equipped with fast-switching Rock Valves for surge-free operation at the hose. Pumping distances have exceeded 400 ft (120 m) with a line diameter at 2 in. (50 mm) where it enters the shotcrete nozzle. "At the end of the day, we wash out the 2 in. (50 mm) hose and blow out the 3 in. (75 mm) line back to the pump," explained Mitchell. "Being that far from the pump, I need to trust the operator and Brundage-Bone's crew is real good. I don't feel like I have to look over my shoulder."

Mitchell hand-formed 200 recesses for light fixtures, with some 8 in. (203 mm) deep. "There is an art to forming the arches and recesses for dramatic shadows," explained Mitchell. "For utilitarian purposes, we can leave a naturally coarse finish, but this wine cave will be enjoyed by the owner and his guests so some rooms will have a smooth finish and some will be covered in plaster or woodwork." A chandelier in the tasting room will appear like a tree root growing through the ceiling. The wine library houses the bottles in racks with sufficient lighting to easily read the labels. Wine of sufficient potential will be sourced and the barrels aged in the cave to be rotated every few months so the sediment can be drawn off. After a couple of years of barrel aging, the wine will be blended and bottled. Humidity will be carefully controlled.

For Mitchell, a 40-plus-year veteran of the wine industry (he began cleaning tasting rooms at 13), it is a satisfying construction career in an area not many people have chosen. "Most of the people in the wine cave industry know each other," explained Mitchell. "I have poured more than a million square feet of cave floors in my career. I still have a 1986 Schwing BP 750-15 back in Napa that pumped most of those cave floors and it still works fine." Mitchell will add to his cave floor square footage when he pours the cave floors with Brundage-Bone pumps later this year.



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Project Details

Excavation
Bacchus Caves
The Woodlands, TX

Engineering
Brierley Associates
Denver, CO

Architects
Slone and Associates
Springfield, MO

Cave Finishing Contractor
Brady Mitchell
Napa, CA

Pumping Equipment
Schwing S17
SP 500 stationary pump
SPT 1000 truck-mounted pump

Cold-Weather Shotcreting

By Raymond Schallom III

The dry-shotcrete process has a long history with placing concrete pneumatically for over 105 years. Additionally, the wet-shotcrete process has been in use for over 50 years and has expanded to all 50 states and 120 countries. The shotcrete process has a wide variety of application uses, such as new construction, tunneling, mining linings, soil (geotechnical), and repair. These proven process methods have shown great versatility and efficiency in concrete placement. Shotcrete placement has been proven to save time and money over conventional form-and-pour methods. As the industry community begins to use these processes more widely, the one constant that hasn't changed is the challenges faced during placement in cold and hot weather. This article will talk about cold weather shotcrete (concrete) practices.

This author has performed and consulted on shotcrete work in temperatures down to –45°F (–43°C), which required close attention to heat protection of the mixtures during transport, placement, finishing, curing, and protection, as well as appropriate thermal clothing for the workers. Work has a tendency to slow down in the colder climate, and there are more safety issues to contend with, that require careful consideration of production while providing full protection of the placed material. These costs are usually worked out with the owner or general contractor well in advance of the cold weather to see if it is feasible to continue work or better to shut down during the winter months.

The shotcrete industry and the American Concrete Institute (ACI) have made great strides to convince the engineering community that shotcrete is simply a placement method for concrete. Therefore, concrete—wet or dry—placed by the shotcrete process, is the same as the concrete covered in ACI 306R-10, "Guide to Cold Weather Concreting," and ACI 306.1-90, "Standard Specification for Cold Weather Concreting." ACI 306R-10 defines cold weather as:

"Cold weather exists when the air temperature has fallen to, or is expected to fall below 40°F (4°C) during the protection period. The protection period is defined as the time required to prevent concrete from being affected by exposure to cold weather."

Concrete placed during cold weather will develop sufficient strength and durability to satisfy the intended service requirements when it is properly produced, placed, and protected. The necessary degree of protection increases as the ambient temperatures decrease.

Because the shotcrete placement is often slower than form-and-pour operations and usually has one surface exposed to ambient temperatures, controlling internal and surface material heat becomes a critical task. One must protect the concrete from early-age freezing during the initial curing process until the compressive strengths reach at least 500 psi (3.5 MPa). At 50°F (10°C), most well-proportioned concrete mixtures reach this strength in a few hours or up to 48 hours in some cases. With shotcrete mixtures generally having a higher paste content and a lower water-cementitious materials ratio (*w/cm*), one can expect to reach the 500 psi (3.5 MPa) stage within a shorter time span—usually within 24 hours.

ACI 506.2-13, "Specification for Shotcrete," and ACI 506R-05, "Guide to Shotcrete," both mention that while actively shooting shotcrete, the ambient temperature needs to be 50°F (10°C) or above. At 40°F (4.4°C), it can take concrete up to 16 hours to reach initial set, while the material temperature needs to be at least 40°F (4.4°C) to start the hydration process. Most DOT work uses the minimum of 50°F (10°C) for ambient, material, and surface temperature ranges unless completely protected and heated.

This author has experienced many temperature variances over the years. The one that stands out that has been a challenge on a few projects is the rapid temperature changes within the repaired areas, particularly before the concrete has developed sufficient strength to withstand induced thermal stresses. Rapid cooling of concrete surfaces or large temperature differences between the exterior and interior (20°F [11°C] minimum change) of the patches can cause cracking and be detrimental to strength and durability. To protect the patch, or new work, the cold weather protection needs to be removed slowly once the curing and protection period has been met, allowing the concrete temperature to change gradually in a 24-hour period as long as the desired strength has been reached. This will help to prevent rapid temperature change in the new shotcrete material.

Figures 1 through 3 show some of the approaches needed for cold weather protection and heat needed to perform shotcrete work during the cold weather months. Concrete construction in cold weather must meet these objectives:

- Prevent damage to concrete due to early-age freezing;
- Ensure that the concrete develops the required strength for safe removal of forms, shores, reshores, and safe loading of structure during and after construction;
- Maintain curing conditions that further normal-strength development without using excessive heat and without causing critical saturation of the concrete at the end of the protection period;

Fig. 1: Cold weather protection Lake Placid bobsled and luge track, which had a fast-track build from 1998-1999 through the winter. The track needed one season to operate before the Goodwill games in 2000

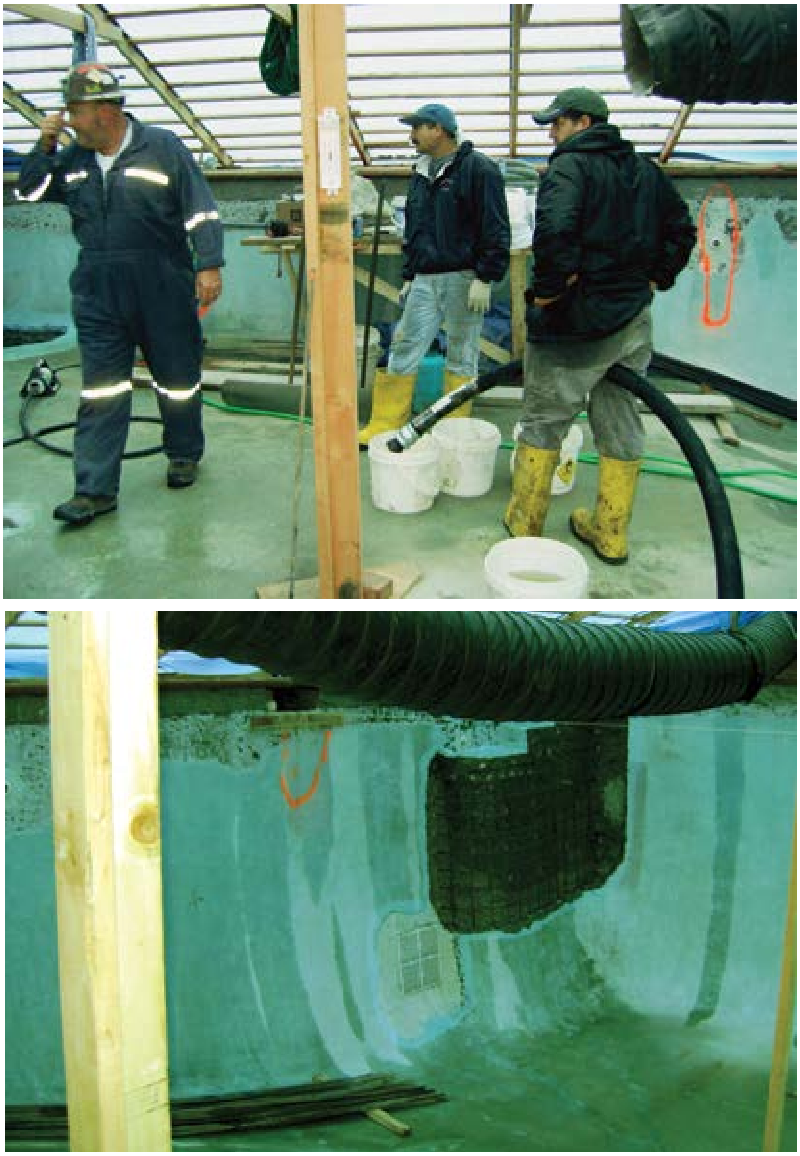

Fig. 2: High-low thermometers for monitoring the 50°F (10°C) heating within the tenting of the pool structures. The 50°F (10°C) was maintained during the shotcrete placement and curing

Fig. 3: *Blankets and thermometers were placed on the concrete surface to monitor the temperatures through the cool night and curing period*

- Limit rapid temperature changes particularly before the concrete has developed sufficient strength to withstand induced thermal stresses; and
- Provide protection consistent with the intended serviceability of the structure.

The actual temperatures of the concrete surface determine the effectiveness of protection regardless of the ambient temperature. Therefore, it is desirable to monitor and record the concrete temperature at the surface of the concrete (Fig. 4). During the temperature recording and monitoring process, consider the following:

- Concrete corners and edges are vulnerable to freezing and are usually more difficult to maintain at required temperatures;
- Maintain the internal temperature of concrete to ensure that excessive heating does not occur;
- Inspection personnel should record the date; time; outside air temperatures; temperature of

Fig. 4: Winter protection for the Volcano skin repair. Temperatures were kept between 47 and 50°F (8 and 10°C) on both sides of the shell. Concrete blankets were placed as added protection. Compression Strengths exceeded the specification for 7 and 28 days. Kings Dominion (Doswell, VA,) November 1, 2015 to March 15, 2016

Table 5.1—Recommended concrete temperatures

		Section size, minimum dimension			
		< 12 in. (300 mm)	12 to 36 in. (300 to 900 mm)	36 to 72 in. (900 to 1800 mm)	> 72 in. (1800 mm)
Line	Air temperature	Minimum concrete temperature as placed and maintained			
1	—	55°F (13°C)	50°F (10°C)	45°F (7°C)	40°F (5°C)
		Minimum concrete temperature as mixed for indicated air temperature*			
2	Above 30°F (–1°C)	60°F (16°C)	55°F (13°C)	50°F (10°C)	45°F (7°C)
3	0 to 30°F (–18 to –1°C)	65°F (18°C)	60°F (16°C)	55°F (13°C)	50°F (10°C)
4	Below 0°F (–18°C)	70°F (21°C)	65°F (18°C)	60°F (16°C)	55°F (13°C)
5	—	Maximum allowable gradual temperature drop in first 24 hours after end of protection			
		50°F (28°C)	40° (22°C)	30°F (17°C)	20°F (11°C)

*For colder weather, a greater margin in temperature is provided between concrete as mixed and required minimum temperature of fresh concrete in place.

Fig. 5: Recommended concrete temperatures—ACI 306R-10, Table 5.1

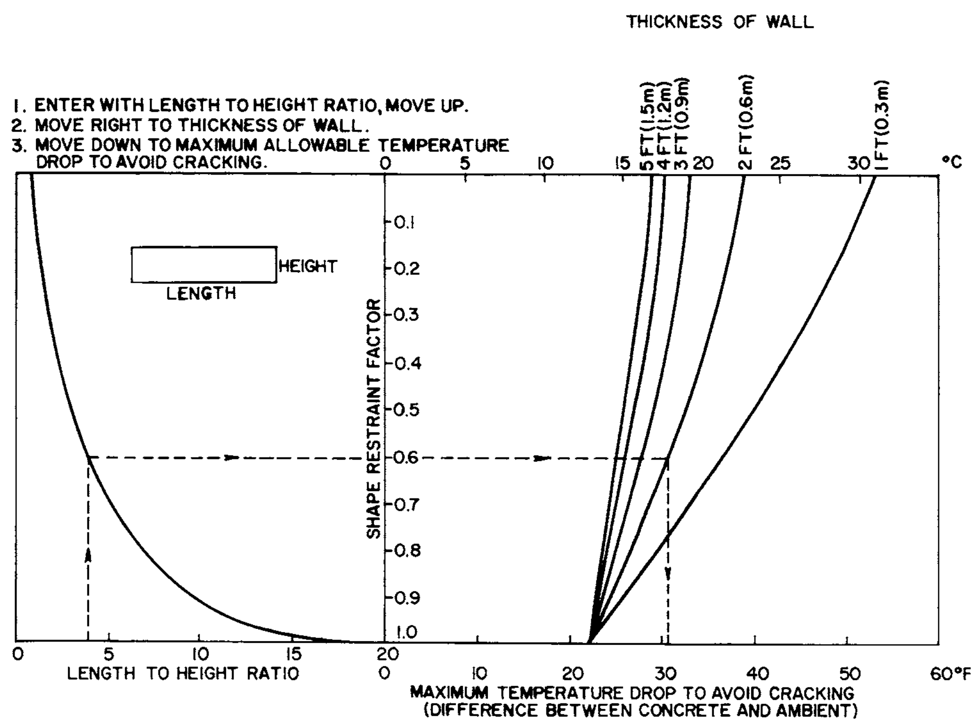

Fig. 6: Graphical determination of safe differential temperature for walls (Mustard and Gosh 1979)

concrete as placed; and weather conditions, such as calm, windy, clear or cloudy; and

- Record maximum and minimum temperature reading at the concrete surface and ambient conditions in each 24-hour period.

Table 5.1 in ACI 306R-10 lists the recommended concrete temperatures at various ambient temperatures during and after the protection period (Fig. 5).

Oftentimes a crew will remove protection immediately after the 7-day curing and protection period, not knowing the concrete should be exposed gradually over a 24-hour period to the ambient temperature. If a crack occurs, it's almost always overlooked or is blamed on the live traffic on the highway bridge, railroad bridge, or even attributed to cold joints/cracks in the structure that run through and behind the repair. Using the material compression strength test results from the preconstruction testing (3-, 7-, and 28-day) will help with the decision regarding when the protection and formwork should be removed. The colder the ambient temperature, the longer the protection stays on.

Proper preparation before placement in cold weather often requires a temperature increase of the formwork, reinforcement, and other surfaces that contact fresh concrete so the temperature of the freshly placed concrete will not decrease below the minimums as placed and maintained found in Fig. 5. There are many techniques for warming formwork, mixing water, concrete materials, and embedded items. This may include one or more approaches, such as heated enclosures, electric blankets, hydronic heating systems, forced air heat, or other acceptable systems. Other methods of accelerating concrete reaching the 500 psi (3.5 MPa) threshold against freezing damage can be provided by concrete mixture acceleration, such as a chemical admixture, decreasing the *w/cm*, increasing the cement content, pozzolan quantity, cold weather admixtures, or going to a Type III cement (high early).

Figure 6 shows the safe differential temperatures for walls as found in ACI 306R-10. Chapters 8 through 11 in ACI 306R-10 provide much greater detail on protection, curing, and acceleration of concrete set and strength, along with many helpful graphs dealing with different exposure temperatures.

When setting up a project, one has to weigh the costs for cold weather shotcreting to see if it is worth the money spent. Some projects have no choice and run right through the winter. Safety of the crew comes first; the added wear and tear on the equipment—as well as the winter protection and heating costs—all play an important role in deciding to continue work or shut down for winter. Since shotcrete is just a placement method for concrete protection and curing of shotcreted sections is the same as for concrete in the winter.

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__Ray Schallom III__ is an underground shotcrete application specialist and President of RCS Consulting & Construction Co., Inc. He has 40 years of experience as a Project Manager, Owner, and Superintendent. Schallom works with State DOT departments with their shotcrete specifications and trains engineering companies' inspectors in the field of shotcrete. He is a Past President of ASA, past Chair of the ASA Education Committee, and is a member of the ASA Publications, Underground, Marketing, Sustainability, and Pool & Recreational Shotcrete Committees. Schallom is also a member of ACI Committees 506, Shotcreting, and C660, Shotcrete Nozzleman Certification, and ACI Subcommittees 506-A, Shotcreting-Evaluation; 506-B, Shotcreting-Fiber-Reinforced; 506-C, Shotcreting-Guide; 506-E, Shotcreting-Specifications; 506-F, Shotcreting-Underground; and 506-G, Shotcreting-Qualification for Projects. Schallom is a retired ACI Certified Nozzleman in the wet- and dry-mix processes for vertical and overhead applications with over 40 years of shotcrete nozzling experience in wet- and dry-mix handheld and robotic applications. He is an ASA-approved ACI Shotcrete Examiner for wet and dry applications. Schallom is also a member of ASTM Committee C09, Concrete and Concrete Aggregates, and ASTM Subcommittee C09.46, Shotcrete.

Traffic Construction Safety

By Ted Sofis

To work safely in and around heavy traffic there are many things to be concerned about. First and foremost is setting up an appropriate traffic pattern. The signing and the requirements are detailed in your state or municipality DOT traffic standards. The requirements vary for two- and four-lane roads, lane closures, and the many different traffic configurations. Working situations may involve flaggers, the need for arrow boards or message boards, crash trucks to protect the crew in their work area, and energy-absorbing traffic attenuators to protect the motorists. All these requirements must be followed.

In addition to the standard construction traffic control procedures, shotcrete operations add additional concerns. Because of the nature of shotcrete work, tarps and barriers are often necessary to protect the passing motorists. In shotcrete repair and rehabilitation of bridges and tunnels, the removal of deteriorated concrete can make it necessary for the erection of platforms to collect the concrete debris and keep it off the roadways. The same can be said for the shotcrete placement phase of the work, where there is a need to protect the motorists from the material overspray and rebound. On slope protection projects, when adjacent to the roadway, it is often necessary to establish lane closures or install barriers for the same reasons (refer to Fig. 1 and 2).

On heavily traveled highways, the state and its cities try to maintain the flow of traffic. Oftentimes, because of political pressure, great efforts are made to avoid inconveniencing the driving public. This often necessitates working in off-peak traffic hours at night or on weekends. Working at night necessitates extra precautions with additional lighting, light plants, and high-visibility safety apparel.

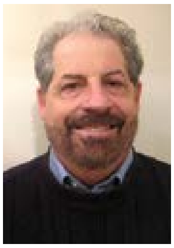
As with other construction, it is necessary to wear the proper personal protective equipment at all times. This typically includes high-visibility and reflective safety clothing, vests, hardhats,

Fig. 1: Wooden barriers are installed in place along I-376 by the Fort Pitt Tunnel in Pittsburgh to protect traffic during the shotcrete placement of this soil nail wall

safety glasses, and hearing protection. The signs, traffic cones, arrow and message boards, crash trucks, and safety attenuators must be properly positioned and in accordance with the appropriate DOT traffic pattern requirements. Fatal accidents can happen in an instant. Therefore, construction personnel need to be aware and vigilant at all times when working near moving traffic.

Old railroad tunnels and bridges over rural roads are often narrow two-lane roads and there isn't much room to work on abutment or tunnel walls. In such cases, it often necessary to set up a traffic pattern with flaggers and alternate the traffic. One lane is closed off where the repair operations are taking place while traffic in each direction alternates in the remaining open lane. In very tight circumstances like this, it is usually necessary to hang tarps, erect barriers, or tie plastic to erected scaffolding to protect the passing cars from shotcrete overspray and rebound. Whenever a lane is closed or restricted it is imperative to have the proper warning signs in place for approaching motorists (refer to Fig. 3 and 4).

Each project has different safety issues. Whether you are working on a rural two-lane road or on a heavily traveled highway, it is important to address the specific safety issues of that location. Set up the appropriate traffic configuration, make sure the workers are protected at all times, and make sure any necessary barriers or tarps are securely in place before the start of shotcrete operations.



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

Fig. 2: On two-lane bridges like the one pictured above, lane closures are often necessary to provide access to the work

Fig. 3: Crash truck with impact attenuator and mounted arrow board, for a lane closure on a four-lane highway bridge in West Virginia

Fig. 4: On two-lane roads, when it is necessary to set up shotcrete operations on the roadway, a lane closure with advanced signing and flagmen becomes necessary

Corporate Member Profile

Schwing America Inc.

Schwing America is a member of the Schwing Group, a worldwide designer, manufacturer, and distributor of premium concrete production and handling equipment, headquartered in Herne, Germany. Schwing is committed to supporting its customers' success. The company excels in producing high-quality concrete equipment used in the most demanding construction applications, through innovative engineering, premier manufacturing, and optimum after-sales support. Schwing offers industry-leading concrete pumps, truck mixers, batch plants, reclaimers, and genuine parts for distribution in North and Latin America.

For the wet-mix shotcrete industry, Schwing brings three different valve types to the market for every type of application—from pool builders to commercial contractors. All models are built at the company's White Bear, MN, factory.

Choose the simplicity of the mechanical ball valve with the SP 88 or a hydraulic ball valve with the SP 160 to pump grout, lightweight concrete, flowable fill, shotcrete, and slurries. A logical upgrade from a ball-valve pump is the transfer tube valve with hydraulically driven components that apply up to 1060 psi (7.3 MPa) on the material. Rock Valve™ pumps are excellent entry-level performers, as well as seasoned professional machines pumping grout, shotcrete, and structural concrete with output up to 118 yd^3/h (90 m^3/h) to impressive distances.

Fig. 1: More than 400,000 ft^2 (37,000 m^2) are dedicated to world-class manufacturing at Schwing's White Bear, MN, factory

With all models, durability and performance come standard. Long-term use is backed by Schwing's Call Center, where knowledgeable staff provides service and parts information 12 hours per day. A fully stocked parts department can dispatch orders the same day.

Schwing's in-house engineering department continues to refine the legendary Schwing shotcrete pumps using the latest techniques to extend performance and durability. Manufacturing of stationary pumps for shotcreting is in a dedicated area where the highest level of craftsmanship is applied to every machine. All pumps are powered by CAT diesels for reliability and convenient servicing. The SP 500 model can be ordered with a 74.5 hp CAT C3.4B Tier IV diesel for California compliance or wherever lower emissions are required.

Schwing pumps are in use everyday in shotcrete applications. Some of the most notable projects include:

- **Parcel A of the Streets of Buckhead** project is larger than a city block and required soil retention along two sides measuring 350 x 450 ft (110 x 140 m) of the 50 ft (15 m) excavation, which became five levels of below-grade parking. To provide structural walls, the contractor used a top-down shotcrete method in 5 ft (1.5 m) lifts. The company placed 35,000 ft^2 (3250 m^2) of vertical surfaces 10 in. (250 mm) thick with finished interior walls of the structure using a Schwing SP 750-15.
- **The University of New Mexico Olympic Pool** shotcrete mixture consisted of a 3/8 in. (10 mm) basaltic rock, known to be a difficult pump

mixture. This very coarse shotcrete mixture helped provide 4000-plus psi (28 MPa) strength at 3 in. (75 mm) slump. The SP 750-15 pump's 70 yd^3/h (54 m^3/h) output and 100 hp, combined with its 1100 psi (7.6 MPa) pressure on the shotcrete mixture to pump every day for 2 weeks, allowed for the project completion without an incident.

- **Niagara Tunnel** project shotcreting was part of the excavation contract to stabilize the borehole perimeter but additional shotcrete was required to fill voids in loose soil conditions. The company used three Schwing SP 500 split units to apply the shotcrete 5 in. (130 mm) thick through handheld hoses and shotcrete robotic arms attached to the tunnel boring machine. The wet shotcrete was applied over reinforcing mats anchored into the tunnel walls. The shotcrete arms provided extra reach to fill voids that occurred when soil conditions were not ideal. A Schwing SP 1000 was used to feed the robotic arm and to provide additional velocity to the shotcrete. Trucks supplied the premixed shotcrete to the electrically powered pumps. More than 160,000 yd^3 (120,000 m^3) of shotcrete was applied over the 5 years of tunneling.

Schwing's Mission Statement of *Concrete Solutions to Build Our World* has been verified from the top of the Freedom Tower to tunnel projects deep beneath the earth's surface. With many record-breaking pumping feats around the world for the largest contractors, the company is just as dedicated to the one-pump owner who relies on quality equipment to make a living.

Fig. 2: Schwing shotcrete pumps have the capability to provide continuous high-output volume required by big projects like this Olympic swimming pool

Fig. 3: Steady output with minimal surging makes for fatigue-free hose work thanks to the fast sequencing valve of the Schwing shotcrete pumps

Fig. 4: Schwing stationary pumps can be truck or trailer mounted with CAT Diesel or electric power

Fig. 5: The SP 500 is available with a Tier IV CAT diesel for low emissions operation in California

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Atlas Copco Strengthening Customer Relations by Appointing New Rental Managers

Atlas Copco Construction Equipment appointed four managers to lead its growing rental market in the United States. Steve Nelson serves the national rental aftermarket as a Business Development Manager, Norbert Matthews works as an Area Sales Manager for the Midwest, Charlie Clarkson serves the Northwest as the Area Sales Manager, and Ronald Repasz is the Area Sales Manager for the Southwest.

"We're committed to building strong business relationships with our customers. Part of that is building a team that continues to provide industry-leading assistance by offering the best equipment, parts, service, and aftermarket support," said Matt Cadnum, Atlas Copco Rental Channel Vice President of Sales.

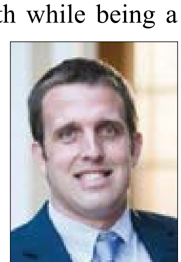
Together, the four new managers have more than 40 years of industry experience.


Steve Nelson

Nelson will focus on growing Atlas Copco's aftermarket revenue and market share through the rental channel. Nelson has been with Atlas Copco for more than 4 years and most recently was the Regional Sales Manager for the West Rental Division. With more than 20 years of industry experience, Nelson said he looks forward to working with customers to promote Atlas Copco's construction equipment and show them what the aftermarket division has to offer.

Matthews, Clarkson, and Repasz will oversee operations at rental centers in their areas and will work to build strong customer relationships. They are dedicated to customer satisfaction and upholding Atlas Copco values and equipment standards.

Matthews works with customers in Ohio, Michigan, Indiana, and Kentucky. He has 15 years of experience in the rental industry working for independent and national companies. In addition, Matthews' experience in the construction and industrial industries will ensure continued growth while being a customer advocate.


Charlie Clarkson

Clarkson manages Colorado, Utah, Wyoming, and Montana. "I enjoy being part of an industry-leading sales team and look forward to sharing that knowledge with customers," Clarkson said. Before accepting this role, Clarkson worked in sales and customer relations at Specialized Transport Service, a freight carrier company.

Repasz holds prior experience in sales and service at Eaton, and said he looks forward to continue working with customers and building trusting relationships. Repasz also shared that he enjoys solving problems and trading solutions, which will help him find success in his new role. Prior to working at Eaton, Repasz served 12 years in the Navy.

Atlas Copco is a world-leading provider of sustainable productivity solutions. The Group serves customers with innovative compressors, vacuum solutions and air treatment systems, construction and mining equipment, power tools, and assembly systems. Atlas Copco develops products and services focused on productivity, energy efficiency, safety, and ergonomics. The company was founded in 1873; is based in Stockholm, Sweden; and has a global reach spanning more than 180 countries. In 2014, Atlas Copco had more than 44,000 employees. Learn more at **www.atlascopco.us**.

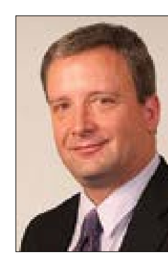
Shannon & Wilson Announces 2016 Staff Promotions

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

Shannon & Wilson announced the following promotions for 2016: Hisham J. Sarieddine to Vice President; Rob Clark, Wendy L. Mathieson, and David C. Ward to Senior Associate; and Dan McMahon, Elliott C. Mecham, Brian S. Reznick, and Scott R. Walker to Associate.


Hisham J. Sarieddine

Sarieddine joined the firm's Seattle, WA, office as a geotechnical engineer in 1988, and has progressively expanded his experience and expertise on projects ranging from small structures to large federal highways. His clients include ports, state and federal agencies, and transit clients. He received both his bachelor's and master's degrees in civil engineering and is a licensed professional engineer in Washington and Hawaii.

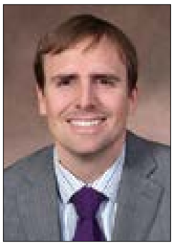

Rob Clark

Clark joined the firm's Seattle office as a geotechnical engineer in 1985 and has developed a specialty with the design, implementation, and monitoring of geotechnical and structural instrumentation for the evaluation of movement and property changes in buildings, excavations, dams, landslides, and tunnels. He received his bachelor's degree in civil engineering and is a licensed professional engineer in Washington and New York.

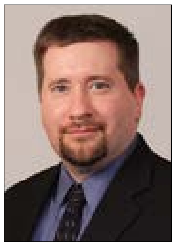
Mathieson joined Shannon & Wilson's Seattle office in 1999 as a geotechnical engineer. She has developed innovative solutions for slope stabilization, ground improvement, and shoring. She received both her bachelor's and master's degrees in civil engineering and is a licensed professional engineer in Washington and Alaska.


David C. Ward

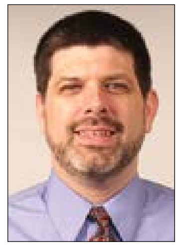
Ward joined the firm's Seattle office in 1997. He is a licensed civil engineer and



Elliott C. Mecham



Brian S. Reznick



Scott R. Walker

licensed engineering geologist in Washington, working primarily on tunnel and underground projects in both soil and rock. He received his master's degree in geological engineering.

McMahon is an environmental scientist in the firm's Anchorage, AK, office. He first began working with Shannon & Wilson in 1997 and has been active with projects involving environmental investigations and cleanup activities in Alaska and Washington. He received his bachelor's degree in environmental conservation.

Mecham joined the firm's Portland, OR, office as a geotechnical engineer in 2014, bringing more than 10 years of experience with pipelines, pump stations, treatment facilities, and other water/wastewater-related public infrastructure. He received both his bachelor's and master's degrees in civil engineering and is a licensed professional engineer in Oregon, Idaho, Utah, and Washington.

Reznick joined the firm's Seattle office as a geotechnical engineer in 2002. His technical experience encompasses design of shallow and deep foundations, shoring, ground improvement, slope stability analysis, settlement analysis, and liquefaction evaluation. He received both his bachelor's and master's degrees in civil engineering and is a licensed professional engineer in Washington.

Walker joined the firm's Denver, CO, office as a geotechnical engineer in 2006. The majority of his projects have been in the fields of water resources and underground engineering. He received both his bachelor's and master's degrees in geological engineering and is a licensed professional engineer in Colorado and California and a licensed geologist in Missouri and California.

Shannon & Wilson is an employee-owned consulting firm with more than 60 years of experience providing geotechnical and environmental consulting services from 12 offices across the United States.

Shannon & Wilson Staff Earns Tunnel Inspection Certification

Peggy Ganse

Shannon & Wilson's Senior Tunneling Services Project Manager Peggy Ganse, PE, PG, recently obtained National Certified Tunnel Inspector (NCTI) certification to perform safety inspections of tunnels nationwide. Ganse attended training provided by the National Highway Institute (NHI) of the Federal Highway Administration (FHWA) and earned the certification under NHI's new NCTI program.

In July 2015, FHWA established new National Tunnel Inspection Standards (NTIS) for highway tunnels. This NCTI certification is now required for inspection of all tunnels on public roads and on and off Federal-aid highways. All key elements of highway tunnels are covered under this program, including structural, civil, mechanical, fire/life safety/security, and electrical and lighting.

Ganse is a geologist and geological engineer with 23 years of experience designing, managing, and performing geotechnical services for tunneling projects across North America. As nationally recognized experts in tunneling and underground services, Shannon & Wilson has performed tunnel work for railroad, utility, and transportation clients for more than 60 years.

Senior Vice President and Denver Office Manager Greg Fischer stated, "We are excited to have NCTI certification as part of our condition assessment capabilities. It will allow us to better serve our clients by guiding them through the NTIS requirements and regulations. It also serves as another tool to help our clients with the important task of asset management."

Blastcrete Equipment Company Named Finalist for Small Manufacturer of the Year

Blastcrete Equipment Company, manufacturer of mixing and pumping equipment for the refractory and shotcrete industries, is one of eight finalists for the Small Manufacturer of the Year award in Alabama. The Alabama Technology Network and the Business Council of Alabama named the winner of the award, which honors the state's leading manufacturers' accomplishments, on April 12 during the 2016 Alabama Manufacturer of the Year Awards luncheon at the Activity Center in Montgomery, AL.

"Our employees take a tremendous amount of pride in what we do here. I'm proud of them, and this is quite an honor for us," said Jim Farrell, Blastcrete CEO. "We're a family-owned business and unique in that we design and manufacture our products in-house. Our 20 employees accomplish the same things as a larger company, only on a smaller scale. That gives us the ability to not only produce great equipment but to also back it up with personal customer service."

Blastcrete is a finalist in the small manufacturers category, which includes businesses with 99 or fewer employees. The award recognizes innovation in manufacturing, commitment to excellence, dedication to employees, and community investment.

"Now in its 17th year, the Business Council of Alabama is honored to salute Alabama's best manufacturers for their valuable participation in not only the state's economy but also the economies of their employees and the suppliers who do business with them," said William J. Canary, President and CEO of the Business Council of Alabama. "The Manufacturer of the Year Awards continues to be a premier event for the BCA, the Alabama Technology Network, the Chamber of Commerce Association of Alabama, and the National Association of Manufacturers. The BCA is proud to be the exclusive affiliate in Alabama to the NAM and the U.S. Chamber of Commerce."

Jim Douglas founded Blastcrete in 1950 in Los Angeles, CA, as a manufacturer of single- and double-chamber gunite machines. Farrell purchased Blastcrete in 1983 and relocated the business to Anniston, CA. The company continues to grow as it designs and manufactures products for refractory, construction, and concrete customers throughout the world.

Blastcrete has been manufacturing safe, reliable, and user-friendly solutions for the refractory and shotcrete industries for more than 60 years. With a complete product line that consists of concrete mixers, pumps, and related products, the company serves the commercial and residential construction, ICF and SCIP building systems, refractory, and underground markets. For more information: Blastcrete Equipment Company, 2000 Cobb Ave., Anniston, AL 36202; (800) 235-4867; fax (256) 236-9824; info@blastcrete.com; **www.blastcrete.com**.

Cemrock Builds Seaworld Habitat with Quikrete Shotcrete and Stucco

Last year, SeaWorld San Antonio (TX) opened Pacific Point Preserve, a new realm designed to teach visitors about sea lions, harbor seals, and Asian small-clawed otters and how to protect them in their natural habitat. A critical element in creating Pacific Point Preserve, which resembles a fishing wharf along the Pacific Coast, was incorporating a home for the Asian small-clawed otters, sea lions, and harbor seals. Cemrock Landscape, Inc., employed a multi-phased process using a combination of QUIKRETE® Shotcrete MS and QUIKRETE Base Coat Stucco – Pump Grade to transform an old existing exhibit into a new natural habitat.

Once the deteriorated exterior of the existing exhibit was removed and repairs were made to the underlying frame, Cemrock Landscape, Inc., spray-applied seventeen hundred 80 lb (36 kg) bags of QUIKRETE Shotcrete MS to create a structurally-sound foundation. Cemrock then spray-applied twelve hundred 80 lb (36 kg) bags of QUIKRETE Base Coat Stucco – Pump Grade over a strategically placed structural armature before sculpting stone and wood features familiar to Asian small-clawed otters, sea lions, and harbor seals. Finally, artisans used colored iron oxide pigments to give the exhibit a truly indigenous appearance.

"The QUIKRETE products proved be a perfect fit for this unique project," said Thomas O'Keefe, superintendent for Cemrock. "The shotcrete provided a sturdy structure and the stucco adhered well to the armature, and was easily molded so the exhibit really looks like a natural habitat. In addition, by spray-applying the materials, we were able to work quickly and efficiently while minimizing waste and rework."

Despite being small and meek in appearance, Asian small-clawed otters average 6.5 lb (3 kg) and can be very destructive, so the long-term durability of the exhibit is important. As a result, QUIKRETE Concrete Acrylic Fortifier was mixed into the stucco for increased strength as well as to provide protection against continuous moisture and salt water.

QUIKRETE Shotcrete MS is a single-component microsilica-enhanced repair material that achieves more than 9000 psi (62 MPa) at 28 days, and features very low rebound and permeability characteristics. QUIKRETE Base Coat Stucco – Pump Grade is a flowable, high-workability plaster particularly designed for spray applications. It is a fiber-reinforced portland-cement-based stucco, designed to be used as the scratch and/or brown coat in a three-coat stucco application, or the first coat in a two-coat application.

The QUIKRETE Companies is the largest manufacturer of packaged concrete and cement mixtures in the United States and Canada, and an innovative leader in the commercial building and home improvement industries. QUIKRETE also offers related products through numerous wholly owned subsidiaries, including SPEC MIX®, Pavestone®, Custom Building Products®, Target Technologies®, Daubois®, and QPR®. Collectively, QUIKRETE products are manufactured and distributed from nearly 150 facilities in the United States, Canada, Puerto Rico, and South America, allowing for unsurpassed distribution and product depth. The QUIKRETE Technical Center also ensures that professionals and consumers alike are provided with the most innovative and highest-quality products available on the market. For additional information on The QUIKRETE Companies or their products, please visit **www.quikrete.com** or call (800) 282-5828.

Hayward Baker Expands Its Regional Presence with New Office Facilities in Connecticut

The new office supports Hayward Baker customers in Connecticut, providing enhanced services and learning seminars

Hayward Baker Inc., North America's leader in geotechnical construction, announces the opening of a new office location in Middletown, CT. The new office is conveniently situated between Hartford and New Haven. The office supports customers and projects in Connecticut, led by Brian Eastman, PE, Project Manager with oversight from Kevin Dawson, PE, New England Area Manager.

Eastman received his bachelor's degree in civil and environmental engineering, as well as a his master's degree in civil engineering with a focus on geotechnical engineering, from the University of Massachusetts Amherst, Amherst, MA, and has been employed by Hayward Baker for 5 years in the New England office. He has worked on a wide range of projects, including ground improvement techniques, structure foundation support, and temporary support of excavations. Eastman is joined by Ray Smith, Superintendent, who brings more than 15 years of project experience including drilled shafts, shotcrete earth support, micropiles, and ground improvement.

According to Dawson, the opening of the Middletown office represents a commitment to serving Connecticut's diverse market of general contractors, geotechnical consultants, and commercial property developers. "We are excited to strengthen our focus in Connecticut. The new office location will enable us to offer enhanced service to our clients and expand our business in New England," he stated.

Recent local projects illustrate the wide range of foundation work Hayward Baker already performs in the region. These include aggregate pier ground improvement and drilled micropiles to support the new Earth Tower Hotel and Sky Connector at Mohegan Sun Casino, Uncaseville, CT. In addition, approximately 4000 ft (1219 m) of steel sheetpile temporary earth support with internal bracing and grouted tiebacks are being installed for the MDC Wet Weather Expansion Project in Hartford, CT.

For the Connecticut State DOT's recent Contract E project in New Haven, Hayward Baker designed and installed over 60,000 ft^2 (5574 m^2) of shotcrete and soil nail temporary earth support, approximately 70 drilled micropiles, plus 30 drilled shafts.

To kick off the opening of the new office, Hayward Baker hosted two seminars in the New England region for developers, contractors, architects, and engineers. Each seminar was a full-day event from 9:00 am to 3:00 pm, with refreshments and lunch included. Engineers had the opportunity to earn PDH credits for these events.

The seminars focused on geotechnical construction and ground improvement, offering a wide overview of projects and techniques such as aggregate piers, rigid inclusions, jet grouting, temporary earth support, geotechnical instrumentation, and driven piles. To schedule a lunch-and-learn meeting, contact David Finocchio at dwfinocchio@haywardbaker.com.

The new Middletown office of Hayward Baker is located at 515 Centerpoint Drive, Suite 116. For more information on the services offered by the office, contact Brian Eastman, Project Manager, at (401) 626-0534. For a complete listing of Hayward Baker's 31 regional and local offices in North America, visit **www.haywardbaker.com/locations**.

Brian Eastman (left) and Ray Smith, Superintendent (right) shown outside Hayward Baker's new office in Middletown, CT. The facility opened in March 2016

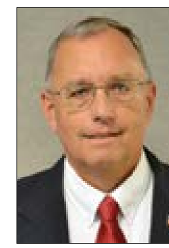
Hayward Baker is North America's leader in geotechnical construction, annually ranked by *Engineering News-Record* magazine No. 1 in foundation construction. With a 60-year record of experience, Hayward Baker offers geotechnical construction technologies through a network of more than 20 company-owned offices and equipment yards across the continent. Project applications include foundation support, settlement control, site improvement, slope stabilization, underpinning, excavation shoring, earth retention, seismic/liquefaction mitigation, groundwater control, and environmental remediation. Visit **www.hawyardbaker.com**.

Hayward Baker Inc. is part of the Keller Group of companies, a multinational organization providing geotechnical construction services throughout the world. Visit **www.keller.co.uk**.

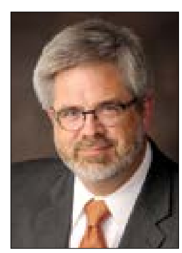
ACI Announces New Officers for 2016

The American Concrete Institute (ACI) introduced its 2016-2017 President, Vice President, and four Board members during The Concrete Convention and Exposition in Milwaukee, WI, in April 2016.

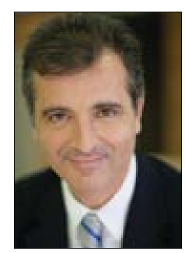
Michael J. Schneider, FACI, Senior Vice President and Chief People Officer at Baker Concrete Construction, Inc., has been elected to serve as President of the Institute for 2016-2017; David A. Lange, FACI, Professor of Civil and Environmental Engineering and Narbey Khachaturian Faculty Scholar at the University of Illinois at Urbana-Champaign, Champaign, IL, has been elected ACI Vice President for a 2-year term; and Khaled Walid Awad, Founder & General Manager of ACTS (Advanced Construction Technology Services), Beirut, Lebanon, is now the Institute's Senior Vice President, which is also a 2-year term. Schneider succeeds Sharon L. Wood, Dean of the Cockrell School of Engineering and the Cockrell Family Chair of Engineering No. 14 at the University of Texas at Austin, Austin, TX, ACI President 2015-2016, who will now assume a position on the ACI Board of Direction as a Past President member. Her position replaces James K. Wight, ACI President in 2011-2012. Wood joins Anne M. Ellis, ACI President 2013-2014, and William E. Rushing Jr., ACI President 2014-2015, to complete the requisite three Past Presidents of ACI serving on the Board as stipulated by the Institute's Bylaws.



Michael J. Schneider



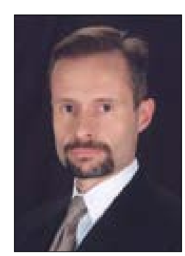
David A. Lange



Khaled Walid Awad

Frances T. Griffith

R. Doug Hooton



Neven Krstulovic-Opara

Antonio Nanni

Additionally, four members have been elected to serve on the ACI Board of Direction, each for 3-year terms: Frances T. Griffith, FACI, Associate Director of the Center for Training Transportation Professionals (CTTP), Department of Civil Engineering, at the University of Arkansas, Fayetteville, AR; R. Doug Hooton, FACI, Professor and NSERC/Cement Association of Canada Senior Industrial Research Chair in Concrete Durability and Sustainability in the Department of Civil Engineering at the University of Toronto, Toronto, ON, Canada; Neven Krstulovic-Opara, FACI, Engineering Associate with ExxonMobil, Spring, TX; and Antonio Nanni, FACI, Inaugural Senior Scholar, Professor, and Chair of the Department of Civil, Architectural, and Environmental Engineering, University of Miami, Coral Gables, FL.

Spring ASA Board and Committee Meetings

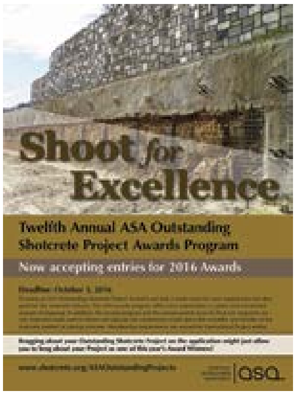
ASA held its Spring 2016 Committee Meetings in Milwaukee, WI, on April 15 and 16. Our Executive Committee met Friday evening and Saturday meetings included our Underground, Pool and Recreational Shotcrete, Education, Safety, Marketing, Publications, and Membership Committees, wrapping up with our Board of Directors meeting. We have seen a renewed interest in members participating in our committees and had nearly 30 ASA members participating in the various meetings in Milwaukee. Vice President Scott Rand worked with each committee on implementation of ASA's Strategic Plan and as a result has helped each committee focus on their highest-priority activities (refer to Scott's article on our Strategic Plan on page 6 of this issue).

Significant actions at the meetings included:

- Welcoming Cathy Burkert as the newly assigned Chair of the Membership Committee, while thanking Tom Norman for his years of service as Chair;
- Reviewing a draft of the proposed Contractor Qualification Program and establishing a standing committee, chaired by Chris Zynda, to finalize development and implementation of the program;
- Reporting on great progress toward updating our on-site seminars, with a great upswing in the number of sessions we've given to engineers, architects, and students across the country;
- Reporting on the increase in presenting to various DOTs and transportation consortiums on the value proposition of shotcrete in highway projects;
- Reviewing the updated Shotcrete Inspector education program that will be balloted by the Board for final approval this Spring;
- Assigning Membership and Pool & Recreational Shotcrete Committees to follow up on contacts made at the International Pool and Spa show, as well as World of Concrete;
- Establishing two task groups: one to refine our ASA policy on some types of nozzleman certification sessions and another to consider our ASA Committee meeting format and develop recommendations to make our committee meetings more effective and efficient;
- Noting both Education and Safety Committees are working together on a new safety-oriented education program, and discussing some alternative delivery formats for future education modules; and
- Approving a new trade show and exhibit summary report recommended by the Marketing Committee.

All in all, it was an extremely busy and productive day of ASA committee meetings. Many of the committee members met for a group dinner at the nearby Capital Grille on Saturday evening, where all could relax and network. The following Sunday, Monday, and Tuesday had many of our ASA members participating in ACI certification and technical committees, including ACI Committees 506, Shotcreting; C660, Shotcrete Nozzleman; and ACI Subcommittee C601-I, Shotcrete Inspector.

ASA Outstanding Shotcrete Project Awards



At our 2016 Annual Banquet, we presented the Outstanding Shotcrete Project awards. In addition to receiving their awards and making short presentations at the annual ASA Banquet in conjunction with World of Concrete, the winners were also highlighted in the Winter 2016 issue of *Shotcrete* magazine.

Now's the time for you to submit your project(s) for consideration in next year's awards. ASA's annual shotcrete project awards provide real-world applications of the exceptional advantages of placing concrete through the shotcrete process. This is a great marketing tool for your company and the great work you do. Our categories include:

- Architecture | New Construction;
- Infrastructure;
- International Projects;
- Pool & Recreational;
- Rehabilitation & Repair; and
- Underground.

We've made the online submittal process as straightforward as possible. You can find the Official Entry Form as well as additional background information on our website at **http://shotcrete.org/pages/membership/project-awards.htm**. *You need to be in it to win it!*

ACI 2015-2016 Concrete Construction Competition Based on a Common Shotcrete Evaluation

A student team from the Department of Engineering Technology and Construction Management at UNC Charlotte were the winners of the 2015-16 Concrete Construction Competition sponsored by ACI, the American Society of Concrete Contractors, and ASA. Along with faculty advisor Dr. Tara Cavalline, team members Ashton Crabtree, Hunter Ballard, Carter Dold, Joshua Beitz, and Mark Stevenson attended The ACI Concrete Convention and Exposition in Milwaukee, WI. There, they presented their work to the ASA Committee members, the ACI Concrete Liaison Committee, and ACI Committee 506, Shotcreting.

The competition required the students to provide their recommendations for construction methods to be used for construction of a foundation wall for a high-rise building. Responses were judged on the basis of clarity, technical quality, and economy.

The students were asked to consider two placement methods for construction of a 16 ft (5 m) tall, 12 in. (305 mm) thick, 120 ft (37 m) long wall:

The first-place team in the 2015-2016 Concrete Construction Competition (from left): Faculty Advisor Tara Cavalline, with Hunter Ballard, Carter Dold, Ashton Crabtree, Joshua Beitz, and Mark Stevenson. All are students in the UNC Charlotte Department of Engineering Technology and Construction Management

- "Form-and-Pour" using two-sided forming; and
- Shotcreting.

Teams were provided general information on the formwork system for the form-and-pour placement, including the spacing for bracing, ties, wales, and studs. However, teams were provided little information on the shotcreting option, and so were expected to refer to industry documents and consult industry professionals for development of their recommendations. Solving the problem required teams to perform design calculations, think through the construction process for each option, and prepare schedules and cost estimates. After considering cost and schedule impacts for the placement methods, the UNC Charlotte team recommended the shotcreting option. Second place was awarded to a team from the University of Georgia, comprising team members Katelyn Stallings, Kyle Cotter, Taylor Hebert, and Amanda Rostin. The team's faculty advisor was Stephan A. Durham. Third place was awarded to a team from the University of Toronto, comprising team members Siu Kwan Amos Chan, Barathan Sureshkumar, and Mark Whitell. The team's faculty advisor was Brenda McCabe.

The 2015-2016 Concrete Construction Competition was organized and managed by Frances Griffith, Associate Director of the Center for Training Transportation Professionals, University of Arkansas, Fayetteville, AR. Griffith is also Chair of the ACI Educational Activities Committee.

Up-and-Comers Shine in Region

Frank Townsend

ASA Board member Frank Townsend was named in *Engineering News-Record* (*ENR*) New York's Top 20 under 40 competition this year. Chosen from more than 40 submissions, the winners of *ENR* New York's Top 20 under 40 competition are a diverse and dynamic group of individuals working in design and construction across the region. The competition accepted entries through an online system for those based in New York or New Jersey who were under age 40 as of January 1, 2016. Submission forms asked nominees to provide information about their industry experience and education as well as career and industry leadership. Candidates were also asked to explain why they chose particular organizations for community service involvement.

Frank Townsend's construction career began with 9 years of active duty in the U.S. Army, with his service, including power distribution systems management for the Corps of Engineers during three hurricanes.

Townsend went on to lead Hurricane Katrina damage repair at Conti Federal Services. Later, he joined Tutor Perini and became East Coast area manager for its Superior Gunite unit 3 years ago, where he has been involved with New York City projects such as East Side Access, the World Trade Center, and Hudson Yards.

It's Baseball Season!

ASA's new logo adds a sharp look to this new baseball cap available for purchase! Order yours online today from our Bookstore: **www.shotcrete.org/bookstorenet**.

AREMA 2016 Annual Conference & Exposition

August 28-31, 2016 | Hilton Orlando in Orlando, FL

The AREMA 2016 Annual Conference & Exposition will take place August 28-31, 2016, at the Hilton Orlando in Orlando, FL. The American Railway Engineering and Maintenance-of-Way Association (AREMA) was formed on October 1, 1997, as the result of a merger of three engineering support associations—namely the American Railway Bridge and Building Association, the American Railway Engineering Association, and the Roadmaster's and Maintenance of Way Association, along with functions of the Communications and Signals Division of the Association of American Railroads. Their mission is: The development and advancement of both technical and practical knowledge and recommended practices pertaining to the design, construction, and maintenance of railway infrastructure.

ASA will be exhibiting at this event. Come visit us in Booth #1002.

SPACE Shotcrete Annual Short Course

September 7-8, 2016 | Colorado School of Mines, Golden, CO

ASA is again a cosponsor for this annual 3-day course on effective and sustainable uses of shotcrete. This course is intended for owners, engineers, contractors, consultants, and equipment suppliers involved in the design and implementation of aboveground structures, support of excavation, tunneling, mining, shaft construction, and heavy civil and architectural projects.

Tunneling Short Course

September 12-15, 2016 | University of Colorado at Boulder, CO

ASA is also a cosponsor for this Short Course. Breakthroughs in Tunneling covers all aspects of conventional and mechanized tunnel design and construction in hard rock, soft ground, and soils. This 3.5-day intensive Short Course brings experts together to present lectures on every aspect of mechanized and conventional tunneling.

Erratum

Corrections to Table 2: Average Flexural Strength for Tekcrete Fast in MPa (psi) from the Fall 2015 issue of *Shotcrete* magazine "Technical Tip" are reflected here.

Specimen type	Flexural strength, MPa (psi)		
	3 hours	1 day	7 days
Bars	8.3 (1200)	9.6 (1400)	11.7 (1700)

Interested in seeing your Association News in this column?

Visit **www.shotcrete.org/pages/products-services/shotcrete-magazine-authors.htm**, contact ASA via e-mail at info@shotcrete.org, or call (248) 848-3780 for more details.

Atlas Copco to Enhance Support for North American Construction Market with New LEED-Certified Facility

Atlas Copco is breaking ground on a new 180,000 ft^2 (17,000 m^2) facility in Rock Hill, SC, to meet the growing customer demand for high-quality equipment and support. The $20 million project will serve as the new production and assembly facility for Atlas Copco's North American Construction Technique division.

"From products to general support, we're committed to being close to the customer. This new facility will be one of our flagship sites when it comes to North American manufacturing excellence, including sustainable productivity, a goal we put forward for ourselves and our customers," said Erik Sparby, General Manager for Atlas Copco Construction Equipment.

Atlas Copco's new Leadership in Energy & Environmental Design-certified facility will help the company grow with customers' demands and offer a wide reach of customer support. Once completed, the Rock Hill facility will produce portable generators and compressors as well as other construction equipment. Atlas Copco expects the new facility to open in April 2017.

The building will be designed for lean manufacturing to enable efficient and flexible processes that are sustainable for the environment. The LEED-certified facility ties directly to Atlas Copco's mission of sustainable productivity.

Atlas Copco's new building will be located in one of Rock Hill's newest mixed-use developments, Riverwalk Business Park, and will replace the company's original facility in Rock Hill.

Atlas Copco Showcases New Electric Compressor at The Rental Show

Atlas Copco Construction Equipment featured its new XATS 900E electric portable air compressor for the North American market. The compressor features four preset flow and pressure selections to give contractors versatility and rental centers greater flexibility in their fleet offering for improved return on investment (ROI).

The compressor features a high-efficiency 160 kW WEG 22 motor. Despite the industry-wide focus on Tier 4 Final regulations, the XATS 900E's electric motor exempts it from emission regulations, so it's usable in any state, province, or territory. In addition, the electric motor gives contractors a cost-effective alternative to traditional diesel-fueled air compressors because electricity prices are less volatile than fuel costs. The XATS 900E operates at a very quiet 73 dB—about the same as a vacuum cleaner—which allows contractors to work in noise-sensitive areas, such as near hospitals or schools.

Atlas Copco designed the XATS 900E for dependable operation and high-quality results. For example, its Star-Delta starter reduces the starting current protecting the compressor and has no limits on number of starts. The compressor comes standard equipped with an aftercooler and water separator with fine filters to reduce moisture as well as oil carryover in the output air and bypass should nonfiltered air be desired.

The XATS 900E features an easy-to-use digital interface, main breaker, sequence phase relay, and external emergency stop button for simple controlling and monitoring of the unit. Operators can use the compressor's digital interface to set the airflow to one of the four preset flow and pressure ratings, which range from 879 to 906 ft^3/min (25 to 26 m^3/min) at 100 to 150 psi (0.7 to 1 MPa) discharge pressure. This essentially gives users four units in one, which allows rental companies to serve a wide range of customers with one machine, resulting in greater ROI.

Atlas Copco also designed the XATS 900E to be compact and robust. The compressor features a heavy-duty, galvanneal steel frame and enclosure, and with a footprint of just 44 ft^2 (4 m^2), it's easy to place at tight jobsites, such as a pit, factory, or warehouse. The compressor's small, durable structure also allows users to stack two high and fit as many as nine units on a 53 ft (16 m) trailer. This gives contractors and equipment managers a cost-effective option for transporting equipment. Additionally, operators can use it on nearly any type of surface because its frame does not require a concrete base. Atlas Copco also offers an optional dual-axle trailer for towing.

The XATS 900E's large doors provide full access to all maintenance and service points, all of which are on one side of the unit to minimize servicing time. The unit also has a heavy-duty air filter that features a safety cartridge, which protects it from the elements to ensure reliability in any environment. Its 100% spillage-free frame will contain all of the compressor's fluids—diesel, both engine and compressor oils, and engine coolant—if a leak occurs. This gives contractors peace of mind on environmentally sensitive projects.

Rental centers and contractors can move the unit with a crane and the compressor's lifting bale or with a forklift and its frame-incorporated forklift slots.

Canusa Introduces the New PDM-1 Continuous Pre-Dampener/Mixer

The PDM-1 unit can be used for both wet- and dry-mix applications, and is rated for 22,000 lb/h (1000 kg/h) continuous use.

The PDM-1 is very unique from other equipment claiming to offer the same results. The dictionary defines a screw conveyor as a device for moving loose materials, consisting of a shaft with a broad, helically wound blade rotating in a tube or trough. While other equipment manufacturers try to mix the materials with a screw conveyor, we use ours to move and meter loose material from the hopper up to our elevated mixing chamber.

The PDM-1 has a special mixer chamber that does all the work to continuously mix the materials. It can mix concrete consistently from a pre-moistened condition to a full wet-mix design. Once the machine is properly set up, there are no adjustments to make for day-to-day use.

Features:

- One-person operation.
- 12 V on/off operation and can be connected to other equipment to operate simultaneously.
- Can be operated by remote.
- Both wet- and dry-mix operation.
- One switch for total on/off operation.
- Designed for easy assembly and disassembly.
- Can be moved by forklift at mixer end.
- No wasted material and very minimal dust.
- Digital flow meter to measure water.
- Revolution counter to meter volume.
- Volume controls to meter speed of conveyor and mixer.
- Precise needle valves to meter water to mixer tub.
- Manual overrides in case of emergency.
- Forward and reverse functions for easy cleanup.
- Epoxy paint.
- Lower auger liner AR 450 and mixer tub AR 400.
- Auger screw uses AR 400 material with hard surface of the leading edge.
- Mixer paddles use AR 400 material with hard surface.
- Can use wide-throat bulk bags or small bags with a bag breaker.
- Weatherproof NEMA 4 control panel ULC and UL certified.
- High-capacity oil to water oil coolers.
- Hour meter/tachometer.
- Emergency stop button and safety cover switches.

The PDM-1 pre-dampener/mixer uses a dual hydraulic system with variable adjustable flow controls. Powered by either an electric- or diesel-powered motor, the simple design makes them easy to operate, troubleshoot, and service. A variety of slump output ranges for dry or wet mix makes the PDM-1 a top performer for any application.

Contact Canusa Equipment at (604) 526-5151 or visit **www.canusaequipment.com**.

Schwing Adds Tier IV Engine | SP 500 Stationary Pump

Schwing is now providing their popular SP 500 stationary concrete pump with a Tier IV-compliant Caterpillar diesel engine. This is a response to government-mandated reductions in harmful exhaust gases from diesel-powered equipment. The California Air Resource Board (CARB) requires Tier IV compliance for stationary pumps used on public and private projects. Other parts of the country are also requiring Tier IV compliance depending on the locale and project. The CAT® C3.4B diesel is rated at 74.5 hp while providing durability and fuel efficiency. Customers will enjoy unprecedented global parts, service, and repair options through the CAT® dealer network.

The SP 500 is a versatile machine with up to 45 yd^3/h (34 m^3/h) output and 1100 psi (8 MPa) maximum pressure on the material. The machine excels pumping grout, shotcrete, or concrete. The twin-cylinder, all-hydraulic pump handles up to 1.5 in. (38 mm) aggregate with its 6 in. (152 mm) diameter pumping cylinders operating through a 39 in. (1000 mm) stroke. Sequencing the concrete to the pumping cylinders is the rock valve that enjoys proven reliability on Schwing's largest concrete pumps. Besides pumping harsh mixtures, the rock valve cleans up faster, using less water for high utilization on multiple projects in a day. Dual-shifting cylinders provide positive valve actuation for smooth discharge. The open loop hydraulic system combines with the CAT engine to provide all-day economy from the 20 gal. (76 L) fuel tank.

Schwing SP models can be provided as skid-, truck-, or trailer-mounted units. A convenient control panel on the side of the machine includes switches for on/off, forward/reverse, and hopper agitator. Electric power is also available. A cable remote is standard with optional radio remote control.

For more information on the Tier IV compliant SP 500 and the entire line of Schwing stationary pumps, visit **www.schwing.com**.

Shotcrete FAQs

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

Question: *I just had a swimming pool built and everything I have read online says that the gunite shell has to be sprinkled with water for several days after the pour. My pool builder says they never do it, and, when I asked why, I'm just told that's the way they do it. I told them I am worried because every other pool builder says to do that except the one I hired and I can get no answer as to why. Is this an acceptable practice? I am worried that years down the line I may have a problem. I live in Oviedo, FL, and the weather has been in the low 70s and the humidity not particularly high. They did hit the water table and have a pump running—would any of this have an impact?*

Answer: ASA recommends a minimum of 7 days curing for all exposed shotcrete surfaces. Wet curing is preferred to supply additional water to the concrete surface. If a spray-on curing membrane is used instead of water curing, the material should be applied at twice the manufacturer's recommended rate for formed surfaces. Curing is important to allow the concrete to develop as much strength as possible and to help resist cracking from internal shrinkage of the concrete. Low humidity, wind, and exposure to sun will increase the need for proper curing. If the site is dewatered, the groundwater is below the concrete work, and not effective in curing the exposed shotcrete surface. The American Concrete Institute (ACI) has an excellent reference, ACI 308R-01, "Guide to Curing Concrete." It appears your contractor is not following the industry standards as documented by ACI.

Question*: Our shotcrete mixture needs to be NSF 61 certified. We have been able to obtain certification of all components with the exception of reinforced fiber. Is there or does fiber reinforcing need NSF 61 approval?*

Answer: Each manufacturer of concrete constituents needs to have their products tested by NSF if they want NSF 61 certification. Whether the fibers need NSF 61 certification is an issue with the local authority having jurisdiction for exposure of components to potable water supply systems in your state. Generally, this is the state EPA-type agency, but maybe a federal agency if on a federal project.

We don't maintain a database of manufacturer products that meet NSF 61. However, you can readily identify contacts for the fiber manufacturers who are ASA corporate members with our Buyers Guide at **www.shotcrete.org/pages/products-services/Buyers-Guide/index.asp**. When entering the Buyers Guide, you can select "Fiber + Reinforcement Sales" and the fiber type subcategory to get a list of our member fiber suppliers.

Question: *I am currently involved with the design of an unreinforced masonry building retrofit. Could you point me toward resources concerning the seismic behavior of a reinforced shotcrete masonry wall? I am interested in learning more about the force (shear) transfer between the masonry/shotcrete interfaces.*

Answer: Shotcrete is a placement method for concrete. Thus, seismic design for concrete is applicable to shotcrete placement. Here's a link to an article in the Winter 2009 issue of *Shotcrete* magazine, titled "Seismic Retrofit of Historic Wing Sang Building," that details the seismic retrofit of a brick building in Vancouver, BC, Canada: **www.shotcrete.org/media/Archive/2009Win_SCM01pg08-12.pdf**.

A second article from 1999, "Seismic Reinforcing of Masonry Walls with Shotcrete," also gives some input on the design: **www.shotcrete.org/media/Archive/1999Fal_Snow.pdf**. In general, the structural engineer must evaluate the condition of the existing masonry structure and determine whether the added shotcrete sections will be supplementing the existing capacity or providing the full resistance to seismic loads.

Question*: I had a concrete pool shell installed using gunite (dry shotcrete method) in July 2013. It was never finished due to unfortunate circumstances and has been exposed to the elements of weather over the last 2 years, mostly filled up with water from rain and, in the colder months, frozen like a pond. We would like to finish the pool but were told by the pool company that the concrete looked odd and we should have it strength tested. We had core samples taken from the walls and floor from a certified testing lab. The results from the six samples ranged from 1700 to 2200 psi (12 to15 MPa). When the pool was blown on July 3, 2013, it was to achieve 4000 psi (28 MPa) compressive strength in 28 days. Is it normal for the shotcrete strength to have weakened so much?*

Answer: Properly produced concrete material shotcreted in place should gain strength over time, not lose strength. ASA recommends that concrete placed by the shotcrete method have a minimum compressive strength at 28 days of 4000 psi (28 MPa). Coring does damage the sample somewhat, so it is common to require core strength to meet 85% of the specified compressive strength. Cores should be no less than a nominal 3 in. (76 mm) in diameter for representative results because smaller cores (less than 3 in. [76 mm] diameter) are more subject to damage from the core extraction, affecting the reported strength. Thus, at 85% of 4000 psi (28 MPa) the minimum should be 3400 psi (23 MPa). Based on the reported values, and assuming a 3 in. (76 mm) diameter or greater core, the concrete strength is well below ASA's recommended strength, and the strength you originally specified in 2013.

Question*: We have a pool designed with the cast-in-place concrete construction method in mind. The project has been awarded to a dry-mix gunite contractor. To accommodate the* *contractor's placement method, we have been working with him on the details. They are planning on casting the floor and shooting the walls.*

There are two main areas of concern/questions that we have. First is in regard to the air entrainment and the admixtures that are appropriate for gunite. They have not used air-entrainment admixtures prior to this project. What is the effect to durability without using air? What are the workability effects of adding air entrainment? Which product is recommended? Second, we have specified a hydrophilic waterstop between the cast-in-place floor and the wall. With the walls using a gunite application, what is the best method for preventing water infiltration in the construction joint? Does it hurt the integrity of the joint by installing a hydrophilic waterstop? If the water stop is omitted, what does the surface roughness need to be to provide a monolithic-type connection?

Answer: Air entrainment will generally slightly reduce the compressive strength of concrete, but significantly increase the resistance to freezing-and-thawing exposure. Dry-mix shotcrete (gunite) is generally a very paste-rich mixture. With modern cements, the normal 28-day compressive strengths easily exceed commonly specified compressive strengths. ASA recommends a minimum of 4000 psi (28 MPa) for shotcrete, and 4000 psi to 5000 psi (28 to 34 MPa) strengths are routinely specified.

1. Air entrainment increases the workability. The small air bubbles act as a form of lubricant to ease internal friction between the concrete mixture components.
2. You should contact one of our material supplier members to see what they offer. You can use our Buyers Guide at **www.shotcrete.org/pages/products-services/Buyers-Guide/index.asp**, and limit your search to "Admixture Sales" with the "Air-Entraining" subcategory.
3. Quality shotcrete shot against a properly prepared concrete substrate should produce a watertight interface. The hydrophilic waterstop at the joint could be considered a secondary method of making the joint watertight. Though not necessary, it is kind of a "belt and suspenders" approach with a relatively low cost to place.
4. In shotcrete construction, surface preparation between layers to provide full bond is important. ACI 506.2-13, "Specification for Shotcrete," specifically addresses this in the requirements of Sections 3.4.2.1 and 3.4.2.2 that state:

"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, 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 condition at the time of application of the next layer of shotcrete."

For more details on bond between shotcrete layers, you may want to refer to an article in the Spring 2014 issue of *Shotcrete* magazine, "Shotcrete Placed in Multiple Layers does NOT Create Cold Joints." A PDF of the article can be found at **www.shotcrete.org/media/Archive/2014Spr_TechnicalTip.pdf**.

Shotcrete Calendar

JULY 25-29, 2016
PCA's Professors' Workshop
Portland Cement Association
Skokie, IL
www.cement.org

Shotcrete course on Thursday, July 27, 2016

JUNE 26-29, 2016
ASTM International Committee C09, Concrete and Concrete Aggregates
Chicago Marriott Downtown Magnificent Mile
Chicago, IL
www.astm.org

AUGUST 28-31, 2016
AREMA 2016 Annual Conference & Exposition
Visit ASA at Booth #1002
Hilton Orlando
Orlando, FL
www.arema.org

SEPTEMBER 7-8, 2016
SPACE Shotcrete Annual Short Course
Co-sponsored by ASA
Colorado School of Mines
Golden, CO
www.csmspace.com

SEPTEMBER 8-9, 2016
SDC Technology Forum #40
DoubleTree Salt Lake City Airport
Salt Lake City, UT
www.concretesdc.org

SEPTEMBER 12-15, 2016
Breakthroughs in Tunneling Short Course
Co-sponsored by ASA
Use discount code: "network"
University of Colorado Boulder
Boulder, CO
www.tunnelingshortcourse.com

OCTOBER 3, 2015
2016 Entry Deadline for ASA Outstanding Shotcrete Project Awards Program
www.shotcrete.org/ASAOutstandingProjects

OCTOBER 22, 2016
ASA Fall 2016 Committee Meetings
Marriott Philadelphia
Philadelphia, PA
www.shotcrete.org

OCTOBER 23-27, 2016
The ACI Concrete Convention and Exposition
Theme: "Revolutionary Concrete"
Marriott Philadelphia
Philadelphia, PA
www.concrete.org

NOVEMBER 2-4, 2016
International Pool | Spa | Patio Expo
Theme: "Where it all comes together"
Ernest N. Morial Convention Center
New Orleans, LA
www.poolspapatio.com

NOVEMBER 9-11, 2016
ICRI 2016 Fall Convention
Theme: "Urban Reconstruction"
The Westin Cleveland Downtown
Cleveland, OH
www.icri.org

DECEMBER 4-9, 2016
ASTM International Committee C09, Concrete and Concrete Aggregates
Renaissance Orlando at SeaWorld
Orlando, FL
www.astm.org

JANUARY 16, 2017
ASA Committee Meetings at World of Concrete
Las Vegas Convention Center
Las Vegas, NV
www.shotcrete.org

JANUARY 17-20, 2017
World of Concrete 2017
Visit ASA's Booth #S10839
Las Vegas Convention Center
Las Vegas, NV
www.worldofconcrete.com

MARCH 25, 2017
ASA Spring 2017 Committee Meetings
Marriott Detroit at the Renaissance Center
Detroit, MI
www.shotcrete.org

MARCH 26-30, 2017
The ACI Concrete Convention and Exposition
Theme: "Driving Concrete Technology"
Marriott Detroit at the Renaissance Center
Detroit, MI
www.concrete.org

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CORPORATE MEMBERS

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