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A quarterly publication of the American Shotcrete Association

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shotcrete MAGAZINE

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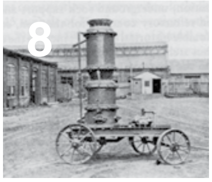
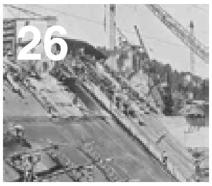
FEATURES





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

American Shotcrete Association
401 Edgewater Place, Suite 600
Wakefield, MA 01880
Phone: 248.963.0210
E-mail: info@shotcrete.org
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Editor's Note: Shotcrete is a placement method for concrete. However, for the sake of readability, the word "shotcrete" is often used either to identify the shotcrete process (method of placement) or the shotcrete mixture (product materials).

Executive Director
Charles Hanskat

Editor-in-Chief
Charles Hanskat

Managing Editor
Tosha Holden

Senior Editor
Alice McComas

Graphic Design
Marci Moon

DEPARTMENTS

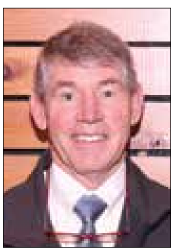
Collage of past Shotcrete magazine issues

As a commemorative issue, we will not be including some of our normal columns including:

- Association News
- Industry News
- New Products and Processes
- FAQs
- Sustaining and Corporate Member Profiles
- New Members

Looking Forward, ASA's Strategic Planning

By Lars Balck



Twenty-five years ago, Milt Colins brought together Shotcrete contractors, engineers, and suppliers (mostly ACI 506 committee members) and encouraged them to start a shotcrete trade association. The association's purpose was to improve the safety, productivity, and quality of shotcrete. Over the past twenty-five years ASA has:

- Published Shotcrete magazines since 1999 with an average of 10 articles per quarter
- Educated and certified 4865 ACI Nozzleman in the last dozen years alone.
- Educated 43 Inspectors have passed the Shotcrete Inspector exam
- Reviewed 9 firms who have passed the ASA Qualified Contactor Review
- Exposed thousands of owners, engineers and specifiers to "Introduction to Shotcrete" seminar
- Gotten ACI 318 to incorporate "Shotcrete" as a placement method
- Conducted three Strategic Planning sessions
- Hosted 4 Shotcrete conventions encouraging networking and exchange of ideas
- Published "Shotcrete Safety Guidelines"
- Conduct 18 "Shotcrete Awards programs" recognizing several dozen contractors for outstanding shotcrete work
- During this time membership has gone from 3 to 870 members

These accomplishments are due to the work of many volunteer members donating their time. One of the most difficult and important, but often thankless tasks, is producing the quarterly magazine Shotcrete. Shotcreters read the magazine cover to cover. Their business is shotcreting, so they are eager to learn how to improve. Getting volunteers, who are busy running their own businesses, to write articles is difficult. We have had the fortune to have several great editors. Mark Jolin was the Shotcrete magazine editor for the first 12 years before Charles Hanskat took over. Please give them your thanks.

Thanks also go to our dedicated staff: Charles Hanskat, our Executive & Technical Director who leads the efforts in shotcrete's acceptance and inclusion in standards development codes, marketing efforts to engineers and public authorities, and general leadership in all ASA programs and activities. Alice McComas our Assistant Director who runs the complex and important ACI/ASA Shotcrete Nozzleman certification program. Alice also administers the Contractor Qualification and the Shotcrete Inspector programs Tosha Holden, as Managing Editor & Marketing Manager, oversees the details for producing *Shotcrete* magazine, manages ASA's presence in social media and administers the Outstanding Shotcrete Project Awards program.

Shotcrete has changed with advances in chemistry and technology. More changes are ahead. Robotics or mechanically assisted placement is increasing and will impact the shotcrete industry

Going forward please give Frank Townsend, our incoming president, your support by getting involved. As several presidents before me have expressed, "Don't silently sit on the back row. Get involved! If you don't, you will miss out on the changes coming to shotcrete."

Education and Safety Committee

By Oscar Duckworth, Education and Safety Committee Chair

knowl·edge [näləj']
(noun) *knowledge; facts, information, or skills acquired by a person through experience or education.*

All of us within the shotcrete industry have one thing in common, shotcrete knowledge. Whether in an office, or operating a shovel, we all started somewhere. What we did from that point forward, was strongly influenced by the knowledge we received. Where have you received your knowledge?

THE TRUE VALUE OF SOMETHING THAT COSTS NOTHING

Have you ever wondered why that shotcrete project didn't quite go the way you had hoped? I'm embarrassed to admit it, but at the beginning of my career, that occurred far too often. When I initially entered the shotcrete trade, one thing which became painfully clear was… Although my competitors appeared quite anxious to tell me where to go, they certainly were not going to teach me anything (constructive).

Back then, trial and error and the ever popular - learn while we earn, might have best described our work, since few shotcrete educational and training resources were available.

In 1999 the American Shotcrete Association's founders launched the inaugural Shotcrete magazine. It was populated with numerous articles, case studies, and valuable information regarding the shotcrete process and its innovative uses. In its first year it won an award for New Magazines and Journals in the APEX 1999 Eleventh Annal Awards for Publications Excellence. Through immense volunteer effort, these dedicated founders formed the building blocks of what is now the world's largest shotcrete knowledge resource.

I'm uniquely qualified to write the foreword to this very special edition, not due to my successes, but due to my failures—and how eagerly reading each edition cover to cover provided an invaluable wealth of knowledge to help master a complex craft—all delivered to me at no cost.

"The Shotcrete Magazine has been one of the most influential elements to mastery of my craft."

A person with an average reading speed can read every article within each edition in a few hours, making significant contributions and gaining valuable insights to grow your personal shotcrete knowledge base.

Enjoy the next two issues of Shotcrete magazine which will feature 25 of the most popular shotcrete articles printed over these past 25 years, in honor of ASA's 25th Anniversary!

ASA EDUCATION AND SAFETY COMMITTEE

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Derek Pay | Oceanside Construction - Secretary

Lars Balck | Retired
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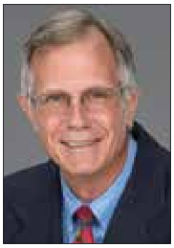
Looking Back and Moving Forward

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



This year our American Shotcrete Association celebrates 25 years of advancing shotcrete. And not just our Association, but the overall shotcrete industry. How did we get here? Though shotcrete is the most creative and efficient concrete placement method, increased adoption and applications do not happen solely by shotcrete's inherent benefits. Our gains happened because of the people in our industry, and our dedicated ASA members.

We started as an Association because our founders in 1998 knew deep down that shotcrete needed a forum to educate and promote our industry. They recognized that a trade association would be the best vehicle for working together and providing the owner and engineering community with a unified voice for the benefits, quality, and efficiency of shotcrete placement. Within a year of its formation, ASA had gained 51 Corporate members and 14 Individual members. Some of those Charter members have passed away, some retired, and some moved on to other challenges, but many are still active and involved in ASA.

As a prime example, our past president Lars Balck was a Charter member, served as our first president, and then after retiring from his firm, served two additional years as our 2021 and 2022 president. Lars has also given decades of service to ACI Committee 506 to help create and update the technical documents that address shotcrete placement. Thank you, Lars. Check out the President's Message in this issue from Lars to learn about some of the significant advancements ASA has made as an Association in the last 25 years.

Of note, and worth repeating, has been ASA's desire and success in advancing shotcrete knowledge and acceptance. We've

- Had strong involvement with ACI to create, administer and update the ACI Nozzleman Certification program. There are over 1800 ACI-certified Shotcrete Nozzleman worldwide in the program, which is now over 20 years old.
- Creating the only magazine, Shotcrete, dedicated to the shotcrete industry. Look at our Committee Chair memo from Oscar Duckworth in this issue for background on the creation and value of Shotcrete magazine to the concrete construction industry.
- Working with ACI to develop the Shotcrete Inspector certification with ASA producing a full-day educational seminar for inspectors.
- Creating liaisons with standards-developing organizations to ensure those codes, standards, reports, and guides include and properly cover shotcrete. We have ASA members with active involvement with ACI, ASTM, ICRI, AREMA, and TRB.
- Starting an annual ASA Convention and Technical Conference. The first one was in 2018, celebrating our 20th anniversary. This annual event is a great forum to learn more about shotcrete with technical sessions, committee meetings, exhibitors, food, and networking.
- Building our Outstanding Shotcrete Project awards program, now in its 18th year, highlighting the best of the best in shotcrete from around the world and in a wide variety of applications.
- Developing the ASA Qualified Shotcrete Contractor program to help owners and specifiers easily identify established shotcrete contractors who have demonstrated quality in their shotcrete work.

Of course, no association does good things without the support of staff. We couldn't have advanced to where we are today without the dedication, resourcefulness, knowledge, and efficiency of our Assistant Executive Director, Alice McComas. Alice has guided ASA in our certification, education, convention, magazine, awards, and administrative tasks for over a decade. Tosha Holden joined us three years ago as Marketing and Magazine Manager. She has advanced ASA in social media, kept our flagship magazine, Shotcrete moving forward, and administered our Outstanding Shotcrete Awards program.

We have much to be proud of in reaching our 25th anniversary. In my long experience in the concrete industry, there is no other group of contractors, engineers, and educators who have exemplified their dedication and passion for their profession than our ASA members. Together as members and staff, we are ASA, and working together, we definitely have a bright future ahead.

asa Sustaining Corporate Members

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

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Featured in Volume 19, Number 4 • Fall 2017

A Brief History of Shotcrete in the Underground Industry

By Dudley R. (Rusty) Morgan and E. Stefan Bernard

It is now generally recognized that Carl Ethan Akeley (1864-1926) was the inventor of shotcrete (Teichert 2002). The process was originally developed for application of plaster to rehabilitate the façade of a building at the Field Columbian Museum in Chicago, IL, but was soon used to apply cementitious materials to various substrates, including wire and cloth substrates for building anatomical models of animals for museum exhibits. The gun invented by Akeley (Fig. 1) operated on the principle of a double chamber. The chambers were placed one on top of the other and were alternatively pressurized with compressed air. One of its earliest underground uses was for lining the Hunter's Brook Siphon for New York Water Supply.

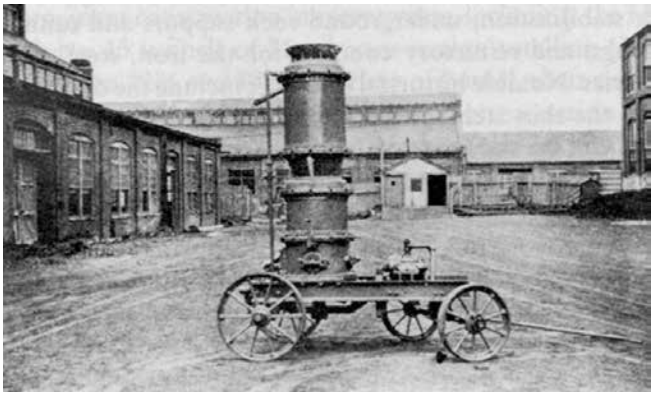

Fig. 1: Original double-chamber gun developed by Carl Akeley in 1907

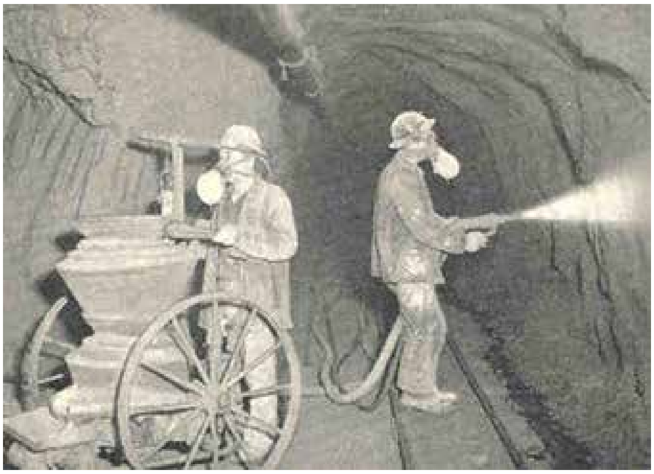

Fig. 2: Lining a tunnel with gunite using a double-chamber gun in the 1920s

In 1912, the Cement Gun Company in Allentown, PA, acquired the rights to Akeley's patents for the cement gun and trademarked "gunite." The gunite process found use in a wide variety of applications, including lining of sewer, water, and railway tunnels; ground support in mines; construction and repair of buildings; protection of structural steel against corrosion and fire damage; repair of bridges, dams, and canals; rock slope stabilization; and construction of water-retaining structures.

By the early 1920s, the use of gunite (Fig. 2) was widespread throughout North America and had expanded to Germany (1921), the United Kingdom (1924), and by the end of the decade, to other countries in Europe as well as India and South Africa. The use of the gunite process continued to expand throughout the world during the 1930s and 1940s, with the double-pressure chamber gun the predominant method for material delivery.

In the early 1930s, the American Railway Engineering Association adopted the term "shotcrete" to describe the dry-mix process and in 1951, the American Concrete Institute (ACI), to standardize terminology, also adopted the term "shotcrete." Initially, the term "shotcrete" applied only to the dry-mix process, but after World War II, with the development of the wet-mix process, ACI adopted the term "wet-mix shotcrete." In Europe, the term "sprayed concrete" is generally used instead of shotcrete.

MAJOR DEVELOPMENTS IN TECHNOLOGY

The development of shotcrete and its application in underground construction has been improved through the advent of a succession of key technologies. These include:

Wet-Mix Shotcrete

A major revolution in the shotcrete industry occurred with the development of the wet-mix shotcrete process. Various individuals and companies had experimented with this process as far back as the 1920s (Sprayed Concrete Association 1999), but it was not until the mid-1950s that the wet-mix process started to find significant application. Numerous equipment manufacturers modified concrete pump designs to make them better suited to wet-mix shotcrete application. It was primarily the development of the swing-tube concrete pump in the late 1970s (Fig. 3) that really made wet-mix shotcrete practical (Yoggy 2002). The cylinders were sized to make them suitable for conveying shotcrete at a rate that could be managed by a nozzleman for hand application. The rate of cycling of the swing tube controlled the surge and volume of shotcrete delivered per minute. With these refinements, the nozzleman could maintain precise control over placement of concrete in a wide range of different shooting conditions (for example, vertical, overhead, downward, open shooting, or shooting congested reinforcing steel and embedments) at a rate of productivity of about four times what was possible by the dry-mix shotcrete process. With the subsequent introduction of robotic manipulators in Norway (Woldmo 2008), which typically used bigger pumps and larger-diameter hoses, even greater rates of production were achievable. These machines are now used throughout the world.

Steel Fiber Reinforcement

The concept of reinforcing shotcrete with discreet, discontinuous fibers was first developed by the Batelle Research Corporation in the United States in 1971 (Morgan 2000). The first practical application of steel fiber-reinforced shotcrete (FRS) in North America was in 1972, when it was used by the U.S. Army Corps of Engineers for rock slope stabilization and lining a tunnel adit at the Ririe Dam on Willow Creek, a tributary of the Snake River in Idaho (Kaden 1974). The first use of steel FRS in Canada was in 1978, when it was used to stabilize a sloughing railway embankment in Burnaby, BC, Canada (Fig. 4).

Synthetic Fiber Reinforcement

Synthetic fiber-reinforced shotcrete first appeared in the 1990s as manufacturers developed products to compete with steel fibers (Bernard et al. 2014). There are basically two types of synthetic fibers: microfibers and macrofibers. Microsynthetic fibers can be used in both wet- and dry-mix shotcretes, but macrosynthetic fibers are mainly used in wet-mix shotcrete. Microsynthetic fibers are typically used at low addition rates of 1.7 to 3.4 lb/yd^3 (1 to 2 kg/m^3) to improve resistance to plastic shrinkage cracking, but in shotcrete they have primarily been found effective in increasing resistance to explosive spalling in tunnel linings subjected to high-temperature fires (Tatnall 2002). Macrosynthetic fibers are used at much higher addition rates of 5 to 15 lb/yd^3 (3 to 9 kg/m^3) and are employed for many of the same reasons as steel fiber reinforcement—for example, to improve toughness (residual load-carrying capacity after cracking) and impact resistance (Morgan et al. 1999; Morgan 2000).

Silica Fume

A milestone in the development of shotcrete technology was the incorporation of condensed silica fume as a supplementary cementitious material in the shotcrete mixture. This was first undertaken in Norway in 1975 (Garshol 1990). The first application of silica fume in shotcrete in Canada was in 1984, when it was used in shotcrete rehabilitation of a pier in the intertidal region in Vancouver Harbour, BC, Canada (Morgan 1995). It was found that the use of silica fume had major benefits, including enhanced adhesion and cohesion, with reduced rebound and fallout in the plastic shotcrete and increased strength and durability in the hardened shotcrete.

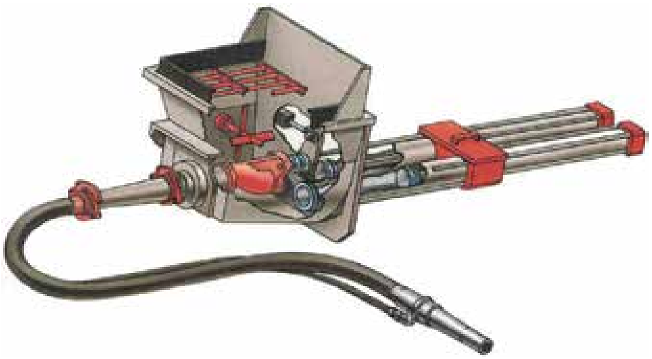

Fig. 3: Schematic of a wet-mix shotcrete pump with swing tube

Fig. 4: Dry-mix steel FRS lining of a railway embankment in Burnaby, BC, Canada, in 1978

Air-Entraining Admixtures

Air-entraining admixtures have been used in wet-mix shotcrete to provide freezing-and-thawing durability since the development of wet-mix shotcrete in the mid-1950s. Research at Laval University in Quebec, Canada, in the late 1980s and early 1990s showed that it was possible to entrain sufficient air in dry-mix shotcrete to provide good freezing-and-thawing durability and resistance to deicing salt scaling (Beaupre et al. 1994). Currently, most dry-bagged shotcrete materials for exterior applications in frost exposure environments are batched with dry powdered air-entraining admixtures (Vezina 2001).

Water-Reducing Admixtures

Conventional water-reducing admixtures have been used in wet-mix shotcretes since the 1950s. However, with the introduction of silica fume into shotcrete applications in North America in the mid-1980s, the use of conventional water-reducing admixtures alone was often insufficient to reduce water demand to the extent needed to provide a suitably low water-binder ratio (*w/b*). Therefore, in the mid-1980s, high-range water-reducing admixtures (also called superplasticizers) started to be used in conjunction with conventional water-reducing admixtures in wet-mix silica fume shotcretes.

Retarders and Hydration Controlling Admixtures

Wet-mix shotcretes typically take longer to discharge from transit mixers than conventional concretes because of the requirement to control the rate at which shotcrete is supplied to the nozzle. Thus, set-retarding admixtures have often been added to wet-mix shotcrete mixtures to extend the workability (pumpability) of the mixture, particularly in hot weather conditions. Conventional set retarders have, however, had their limitations, particularly in tunnel and mining applications, where there are often long delays (sometimes 4 to 8 hours) from the time of batching to completion of discharge of the shotcrete. The introduction of hydration controlling admixtures in the 2000s had a major beneficial effect on the shotcrete industry. It is now possible to put the shotcrete "to sleep" for 12 hours (or even longer, if required) and then instantly wake it up with shotcrete accelerator addition at the nozzle.

Shotcrete Set Accelerators—Underground

Shotcrete set accelerators are an essential component of shotcrete in underground applications, particularly for overhead applications in tunnels and mines. In dry-mix shotcrete, they can be added either as dry powdered materials to the dry-mix shotcrete materials before introduction into the shotcrete gun, or as liquids added at the shotcrete nozzle. In wet-mix shotcretes, they are added as liquids at the shotcrete nozzle (Fig. 5). Early (circa 1960s to 1990s) dry-mix shotcrete accelerators were mainly highly alkaline (>12 pH) sodium or potassium-aluminate-based dry-powdered products, or liquid-alkaline-sodium-silicate-based products. These tended to have detrimental effects on the longer-term compressive strength, permeability, and durability of the shotcrete, with the effect being more pronounced the greater the accelerator addition rate. A major advance in shotcrete technology was the introduction in the 2000s of so-called "alkali-free" shotcrete accelerators. These liquid accelerators are mainly based on aqueous solutions or suspensions of aluminum sulfate compounds and have a pH of approximately 3. They have less negative effect on the compressive strength, permeability, and durability of shotcrete (Millette and Jolin 2014) and are compatible with most hydration-controlling admixtures. They are now used widely throughout the world in underground applications.

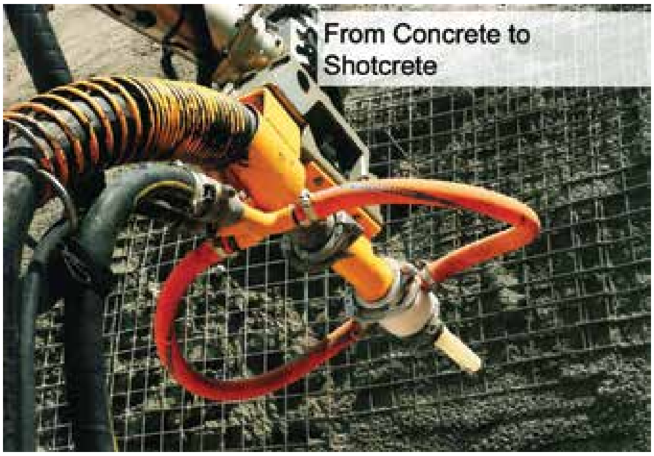

Fig. 5: Accelerator addition at nozzle in remote control wet-mix shotcrete

Fig. 6: Hand application of dry-mix shotcrete in a tunnel in British Columbia, Canada, in the 1970s

SHOTCRETE IN TUNNELS

The first reported use of shotcrete for underground support in North America was the use of gunite (dry-mix shotcrete) in the Brucetown Experimental Mine in 1914. It was used primarily to protect and maintain excavated rock surfaces from deterioration from exposure to water and air (Kobler 1966). Thereafter, for the next three decades, gunite continued to be used in underground applications in many tunnels and mines across North America, although mainly in semi-structural applications (Fig. 6).

Critical to the use of shotcrete in underground support was the development of design methodologies that allowed engineers to replace conventional steel sets and timber lagging-type designs, or cast-in-place reinforced concrete lining designs with rock bolt and shotcrete designs. Preeminent among these design methodologies was the so-called New Austrian Tunneling Method (NATM), which was developed by Rabcewicz and his colleagues in Austria in the late 1950s and early 1960s (Rabcewicz 1964, 1965). This was followed by the development of the so-called Norwegian Method of Tunneling (NMT) in the 1970s (Barton et al. 1995).

In North America, dry-mix shotcrete in conjunction with rock bolts and mesh reinforcement and other types of reinforcement (for example, lattice girders and/or steel sets) was used in construction of eleven Washington, DC, subway stations during the 1970s and 1980s (Plotkin 1981). In Canada, permanent dry-mix coarse aggregate shotcrete linings with mesh reinforcement and rock bolts was used in construction of the Canadian National Railways Tunnel (the Thornton Tunnel) near the Burrard inlet in Vancouver, BC, Canada in 1968 (Mason 1968). Also, mesh-reinforced dry-mix coarse aggregate shotcrete, in conjunction with steel sets, was used in construction of reinforced linings in a subway tunnel in Toronto in 1961 (Kobler 1966). The first major use of the NATM process in Canada (although the designers referred to it as the Sequential Excavation

Method [SEM]), was construction of the underground Grandin Metro Station in soft ground in downtown Edmonton, AB, Canada (Brandt and Phelps 1989).

NEW AUSTRIAN TUNNELING METHOD (NATM)

The NATM method was primarily developed for tunneling in weak or squeezing ground. Many hundreds of different tunnels and other underground openings have been constructed using the NATM method, most of them successfully (ITA-Austria 2012), but with some notable failures (Institution of Civil Engineers 1996). Conceptually, the NATM process involves stabilizing the ground around an underground excavation in the most safe and economic manner possible by using the bearing capacity of the ground with the help of shotcrete and other support elements, together with continuous measurement of ground and lining deformations and stresses during the construction process.

The Austrian Chapter of the International Tunneling Association publication *50 Years of NATM* (ITA-Austria 2012) provides many examples worldwide of completed NATM projects. It provides a comprehensive overview of the historical development and advances in the use of the NATM process over a 50-year period. In the United Kingdom, the term "sprayed concrete lining" (SCM) is sometimes used to describe the NATM process. In North America, the term "sequential excavation method" (SEM) is sometimes used to describe the NATM process.

Barton et al. (1995) provides a useful summary of the principles of NATM design together with some examples of different NATM projects. In Scandinavia (Barton et al. 1995) and North America (Chan et al. 2002a,b), permanent shotcrete linings with high quality, low permeability, low leachability, and good durability were being produced in the 1980s for underground support in tunnels and mines using steel fiber and silica fume. These projects demonstrated that it was possible to provide high-quality, permanent, durable shotcrete linings, with shotcrete mixtures well-suited to the construction process, using either the wet- or dry-mix shotcrete processes. These findings gave rise to an interest in the concept of a single shell shotcrete lining—that is, a lining comprised of a high-quality initial shotcrete lining (with or without a waterproofing membrane) and a final (inner) reinforced permanent shotcrete lining in lieu of a cast-in-place final concrete lining.

NORWEGIAN METHOD OF TUNNELING (NMT)

Much of the tunneling work done in the Scandinavian countries has been in harder, jointed rock, which had been excavated using drill and blast methods. This excavation process often resulted in overbreak, with irregular rock surface profiles. Such excavation profiles are not well-suited for use of the NATM process (Barton et al. 1995). Prior to the 1970s, such drill and blast-excavated tunnels, where required, were supported by rock bolts and mesh covered with a plain shotcrete. These single shotcrete lining systems, while they worked reasonably well, were not optimal from either a cost or technical performance perspective. This is because of the large volumes of shotcrete required to fill the voids behind the mesh, as well as the difficulties sometimes encountered in getting good bond of the shotcrete to the rock behind the mesh and fully encapsulating the mesh. With the advent of steel FRS in the 1970s (Vandewalle 1990), and later macrosynthetic FRS (Bernard et al. 2014), these concerns could be ameliorated.

These advances were critical in the development of the Norwegian Method of Tunneling (NMT) as we know it today. The NMT is based on a quantitative (numerical) rock mass classification system (the so-called Q-System), developed by Barton and his colleagues (Barton et al. 1974; Grimstad and Barton 1993). Briefly, this design method makes recommendations for various reinforcement categories depending on rock mass classifications (rock classes varying from exceptionally good to exceptionally poor), and the underground opening span or height divided by the excavation support ratio (ESR). Papworth (2002) published a modified version of the Q-system (Fig. 7) in which recommended toughness requirements were added based on tests conducted on FRS in accordance with ASTM C1550. There were some merits in this recommendation, but more appropriately, the varying energy requirements for FRS in Joules are best included in the different envelopes. By 2005, macrosynthetic FRS was becoming widely used underground, so the modifications suggested by Papworth (2002) were applied to shotcrete reinforced with both steel and macrosynthetic fibers.

The Q-System for rock mass classification has now been used for over 40 years for assisting in selection of reinforcement systems for rock tunnels and caverns. During the past 30 years, the use of mesh reinforcement has been largely eliminated in Scandinavia and most NMT tunnel design has been based on the use of FRS reinforced with either steel

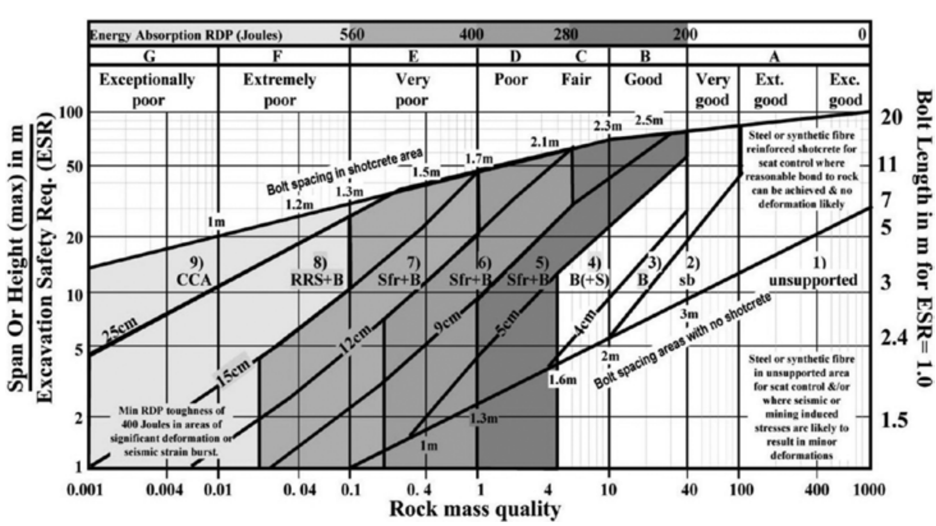

Fig. 7: Modified Barton Q-System Chart (Papworth 2002)

or macrosynthetic fibers. Many hundreds of underground structures and thousands of miles (km) of tunnels have been successfully constructed using the single-shell FRS NMT method in Scandinavia and elsewhere (Barton and Grimstad 2014). Much of the tunneling work carried out in hard rock tunnels and mines in North America since the early 1980s has also used FRS in single-shell lining systems analogous to the NMT designs.

Shotcrete in Mining

The original sand-cement gunite (dry-mix shotcrete) system developed by Carl Akeley was used, albeit with advances in shotcrete mixture designs and application equipment, in underground mines in North America and elsewhere from 1911 through to the 1950s. During this period, however, it was not the primary means of ground support and control in underground mines. Traditional ground support and control methods, such as timber and/or steel sets and timber lagging and rock bolts and screen (heavy-duty wire mesh) were the predominant methods used. Gunite was used as an auxiliary component of the support system in selected applications. During the 1950s to 1980s, most shotcrete applied in underground mines was dry-mix shotcrete applied by handheld nozzles. By the early 1980s, however, specialized shotcrete-spraying remotely controlled manipulators started to be used in mines (FIg. 8) in both aboveground and underground applications (Rispin et al. 2005).

Fig. 8: Remote control wet-mix FRS ground support in mine in North America

Fig. 9: Large underground opening for workshop in mine in Sudbury, ON, Canada, lined with macrosynthetic FRS

This acceptance was not without its challenges, as initially many miners were skeptical about the ability of a relatively thin layer of reinforced shotcrete (typically 2 to 4 in. [50 to 100 mm] thick) to support the ground in challenging mining environments with high ground stresses and deformations and seismic (rock-burst) conditions. They were used to observing problem areas in the mines by the "loose" (fallen chunks of rock) found hanging in the overhead screen and many looked at shotcrete as hiding potential problem areas. It took many training sessions and seminars and case history examples to demonstrate the theory of how shotcrete worked to provide ground control and how it helped in locating problem areas by identifying visible cracks in the shotcrete when there was significant ground movement (Larsen et al. 2009). Ground support strengthening could then be installed in areas where the shotcrete displayed significant cracking. Thompson et al. (2009) provided a useful overview of how cracks develop in shotcrete in rock under high stress and dynamic conditions and what constitutes significant cracking that would give rise to the need for remedial works.

By the 1990s, wet-mix robotically applied shotcrete was enjoying widespread use in many of the world's large mechanized underground mines (Fig. 9). Larsen et al. (2009) reported that in the 2000s, the Vale Inco Frood and Stobie underground mines used between 7800 and 10,500 yd^3 (6000 and 8000 m^3) per year of robotically applied wet-mix FRS. In Australia, since 2000, approximately 650,000 yd^3 (500,000 m^3) of wet-mix FRS (initially steel fiber-reinforced but now almost all macrosynthetic fiber-reinforced) are applied annually in metalliferous mines (Bernard et al. 2014). Macro-synthetic FRS is also developing as an essential component of ground support and methane gas control in underground coal mines, replacing the previous reliance on mesh and stone flour.

Summary

Shotcrete has come a long way since it was first developed by Carl Akeley in 1907. Modern underground support systems in tunnels such as NATM and NMT would not be possible without the use of shotcrete. Also, there are many underground mines around the world that would not exist were it not for the use of shotcrete to support underground openings during the mining cycle.

Acknowledgments

The photographs in this paper are provided by the courtesy of the American Shotcrete Association.

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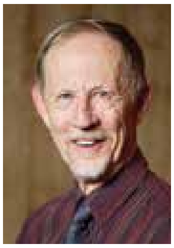

Dudley R. (Rusty) Morgan*, PhD, P.Eng, FACI, is a civil engineer with over 50 years of experience in the concrete and shotcrete industries. He is a Fellow of the American Concrete Institute and was a member and Secretary of ACI Committee 506, Shotcreting, for over 25 years. He was a member of ACI Committees 365, Service Life Prediction, and 544, Fiber-Reinforced Concrete. Morgan is a Founding Member and Past President of ASA. He is an ACI Committee C660 approved Shotcrete Nozzleman Examiner and presenter for the ASA Shotcrete Nozzleman Education course. He is a past member of the Canadian Standards Association Concrete Steering Committee and was Canadian Representative on the International Tunneling Association Committee: Shotcrete Use. Morgan has worked on over 1000 concrete and shotcrete projects around the world during his consulting career and has edited five books and published over 150 papers on various aspects of concrete and shotcrete technology. In 2001, he was elected as a Fellow of the Canadian Academy of Engineering.*

E. Stefan Bernard *is Chair of the Australian Shotcrete Society, Vice Chair of the ITA WG12 on sprayed concrete, and a member of ASTM Subcommittee C9.42 on FRC and RILEM. He is active as both a researcher and consultant on all aspects of shotcrete use and design and is also involved with developing and understanding test methods for fiber-reinforced concrete.*

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History of ASA

By Scott Rand

Much of the initial credit for the creation of the American Shotcrete Association (ASA) goes to Milt Collins. Collins was managing the International Concrete Repair Institute (ICRI) back in the late 1990s and had been talking about the concept of a trade association for the shotcrete industry for a couple of years. In 1997, he approached George Yoggy and Pete Tatnall with his thoughts, even going to the extent of arranging and financing the first meeting at his own expense. There was terrific interest and the Association was chartered in March 1998 with the mission to "promote shotcrete." The first formal ASA general membership meeting was held later that year, just prior to the 1998 ACI Fall Convention in Los Angeles, CA. The Association's Charter Memberships totaled 76 Corporate and 40 Individual members. Lars Balck was elected as first President and Milt Collins acted as first Executive Director (Collins & Associates).

One of the early objectives of the newly organized group was to produce a quarterly magazine. *Shotcrete* magazine was created and in its first year, it won an award for New Magazines and Journals in the APEX 1999 Eleventh Annual Awards for Publication Excellence. Today, *Shotcrete* magazine is distributed around the world and continues to speak directly to that original mission. Beyond its numerous articles, one of the magazine's regular columns is the ASA President's Message. Lars Balck, the Association's first President, took the time to thank a few industry pioneers in his initial memo, namely Ted Crom, Al Litvin, and George Houston Carroll Sr. Twenty years later, there are many more who could be added to that list, including the two gentlemen that Collins originally approached, Yoggy and Tatnall. Another industry notable, Dudley (Rusty) Morgan, quickly became involved and lent tremendous credibility to both the Association and the magazine with his worldwide consulting experience. One of Morgan's earliest pieces discussed the difference between performance and prescriptive specifications. Morgan, in his last Message while President years later (Winter 2008), paid credit to further industry notables, adding to the list above Leon Glasgold, Steve Gebler, Merl Isaak, and Pietro Teichert.

The 1999 Las Vegas World of Concrete meeting was attended by 51 people and interest in the Association was growing. This marked ASA's first year as a pending co-sponsor candidate and our first booth at World of Concrete. By April of that year, the Association had already secured 142 members. The Board of Directors organized five committees to focus on the Association's goals, namely Certification/Education, Marketing, Membership, Publications, and Safety. By August 1999, with membership at 152, planning had started for the first ASA Nozzlemen Certification/Training session in Streetsboro, OH. You may remember that until that point, there was a document that detailed certification procedures (ACI 506.3R, "Guide to Certification of Shotcrete Nozzlemen,") but there was no single group to administer a formal program and give it credibility.

ASA teamed up with ICRI to deliver a joint Concrete Repair seminar at World of Concrete 2000. It was well received by those in attendance and Morgan spoke to the audience about many aspects of the shotcrete process. That seminar marked the first of many presented by the Association during subsequent World of Concrete events. That same year, the Association entered into a management contract with Association Concepts, a for-profit subsidiary of ACI (now known as Creative Association Management) and Rich Heitzmann was named the Executive Director. During that same year, I remember working on the task group that developed the original American Shotcrete Association brochure, first in Quebec City with Marc Jolin, Denis Beaupre, Jean-Francois Dufour, Joe Hutter, and Pete Tatnall, but the finishing touches were truly applied at a follow-up meeting at the ACI offices in Farmington Hills, MI. There, with the help of Marilyn Netter, the day was spent with both Yoggy and Tatnall. Pete told numerous, colorful stories and kept the mood fun while George let us scan through his tremendous historic photo archives. The fact that I can still picture that moment is a testament to both of those fine gentlemen. The year 2000 also brought the development of our website, **www.shotcrete.org**; the formation of the Underground Committee; and the presidency of Tatnall.

World of Concrete 2001 generated more significant advancements. ASA was added officially as a WOC co-sponsor and hosted its first Nozzleman Certification/Mega Demo. Although it takes an army to pull off such a feat, much of the organizational appreciation went to both Yoggy and Chris Zynda. Steve Gentry took over as President and hoped for a greater alliance with the National Spa and Pool Institute. The result was the development of the Pool & Spa Committee.

Shotcrete certification had always been at the heart of the Association. As early as 1994, Heitzmann (then

World of Concrete 2001 ASA Nozzleman Certification/Mega Demo

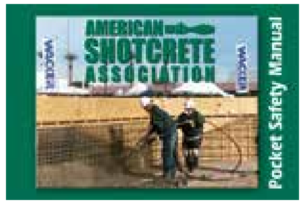
World of Concrete 2005 ASA Mega Demo

heading ACI Certification) helped Lars Balck get ACI Board approval to develop a formal certification program to replace the qualification efforts under the old ACI 506.3R. Activity then seemed dormant until 1997, when John Nehasil became ACI Certification Director and asked CPC member Merlyn Isaak to find out what happened to that initial commission. This resulted in a whirlwind of effort to put a program together, culminating in a pilot ASA certification session in Streetsboro, OH, in September 1999. Another public session took place in Orlando, FL, in April 2000 before the program was turned over to ACI Committee C660, Shotcrete Nozzleman Certification, and the Association became the National Sponsoring Group for the program. ASA then hosted a large public certification session and Mega Demo at World of Concrete 2001, with a total of 12 ACI Shotcrete Nozzleman Certification sessions hosted that year. The certification program started to gain serious momentum!

Ray Schallom III became the fourth President in 2002 and with the ASA Certification program now fully endorsed, the focus became centered on the new 90-minute promotional CD. The hope was that specific disciplines such as Concrete Repair, Civil Tunneling, Mining, Seismic Retrofit, New Construction, Pool & Spa, and Specialty Applications would follow. The Association felt that $50,000 would need to be raised to cover the cost of the professional services. The industry came together at the Burlington, ON, Canada offices of King Packaged Materials Company to undertake the development of this overwhelming task.

In 2003, Ed Brennan focused on developing a formal strategic plan for the Association's future. Meetings were held both at the ACI offices in Farmington Hills, MI, and at the ACI Fall Convention in Boston, MA. The result was a new vision, "that the shotcrete process be understood and used in every beneficial application," and a new mission "to encourage and promote the safe and beneficial use of the shotcrete process." Janice Fisher took over as President in 2004 and Thomas Adams became the new Executive Director.

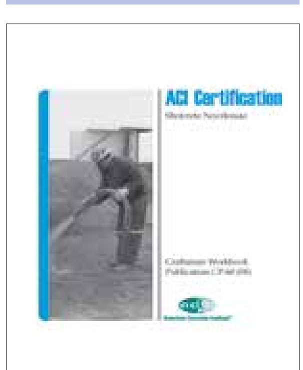
In front of an estimated crowd of 2500, ASA hosted its second Mega Demo in 2005 at World of Concrete in Las Vegas, NV. Incoming President Larry Totten spoke about the fact that skepticism still surrounded the shotcrete industry despite the recent success and how shotcrete is tested to a level far greater than cast-in-place concrete. Attempting to increase the level of reliability for sodium bentonite waterproofing installations, a meeting was held in July 2005 in San Leandro, CA. The result was to shoot mockups to verify the compatibility of using shotcrete in conjunction with these systems. Safety Committee Chair Zynda was credited for introducing a Pocket Safety Manual, available in both English and Spanish.



During an impromptu meeting in the stands following the 2005 Mega-Demo, Hutter and Brennan first initiated the idea of an ASA's Annual Outstanding Shotcrete Project Awards Banquet. The idea was developed to bring members of the industry together for one night where it could recognize the most outstanding shotcrete projects from the previous year. The Association's inaugural banquet was held at World of Concrete 2006 and the five categories honored were Architectural, Infrastructure, Pool & Recreation, Repair & Rehabilitation, and Underground. The event was attended by 110 people and was an overwhelming success.

Morgan began his two-year term as President in 2006 and in one of his messages spoke to the popular belief that Carl Akeley, inventor of the dry-mix gun, had created it for shooting large frames that were covered with animal skins for museum exhibits. While that practice was true, the real development was for repairing the Field Columbian Museum façade in Chicago, IL. This significant shotcrete industry development was described in great detail in an article written by Teichert in *Shotcrete* magazine's Summer 2002 issue.

The certification program continued to excel and successful nozzlemen now totaled 417 wet-mix and 127 dry-mix, completed by the 10 ACI-approved examiners. ACI's CCS-4, "Shotcrete for the Craftsman," was originally developed, primarily written by Balck, along with Steven Gebler, Merlyn Isaak, Dudley Morgan, and Philip Seabrook. CCS-4 saw a complete revision under the direction of Jean-Francois Dufour and Marc Jolin in 2008. That revision subsequently served as the core material for the ACI Certification Shotcrete Craftsman Workbook, CP-60, that with minor edits still serves as the study material for the nozzleman certification program today. With 32 *Shotcrete* magazine issues and 180 articles to date, the digital archives were becoming a wonderful industry resource and for ease of future access, were added to the website.



A new International category was added to the Annual Project Awards, and joining the President's Award was the newly created Carl Akeley Award in recognition of the 100-year anniversary of his development of the shotcrete gun (1907). In one of his 2008 addresses, new President Zynda spoke of the evolution that he had witnessed over his long career and some of his predictions for the future. He stated that the creativity and versatility of shotcrete contractors should benefit them during these challenging economic times. Chris Darnell took over the responsibility as Executive Director and became a valued part of the executive team.

In 2010, Patrick Bridger, having already spent eight years on the Executive Committee, became the Association's 10th President. Bridger worked together with ICRI and ACPA to further the membership reach. One of Bridger's main objectives was to ask the Education Committee to first analyze and then modify the current procedure and policy for examiners, hosts, and nozzlemen, especially the work experience verification. The committee put forward a recommendation for restructuring, which was fully supported by the Board. Their three main goals were to reduce the administrative work for examiners, allowing them to be objective in their evaluations; standardizing the system as far as costs and timelines to level the playing field; and to create a system of continual evaluation of the ASA Examiners, ultimately making the program more transparent, objective, and consistent. It was a monumental task for the committee who was also working on updating the ASA Educator training module, based on CP-60.

As part of the continuous outreach objective, the Association exhibited for the second time at the International Bridge Conference in Pittsburgh, PA. ASA became one of 27 unified concrete associations in the Concrete Joint Sustainability Initiative to promote the sustainability benefits of concrete. A committee was set up to summarize those benefits specific to shotcrete, chaired by Charles Hanskat. Development also started on the Shotcrete Inspector Education program. In an excellent piece written by Bridger on pre-dampening, he stated that the pros had been well documented since 1922, but still not adopted across the board. They may become more important than ever understanding the U.S. Department of Labor Occupational Safety and Health Administration's new respirable crystalline silica standards.

In 2011, in an effort to appeal to more specifiers, ASA presented at the Midwest Bridge Working Group in Schaumburg, IL. The Association also created and began offering free membership to Employees of Public Authorities/Agencies.

Hutter took over as President at World of Concrete 2012 and while remarking about that year's Awards Banquet, stated that it was perhaps the best to date. The Paris Hotel & Casino provided the finest venues so far, attracting the event's largest attendance, and a record number of projects were submitted, which also helped to secure the greatest number of sponsors to date. The website underwent quite a modification and it was unveiled late in 2012.

Michael Cotter, incoming 2013 President, set out to right the wrong with the Nozzleman Certification program. The unintended circumstances that stemmed from nozzlemen certification was the emphasis placed on the nozzleman, while very little was placed on the qualification of the shotcrete contractor. The Contractor Qualification Committee was developed with the goal of developing a comprehensive program. Mark Campo took over the responsibility as the new Executive Director of ASA.

In 2014, incoming President Hanskat made one of his top priorities to develop a new strategic plan that would guide the Association through the next 5 to 10 years. Hanskat enlisted the help of Jon Hockman, a Washington, DC-based facilitator, and a task group was assembled in Farmington Hills, MI. The group's enthusiastic ideas were written as specific objectives separated into four strategic priorities (Professional Development, Outreach, Credibility, and Organizational Strength). The next step was to sit down with each of the committee Chairs to discuss the division of objectives. In December 2014, the Board unanimously approved the full-time position of Executive Director, to be assumed the first of the year by Hanskat.

Marcus von der Hofen took over the reins as President in 2015 and to further the "Shotcrete is Concrete" education, reestablished the Underground Committee and created a new Technical Committee. Coming out of The ACI Concrete Convention and Exposition – Spring 2015 in Kansas City, MO, it was apparent that the new strategic plan required more focus. The Concrete Convention and Exposition – Fall 2015 in Denver, CO, let the newly formed Strategic Plan task group start the meeting by reviewing all Association committee goals and objectives, achieving consensus not only on what committee should be responsible for each objective but also in which specific priority and by what end date they should be completed. The result was a greater focus and commitment to our next steps. In preparation for World of Concrete 2016, the Marketing Committee unveiled a new logo and updated the entire Association branding at the end of the year.

Bill Drakeley took over as President next and continued to emphasize the importance and accountability of the Strategic Plan scorecard. The Association was realizing tremendous efforts from many groups and the scorecard gave the ability to view all accomplishments or required next steps in one report. Drakeley reminded all members that the only logo you should wear in all meetings is the new ASA one. He also summarized the need for elevated training industry wide, the possible consequences without it, and introduced the NIT program. The Association meetings moved to a dual-track format at The ACI Concrete Convention and Exposition – Spring 2016 in Milwaukee, WI, meetings and worked very well, shortening the common Saturday committee meetings day.

ASA Acknowledges the Contributions and Dedication of our Past Presidents and Executive Directors in shaping the first 20 years of the American Shotcrete Association.

ASA Presidents

1998	Lars Balck
2000	Peter Tatnall
2001	Steve Gentry
2002	Ray Schallom III
2003	Ed Brennan
2004	Janice Fisher
2005	Larry Totten
2006	Rusty Morgan
2007	Rusty Morgan
2008	Chris Zynda
2009	Chris Zynda
2010	Patrick Bridger
2011	Patrick Bridger
2012	Joe Hutter
2013	Michael Cotter
2014	Charles Hanskat
2015	Marcus von der Hofen
2016	Bill Drakely
2017	Scott Rand

Executive Directors

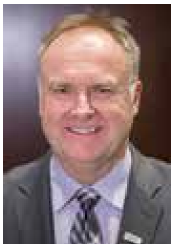
1998	Milt Collins
1999	Richard Storey
2000	Richard Heitzmann
2004	Thomas Adams
2008	Chris Darnell
2013	Mark Campo
2015	Charles Hanskat

At World of Concrete 2017, Scott Rand took over as President. Rand, managing the Strategic Plan task group, commented that with over 50% of the objectives complete, it was time to write the next chapter of the existing plan. A task group was assembled for a meeting held at the ACI offices prior to The ACI Concrete Convention and Exposition – Spring 2017 in Detroit, MI. One of the ideas that came out of the meeting was to host the Association's 20th Anniversary in Napa, CA, in March 2018. A group of Board members was put together to work on the ASA Shotcrete Convention. ASA will not only host its regular committee meetings and Outstanding Shotcrete Project Awards Banquet at the event but also a technical shotcrete session.

Hanskat is presenting our newly completed Inspector Training Seminar to various Departments of Transportation with the anticipation of a full release early in 2018. The Association will conduct Nozzlemen Certification Education sessions in both English and, for the first time, Spanish at the upcoming 2018 World of Concrete. ASA will also present a seminar on "Advanced Shotcrete: Innovative Techniques for Architectural & Structural Projects" at the Convention.

Today, ASA continues to provide excellent resources to the shotcrete industry. Nozzlemen Certification is quickly approaching the 2000 mark, an incredible achievement. Our Committees are more active and productive within ASA as well as support for ACI 506 activity, and outreach to other standards developing organizations that impact concrete construction. Our reach is more frequently extended beyond the North American borders via certification sessions, association alliances, and more. If shotcrete is your industry, ASA is your resource to grow and develop!

Many people beyond those who have been mentioned in this quick article have had a hand in the success of this Association. While it was not my intention to overlook anyone in the aforementioned summary, there was also an unfortunate realization that more than were mentioned deserve our sincere appreciation. The growth of the ASA programs has required a tremendous amount of support from a long list of outstanding Executive Assistants (Marilyn Netter, Jessie Bournay, and Melissa McClain). This is especially true for current ASA Program Coordinator Alice McComas, whose incredible contribution is essential and much appreciated. To the numerous committee members, especially the Chairs, the various Board members and to the staff behind the scenes working on the magazine, the website, from graphics to logistics...thank you for your contribution over the years.



Scott Rand *is Vice President, Sales, for King Packaged Materials Company, where he is responsible for the Construction Products Group. Rand has over 30 years of experience in the concrete industry and has spent the past 20 years with King. He has had a major contribution in the growth of the King Shotcrete Solutions brand and its leading position in the North American shotcrete industry. Rand has been involved in high-profile projects in numerous cities from New York to Chicago. He is the 2017 President of ASA and a member of ICRI, UCA of SME, CIM, and ACI.*

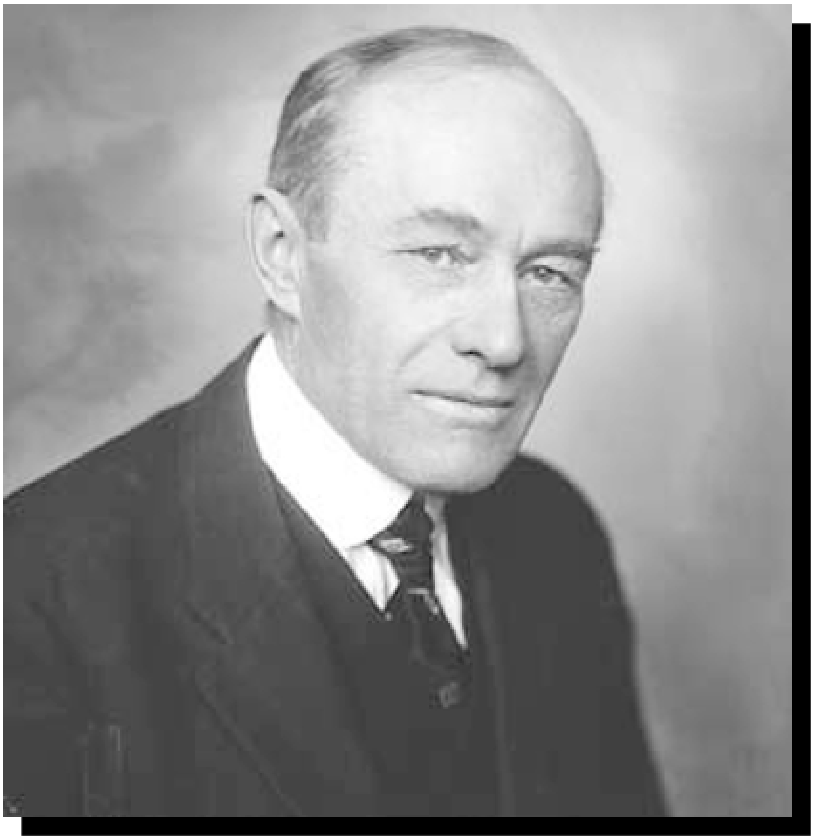
Carl Akeley - Tribute to the Founder of Shotcrete

By Pietro Teichert

I only recently joined the American Shotcrete Association. But, in reading through the issues of *Shotcrete* and ASA's excellent brochure, I was struck by how little seems to be known about Carl E. Akeley, the man to whom we all owe our livelihoods. What's more, I'm told by the literature that he invented the cement gun "to apply mortar over skeletal matrices to form the shapes of prehistoric animals" (not true); that he was a Doctor (his schooling was limited to three or four years of grade school); and that the "development of the original cement gun started in 1895" (it actually started twelve years later).

Please allow me to tell you more about Carl E. Akeley and his fascinating life...

Carl Ethan Akeley was born on May 19, 1864, in the little crossroads hamlet of Clarendon, Orleans County, NY, which is located west of Rochester on Lake Ontario. His father, Webster, moved there from Vermont at the beginning of the Civil War and operated a heavily mortgaged 60-acre farm. Even as a boy, Akeley—the second oldest of three brothers—was an enthusiastic birdwatcher. He was also very interested in taxidermy, a skill he learned from Englishman David Bruce in the nearby town of Brockport. At the age of 19, Akeley embarked upon a taxidermy apprenticeship in Rochester for a wage of $3.50 per week at the Natural Science Establishment of Professor Henry A. Ward, a recognized authority in the field who supplied exhibits to the best American museums. Akeley seems to have learned a great deal quickly but, above all, he came to be sickened by the unfeeling way the animal skins were stuffed in those days. In 1888, he took a job at the Milwaukee Public Museum and worked there for about 7 years, but failed to find the freedom to try out his own ideas that he was seeking. So, in 1895, he was happy to accept a job offer from the Field Columbian Museum in Chicago, now the Field Museum of Natural History. Over the next 14 years, Akeley went on to develop revolutionary taxidermy methods that ultimately earned him a worldwide reputation in the field and started an entirely new movement for the lifelike presentation of animals in natural history museums all over the world.



Carl Ethan Akeley (1864-1926), around 1910.
(Photo courtesy of the American Museum of Natural History, New York)

During that period, Carl Akeley invented modern dermoplastics, or the process of building a faithful anatomic model with tubes, wire, cloth, and plaster, and then covering it with the tanned animal hide. Akeley presented groups of animals— most of which he had shot on his own expeditions—in very naturalistic surroundings, and created entire panoramas of the animals' habitats with painted background vistas. During these years, Akeley effectively revolutionized taxidermy and natural history exhibits (to this day, an Akeley Award is presented at the World Taxidermy Championships).

At that time, the Field Columbian Museum was housed in a building that had been erected in 1892 for the World Exhibition in Jackson Park. One day, in the spring of 1907, Akeley was working together with mechanic and model-maker Clarence L. Dewey in a workshop when museum director Frederick J. V. Skiff came looking for him. Akeley was working on two African elephants, and Dewey was busy painting some imitation rocks for another group under construction. Dewey was using an enlarged atomizer built by Akeley that used compressed air to spray on colored plaster of paris. Skiff began to complain about the awful condition of the museum's facade because the trustees had been nagging him about it. Suddenly, he said to Akeley, "Ake, why can't you and Dewey make a big machine like that squirtgun Dewey is using and paint this old shack with plaster of paris?"[1] The amazingly versatile Akeley, who loved nothing more than a technical challenge, took the bait immediately. He and Dewey got right down to work and, after a few disappointments, proudly unveiled the result on June 24, 1907—a very rudimentary machine, called a "plastergun" by Akeley, that forced dry plaster through a hose using compressed air. When it reached the nozzle, the necessary water was added from another hose. With the emerging jet of plaster, water, and compressed air, Akeley applied a ¼-inch layer to the outer wall of the museum. At least, he did so for an hour, until the hose clogged up. But the experiment had shown that the system did indeed work. The machine functioned on the double-chamber principle: the material entered the conveying hose from two chambers placed one on top of the other, and the two chambers were pressurized alternately. The double-chamber gun was born.

The original machine used in 1907 to recoat the facade of the Field Museum of Chicago. (Photo courtesy of J.J. Shideler, Portland Cement Association, Skokie, IL)

In fact, then, Akeley's invention resulted from the need for an efficient method of recoating building facades. In the literature, the story usually states that he designed the gun to coat animal models with plaster or to create imitation dinosaurs or artificial rocks for his animal groups. Akeley himself was amused by these stories and didn't bother to set them straight. On the other hand, there is evidence (including photographs in Gunite Contractors Association brochure G-84) that other people used Akeley's machine years later to produce large animal sculptures. But many improvements had to be made before this became feasible. During this period, Akeley was able to count on strong support from none other than U.S. President Theodore Roosevelt. Akeley had met Roosevelt in 1906 after he returned from his second African expedition. Both men were great nature lovers with all sorts of interests. A lively correspondence ensued between them. In the fall of 1909, Akeley accompanied Roosevelt—no longer President at that time—and his son Kermit on a trip to Africa during which a close friendship developed. Apparently, it was Theodore Roosevelt who saw the commercial potential of his friend Akeley's plastergun and encouraged him to perfect it. Akeley did just that in the years 1908 and 1909.

Akeley, who had been hired by the American Museum of Natural History in New York a few months previously, applied for a patent on his machine on September 13, 1909. It appears that financial support from the McElroy Shepherd Company of New York enabled him to add 52 changes, improvements, and amendments by the time the patent was finally issued. On May 9, 1911, Patent No. 991814 was issued for an "Apparatus for mixing and applying plastic or adhesive materials." Although Akeley's name was on the patent, it seems that others were busier promoting the invention than he was. In December 1910, the "Cement Gun" was already exhibited at the Cement Show in New York's Madison Square Garden. At the 7th Annual Convention of the National Association of Cement Users held during the show, a paper delivered by G. L. Prentiss, Vice President of Parsons Manufacturing Company, NY, about the cement gun and its use— particularly in lining the Hunter's Brook Siphon of the New York Water Supply at Yorktown Heights—impressed the audience just as much as the machine itself. A civil engineer by the name of S. W. Taylor was especially quick to appreciate the wide variety of uses to which the cement gun could be put. His engineering company in Allentown, PA, acquired the rights to the machine, and he soon renamed the firm the "Cement Gun Company." It is not known just how much Akeley was paid for his invention. "The Cement Gun Company lined the pockets of his backers quite nicely, but never made Akeley a rich man; he had given up all financial interest in the company soon after its founding, characteristically moving on to other work."[2]

Carl Ethan Akeley died of a fever on November 17, 1926, in the Belgian Congo during his fifth African expedition. Mary L. Jobe Akeley, whom he had married only two years before his death, buried him at Kabara on the saddle between the volcanoes Karisimbi and Mikeno—which Akeley himself considered "the most beautiful spot in all the world."[3] The grave is situated in territory of the Democratic Republic of Congo, the former Zaire and, in Akeley's time, the Belgian Congo, inside the Parc National des Virungas. This is part of the former Parc National Albert, which was established by the Belgian king in 1925 at Akeley's suggestion to protect the rare mountain gorillas. In 1978, local vandals ransacked the tomb and scattered Akeley's bones about the meadow. Twelve years later, Akeley's remains were secured and his grave rebuilt by Penelope Bodry-Sanders,[2] a member of the staff of the American Museum of Natural History in New York.

Carl Ethan Akeley, the great explorer, hunter, conservationist, taxidermist, and sculptor, rose from a poor farm boy with 3 years of schooling to a man of the highest repute through persevering self-education. An amiable, strong-willed, and exceptionally creative human being, he received a monument in his memory from the American Museum of Natural History in New York, his last and most fruitful workplace. The impressive Akeley African Hall there, containing a wonderful gorilla group with Mount Mikeno as a backdrop, evokes memories of Akeley and his wife. (A personal note: Have you ever seen Akeley's wonderful dioramas in this marvelous museum? Go there with your children and grandchildren, and admire what the inventor of the cement gun created eighty years ago, "what he handed on to posterity of the beauty and truth of a vanishing wildlife, with the accuracy of the scientist, completed with the imagination of the artist."[4])

But Carl Akeley has also gone down in history as a many-sided inventor. Besides the cement gun, for which he was awarded the Franklin Institute's John Scott Legacy Medal for the Promotion of the Mechanical Arts on June 14, 1916, he also invented the first rotary motion picture camera (for which he was honored again by the Franklin Institute in 1926). Another invention was a powerful searchlight used by the U.S. Army in the First World War. From 1895 to 1921, Akeley was awarded no fewer than 37 patents. "Carl Akeley was a self-made man in the fullest meaning of the word, and attained his eminent position in the world through his own efforts by dint of hard, painstaking work and an unshakable faith in his ideals. His entire career was one continuous struggle in the face of many obstacles, insurmountable except for his indomitable will."[5] So much for Akeley and the invention of the cement gun. Of course, there is more to be told about the story of the cement gun and gunite and their rapid and successful expansion across the U.S. and, indeed, the whole world, between 1910 and 1920. I would be happy to tell this story, too, if the editors of Shotcrete feel disposed to provide space in an upcoming issue.

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Pietro Teichert *is the Managing Director of Laich SA, Avegno, Switzer-land. He received his civil engineering degree in 1961 from Winterthur Polytechnic and has worked exclusively in the shotcrete field ever since.*

The History of Shotcrete

Part I of a Three Part Series

By George D. Yoggy

At the beginning of the 20th century, significant pieces in the foundation of America's Industrial Revolution were established in the Lehigh Valley of Eastern Pennsylvania. Iron and steel, important products to the early development of our continent, were produced in Bethlehem, Pa., and the first production of portland cement in North America took place in Coplay, Pa. The Lehigh Portland Cement Company was founded in Allentown in 1897, and cement production is still an important industry in the area. Several support businesses and professions, as well as Lehigh University, resided in the valley to provide engineering, design, testing, and manufacturing services for the production of cement and steel. Also early in the century, in 1904, the American Concrete Institute (ACI) was established, and the Portland Cement Association was formed in 1916.

The development of both the cement gun and the Gunite process in Allentown was not coincidental. In the community, there was abundant understanding of and interest in cement and concrete, concrete construction methods, and design and fabrication for a commercially viable machine to apply materials, as invented by Carl E. Akely. The first machine was introduced at the Cement Show, in New York, in December 1910.

Figure 1. 1920's Gunning Crew

Figure 2. Nozzleman applying "Gunite" for a water storage facility in Pittsburgh, 1919

The term Gunite was coined in 1912. The unique idea of applying mortar onto a surface at high velocity was an immediate success. Early projects included encasement of structural steel support elements in New York's Grand Central Station to strengthen and protect them against fire and corrosion. The density, bond characteristics, and compatibility with structural steel elements, as well as the longevity of protection, created a design and construction demand for this type of application throughout the rail and bridge industries. Water transport and storage facilities became common Gunite construction applications because of the reduced forming requirements and the superior properties of concrete placed by the pneumatic spray method.

By 1915, The Cement Gun Company had grown to become a large contracting organization, and their numerous application projects included construction and repair of buildings, bridges, reservoirs, dams, tunnels for sewer, rail, and water and repair of furnace linings in steel production and other high temperature process facilities.

The early 1920s saw widespread use of this sprayed concrete application process, and eventually, growth in sales of the machine that included instructions for its use as

Figure 3. Restored, reinforced "Gunite" flue at American Smelting and Refining Co., Helena, Montana, 1924

well as permission to use the name Gunite by the franchisee. Gunite construction projects spread throughout North America, and some firms were formed from crews of the original company after completion of a project in a given area. Other contracting companies were formed to satisfy a demand in a given market. Patent documents and copyrights were clear on the mix design and application requirements, and only material placed by a genuine "cement gun" could be called "Gunite". The process crossed the Atlantic and a UK Cement Gun Company was founded. Successors to many of the early franchises still exist (in name) today, and the UK sprayed concrete (gunite) industry is alive and well, all born from the original Allentown activity.

Bryan C. Collier, the first president and one of the founders of the Cement Gun Company, exhibited a strong interest in producing and publishing test data to confirm the quality and versatility of "Gunite" in support of the designers and users of the process. Early tests to establish the compressive strength, bond, and density, believed to be greater than that of cast concrete because of the compaction

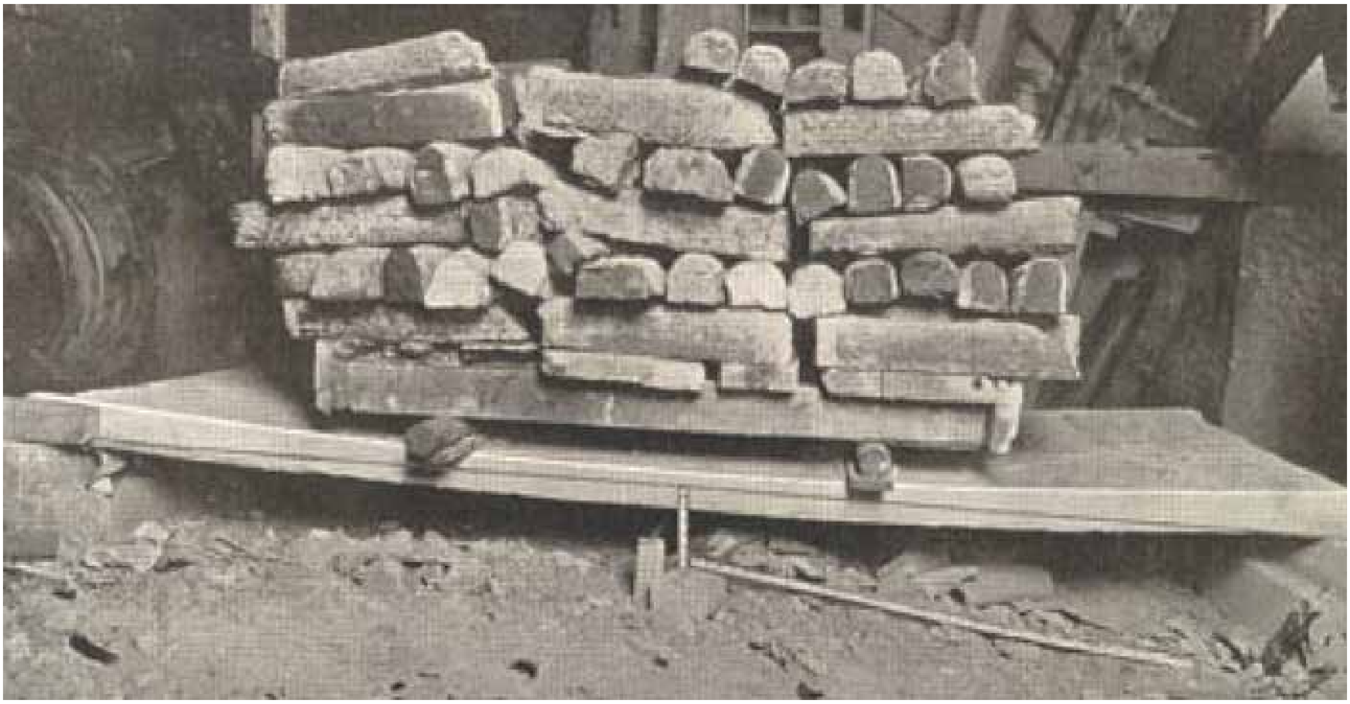
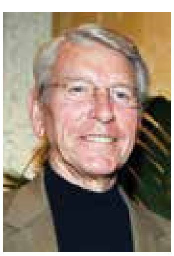


Figure 4. Test of "Gunite" slabs made under supervision of Prof. M. O. Fuller, Lehigh University.[The tests were started in 1920 and ran through 1934. The 8' 0" (2.4 m) span, 3-1/4" (82.6 mm) thick, deflected 2" (50 mm) by 1922 and stressed the reinforcing to 36,000 lb (160 kN) at completion. No further deflection occurred after the 3rd year.]

capability, were carried out at Lehigh University by Professor M. O. Fuller. Data showed significant qualities in both vertical and horizontal shot specimens. Subsequent tests were carried out at the University of California that confirmed the superior properties of concrete placed by the pneumatic method. The density and "water tightness" made "Gunite" valuable for construction of water storage tanks and facilities, as reported in the proceedings of ASCE, August 1917. Further data followed from studies at Toronto University, the Bureau of Standards, the Department of the Navy, and many others, all before 1939.

Today, our industry is often faced with challenges by the engineering community to provide data that support the quality and properties of pneumatically applied mortar and concrete. There is a generous history and much information available if one researches the literature from the universities mentioned, as well as early publications of Engineering News Record, ASCE Proceedings, and project case studies beginning in 1912 and continuing into the 1930s. What we call "Shotcrete" today is perhaps the most unique and technologically advanced concrete construction method available to us. I'm not sure where the information gap started. We will endeavor to identify the period of change as this series on the history of shotcrete continues.



***George D. Yoggy** has been directly involved in shotcrete and concrete applications for underground, heavy construction, and repair of concrete structures for more than 40 years. From 1967 to 1986, Mr. Yoggy owned and operated Concrete Equipment Corp. and Shotcrete Plus, Inc., a business engaged in the design, manufacture, and supply of equipment for ground support, shotcreting, and concrete placing systems in the North American tunneling, repair, and mining industry. In 1986, the company was acquired by Master Builders, Inc., and he established the Underground Construction group for MBT Americas.*

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The History of Shotcrete

Part II of a Three Part Series

By George D. Yoggy

The machine known throughout the world as the "Cement Gun" and its integral process *Gunite*, followed a curious route since its invention in 1909, originally for recreating animal skeletons, by naturalist Carl Akeley. Introduced at the Cement Show in New York in 1910, the machine and the process became an almost immediate success as a construction tool that was as unique as it was versatile. The first 5 years of its career saw several changes and improvements in the "gun," as experience and testing begat modifications to suit the many uses in civil and industrial applications. Crossing the Atlantic in 1915, the *Gunite* process spread quickly throughout the world, and by 1922, the Cement Gun Company and the process was global, before the term was popular or even understood, *Gunite*, as a useful and important construction method, flourished through the 1920s, 30s and 40s in all of the industrial centers of the world. By 1950, nearly 5000 machines had been delivered to projects or contractors in every state and more than 120 countries.

The contracting activities of the Cement Gun Company provided nearly unlimited opportunities to prove the versatility and technical characteristics of pneumatically applied concrete. While it may seem that there is a great deal of emphasis on the company itself and its activities, one must remember that they were the only ones engaged in the production AND use of the machine for many years. Affiliate concerns were formed in Europe to service the countries of the world that had industrial and construction needs. A continuous effort of testing, comparing and communicating results and procedures was a mainstay of the global company's activity. As independent contractors and franchises were started, standards established by the Cement Gun Company and recognized testing and specifying authorities of the time prescribed strict procedures for the *Gunite* process. Gradation and proportioning of materials, operating procedures, application and design specifications, finishing, and curing were clearly directed by the company through bulletins and technical papers. Quality was assured through clear communication of the prescribed and proven steps.

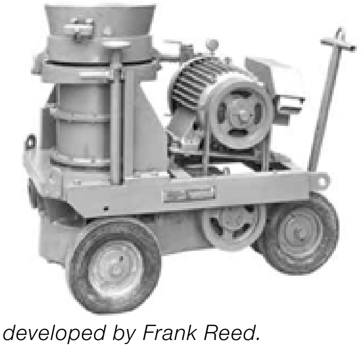

Figure 1 (left). Bowl type gun developed by Frank Reed.
Figure 2 (right). Meyco GM 57 rotor type machine

Throughout most of the period described, *Gunite* proved to be a technical process embraced by the engineering and contracting community. Refractory applications were also a prominent use for the process, since many combinations of cements, aggregate, and granular filler materials could be conveyed, wetted and applied to a substrate with predictable performance results. About half of all of the machines that went into service around the world did so in the melting shops of industry: smelters; mills; foundries; chimneys; boilers; refineries, etc. The other half were used to construct water storage and transport systems, protect steel structures, and to repair, construct, and support concrete and earth structures for countless industrial and commercial uses. History reveals that the *Gunite* industry and business was very successful, useful and respected in nearly every facet.

Then, a funny thing happened on the way to "prosperity." In about 1950, (give or take a couple of years depending on where you look), changes began to occur! Considering the process was pushing 40 years, perhaps it was a "mid-life crisis." Certainly the years following the war effort changed our culture and the way we lived and worked. Technology born out of necessity in the preceding years became available and useful in all phases of our lives. The world became "smaller" as the population became more mobile. While it may have seemed unusual that in 1920, *Gunite* found its way to Europe, India, and South Africa before it caught on in California, a glance at a globe reveals that the distance was the same (from Allentown), but there was a lot more going on in Europe than on the west coast, and many of the roots of industry were east rather than west, in those days. The mid-40s changed all of that forever!

Following World War II, change became the norm. New types of machines were developed, as well as the first

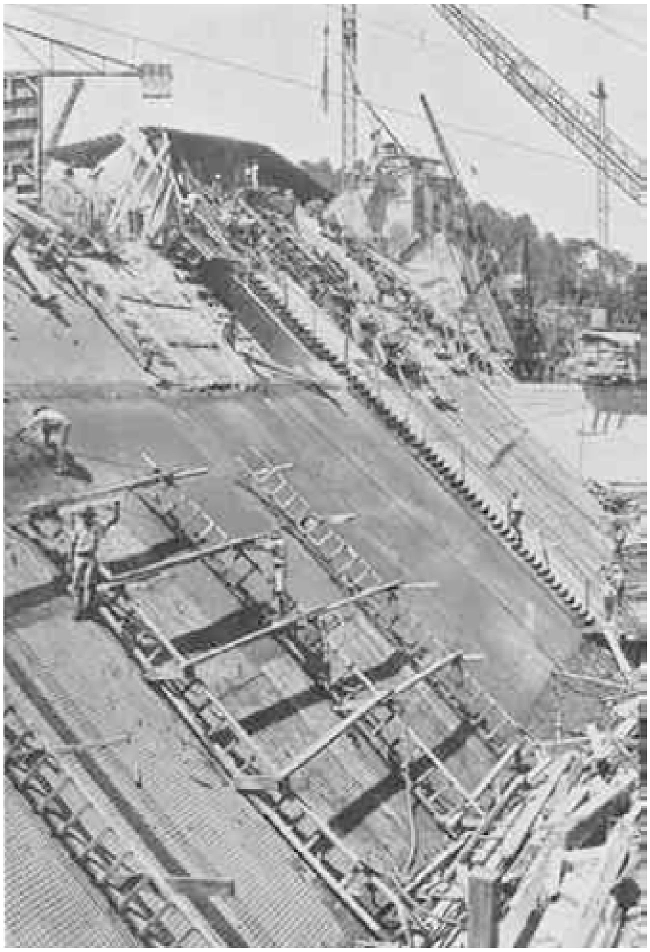

Figure 3. Gunite overlay for water proofing was done during construction of Chendorah Dam, Federated Malay States, c1930

equipment changes since the original invention. Some succeeded, and some faded away. Frank Reed developed a successful bowl-type machine that proved to be productive and simple to operate. The Jetcreter came out of Iowa and led to the Meynadier development of the Meyco rotor-style gun. Jack Ridley came up with a mixing and feeding system that combined a double tank gun and a trailer that is still referred to as a "Micon Rig", no matter who built it. Aliva came into the foreign market shortly after Meyco with a rotor style machine, and there are still a few modified versions of the basic designs produced around the world. The so-called "continuous feed" guns were a significant change, and are still in use today along with a variety of batching, mixing, and feeding devices. The wet process was yet to come. We'll talk about that in Part III.

The real issue of the "mid-life crisis", however, was the complete disconnection throughout the American *Gunite* industry that damaged the quality and credibility of the process. Perhaps it was that the new machines required less skill to operate, and the original company had no direction. Maybe it was the rapid spread of business and construction credit must be given to those that maintained the bridge of knowledge and dedication that spanned the chasm of confusion and carelessness. Names such as Crom, Maier, Fredericks, Reading, Moore, Carroll, Truman, Warner, Esposito, Rappa, Zynda, Lorman, Glassgold and a host of others were diligent in the work they performed and the procedures they advocated. Still, the free enterprise system that we all believe in also allowed many to do as they pleased, sometimes with little guidance, and too often, with much criticism and disagreement.

The 40 years from inception to outstanding growth and accomplishment could easily be called the period of "success." The 40 years following should be called the period of "demise," by comparison. However, there are clear signs of recovery all around us: sound technical procedures and a growing circulation of information that is valid; research and contract practices suitable to specification and design requirements; materials and equipment capability that incorporate the latest in concrete technology. Much has happened in the first decade of the third 40-year period. Are we truly in the age of "recovery?"

Consider this. The definition of shotcrete that our industry lives by, "…concrete or mortar applied to a surface at high velocity…" has been included in ASTM V. 04.02–Concrete and Concrete Aggregates, the majority of the past 40 years, and in throughout the nation. Was there too much opportunity? Was it the west-coasters doing "their own thing" while some of the easterners shrouded their activity in mystery to protect their business? What happened to the assured quality that the carefully honed procedures established so well and shared for the first 40 years? What about the test and design data from Lehigh, UC, the Corps, and the Cement Gun Company? How did the love/hate attitude toward *Gunite* happen? And why did it happen only in the U.S?

There are likely as many opinions as there are people involved in the industry, and debate on the subject could fill more pages than are available. However, there is no question that the industry suffered, and its growth and acceptance was stifled for many years. Test data and project performance information that once flowed freely and orderly began to fade away. There was pitifully little

Figure 4. MiCon rig, introduced by Jack Ridley

documentation available to engineering schools, and the engineering community was reluctant to “gamble” on a process that it did not understand. If the decision maker had a good experience with *Gunite*, he would specify or approve it. If his experience or information was negative, *Gunite* was out—a situation experienced by too many gunners, too many times. Even the new term Shotcrete, along with its official ACI definition, failed to turn the heads of designers except in a few cases.

There is no question that the *Gunite*, now called Shotcrete, industry lived through an extremely difficult period. There were many successful projects and companies that also lived through the same all five volumes of the ACI Manual of Concrete Practice, yet we have struggled to make our case to the engineering community with only 45 pages of Volume 5 dedicated to shotcrete (ACI 506). That was not enough. “Shotcrete” is a method of placing concrete. All technology applies! Proper training, education, practice, research and communication are required. This is what Collier et al intended. This is the path forward, regardless of how we fell off the track.

We’ll assess the “recovery” in Part III.

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The History of Shotcrete Equipment—Wet Mix

Part I: Aussie Innovation with S-Tube Shotcrete Pumps

By Ian Hay

In Australia, when concrete swimming pools started becoming popular with the average home owner in the late 1950s and early 1960s, the pools were typically sprayed with dry-mix shotcrete (gunite). However, we recognized that using premixed concrete with a form of shotcrete gun may have many benefits. The first attempts used a hopper with a rotating chain belt at the bottom, much like a dry-gun rotor but with 3 in. (75 mm) washers spaced at 4 in. (100 mm) with the chain in the center of the washer to form a material cavity. It ran in a 3 in. (75 mm) rubber tube and had a 600 ft^3/min (17 m^3/min) air compressor that blew the wet mix out of the cavity and up the delivery line. They were dusty, noisy, huge, and unreliable.

Later in the early 1960s, imported "squeezecrete" pumps were used to shotcrete pools. These were much cleaner and could have the wet-mix concrete delivered in a transit mixer. However, the distance from curbside concrete delivery through the hose to placing in the pool was a restriction, as the squeeze tubes could not withstand high pressure.

I had always lived on the Northern beaches and the Brookvale industrial area was where the concrete ready mix industry started with Pioneer Concrete, which ended up being a global company (now Hansin). So, I was hanging around the area and, being young, could just walk in to these outfits. The Fowler Wood factory made transit mixers and there were three ready mix plants close together. When I started to build the first Transcrete pump, I used the "bullet" valve system. There were dozens of small engineering and machine shops that made parts for Fowler Wood so it was easy to get parts made. Pioneer even supplied the paint and yard space to spray our first pump (they did not give a toss if it had to be "Pioneer Green & White"). All three plants provided assistance in developing pumpable concrete mixtures. Their concrete mixture design engineers were only too eager to give me the "secrets" of mixture designs.

Once we had a concrete pump, we sold 36 pumps in the first full year of production. We were approached by swimming pool sprayers wanting to ditch the squeezecrete pumps. We tried the "bullet valves" and while they worked when in perfect condition, once they had excessive wear, they were a waste of time.

In 1974, we received an order for several new pumps from a New Zealand equipment dealer. At the time, the only way you could import a concrete pump to New Zealand (NZ) was to apply for an import license, and it was rare that one would be issued. The NZ dealer told us that he had such a license, but as it turns out, he was only hoping to get approval. Now with $50,000 of finished pumps and a severe recession, I jumped in a plane and tried to convince the NZ Customs Department to issue a license. No such luck. However, as I was in NZ, I made several calls to local concrete pumping operations. It was obvious that Transcrete pumps, 60 to 90 yd^3/h (45 to 70 m^3/h) were way too big for the NZ market and what they needed was a much smaller 30 yd^3/h (25 m^3/h) pump, trailer-mounted and suitable for masonry block filling ("3/8 in. [10 mm] piss and pebbles.").

The NZ pumpers were using a lot of Mayco C30HD mechanical ball valve pumps. There was no way bullet valve pumps would work, with the smaller the output and being more costly to operate due to wear.

I jumped on a plane back to Australia and on the flight back came up with the S-tube idea. We had the first unit built in 2 weeks and the first Mark 1 pump sold.

To get over the NZ license problem, the importer suggested we build in NZ and send back to Australia as well as export to Southeast Asia, as we had entered the Asian market in 1974. I ended up with a factory full of finished concrete pumps, a recession, and creditors snapping at my heels. So, I put all the finished pumps in boats to Hong Kong, Singapore, Malaysia, and the Philippines. At least I was in control of disposal at full value.

After 1 year, we were back in a strong financial position and ready to start producing S-tube trailer pumps. The NZ venture was a failure quality-wise, so we manufactured in Australia. However, the S-tube pump was too small for Australian pumpers and not suitable for Asian concrete mixtures. I had made several trips to Los Angeles, CA, in 1974 with the view of selling our bullet pumps. Unfortunately, the market in the United States was also in a recession, but I established some good contacts and passed out S-tube brochures to people using Mayco C30HD ball valve pumps. At that time, the market primarily consisted of ball valve trailer pumps or truck-mounted boom pumps. Whiteman had a small 30 yd^3 (25 m^3) pump but it was a sliding gate valve design and never took off.

Why the United States? Here I was sitting on a large bank balance, no local sales; the Southeast Asia market was 20% of sales and 80% of the problems. Considering the cost of transport, hotels, language, and other factors, I realized that the United States was the place to be. The Mayco ball valve pumps were having problems pumping structural pea gravel concrete mixtures due to a cement shortage. The S-tube pumps we sold in Australia were handling low-slump 0.75 in. (19 mm) pea gravel mixtures and pumped fast enough for normal home foundations.

We had also started selling S-tube pumps to the swimming pool industry with great success both in performance and reliability. I spoke to a customer who had replaced his squeeze-crete rigs with Transcrete S-tube models and asked him how they compared with his old pumps. His reply: "The only thing I miss is the monthly invoice for replacement tubes."

At that time, we were selling the trailer-mounted S-tube pump for A$ 20,000.00 (US$ 16,000.00), each factory direct with no dealers.

Jumpstarting the United States Market

I had given out S-tube trailer pump brochures to several contacts in the United States and the details included the phone number of my in-laws living in La Mirada, CA. My office phone rang on a Saturday morning and it was my mother-in-law, saying some guy wanted to contact me, and that he wanted to buy a concrete pump. I phoned the number given and low and behold it was Fran Wilson, who was working as a design consultant with Allentown. Fran and I had been corresponding for years and unbeknownst to me at the time, he was designing a small S-tube pump for Mayco. Fran was using my information and selling the ideas to Mayco.

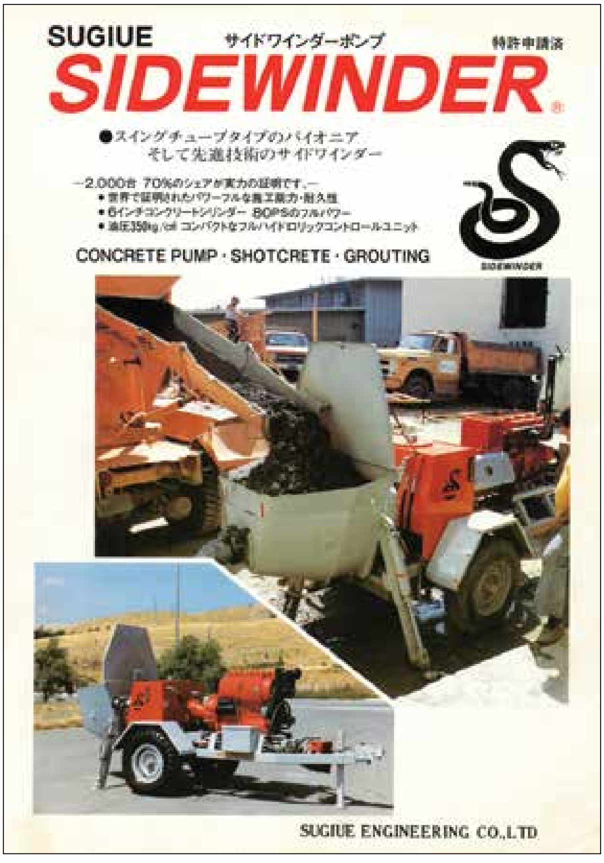
Fran had received a call from Joe Cerretini, a pumper based in Binghamton, NY, who wanted to buy a 30 yd^3 (25 m^3) trailer pump. Fran gave me Joe's phone number and I called him straight away. We spoke for quite a while and I suggested that if he was keen and had the money to buy a pump, I would bring a pump over to New York and give him a demo, provided he paid up if it does what I told him it would do.

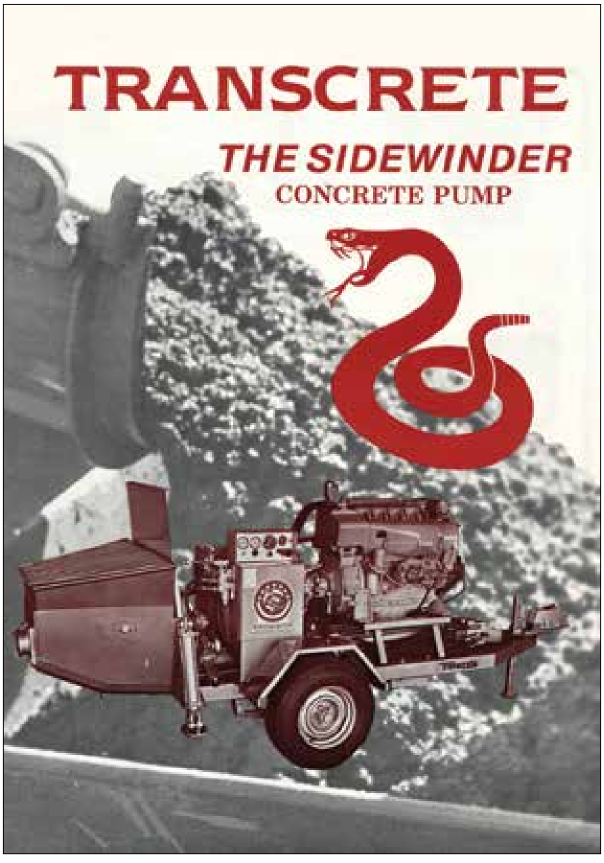
By this time, I had made up my mind that we were going to sell into the United States and called the pump a "Sidewinder." We were already air freighting pumps into Southeast Asia because we didn't want our investment going on a "3-week cruise." We also discovered an airline tariff concession for "mining" equipment.

So, I put a new Sidewinder on a plane to New York and followed it on a separate flight. There was drama using a Greek airline from Australia that offloaded the pump in Europe and then an Irish airline from Europe to New York… but that's another story.

First Use and Expansion in the United States

Fran had advised Bill Roberts at Allentown about the Sidewinder demo at a site in Syracuse, NY. So, on the day of the demo, we had Fran, Bill Roberts (President), and Earoll Roebuck (VP, Marketing) from Allentown, plus their design





engineer in attendance. The demo was a great success and Joe paid me in full for the pump. Bill Roberts immediately invited me to the Allentown factory, as he was keen to be the Sidewinder importer.

The Allentown facility was great as far as real estate goes, but there was not much going on as far as manufacturing. I could see that they were way behind on the technical side. Bill presented a proposal whereby Transcrete would ship Allentown Sidewinder pumps, fewer diesel engines, and a few other components. His reason was: Why import a diesel engine from Europe to Australia, then fit it and ship to the United States? Why not just buy the diesel engine in the United States and fit it in the Allentown factory? I replied, “Bill, don’t complicate things…you buy a complete pump at a fixed price delivered to your factory loading dock.” Why mess with extra time and effort and not save any money? We are buying diesel engines at far less than you can buy them. Apart from his “economic logic” he wanted to call the pump “son of Pumpit” after Allentown’s large trailer pump. When I asked what number of pumps he would buy, he came back with one a month, maybe! I replied, “Bill, we are selling 20 per month in Australia alone.” It was obvious that Transcrete was a much stronger company than Allentown, so I did not conclude any business with Allentown.

Bill did meet me in Honolulu, HI, on my way back to Australia, but I was still not comfortable with him—besides, I had already done a deal with Bennett Brothers. Prior to doing the Bennett Brothers deal, I had approached Rick Horsfall, Vice President at Thomsen, with the offer to sell Thomsen our Sidewinders. Interestingly, in all the time I spent with Bill, shotcrete never came into the conversation.

SPRAYING CONCRETE! THEY JUST USE THE SIDEWINDER IN AUSTRALIA

The deal I made with Bennett Brothers was that Transcrete would provide finished pumps on consignment, with payment within 7 days from sale and paid invoice. Transcrete would provide, design, and pay all advertising costs. We agreed to send over several pumps to kick the deal off. I ended up spending several weeks with them initially. During the first week at Bennett Brothers, Dick Bennet was having a discussion with a customer having problems spraying rail culverts using a Thomsen boom pump that Dick had modified to handle shotcrete mixtures. He said to me, “What pumps do they use in Australia to spray concrete?” I replied, “Squeezecrete pumps were popular but they now use Sidewinders.” Dick came back with, “Like the Sidewinders outside?” Sure, the same.

Dick quickly organized a demo for the Sidewinder down in San Clemente. The contractor laid out over 180 ft (55 m) of 2 in. (50 mm) hose. I think he was trying to show the smartarse Aussie a thing or two. The demo was a great success and they sold two Sidewinder pumps that day. Dick had a salesman, Marion Ryder, who had been in the industry since concrete pumping started and knew pumpers all over the United States. Marion was over the moon and started calling pool builders and gunite contractors. He contacted Action Equipment in Arizona and another pool sprayer, Al Connors. Al was a large contractor in Arizona and was running Mayco C30 HD machines, one on each pool with a backup in the workshop. If one crashed on the job, they would just haul out another. The Sidewinder was diesel powered; Mayco ran on gasoline. Gas was costly and hard to get due to the price rise in the Middle East. So apart from the Sidewinder being reliable, and did not wear out fast, it provided the side benefit that the pumper could siphon diesel out of the concrete truck to run the pump.

Cheers! Part Two will complete the story in a future issue of *Shotcrete* magazine.

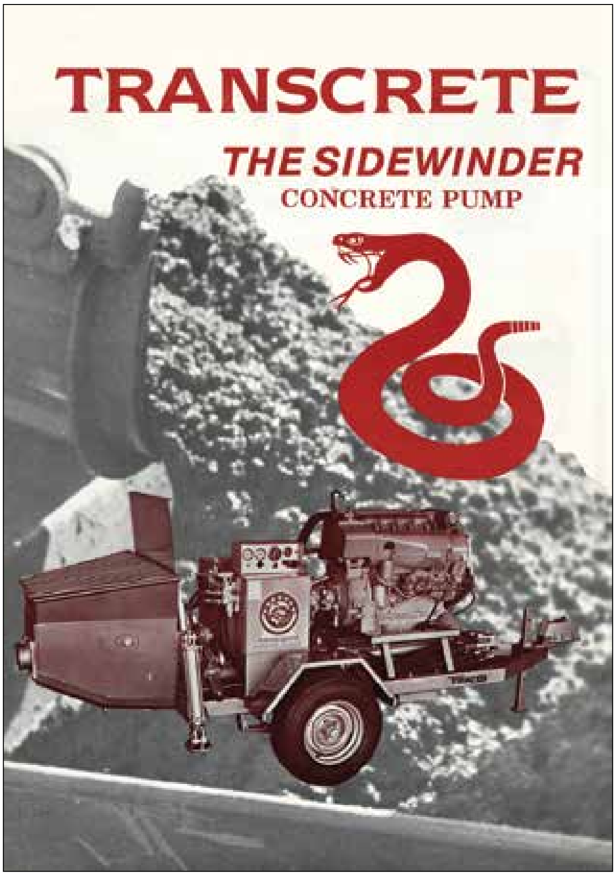
*Born in Australia in 1941, **Ian Hay** has spent a lifetime in widely diverse careers, including as a butcher, selling neon and outdoor signage, concrete placement, real estate, and eventually selling the Sidewinder S-tube pump for shotcrete placement.*

The History of Shotcrete Equipment

Part II: Sidewinder—Why So Great with Shotcrete Mixtures?

By Ian Hay

Transcrete specialized in building pumps for high-rise buildings and large concrete placements. The concrete used on these projects was normally low-slump, high-strength mixtures. Transcrete's formula required diesel engines developing 2 hp/yd^3 (2.6 hp/m^3) output with a hydraulic ratio of 4:1 between the hydraulic and concrete cylinders. The Sidewinder was designed to pump low-slump mixtures for small construction projects. As the Sidewinder was to have 6 in. (150 mm) bore concrete cylinders, we required 3 in. (75 mm) hydraulic cylinders to maintain a 4:1 ratio. However, we could not source 3 in. (75 mm) cast iron piston rings; the closest were 3.250 in. (82 mm). By sheer luck, not engineering skills, we ended up with a higher-pressure pump with a 3.41:1 ratio. Using the air-cooled 80 hp diesel and vane pump that would run at 3500 psi (24 MPa), we turned the Sidewinder into a powerhouse developing 1000 psi (7 MPa)—a higher line pressure than most concrete pumps on the market at that time. That's why the Sidewinder could handle the low-slump shotcrete mixtures.



BEYOND ARIZONA

Anthony Pools, through an Arizona contact, found out that Bennett Brothers was selling a hydraulic-powered shotcrete pump. In the Los Angeles, CA, area, Anthony Pools was using dry-mix shotcrete (gunite) because the local ready-mix producers would not supply concrete to pool builders, as they disrupted their delivery schedules due to the unreliable mechanical ball valve pumps they used. Dick Bennett and I arranged to meet Anthony Pools management on a site in Beverly Hills, CA, where they were shooting a pool at an existing multi-million-dollar home.

It was quite a circus. Bulk piles of sand and bags of cement were dumped on the grass in front of the home. A

One of Anthony Pools' shotcrete rigs with proportional mixer, Sidewinder pump, diesel generator to run the mixer, hydraulic power to run the concrete pump, and a 350 CFM compressor huge Ridley chamber dry-mix gun machine and 600 ft^3/min (17 m^3/min) air compressor were parked at the curb. Dust covered the whole area. The Anthony site supervisor called me to one side and quietly confessed that due to cement shortages at the time he was losing money with dry-mix; he had a special "cleanup" crew that followed up the next day to collect any sand left on the job as well as cement bags. "Are you sure your pump will handle wet-mix without breaking down? If so, you will save my backside!" I told him to let us know his next job location and we would provide a Sidewinder pump and the concrete supply. He seemed quite scared about the proposal so I told him we would pay for the concrete should the Sidewinder not perform.

I also added a "kicker"—if we perform, they would place an order for a Sidewinder. Several days later, Dick and I turned up to the next pool job with a Sidewinder hooked to a small pickup truck and a 120 ft (37 m) of 2 in. (50 mm) hose. The Anthony Pools crew set up the hoses and operated the pump with their own crew. The Sidewinder discharged the transit mixers in 30 minutes and the pool was shot and cut in a little over 2 hours. We were given a purchase order before we left the site. In addition, management wanted a meeting with Bennett Brothers to discuss building special volumetric mix rigs for all their operations country-wide.

MIXTURE DESIGN PROBLEMS

Bennett Brothers, in a joint venture with Bob Morgan, an Orange County manufacturer of volumetric mixers, built the first of many custom Anthony rigs mounted on "lowboy" trailers. There was a huge diesel generator and hydraulic power pack to provide electric power for the mixer and hydraulic power for the Sidewinder pumping module. The rig also had dry cement and aggregate boxes that were hoisted over the mixer hopper. We found that electric-powered mixers held their output settings much better than hydraulic systems that could vary as the oil heated up.

A week before the Thanksgiving holiday, Dick Bennett called to say, "Ian, the Anthony Pools' rig is using extra-high pumping pressures and getting as hot as a pistol." My response was, "Dick, it sounds to me like a mixture problem." He seemed very worried, so I jumped on the next plane to Los Angeles. Upon arrival, Dick and I met up with Anthony Pool's supervisor to discuss the mixture problem. I checked the material they had in their bins and asked the supervisor to take me around to his sand supplier, where he replied, "What is the point in that? Sand is sand." I replied, "Not exactly. It may not matter with gunite mixtures but with wet-mix, sand is very important! Your sand in the yard can contain a large amount of rock and coarse sand. Sand suppliers have a wide range of sands: plaster sand, masonry sand, concrete sand, stucco sand, and even sand for cats to pee in."

We went to the sand supplier and I gathered bags of different sands and aggregates. Next, we purchased a set of material grading screens. Back at Bennett's yard, I spread out the different sands in the sun to dry out and then made up

Close-up of the Anthony Pools rig used in Los Angeles and some in Texas

Gunite machine used in Beverly Hills by Anthony Pools when we were invited to inspect their operation. These machines were "dust producers." In today's market, the EPA would fine any company using such machines cardboard boxes so I could get specific weights. I selected what I felt were the two correct gradations of sand and then issued the highly technical blending process that follows:

- When the supplier loads your sand in his dump truck, he must put two scoops of the No. 1 sand followed by one scoop of the No. 2 sand...then repeat until he has a full load. I knew that between loading, delivery to Anthony Pools' stock pile, then reloading into the mixer boxes, the sand would be mixed enough.
- The secret sand was the one that passed the No. 100 screen. You need 3 to 5% of that sand in your total amount.

As it was coming up to the long weekend holiday period, I flew back to Australia. The following week, Dick called to tell me that the mixture was great, pump pressures were very low, and the mixture would "stack well" in vertical placements. I had also increased the rock content to 2000 lb (900 kg) to reduce pressure and decrease build up in the Sidewinder S-tube.

FLY ASH

Australia had an abundance of coal-fired power plants close to major cities that were producing a large amount of coal ash that was difficult to dispose of. However, in the early 1960s, an American by the name of Peabody had a bright idea to "help" the power plants solve their waste ash problem. Peabody entered into long-term disposal contracts with the power plants to remove their waste ash free of charge. At the same time, he had his daughter packing pozzolanic cement (fly ash) into plastic bags and sending off sample bags to all the ready-mix producers.

It turned out that by using a 75% portland cement and 25% fly ash blend in a concrete mixture it would improve long-term strength and reduce their costs, plus it made our concrete pump mixture designs in Australia much more pumpable. I kept telling everyone in the United States, "you should be using a fly ash blend rather than neat portland cement for shotcrete and pumping mixtures." At that time, they all called me crazy! I later found out that it would be another 4 to 5 years before fly ash blends were accepted in the United States.

Sidewinder exported to Bennet Brothers in starting their dealership

SIDEWINDER SALES TAKE OFF

By late 1980, Action Equipment salesman, Dave Rudin, was selling five Sidewinders per week in Arizona. Marion Ryder sold pumps to Shasta Pools and Sylvan Pools in Pennsylvania. Anthony Pools was running their special rigs in Texas. Haines Gunite and Superior Gunite were running Sidewinders. The Sidewinder became the "pump of choice" for shotcrete applications. We were air freighting one Sidewinder per day to Bennett Brothers in Los Angeles. Every month, a Sidewinder would be air freighted direct to dealers in New York or Pennsylvania. Air freight cost 46 cents per pound, Australia to Los Angeles, and an extra 18 cents to the East Coast. It turned out that the additional air freight cost was about the same as road freight for shipping a Sidewinder from Los Angeles to the East Coast.

SIDEWINDER DISAPPEARS

Around late 1981, Dick Bennett was approached by Jim Leach, President of Pacific Alloy Foundries, with a "buyout" proposal. Dick wanted to know if I had any problems with such a proposal, adding a "kicker" that if the deal goes through, Bennett Brothers would be able to settle all outstanding monies owed to Transcrete. Bennett Brothers was only a startup business when they became the lead dealership for Sidewinder pumps. Once Sidewinder sales took off, it was difficult for the Bennetts to have adequate cash flow for the operation. Their bank would not commit to funding such a new operation. As a result, Transcrete provided funding for new Sidewinders, with end buyer and distributor financing. Bennett Brothers' outstanding account was well over $500K US, so naturally I agreed to the sale.

Pacific Alloy's manufacturing skills were first class, so we agreed that they would only buy the Sidewinder pumping cell from Transcrete and do the rest on their premises. Money was never an issue, but their marketing ability was not that great. Thomsen Division, once the top pump manufacturer in the United States, had some difficulties with a management buyout, so we created a deal where Pacific Alloys would supply Sidewinder pumps to Thomsen, which in turn would be sold as "Thomsen Sidewinders." I felt that Transcrete should apply for trademark protection. We applied for and were granted the Sidewinder "snake" trademark. We found out from the U.S. Patent and Trademark Office that the Thomsen lawyers had also applied for the Sidewinder trademark. Fortunately, our application was lodged several hours before Thomsen. So much for "straight shooters." Thomsen was doing a great job; however, I could not see how a $25,000 trailer pump could solve Thomsen's financial issues. Then, we found out that Pacific Alloy Management was developing their own clone of our Sidewinder. Needless to say, Transcrete and Pacific Alloys parted company.

SIDEWINDER CLONES APPEAR

Transcrete attended the Atlanta World of Concrete to market Sidewinder pumps under the Transcrete brand. At the show, I was approached by the President of Security Pacific, the financiers of the Thomsen management buyout. Security Pacific wanted to dispose of Thomsen, and they presented me with a proposal that appealed to me. A handshake deal was made on the amount and terms. A week after the show, I received a Telex from Security Pacific Management advising me that Putzmeister had made an offer far higher than Transcrete was willing to pay and Putzmeister would be the successful bidder. As a matter of interest, Security Pacific would be providing funds to Putzmeister so they could buy Pacific Alloy as well. Under the Transcrete/ Pacific Alloy venture, the manufacturing agreement was not transferrable to another concrete pump manufacturer. A legal action was to follow.

I attended a meeting with Putzmeister and Pacific Alloy's "legal eagles" in Los Angeles. The theme was that the Pacific Alloy agreement should stand without the "not transferrable" clause, as my lawyer should not have included the clause. I explained that Pacific Alloy's team of three lawyers presented me with the Bennett Brothers buyout agreement 45 minutes from my air flight from Australia.

I read the agreement and asked if I could go up to the diner, to have a cup of coffee, and closely study the agreement. As I reviewed the proposed agreement, I made a few amendments. I returned 40 minutes later and presented the lawyers with my amendments. Jim Leach, Dick Bennett, and the three lawyers all agreed to my amendments. My reason for not wanting to change the legal document was I was not a lawyer and Jim Leach's three legal people should have advised their client(s) as to what they were signing.

Putzmeister accepted the document and proceeded with development of the Sidewinder copy they were to market as Putzmeister "Thom-Katt." It was many years before most Sidewinder parts were designed out of the Thom-Katt.

THEY BURY SIDEWINDER

In 1984, just prior to the LA Olympic Games, Transcrete sold a Sidewinder license to the Japanese manufacturer Suguie Ltd. In 1983, I purchased a home in the San Diego area and leased an office in La Jolla, CA. Dave Stoner, Vice President of Reed Manufacturing, contacted my office and was seeking a meeting to discuss the Sidewinder. I drove up to Reed's office in Walnut, CA, to meet with Dave. Reed was manufacturing the Reed dry-mix gun machine and could see the increased popularity of wet-mix shotcrete. Reed was a division of the Shea Construction group, so I felt comfortable with their capacity to manufacture the Sidewinder. A license agreement and the sale of the Sidewinder trademark was reached on the same terms as the Japanese deal. For tax purposes, we agreed to a monthly payment rather than a lump sum. We transferred Bruck Buckner and his partner Lisa to assist Reed's manufacturing program. Bruck and Lisa stayed on the Transcrete payroll for several years and finally transferred to Reed. For reasons best known to Reed, they proceeded to manufacture concrete pumps but dropped the use of the Sidewinder brand.

Back in Australia in 1987, Jacon Industries Pty Ltd., a Transcrete subcontractor, made an offer to buy the Sidewinder trademark and the rights to manufacture pumps. They started manufacturing pumps but did not use the Sidewinder brand. Jacon now specializes in manufacturing robotic shotcrete rigs for underground mining and tunnel applications that they sell worldwide under their own brand name.

Transcrete agreed to vacate the North American market for 5 years (and we did). Transcrete established a joint venture manufacturing plant in Los Angeles in 2002. Transcrete America Inc. moved into a larger factory in Pomona, CA, in mid-2016 and still manufactures the Trojan shotcrete pumps for the North American market. Dave Stoner asked Transcrete to design a new small, lower-cost trailer pump to tackle Mayco and Putzmeister models. In 1989, a production model Trojan was delivered to Reed. Stoner did not want to commit to ordering Trojans in large numbers. Transcrete, based on early discussions with Stoner, had tooled up to manufacture a batch of 100 Trojans for Reed and other markets. The Trojan is now the best-selling shotcrete pump in the Australian market. The North American market is very competitive with Sidewinder clones produced by Putzmeister, Warrior, Reed, Mayco, Airplaco, Schwing (S-tube model), and Olin—all with a touch of Sidewinder DNA.

THE PEOPLE BEHIND THE SIDEWINDER SUCCESS

The Sidewinder success was due to a large group of skilled people who made it their mission to sell the features and benefits of the Sidewinder for shotcrete applications: The Bennett Brothers, Al Connors and Dave Rudin in Arizona; Marion Ryder with his wide-ranging United States contacts; Fran Wilson; Bill Erwin, who attended a demo in Los Angeles whilst on Thomsen's payroll (Bill lent us a set of Allen wrenches when we had a minor hiccup during the demo); Michael Wilkman, the Northern Californian Sidewinder dealer; Pat Ingles, President of Pioneer Pumping Group who had the vision to buy a stock unit at Marion Ryder's suggestion; and finally all the dry-mix guys who switched to wet-mix. Today, it would be nearly impossible to assemble another group of people with the capacity to pull off what these gentlemen achieved in such a short time.

Born in Australia in 1941, ***Ian Hay*** *has spent a lifetime in widely diverse careers, including as a butcher, selling neon and outdoor signage, concrete placement, real estate, and eventually selling the Sidewinder S-tube pump for shotcrete placement.*

Featured in Volume 19, Number 4 • Fall 2017

A History of Shotcrete in Refractory

By Ted W. Sofis

THE EARLY YEARS OF REFRACTORY GUNNING

It wasn't long after Carl Akeley developed the dry-mix process (originally trademarked by the Cement Gun Company as "gunite") in the early 1900s that dry-mix started to be used for the fireproofing of mines. The earliest refractory gun mixtures were proportioned and mixed in the field. Mixtures such as the 1-2-4 mixture were widely used for industrial ductwork and petrochemical applications. The 1-2-4 mixture consisted of one part lumnite, or calcium aluminate cement; two parts haydite, an expanded shale; and four parts vermiculite. These early refractory mixtures were mixed on the ground or with paddle mixers—on jobsites—and they provided a low-density insulating refractory that could be gunned in place and handle the high temperatures.

DRY-MIX GUNNING MATERIALS

Manufactured refractory mixtures date back to the 1930s, but they were generally mixtures made for cast-in-place applications. In those days, gunning castables usually involved pre-dampening and aging the material for a period of time prior to gunning to get a successful result. In the 1960s, ball clays and chemical additives were incorporated into the refractory mixtures to help the material hang better and stay in place. The ball clays gave the mixture a sticky quality and chemical additives aided set times. A good gun mixture needed to have enough sharp aggregate to keep the gunning hoses clean from buildup and enough clay to help hold the material in place until it began to set. In the 1970s, gun mixtures were refined further to widen the water threshold and rebound was greatly reduced. Gunning products quickly gained acceptance in the steel industry for addressing refractory wear areas in steel ladles, soaking pits, and furnaces.

The speed of installation soon led to the use of monolithic gunned refractory materials in blast furnace troughs, blast furnaces, and many other applications.

STEEL MILL AND INDUSTRIAL APPLICATIONS

I personally began working in the shotcrete industry gunning refractory in steel teeming ladles. After a teeming ladle finished emptying its steel into molds, the empty ladle would be laid on its side and a thin layer of clay-based refractory would be gunned on red glowing ladle brick. This thin refractory coating would instantly dry on contact. When a ladle went off for repairs, we would take advantage of the opportunity to gun the ladle with a thicker application. The refractory coatings would extend the life of the ladle brick from 17 heats per ladle to 50 or 60 heats. In 1975, we worked with the first spinner prototype for gunning ladles. The spinner gun was a rotating nozzle system that was lowered into

A 9 in. (225 mm) thick dry-mix process installation of high-strength 2600°F (1400°C) refractory in a power plant ash hopper

Gunning a high-temperature refractory with the dry-mix process in the burners of a coal-fired power plant. The refractory material did not use portland cement the upright ladle to enable the operator to shoot ladles by remote control.

In blast furnace departments, we would routinely gun refractory materials to reline the blast furnace troughs. Because the refractory gunning could be performed quickly, blast furnace down time was greatly reduced. This enabled the blast furnace to get back on line quicker and possibly get an additional cast in that day. In steel making, lost production time is expensive and can often be costlier than the repair work.

In the power industry, gunned monolithic refractories began to replace fire brick in power plant ash hoppers. Large boiler design and engineering companies such as Babcock & Wilcox and Combustion Engineering developed their own refractory gun mixtures, including a prepackaged version of the old 1-2-4 mixture.

A variety of specialty gunned refractory materials, including high-strength refractories for ash hoppers; chrome alumina, for cyclones; and medium-density and lightweight insulating gunning mixtures, are currently used in power generation facilities.

“Hot gunning,” common in the steel industry, is where gunning repairs are made to vessels, soaking pits, or coke ovens while the units are still hot. These gunning repairs can be done with a handheld lance or with a remotely operated nozzle.

Advances in Dry-Mix Gunning Equipment

Initially, most of the refractory maintenance gunning was done with single-chamber, batch-type guns, where the gun was loaded with material, pressurized, and then the material discharged. The development of the continuous-feed rotary gun (National Foundry’s Jet-Creter, a straight drop rotary gun with a rotating air lock) opened refractory shotcrete to greater use in the steel industry.

The Reed Gun that followed was the first bowl-type continuous-feed rotary gun to be widely used for refractory gunning. The Reed Gun gained popularity in the mid-1970s because it was easy to use and small enough to be stationed at various steel mill locations where maintenance gunning was done on steel ladles, blast furnace departments, and soaking pits. Pre-dampening of the prepackaged refractory materials was initially accomplished with paddle mixers. This required adding a premeasured amount of water, mixing for a few minutes, dumping the mixture out of the mixer, and hand shoveling the dampened material into the gun. Allentown developed a gunning system with a mixer, conveyor, and hopper, and provided a method to pre-dampen without having to double-handle the material. In the 1970s, auger-type pre-dampeners emerged, most notably the Reed-Mate and the B & B Pre-dampener. They provided a more efficient means of pre-dampening dry packaged refractory material.

In my time in the business, I worked through the early years using paddle mixers, then the conveyor hopper rigs, and on to the auger type pre-dampeners that we still use today.

The Jet-Creter was the first straight-drop rotary gun used for refractory installations in the United States. They typically had gasoline engines to run the rotor and were mounted on wheels with a trailer hitch for towing

An auger-type pre-dampener used in dry-mix process refractory installations

A typical setup used in dry-mix process refractory installations with a rotary gun and an auger-type pre-dampener for gunning dry prepackaged refractory material

WET-MIX PROCESS SHOTCRETE REFRACTORY

The emergence of wet-process shotcrete for refractory installation lagged behind the civil and building industries for a few reasons. First, the technology in refractory shotcrete pump mixtures had not yet been developed. That work

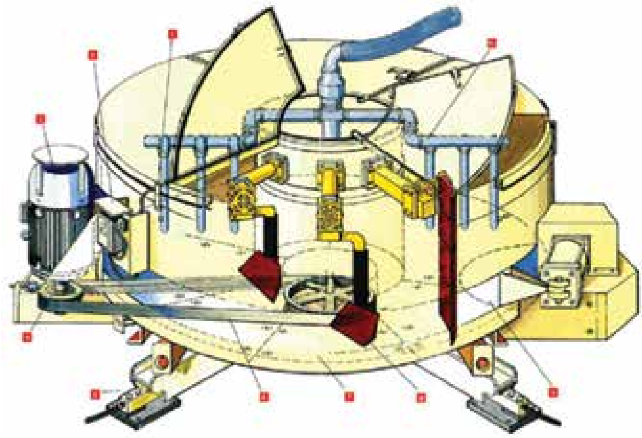


Diagram of a turbine mixer. The wet-mix process didn't become viable for refractory installations until the 1990s, when mixers were developed that could mix quickly enough to keep pace with the higher-volume wet-mix shotcrete pumps

Wet-mix shotcrete pump with a pan mixer for handling bulk sacks works well for mixing and placing large volumes of material

was first undertaken at Harbison Walker in the mid-1990s. The patent was applied for in 1996, by inventors Mark C. Langenohl and Gustav O. Hughes, for "non-slumping, pumpable, castable, and method of applying same" for shotcrete application. Another obstacle was mixing dry, pre-packaged refractory materials quickly enough to keep pace with concrete pumping. The existing refractory mixing equipment, at the time, was not adequate to mix and handle a volume of material that could be pumped. Early installations used continuous mixers or a dedicated concrete truck to mix the refractory materials. This problem was later overcome with the development of turbine-style pan mixers with high-speed mixing blades.

The pan mixers and the new technologies in pumpable shotcrete refractories opened the door to high-volume wet-process shotcrete installations.

ROBOTIC SYSTEMS

The progression to robotic systems for remote manipulation of the nozzle created many innovations. In years past, hot gunning was mainly done with long, handheld lances and protective clothing. The major problems with hot gunning by hand involved contending with the intense heat and the difficult and awkward gunning angles. Today, with the technology available, basic oxygen furnace vessels can be shot with robotic systems. Visibility in hot vessels and the intensity of the high temperatures present major difficulties. However, these issues can be effectively dealt with by using a computer-programmed robotic gunning system. The areas in need of repair are located by a laser that scans the inside of the vessel. The nozzle is then directed to these areas where the refractory material is gunned in place. The refractory material can be efficiently installed without the exposure and difficulties of using a handheld nozzle.

LOOKING FORWARD

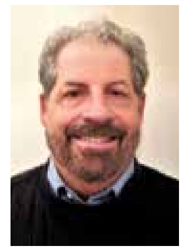
Refractory mixtures continue to evolve. In recent years, ultra-low-cement gunning mixtures have become more common. There are ultra-low-cement gun mixtures for the dry-mix process gunning and ultra-low-cement pump mixtures for wet-mix shotcrete. Refractory gun mixtures with no cement, with enhanced refractory properties, have been introduced and are being used effectively in a variety of applications.

Refractory-lined 0.25 mile (0.4 km) long tunnel was placed with shotcrete

In the 42 years that I've been involved in gunning refractory, we've seen substantial advances. I've had the good fortune to work with many talented, dedicated, and innovative people in both the material and equipment sides of refractory applications. When we had problems gunning, they listened and made adjustments with grain sizing and other aspects of their mixtures to make better gunning refractory products. It's remarkable how far we've come and how much progress has been made in such a short time. With the 20th anniversary of the American Shotcrete Association, it is fitting to look back at the progress we've made in the rather specialized refractory shotcrete business and detail the accomplishments we've made along the way.

Acknowledgments

Gus Hughes, President, Mt. Savage Specialty Refractories.



__Ted Sofis__ and his brother, William J. Sofis Jr., are the Principal Owners of Sofis Company, Inc. After he received his BA in 1975 from Muskingum College, New Concord, OH, Ted began working full time as a shotcrete nozzleman and operator servicing the steel industry. He began managing Sofis Company, Inc., in 1984 and has over 40 years of experience in the shotcrete industry. He is 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.

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Evolution of Shotcrete Materials in the Past 20 Years

By Nicolas Ginouse and Simon Reny

Shotcrete has evolved significantly since the early 1900s. We've certainly achieved remarkable progress since the early 1980s when volumetric batching of sand and cement was the norm. This simple technology had its uses, but volumetric batching often led to inaccurate (and usually high) cement contents. High cement contents, combined with a lack of coarse aggregate, resulted in high shrinkage values, resulting in increased cracking potential and porosity. Advances in traditional cast concrete mixture designs have translated well to mixtures placed using the shotcrete process. In this article, we discuss the evolution and sophistication of shotcrete materials primarily governed by industry demand for high-quality, durable, and robust solutions for a wide range of new construction, repair, retrofit, and ground support applications. New chemical admixtures, additives, pozzolan, and cement technology have provided numerous technological breakthroughs for the shotcrete industry. The shotcrete industry has embraced

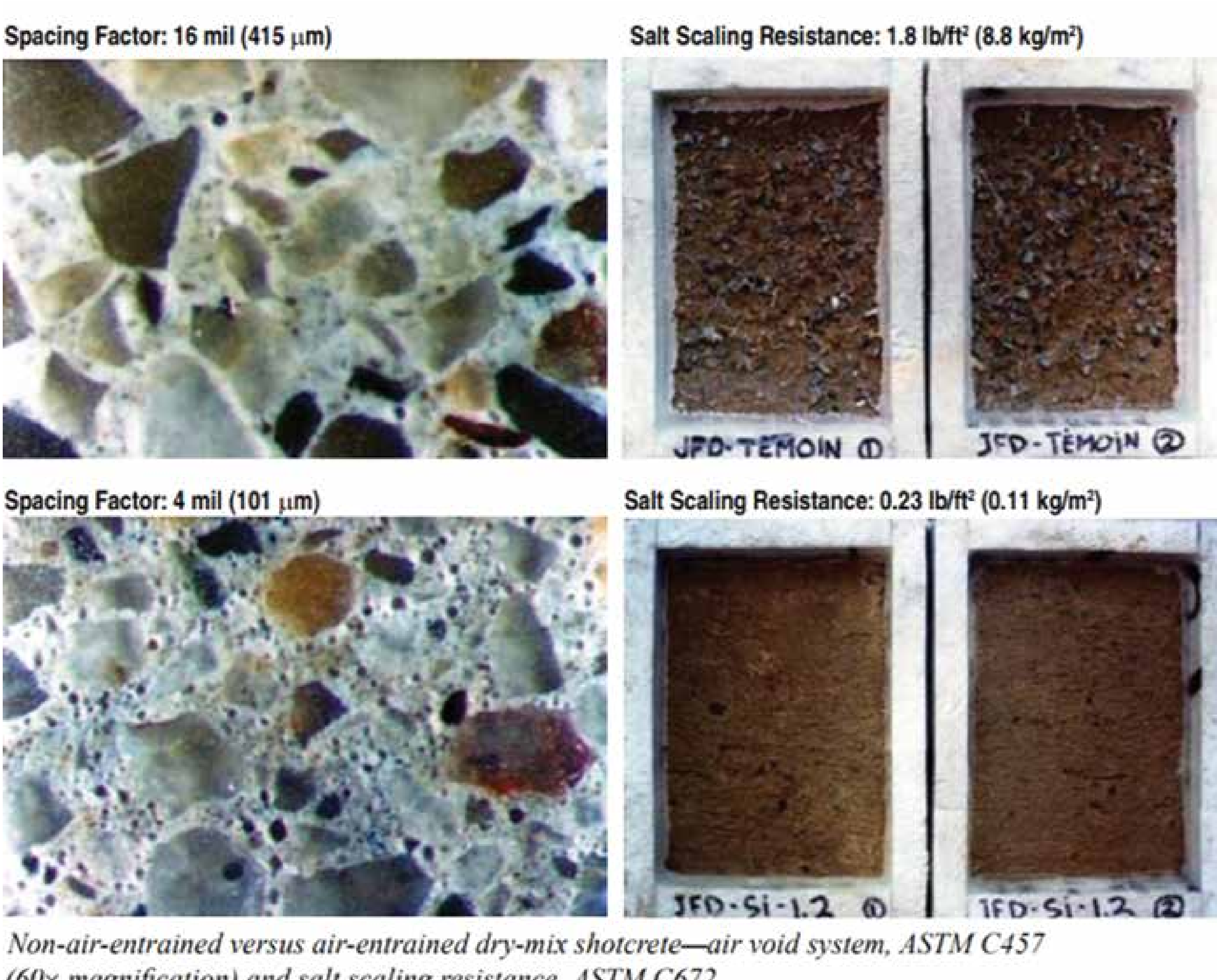

Fig. 1: Effect of air-entraining in dry-mix shotcrete[2]

these technological breakthroughs and left the old sand and cement days, with all its potential weaknesses, behind.

POWDER AIR ENTRAINMENT

In 1996, the addition of air entrainment in wet-mix shotcrete was not new. However, the introduction of powder air-entraining admixtures in the dry-mix shotcrete was a new phenomenon. It was widely assumed that dry-mix shotcrete durability could only be achieved with silica fume, proper compaction, and low water-cement ratio (*w/c*) (all of which resulted in low permeability). Studies completed at the University of Laval in Quebec City, QC, Canada, however, proved that the addition of air entrainment in dry-mix shotcrete was not only feasible but it also consistently provided significantly improved long-term durability.[1] Figure 1 shows how dramatically salt scaling resistance can be improved using proper dosages of air-entraining additives, which stabilized air void systems and reduced the air void spacing factors.[2] This technology has been adopted by many Specifiers, especially those in northern climates where concrete structures are exposed to extensive freezing-and-thawing cycling. Since 1996, thousands of structures throughout North America have been successfully repaired using dry-mix shotcrete mixtures that are enhanced with powder air-entraining admixtures.

MACRO-SYNTHETIC FIBERS

Although high-volume macro-synthetic fibers were used in wet-mix shotcrete applications as far back as 1988, and even earlier for concrete slab applications, the length and shape of macro-synthetic fibers made them impractical for dry-mix applications. The use of macro-synthetic fibers adapted well to wet-mix shotcrete formulations, primarily because of the similarities in the mixture design, but as reported by Morgan and Rich[3] in 1998, attempts to use macro-synthetic fibers in dry-mix shotcrete applications failed for a variety of technical reasons. To adapt macro-synthetic fibers to the dry-mix shotcrete process, it took almost another decade of research. Dufour et al.[4] developed a solution that was immediately adopted by some Canadian mines to improve flexural toughness and reduce wear on shotcrete equipment. In the construction of the pedestrian tunnel connecting Billy Bishop Island Airport to the mainland in downtown Toronto, ON, Canada, macro-synthetic fibers were chosen over steel fibers to avoid compromising the waterproof membrane (Fig. 2), as reported by Croutch.[5]

IMPACT AND ABRASION RESISTANCE

Over the past 20 years, many studies have been completed to improve the resistance of shotcrete linings to impact and abrasion. Primary applications included mining industry examples such as ore pass and ore bin linings. Other applications included the rehabilitation of cold climate lighthouses and other marine structures subject to impact by ice flows. Studies proved that dry-mix shotcrete applications using an optimized mixture design, combining the proper cementitious matrix with hard aggregates and steel fibers at the optimum dosage, provided a durable protective lining even if exposed to aggressive abrasion and impact.

These high-performance dry-mix shotcrete mixtures were first used to repair a lighthouse on the St. Lawrence River (as reported by Gendreau et al.[6]), and the technology has gained acceptance on numerous other high-impact or high-abrasion applications. Ease of application and long-term performance led to its use on numerous projects across North America.[7] Today, most ore passes in Canadian mines are excavated and lined using high-performance, high-dosage, steel-fiber shotcrete to ensure the long-term performance of these critical infrastructures[8] (Fig. 3).

SELF-CONSOLIDATING WET-MIX SHOTCRETE FOR MINING APPLICATIONS

After the development of flowable/pumpable self-consolidating concrete, similar wet-mix shotcrete materials were

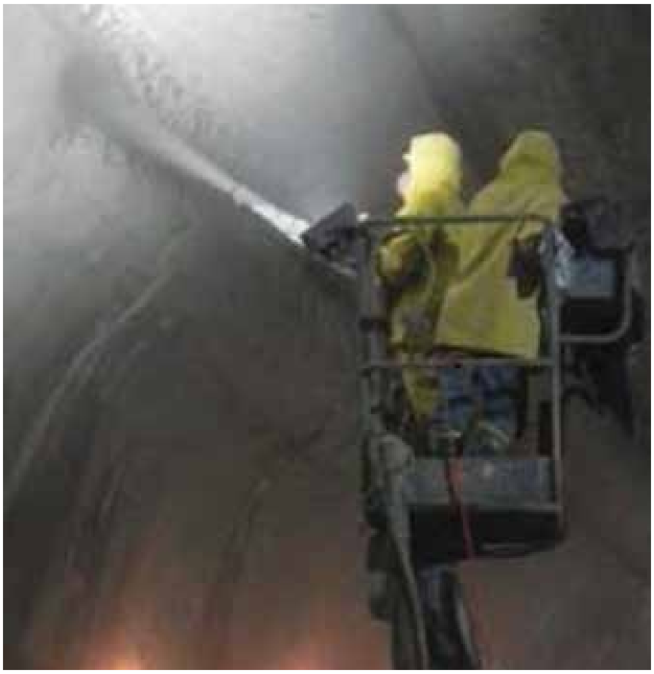

Fig. 2: Application of macro-synthetic fiber shotcrete in the Billy Bishop Pedestrian Tunnel[5]

Fig. 3: Construction and installation of protective shotcrete lining for critical ore pass in a Northern Quebec gold mine

introduced in 2003 at deep, hard rock mines in Québec, Canada, to address material delivery challenges.[9] For these applications, shotcrete mixtures were mixed on the surface before being dropped several thousand feet (m) through a steel pipe (slick line) and then transferred to an agitator truck for underground delivery and placement. This innovative solution was possible using advanced technology high-range water-reducing admixtures, viscosity modifiers, and hydration control admixtures and significantly increased shotcrete placement production at these depths. The development and application of these admixtures for mining and tunneling applications undoubtedly contributed to the increased use of wet-mix shotcrete.

These advanced admixture technologies have expanded into preblended, prepackaged, self-consolidating wet-mix materials, supplied in bulk or bagged formats. This technology, where all components are preblended in dry form, provided further flexibility and allowed shotcrete crews to produce their own shotcrete "on demand," simply by adding water to the dry, preblended material[10] (Fig. 4). These products have been successfully used in many operating mines across North America.

ULTRA-RAPID-STRENGTH DRY-MIX SHOTCRETE

Initially introduced in Canada in 2013 for mining applications, ultra-rapid-strength dry-mix shotcrete was developed to accelerate the underground development cycle (drill, blast, muck, shotcrete) to improve productivity. Shotcrete mixtures produced with this new technology provide—in only 2 hours—the same 24-hour compressive strength values achieved with portland cement-based shotcrete mixtures[11] (Fig. 5). This innovative technology combines a shotcrete mixture using a very reactive ettringite-based cement using the dry-mix process and allows proper and consistent placement without the risk of blocked hoses. This technology has also been combined with macro-synthetic or steel fibers to overcome challenging ground support applications and to provide more rapid impact and abrasion resistance solutions.

ENGINEERED HIGH-PERFORMANCE, FIBER-REINFORCED DRY-MIX SHOTCRETE

Initially developed and used in Japan for civil applications, this technology was introduced in Canada a few years ago for mining applications in areas of considerable seismic activity and extremely poor ground conditions. In many of these situations, conventional fiber-reinforced shotcrete possessed limited effectiveness due to poor resistance to spalling under these conditions (Fig. 6). The extremely high flexural and tensile toughness provided by this innovative mixture design technology has provided an effective protective lining for areas affected by blasting.[12]

SUSTAINABLE DRY-MIX SHOTCRETE USING SUSTAINABLE MATERIAL

As in traditional concrete mixtures, sustainable and recycled materials including aggregates,[13] recycled glass filler, blast-furnace slag, plastic (Fig. 7), rubber (Fig. 8), and others[14] have been shot using the dry-mix shotcrete process. By nature, dry-mix shotcrete does not require pumpability as a mixture characteristic and therefore provides a unique ability to

Fig. 4: Mobile concrete mixing unit integrated with a lifting system for bulk, preblended concrete, and shotcrete material bags[10]

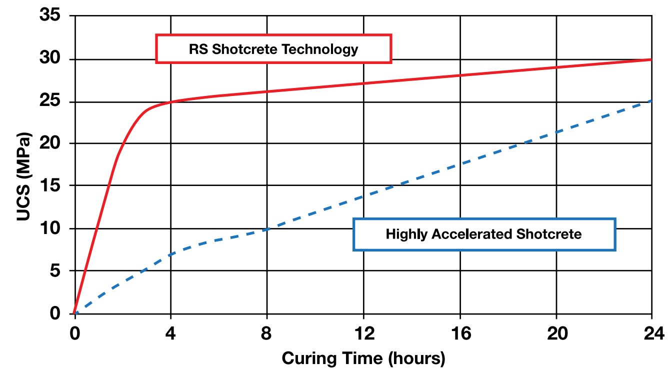

Fig. 5: Typical strength development curve of King RS Shotcrete Technology versus highly accelerated portland-cement-based shotcrete[10]

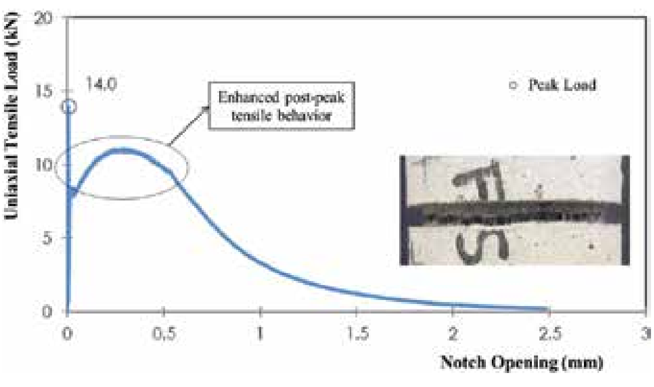

Fig. 6: Post-peak tensile behavior of an engineered high-performance fiber-reinforced dry-mix shotcrete[11]

spray extremely complex materials. Many of these materials would be impossible to pump with a conventional concrete pump due to their high viscosity, rapid reactivity, or unstable rheology. Current research is developing analysis tools that can evaluate the environmental impact of shotcrete mixtures with the objective to optimize sustainability.

DEVELOPMENT OF HIGHLY CRACK-RESISTANT SHOTCRETE

When used in repair, shotcreted materials can be subjected to high restrained shrinkage conditions. Shotcrete's ability to accommodate the restraint without cracking is critical to ensuring long-term durability. There are a limited number of testing methods to evaluate cracking potential of cast concrete or mortars. These test methods designed for casting materials require modification to make them suitable for concrete placed using the shotcrete process. Recent studies detail the adaptation of existing test methods to shotcrete mixtures to determine crack resistance of the material as shot.[15] The test method uses molds in ring form as per AASHTO T 334 (Fig. 9 and 10) and reproduces restrained shrinkage conditions. The development and use of this test method for shotcrete paves the way for mixture design optimization and improvement of the crack resistance and durability of shotcrete materials.

Fig. 7: Shotcrete core containing shredded recycled plastic[14]

Fig. 8: Shotcrete core containing recycled rubber beads[14]

CONCLUSIONS

Over the past 20 years, new shotcrete materials technology has evolved faster than in the previous 100 years. These technological developments have produced dramatically improved quality and superior performance of shotcreted materials. This evolution of materials has served the shotcrete industry well, and together with advancements in equipment design, improved training and education, certification of shotcrete nozzlemen, and recognition of qualified shotcrete crews and contractors

Fig. 9: Sketch from the AASHTO T 334 restrained ring test[15]

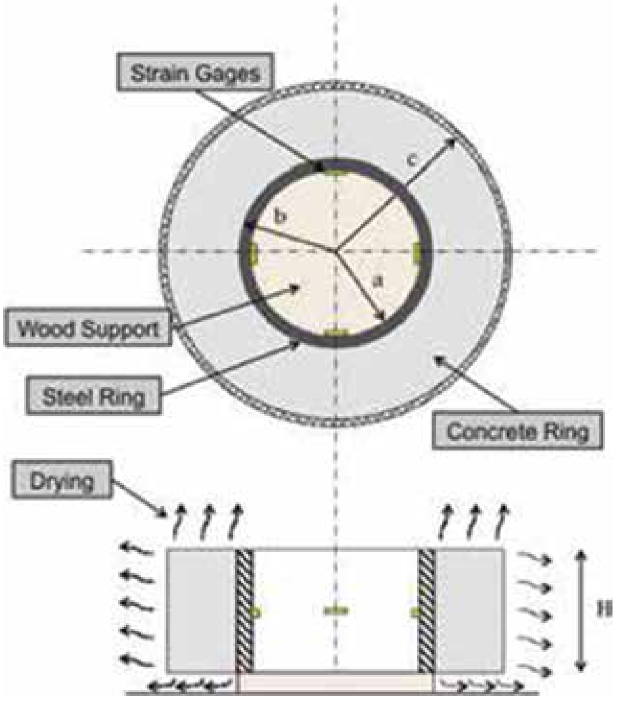

Fig. 10: Modified AASHTO T 334 restrained ring test orientation during shooting allows proper consolidation of the test specimen[15]

has led to sizable growth in the shotcrete industry. Moving forward, our industry must take advantage of these new, commercially available and innovative shotcrete materials and technologies. Most of the technologies presented in this brief article have been used successfully and are lightyears ahead of the old sand/cement mixtures developed at the beginning of the 20th century.

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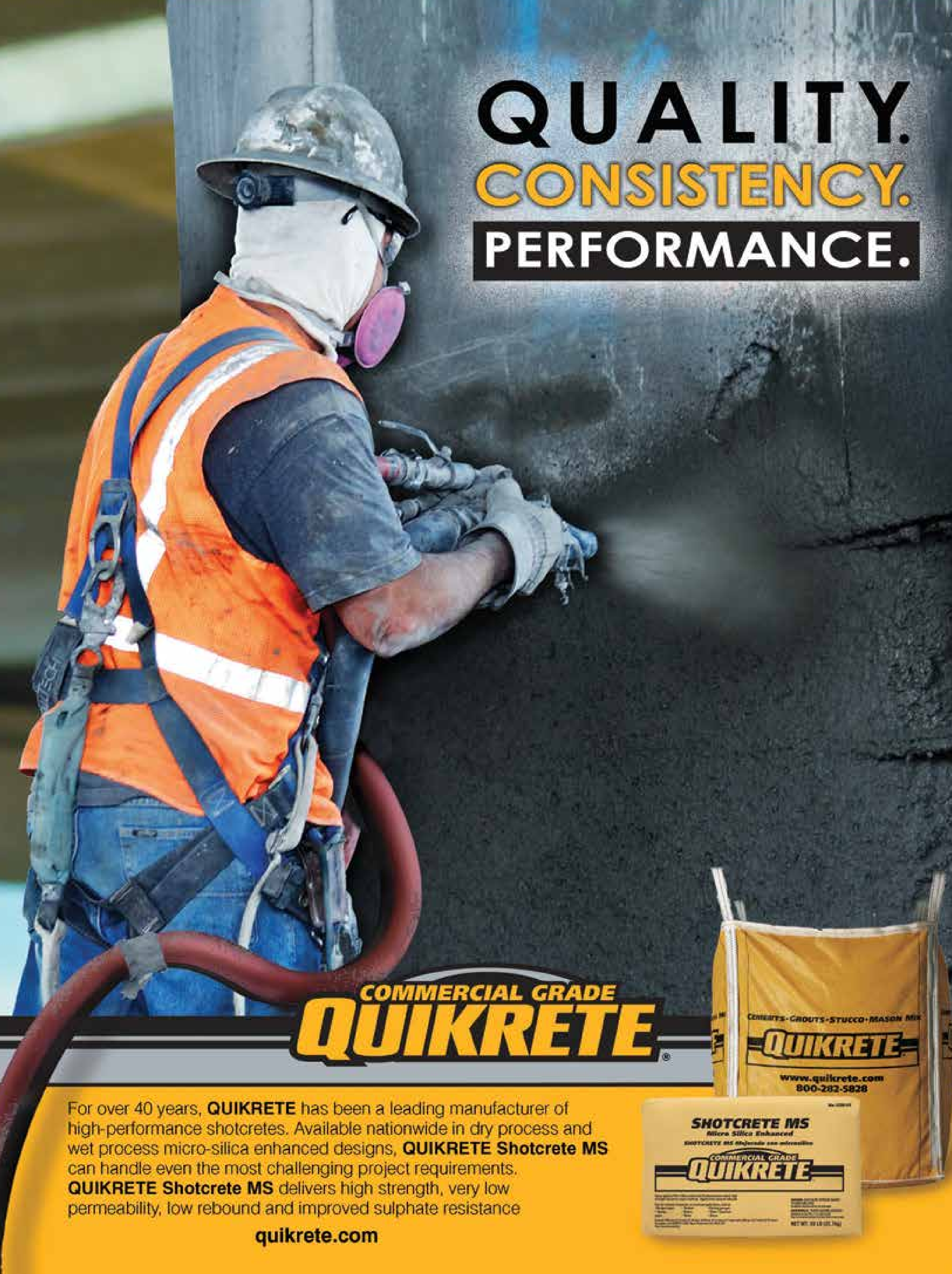
Nicolas Ginouse *is a Research and Development Engineer for King Packaged Materials Company and Associate Professor at Laval University, Quebec City, QC, Canada. His research interests include all the aspects involved in shotcrete technology, whereas his expertise contributes to the development of new cementitious materials for mining, tunneling, architectural, and repair applications. Ginouse received his degree in mechanical and industrial engineering from Art et Métiers Paritech, Paris, France, in 2010 and his PhD in civil engineering from Laval University in 2014. He is a member of ACI Committees 239, Ultra-High-Performance Concrete, and 506, Shotcreting.*

Simon Reny*, P.Eng, is the Business Development Manager, Canadian Markets, King Shotcrete Solutions. Reny began his career at King in 2004 as a Technical Sales Representative after receiving his degree in civil engineering from Laval University. Then, as Manager of Technical Services, he helped build a strong technical team to serve both internal and external customers. After 6 years in that position, Reny is now responsible for the sale of King Construction Products throughout the Canadian mining and construction markets. He is a member of ACI Committee 506, Shotcreting, Chair of the ACI Shotcreting-Evaluation Subcommittee; and a member of the American Shotcrete Association.*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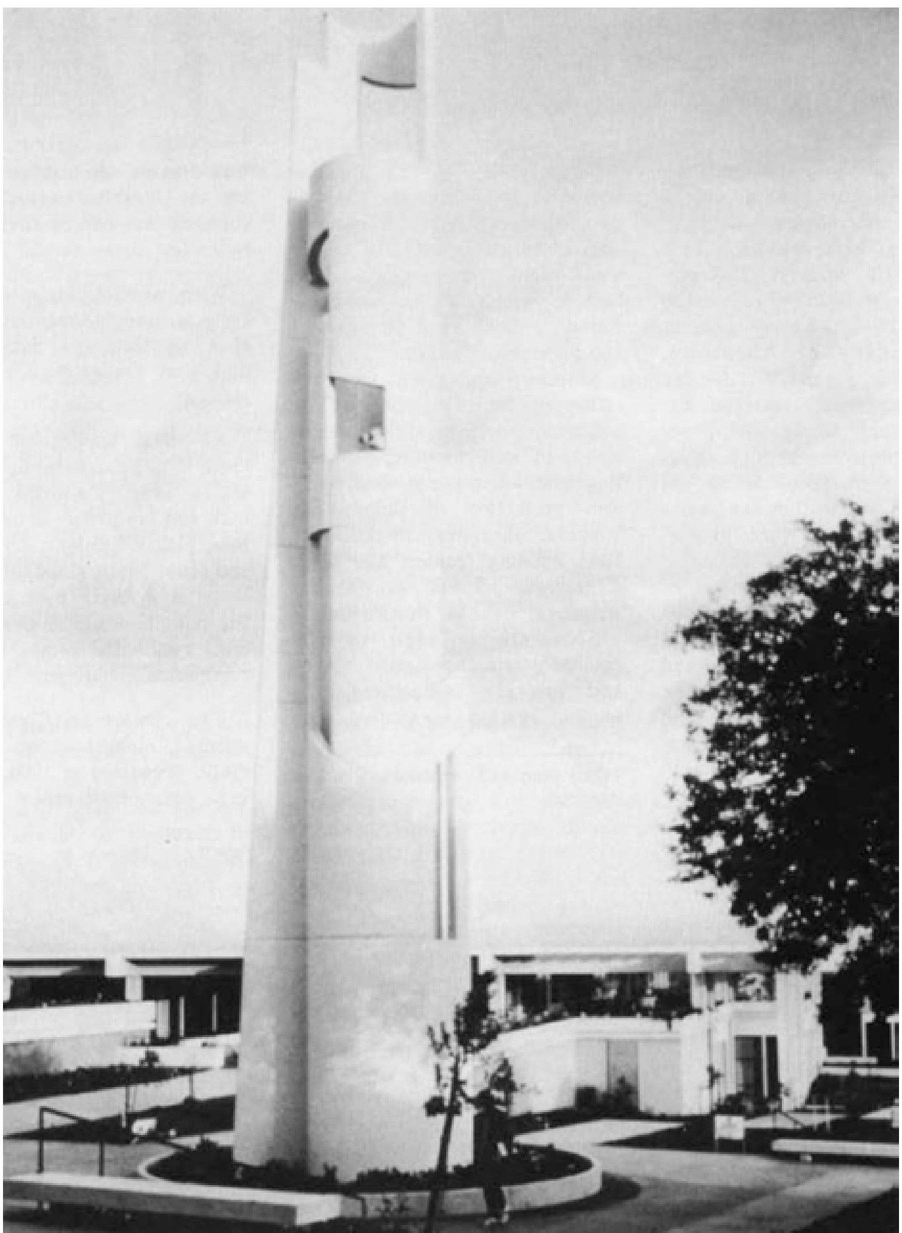
Introduction: Application and Use of Shotcrete

By Theodore Crom

The following article was reproduced from the January 1981 issue of Concrete International with permission from the American Concrete Institute. The author, Theodore R. Crom, was Chair of ACI Committee 506, Shotcreting, at that time. Crom was a contractor specializing in the construction of prestressed concrete water storage tanks. Crom is recognized as one of the "Shotcrete Greats" (see the President's Message) and was well-known for his definitive writing on dry-mix shotcrete nozzling techniques, still used as the basis for training today.



This memorial tower is an outstanding example of the use of shotcrete as a structural and architectural material

SHOTCRETE, by the American Concrete Institute definition, is mortar or concrete pneumatically projected at high velocity onto a surface (ACI 506.2-77). The still common term "gunite" is a trade name established by the Cement Gun Company of Allentown, Pennsylvania, around 1911 for dry mix fine aggregate material, hydrated at the nozzle, and pneumatically projected at high velocity onto a surface. Many old established application companies still incorporate the word "gunite" in their names.

In recent years, a number of manufacturers have developed widely different types of equipment for spraying both wet and dry-mix shotcrete. Some of the equipment is capable of handling a mix incorporating coarse aggregate up to about ¾ in. (19 mm) in size.

Today both wet-and-dry-mix shotcrete are extensively used in new construction for curved or folded section roofs, shell roofs, walls, canal, reservoir, and tunnel linings, swimming pools and other water containment structures, and prestressed tanks.

Shotcrete is excellent for restoration and repair of concrete, repairing fire damage and deterioration, and waterproofing of walls. It provides long-term steel corrosion protection of piling, coal bunkers, oil tanks, smokestacks, steel building frames, and other structures, as well as encasing structural steel for fireproofing.

Shotcrete is used to permanently stabilize rock slopes, and provide

A skatepark constructed by using shotcrete

temporary protection against excavation side wall erosion, air slaking or raveling of freshly excavated rock surfaces that will be covered with concrete.

With special materials, shotcrete is used for refractory lining of kilns, chimneys, furnaces, ladles, and similar high-heat applications.

An ideal application of shotcrete is to produce sculptures and statues over wire forms, imitation rock and landscape formations for zoos, plazas, gardens, arboretums, and other "natural looking" formations. It is being used in coating the outside walls of precast concrete residential homes as well as commercial buildings.

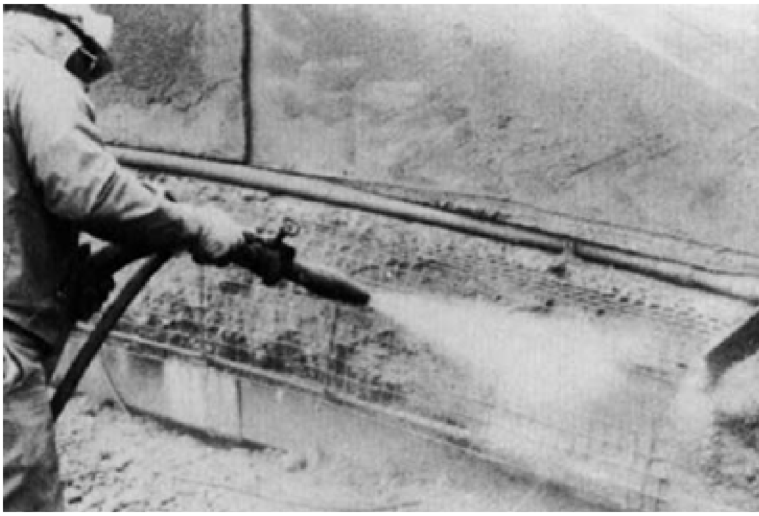
The American Concrete Institute Committee 506 on Shotcrete, organized in 1960, is active in a number of areas. The first publication of the committee was a "Recommended Practice for Shotcreting" (ACI 506-66), which is still current. An expanded and updated version of the Recommended Practice is now being drafted.

"Specifications for Materials Proportioning and Application by Shotcrete" (ACI 506.2-77) was prepared by the committee for the use by architects and engineers as a reference in their work.

Committee 506 is also developing a program for certification of nozzlemen. The preliminary draft suggests that any firm can establish their own certification program for in-house use. For more creditability or recognition, a local testing laboratory or independent agency could conduct the examinations recommended and issue the certification. Such nozzleman certification, once the procedure is established, might be required by the job specifications. It is conceivable that eventually there may be a national certification by an independent agency such as the ACI.

Another activity of Committee 506 is preparing a State-of-the Art paper on underground shotcrete. Preliminary drafts are completed.

Another wide-spread use of shotcrete is for the protection of pipe from corrosion. It is also often used to coat the interior joints of mortar-lined pipe



Shotcreting fascia beam; area to right is overshot

ACI Committee 506 is also preparing a bibliography of shotcrete publications.

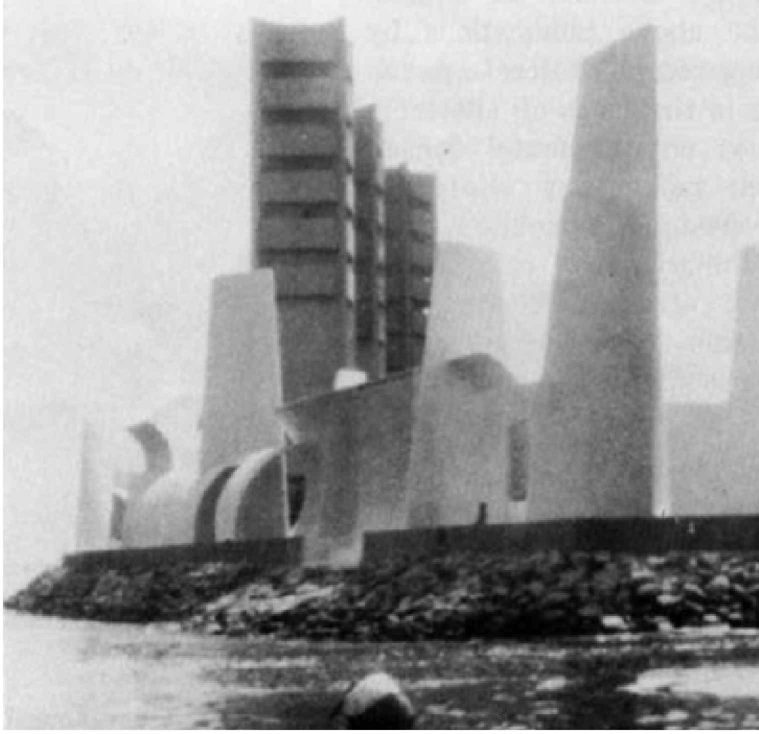
Other ACI publications currently available on shotcrete include: SP-14, Shotcreting, a collection of papers prepared from an ACI Symposium in 1955 and much of the information contained in SP-14 is still current, SP-14A, Engineering Properties of Shotcrete; SP-45, Use of Shotcrete for Underground Structural Support, a collection of 39 papers presented at an Engineering Foundation Conference in 1973; SP-54, Shotcrete for Ground Support, containing 43 papers presented at a similar conference in 1976; and SP-65,

Because of the high copaction density achieved by air placement, finishing operations can start immediately

Shotcrete is often placed from a boom bucket as well as from grade level

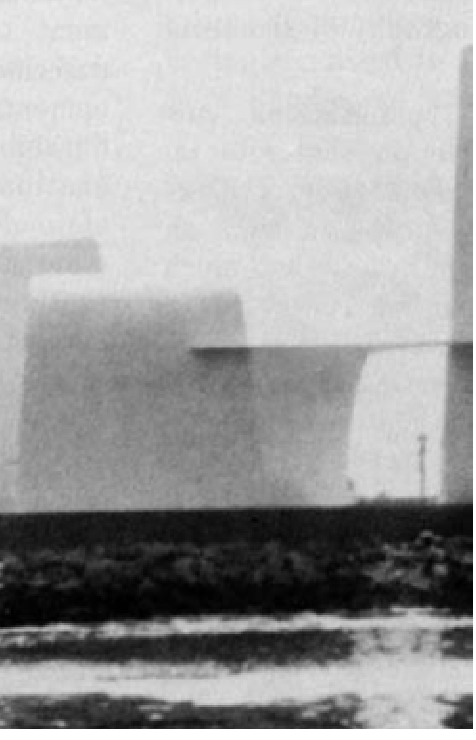
Shotcrete expansion dam became loose, had to be rewelded

Shotcrete being applied over existing wood piling that had considerable erosion damage. By use of mesh-reinforced shotcrete, the pier was salvaged and is back in use



Wetting down an area prior to shotcreting

Water-jetting equipment from a fountain is being encased in air-placed concrete. The nozzleman is directing the stream around this equipment to ensure proper imbedment

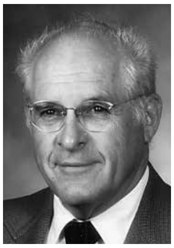


Another unusual use of shotcrete as a material. This photo shows free-form shapes that hide gas and oil drilling platforms constructed on man-made islands in Long Beach, CA, harbor. Some of these structures are over 120 ft high

Performance of Concrete in Marine Environment, containing 2 papers, "Shotcrete Repairs of Concrete Structures in Marine Environment," and "Deterioration and Repairs of Navigation Lock Concrete." (The synopses of these two papers are published in this issue.)

The following articles in this Special Issue of Concrete International are intended to supplement the above publications by describing recent shotcrete developments in the areas of: shotcrete durability; environmental considerations; refractory shotcrete state-of-the-art; evaluation and state-of-the-art of steel fibrous shotcrete; accelerated shotcrete; current tunnellining experiences; proper nozzling; and a comparison of the German shotcrete standard.

Materials for these articles were presented at a Symposium on the Application and Use of Shotcrete, ACI Fall Convention, November 1979, Washington, D.C. In that ACI Committee 506 has now been a committee for almost 20 years and shotcrete is still developing, improving, and changing, it might be reasonable to assume that the committee will be serving the industry for years to come. I hope the following articles will be informative and useful to our readers.



***Theodore R. Crom**, **FACI** was founder and chairman of the board of The Crom Corporation, a leading design-build firm specializing in wrapped prestressed concrete tanks headquatered in Gainesville, FL. He was a long time member of ACI 506 Shotcrete, ACI 344 (now ACI 372), and ACI Certification E902 and served as chair. A great supporter of students he was actively involved with a variety of engineering student groups at the University of Florida. Crom held a civil engineering degree from the University of Florida.*

Evolution of Fiber Reinforced Shotcrete

By D. R. Morgan and R. Heere

Figure 1. Rock slope stabilization with SFRS, Snake River, Idaho, 1972

The Batelle Research Corporation in the USA in the early 1970's. The first practical application of steel fiber reinforced shotcrete (SFRS) was in 1972 when the US Army Corps of Engineers used dry-mix SFRS for rock slope stabilization and lining of a tunnel adit at the Ririe Dam in Idaho (Fig. 1). A photo of this slope stabilization work is shown in Figure 1. In Canada, the first use of SFRS was in 1977 when work was conducted to stabilize a sloughing railway embankment in Burnaby, British Columbia. Figure 2 shows this work in progress. The first author of this paper was involved in this Burnaby project and has had the opportunity to examine it after 23 years of service. It is still performing well.

APPLICATIONS

Since these early years, SFRC has evolved from a novel concept to a mature technology, with many hundreds of thousands of cubic meters of SFRS being used annually around the world on a wide variety of civil engineering and mining applications. Civil engineering applications include:

- Primary (initial) and final linings in road, rail, sewer, and water conveyance tunnels;
- Permanent linings in large caverns such as sports arenas, hydroelectric power houses, desilting chambers, railway stations, and military installations;
- Lining of ventilation shafts in road and rail tunnels and pressure surge shafts in hydro electric projects;
- Construction of water and ice control systems in road and rail tunnels;

Figure 2. Railway embankment stabilization with SFRS, Burnaby, British Columbia, 1977.

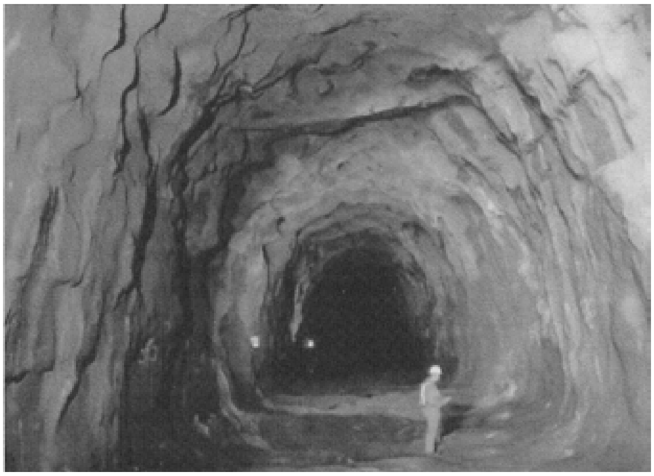


Figure 3. SFRS final tunnel lining, Stave Falls Hydro Electric Project, British Columbia, 1998.

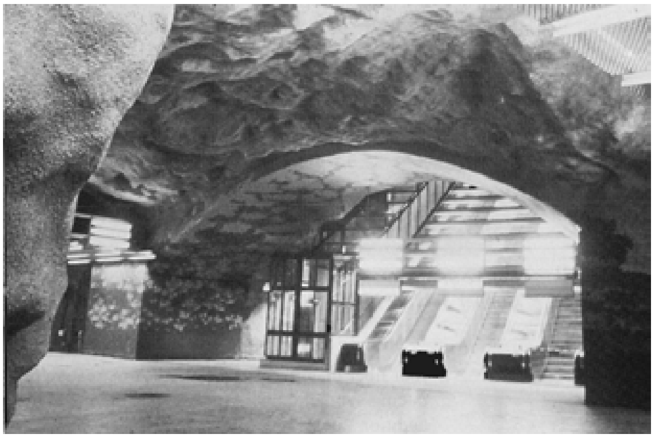


Figure 4. SFRS final tunnel lining of underground metro (passenger railway station) in Stockholm, Sweden.

- Repair and seismic retrofit of infastructure, including dams, bridges, and marine stmctures (2).

References 2 through 10 provide numerous case history examples of such SFRS applications in civil engineering projects. Figure 3 shows the final SFRS tunnel lining in one of the Stave Falls, British Columbia, hydroelectric pressure headrace tunnels (10). Figure 4 shows an architectural treatment on a permanent SFRS tunnel lining in the underground metro (passenger railway station) in Stockholm, Sweden.

In addition to civil engineering applications, SFRS is now finding increasing use in lieu of screen (welded wire mesh fabric or chain link mesh) in many mining projects worldwide. References 2,4,5,6,8,9,10,11,12, and 13 provide numerous examples of the uses of shotcrete in mining applications. In many mines, SFRS, used in conjunction with rock bolts and other ground support systems, where required (e.g., conventional reinforcing, lattice rib girders, cable lacing), has become the prime method of ground support in both permanent ways (drifts, raises, declines, shafts) as well as in ore extraction areas. A number of reports indicate that SFRS not only provides a more economical alternative to conventional ground support methods, but has also resulted in a marked reduction in injuries and fatalities in mines (8).

SFRS has also found increasing use in mines as a substitute for cast-in-place concrete in underground applications such as lining of crusher chambers, pump stations, ore bins, conveyor drives, and building of ventilation seals and drainage barricades (8).

SYNTHETIC FIBER REINFORCED SHOTCRETE

In the l980's, synthetic fiber reinforcement started to be used as a shotcrete reinforcement (14, 15). The first synthetic fiber reinforcement used was collated, fibrillated, polypropylene fiber. In research studies and early field applications, it was added to the shotcrete at addition rates ranging from about 4 to 6 kg/m^3 (7 to 10 lb/yd^3). Early applications of the technology included:

- Rock slope stabilization;
- Canal lining and creek channelization. (A 5 mile long water interceptor canal around a tailings dam at Lead, South Dakota was lined with SnFRS);
- Capping and sealing an exposed sandstone/ mudstone in tunnel portal areas and a dam spillway at the Oldman River Dam in Alberta in 1986:
- Permanent lining of small 3 m (10 ft) diameter drainage tunnels at the Oldman River Darn in Alberta in 1987 (SnFRS).

In the mid-1990's, new generations of synthetic fibers were developed. These fibers were suitable for much higher addition rates to shotcrete than the earlier generation collated fibrillated fibers mainly because of their lower surface area. Some fiber types were able to be shot at fiber addition rates as high as 20 kg/m^3 (34 lb/yd^3), but most practical applications were for fibers at addition rates of between 7 to 13 kg/m^3 (12 to 22 lb/yd^3), with 9 kg/m^3 (15 lbyd^3) or 1.0% volume of fiber being a fairly common addition rate for some of the better performing fiber types. Most of the new generation synthetic fibers are either monofilament type fibers, or bundled assemblies of fine fibers with a monofilament appearance. Some of the fiber types have a slight

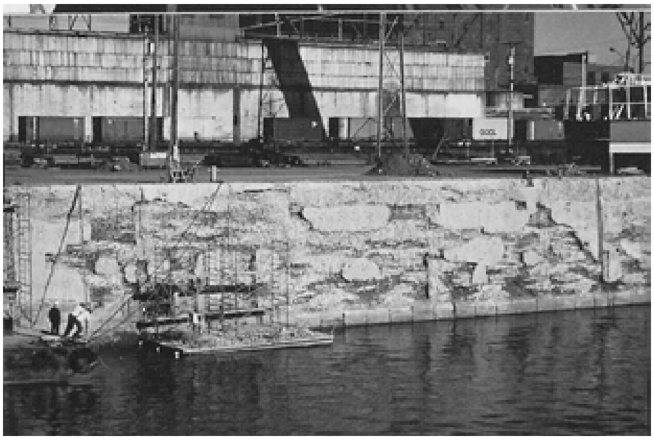


Figure 5: Preparation of shipping berth faces at Port of Montreal, Quebec, Canada

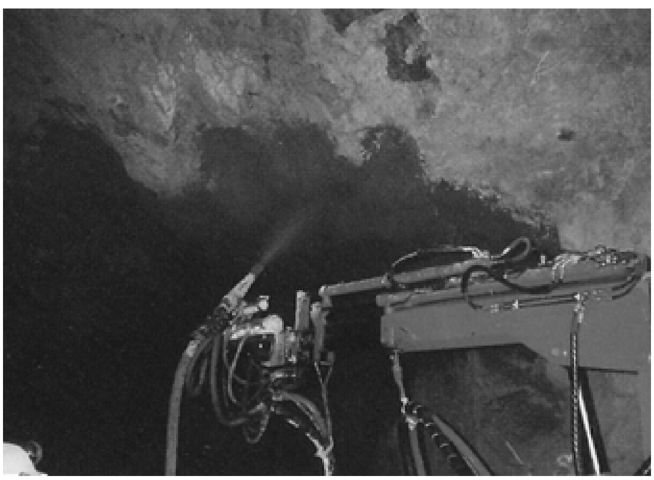


Figure 6: Manipulator arm application of SFRS in Deep Copper Shaft at Mt. Isa Mines, Queensland, Australia

fibrillating characteristic on mixing and shooting. Currently, four fiber manufactures in North America are producing synthetic fibers for use in shotcrete at high addition rates.

Examples of applications of this new high volume synthetic fiber reinforced shotcrete technology in civil engineering applications include:

- Rock slope stabilization;
- Capping and sealing acid leachate generating rock in airfield and new highway construction in Nova Scotia, Canada (15);
- Capping and sealing municipal incinerator waste ash in a disposal cell, in Vancouver, British Columbia, to minimize generation of leachate;
- Repair of deteriorated shipping berth faces at the Port of Saint John, New Brunswick, Canada, and the Port of Montreal, Quebec, Canada (15); see Figure 5.

Extensive research bas been conducted in South Africa (11, 12) on the use of SnFRS in the deep gold mines. There, the deepest mines are currently operating at depths of around 4000 m (13,000 ft) beneath the surface. At these great depths, the rock temperature is around 60° C (140°F), and openings in the hard rock are vulnerable to pressure bursts. A great deal of effort is being extended into developing pseudo-ductile, insulated linings that will provide a suitable mining environment for miners. Insulating, fiber reinforced shotcretes made with either steel fiber or high volume synthetic fiber reinforcement, used in conjunction with other ground control methods, such as deforming rock bolts (cone bolts) and cable lacing, are being used to control rock-bursts and ventilation air refrigeration costs. Some of the South African gold mines are currently actively planning to mine at depths of up to 5000 m (16,400 ft) beneath the surface, where rock temperatures are about 70° C (160°F). Pseudo-ductile insulating shotcretes are likely to be an integral component of such developments, and the South African research (11, 12) is helping to advance the state-of-the-art for fiber reinforced sbotcrete in mining applications.

In addition to these high fiber volume SnFRS projects, extensive use is now being made of fine, low volume, 0.1 to 0.3% volume, or I to about 3 kg/1113 (1.5 to 4.5 lb/yd^3) of either collated, fibrillated, or monofilament synthetic fibers. These typically shorter, 12 to 20 mm (1/2 to 3/4 in) long fibers have been found to be very effective in mitigating plastic shrinkage cracking (13). They also provide improved rheological properties to the shotcrete, improving its green strength or cohesion. This increases the thickness of build-up achievable in a single pass, and reduces the incidence of sloughing (shotcrete fall out) during application and finishing operations.

Some research is now being conducted with hybrid fibers, i.e., combinations of steel fibers and typically lower volumes of synthetic fibers. Some of the early research data show a synergy between the two fiber types, i.e., benefits accrue that would not be provided by only one of the fiber types in isolation.

SUMMARY

Great strides in the development and use of fiber reinforced shotcrete have been made since SFRS was first introduced in the 1970's and high volume SnFRS in the 1980's. The technology has evolved from a novel concept, to a mature industry, where many hundreds of thousands of cubic meters of fiber reinforced shotcretes are being used annually in civil engineering and mining applications around the world. In countries such as Norway, it is claimed that over 70% of all shotcrete installed is made with steel fiber reinforcement (6). Certain mines in Australia could likely not be mined were it not for SFRS, as traditional ground support methods (steel sets and lagging or screen and bolt) have not been able to maintain economical and safe working underground openings. In brief, the advantages of using SFRS or SnFRS over other conventionally reinforced construction methods have been demonstrated on numerous projects around the world for almost three decades. Even greater use of this technology is envisaged as more engineers and owners gain experience with this construction medium and the ever evolving new generations of enhanced fiber reinforcements find their way into the marketplace.

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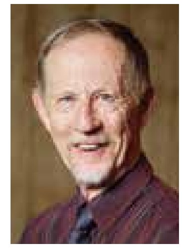

Dudley R. (Rusty) Morgan, Ph.D, PEng. *is a Vice President and Chief Materials Engineer with AGRA Earth & Environmental Limited in Vancouver, BC, Canada. He is Secretary of the American Shotcrete Association and the American Concrete Institute AC! 506 Shotcrete Committee. He is a Fellow of the American Concrete Institute and a member of A Cl and ASTM committees dealing with fiber reinforcement and shotcrete technology. He is active in shotcrete consulting design, specification QA/QC, and research and development in countries around the world, and has authored or co-authored over 60 shotcrete publications.*

Roland Heere *is a materials engineer-in-training at AGRA Earth & Environmental Limited in Vancouve1; BC, Canada. He has a Masters Degree in civil engineering from. the University of British Columbia. His Masters thesis was on the Evaluation of Shotcrete Repaired Dams. He is active in shotcrete research and development, consulting, specification, construction monitoring, and QA/QC. He has extensive experience in the production and testing of fiber reinforced concretes and shotcretes.*

Featured in Volume 14, Number 4 • Fall 2012

The Oregon City Bridge Part I

By Marcus H. von der Hofen

The Oregon City Bridge, over the Willamette River has served the community for nearly a century before recently getting a major overhaul. Originally completed in December of 1922, this steel box girder arch bridge was, and still is, a beautiful landmark of the region. Designed under the direction of State engineer, Herbert Nunn, the plans of State highway engineer, C. B. McCullough, were adopted and carried out. A unique feature of the project was the encasement of the steel structure in what was called "Gunite" to protect it from the emissions of the paper mill located close by.

The bridge is a total of 900 ft (274 m) long including the viaduct design approaches. The center section of the bridge measures a horizontal distance of 140 ft (43 m) with the supporting arches above built on a 160 ft (49 m) radius. The remaining 210 ft (64 m) of center span are supported from below by the continuation of the arches on a 306 ft (93 m) radius. The box beam arches start with a section of 10 ft (3.0 m) deep at the base, reducing to a 6 ft (1.8 m) depth at the top with the width remaining the same throughout. This all supports a roadway deck 18 ft (5.5 m) across curb to curb, with a side walk on each

Oregon City Bridge during construction
Photo courtesy of the Oregon Department of Transportation

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Photo courtesy of the Oregon Department of Transportation

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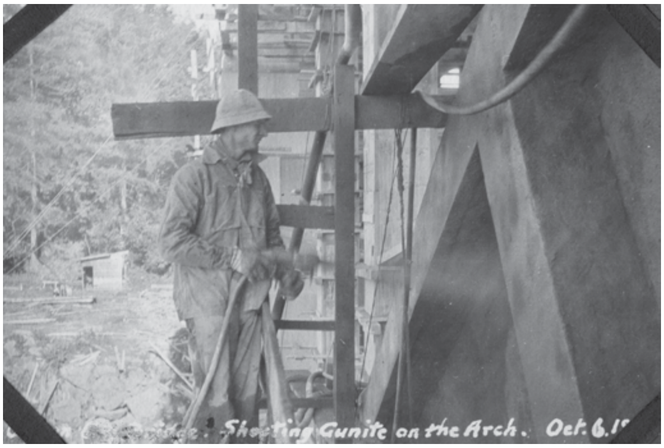
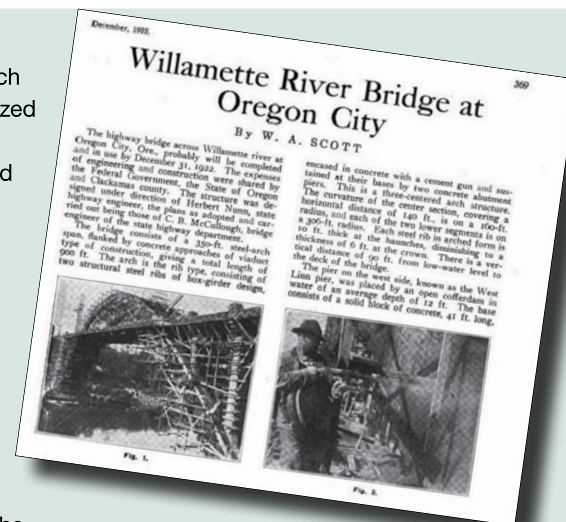


Oregon City Bridge during construction
Photo courtesy of the Oregon Department of Transportation

side, and the added bonus of restrooms located at the piers under the sidewalk at each end. All of this could be yours in 1922 for a published cost of $300,000[1] dollars. As of 2000, the bridge carried 12,800 vehicles per day, which represents only a 40% growth in traffic since 1953.

The bridge was built to replace an 1888 pedestrian suspension bridge. Workers used the old bridge to begin construction of the present bridge's box steel ribs.[2] Construction was made difficult by the great depth of the river at the bridge site and by the water traffic during construction. Construction workers used the cables of the old bridge to support the arch prior to completion by running cables from the arch, over the cables to an anchor on the far side. Once the new arch was completed, the old suspension bridge was dismantled.[3]

During my research, I was able to track down an excellent article written by W.A. Scott published in the December 1922 issue of "Engineering World" that gave a detailed account of some of the Gunite operation. Scott wrote the following in his article[4]:


December, 1922.

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Willamette River Bridge at Oregon City

By W. A. SCOTT

The highway bridge across Willamette river at Oregon City, Ore., probably will be completed and in use by December 31, 1922. The expenses of engineering and construction were shared by the Federal Government, the State of Oregon and Clackamas county. The structure was designed under direction of Herbert Nunn, state highway engineer, the plans as adopted and carried out being those of C. B. McCullough, bridge engineer of the state highway department.

The bridge consists of a 350-ft. steel-arch span, flanked by concrete approaches of viaduct type of construction, giving a total length of 900 ft. The arch is the rib type, consisting of two structural steel ribs of box-girder design, encased in concrete with a cement gun and sustained at their bases by two concrete abutment piers. This is a three-centered arch structure. The curvature of the center section, covering a horizontal distance of 140 ft., is on a 160-ft. radius, and each of the two lower segments is on a 306-ft. radius. Each steel rib in arched form is 10 ft. thick at the haunches, diminishing to a thickness of 6 ft. at the crown. There is a vertical distance of 90 ft. from low-water level to the deck of the bridge.

The pier on the west side, known as the West Linn pier, was placed by an open cofferdam in water of an average depth of 12 ft. The base consists of a solid block of concrete, 41 ft. long.

Fig. 1.

Fig. 2.

"A feature of special interest was the work of encasing the steel ribs of the arch with concrete, which was applied with a cement gun. The cement gun was utilized also in producing a concrete web, extending from rib to rib on the underside of the arch. The gunite web was backed by steel reinforcing on the steel struts and braces between the ribs.

The guniting was done under subcontract by Lanning & Hoggan and was directly supervised by A.C. Forrester, Civil engineer. The outfit used was the N-1 type cement gun of the Cement Gun Co., Inc., and the necessary auxiliary equipment. The latter comprised a J. I. Case 45-hp tractor engine, an Ingersoll-Rand single stage air compressor of 325 cu. ft displacement. The air was conducted through 100 ft of 1 ½ in. rubber hose to the cement gun on the east shore. A line of Pioneer Rubber Mills' 1-¼ in. sand blast hose extended from the cement gun to the points of gunning, this distance varying from 100 to 450 ft laterally and to a maximum of 120 ft vertically. A ¾ in. water line, connected to a city main, served to deliver water to the engine and for cooling the air compressor, as well as furnishing a supply to the 1 in. gunite nozzle.

The cement gun charge was made up in the ratio of 1 part cement to 3 parts washed river sand, the latter being graded from ½ in. down to fines. The moisture in the mixture was reduced by a railroad sand drier. However, this moisture reduction was varied some according to the humidity of the atmosphere. The volume of water coming in contact with the sand and cement in the gunite nozzle was so regulated by the operator as to produce concrete that would conform to stand practice—admitting water sufficient to hydrate the cement. In applying the gunite a distance of about 3 ft was maintained between the nozzle and the surface being gunited, the gunite being shot at a velocity of about 300 ft per sec. under an initial pressure of 60 lbs.

This work required 40,000 sq. ft of 2 in. guniting on the steel ribs; 1200 sq. ft of 6 in. gunite for the web on the underside of the arch; 800 sq. ft 4 in. thick; 1200 sq. ft of 3 in. and 2800 sq. ft varying from 6 in. down to 2. The 2 in. gunite coat over the steel ribs was shot against No. 28 U.S. Steel Co. wire mesh, fastened to steel rods, the latter being spot-welded to the steel structure. On this particular part it is figured that 75 sq. ft of gunite resulted from each CY of sand used. The 6 in. gunite was applied to build up the concrete web between the steel ribs and this extended from the base of the arch up to the first panel. This web was continued higher up in 4 and 3 in. coats. All inside struts and braces below deck were wrapped with wire mesh and sheathed with gunite. Relative to applying the 2 in. gunite which constituted the major part of the job, it is stated that the work carried on at the rate of 500 sq. ft per day of 8 hours.

In the illustrations given herewith there is shown some of the scaffolding required in carrying through this unusual job of guniting. All the gunited surfaces were gaged by straight edge to a true plane, giving them a finished appearance. The efficiency of the cement gun and accessory equipment on this piece of work was demonstrated to the satisfaction of those assumed responsibility for the character and speed of construction. The aesthetic features of the bridge as they appear in the general view, will commend themselves to those who like to see a touch of the artistic imparted to a structure of severe utility."

1 inch = 25 millimeters 1 foot = .3 meters 1 square foot = .09 square meter 1 pound = .45 kilogram

During my first visit to inspect the bridge, I must say I was more than a little overwhelmed by the craftsmanship of this structure. It was and still is amazing to me. The quality of the Gunite that these crews produced so long ago is impressive. Not that there weren't any problems, but for the most part the Gunite has held up incredibly well over the years. The finish, the consistency and again, the overall craftsmanship produced by the crews must have made subcontractor Lanning & Hoggan immensely proud (and I hope some money). Most of the deficiencies I saw really didn't have anything to do with the Gunite but were inherent to the design. It was amazing to see reinforcing steel mesh exposed in a hydro-demolition test area in the same condition as it was when placed on the bridge 90 years earlier.

As I walked the job, it became more and more amazing to me what these early shotcreters had accomplished nearly a century ago. Even with all the modern shotcreting tools we have today, duplicating the quality of the shotcrete work on this bridge would be a major challenge.

In April of 2010, Wildish Contractors was awarded the Contract for the Rehabilitation of the Oregon City Bridge. Its goal was to upgrade the structure to regain the capacities it once had, while keeping the original appearance of this Historic Icon. A great deal of work would be necessary to carry out this upgrade within the short time frame of only two years. The history behind the building of this Bridge plays a large role in this two part story of an old bridge becoming new again. Stay tuned in 2013 for the second half of this transforming story!

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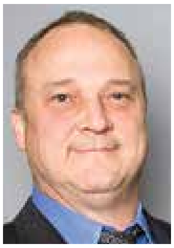
4. Scott, W.A., Engineering World, December, 1922 Original vintage photos of the Oregon City Bridge during construction, Courtesy of The Oregon Department of Transportation: Fig. 1 - 5



***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 Secretary to the ASA Executive Committee.*

The Oregon City Bridge Part II

By Marcus H. von der Hofen

This is the second of two articles discussing the Oregon City Bridge. The first article, "The Oregon City Bridge, Part I," was published in the Fall 2012 issue of Shotcrete *and discussed the historical background of the bridge. This article covers the recently completed rehabilitation project.*

The Oregon City Arch Bridge Rehabilitation project was officially completed on October 31, 2012, by the Wildish Standard Paving Company. Dedication to quality and professionalism, along with a true partnering between owners, contractors, and suppliers, helped find ways to solve problems that could have easily turned the project into overwhelming confrontation and failure. This article is dedicated to those who pride themselves on working toward the best solutions.

Wildish was tasked with renovating a historic bridge that is 90 years old, replacing structurally deficient components and accurately replicating the details and architectural features of this Conde McCullough through-arch bridge. McCullough's signature detailing is evident in the arches, obelisk pylons with sconce light fixtures, ornate railings, and art deco piers. It is believed to be the only bridge of its kind in the entire United States—a through-deck steel arch covered with shotcrete that incorporates concrete spandrel columns, corbels, a sidewalk, deck approach spans, and a bridge rail (refer to Fig. 1).

The shotcrete covering had caused many a bridge expert to be deceived into thinking this was a structure made entirely of concrete. In all actuality, it is a steel structural arch design encased in shotcrete to protect it from the emissions from industries located in close proximity. Originally placed using the dry-mix method nearly a century before, the protective concrete would need to be removed and replaced to the original lines and grades (refer to Fig. 2 and 3).

One of the first questions to contemplate was: Should it be done wet or dry? Should it be both? Today's shotcrete technology offers efficient site batching of material in small amounts both wet and dry; state-of-the-art batch plants and testing facilities also allow ready mix producers to perform various adjustments and quality control that simply was not available 90 years ago. The project has areas that really lend themselves to either method. The bottom line in this case came down to what the personnel felt the most comfortable with. I don't find this reason brought up in the discussion very often, but it really should be part of the process. Many contract specifications are written making the choice, and I personally don't think that is the right answer. The fact is that many jobs can be done efficiently and correctly either way, so the choice should be left up to the qualifications of the contractor.

Fig. 1: Oregon City Bridge—multiple access methods

Fig. 2 and 3: Shotcrete placement inside the arches

In this case, my personnel and I agreed that we could perform the job more effectively using the wet process. At first, I believed that we would do the project using both site-batched bagged material and ready mix. After initial testing, I became convinced that the ready mix supplier CEMEX, with whom I had a long working relationship, could lend invaluable expertise to the project. As it turned out, it was a good decision (or maybe just lucky) on my part, as their ability to provide extensive resources, quality information, and testing played a large part in the success of the project.

Initial trial batches based on the project specification seem to function reasonably well, but there were definitely some issues. The specification called for specific levels of 8% or less boiled absorption. The initial test came back at 7.6 to 7.9%, leaving little margin for variation. Secondly, there was a great deal of reluctance to allow a hydration stabilizer because it might affect the bond. The bond was specified at 150 psi (1 MPa) shotcrete-to-steel, but no data were available showing this was achievable. The specification required hydrodemolition of the existing shotcrete followed by an abrasive blast of the surface. This created some degree of ambiguity. Thus, it was decided that a surface preparation mockup test should be conducted.

The initial surface preparation test section was divided into three areas: one with a walnut shell blast, the second with a light sand blast, and the final area with just an air and water blast. The initial process was the belief that minimizing the removal of the existing material (steel surface and attached mesh) would be a good approach, and to then build the sections back up from there. The surface preparation tests had almost identical results from each of the three methods, with values ranging from 0 to 120 psi (0 to 0.83 MPa) with the majority being 0. After this initial test, it was obvious that more extensive testing would be required. Steel road plates were used to represent the bridge surface during the next test, which included a variety of differing parameters, including more extensive sand blasting, bonding agents, accelerators, hydration stabilizers, and different curing methods. In the end, a complete white blast of the steel surfaces proved to be the most effective with a multi course sandblast material. But even then, the results were still not very consistent. Sections would bond well and meet the specification and others would have no bond at all. Another effect that seemed to be creating the variability was the shrinkage and

Fig. 4: Repairing mesh prior to shoot

Fig. 5: Positioning the equipment for the next shoot

Fig. 6 and 7: Ever-changing shooting positions the flexural properties of the shotcrete material. The specification called for minimum levels of silica fume and cement, but we decided we needed to rethink this.

This is typically where I've seen a great number of projects become dysfunctional. The focus changes from getting the job done correctly to minimizing the damage and protecting one's best interest. The parties become more adversarial than trying to work together to solve the problems and move forward. Fortunately, with this project, the Oregon Department of Transportation (ODOT) and its team stepped up not only financially but also (and more importantly) remained focused on finding the best solutions. I believe their role was instrumental in allowing both the contractors and suppliers the means to find the best answers in a timely manner. I think a statement made by a member of Wildish Standard Paving sums it up best:

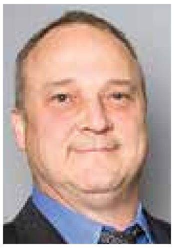
"Our shotcrete applicator was committed to achieving the very best mix design that could be developed. From the original mix we reduced the silica fume content; used other supplemental cementitious material, including fly ash and added fiber; and a W R Grace retarder to slow the set time. After developing eight different trial batches for the project, they were able to identify a concrete mix that exceeded the requirements of the specifications, while offering better adhesion and more elasticity than originally specified. Were it not for their perseverance in obtaining the best possible product, the shotcrete applied to the bridge might have met the original project specification, but would not have been as durable over the years. From the original mix, which produced a 10 to 30 psi (0.07 to 0.21 MPa) bond pulloff strength, we increased to getting over 300 psi (2.1 MPa) with the final mix."


Fig. 8: Overhead finishing


Fig. 9: The finished product

I would add, it was really the commitment of all the parties to achieve the best quality and durability that allowed this to take place (refer to Fig. 9).

As a result of the efforts by many, including Wildish Standard Paving, Johnson Western Gunite, CEMEX, and ODOT, the project team rehabilitated a beautiful historic landmark of the region in a safe and effective manner. Through working together toward a mutually desired end goal, I believe we produced a durable, serviceable, and aesthetically pleasing project that will be enjoyed by many generations to come. For information on the concrete mixture designs and specific test results, please contact ASA.


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 Secretary to the ASA Executive Committee.*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