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The History of Shotcrete

by George D. Yoggy

1920s Gunning Crew

Part I of a Three-Part Series

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.

Nozzleman applying "gunite" for a water storage facility in Pittsburgh, 1919

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.

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 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

Restored, reinforced gunite flue at American Smelting and Refining Co., Helena, Montana, 1924

requirements, and only material placed by a genuine cement gun could be called gunite. The process crossed the Atlantic and the 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 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.

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

Part II of a Three-Part Series

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.

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

Bowl type gun developed by Frank Reed

Meyco GM 57 rotor type machine

MiCon rig, introduced by Jack Ridley

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 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 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 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 period. If we are now in the reversal period, 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.

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

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, and 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 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 506R). That was not enough. Shotcreting 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.

Part III of a Three-Part Series

There is little question that the history of shotcrete is fascinating and useful. The invention, the evolution, the successes, the "crash," and the struggle to recover through parts of the century is somewhat unique to the shotcrete process. How shotcrete is viewed in today's construction industry, however, is very serious and very important. What of this recovery from the seeming demise of a construction method that achieved such success for so many years and then wandered away from the technical foundation and discipline of application?

The properties and performance of gunite were carefully established, meticulously tested, documented, and communicated to the industry. This sprayed-concrete process was widely accepted around the world and produced cost-effective results in countless applications. In some times and places, the technology was lost, abused, and ignored as we wandered away from the path of the original process. But some changes in the modern era have brought improvement, advancement, and new opportunities for the shotcrete process. Several new ideas were part of the midlife crisis, but the most important change may have come with the development of those new machines of the '60s and '70s and the material possibilities that accompanied them.

The invention of the rotor-type continuous-feed gun for dry-mix material provided two distinct advantages over the standard double tanks that dominated the process for more than half a century: higher production and large aggregate mixtures were now achievable as norms. The door had been opened for more flexibility in sprayed concrete applications, as well as for more versatility in concrete mixture design. Spraying wet concrete would soon become a part of the process.

The introduction of the Rotary Gun in 1957 paved the way for large aggregate and high-volume shotcrete

Chemistry began to play a role, and confusion over terminology quickly set in. The term "shotcrete" was used in a railroad publication some years previously to describe changing mixtures and methods. Shotcrete was used by some to describe mixtures with large aggregate (up to 5/8 in. [16 mm]) rather than gunite, which was considered to be sand and cement only. Others described the new wet method as shotcrete to differentiate from the long-established gunite system. Finally, ACI stepped in to end the confusion and define pneumatically applied concrete or mortar as "*shotcrete*, including the wet-mix method and the dry-mix method," and a new era for the industry really had its beginning.

Some would argue that this was the start of the real period of decline—confusion perhaps, but not really a step backward, other than the fact that many choices allowed many results, and some were not very good, which is often a price paid for progress. We could spend a great deal of time reviewing results; however, that should be done at another time. Traditional gunite applications continued in a very healthy way in many areas, even though they were questioned in others. The fact is, however, that shotcrete became a renewed construction method by the late '70s with nearly endless opportunities and a few rough edges. Higher-volume output now kept pace with other advances in equipment and materials that provided for growth in construction. Advances in concrete technology that started to make great strides in the '70s also contributed to advancements in the shotcrete process, especially the wet-mix method. This culminated with the development of the swing-tube concrete pump that really made wet-mix shotcrete practical. The industry was changed forever. Almost anything could now be done with shotcrete, and it seemed that almost everyone was trying it. Was the industry about to take another step backward? The answer here could be "almost." Fortunately, it's probably "not quite."

The early years of large aggregate, high-output, dry-mix shotcrete set the pace for the soon-to-be-developed wet-mix method, especially in underground construction. Shotcrete was proving to be invaluable as a method for supporting rock and earth excavations in tunnel and mine construction. High volumes placed in many underground projects (50,000 yd³ [38,000 m³] was common

for a tunnel job) provided countless opportunities to study the performance of both materials and equipment, leading to still more innovations and improvements. Since a large portion of this concrete placed underground was overhead, chemical accelerators were introduced to provide for fast set and early strength development. Chemical compatibility and in-place performance became important considerations, and even more was learned about this method of placing concrete as laboratory work and pre-job testing accompanied more applications. Progress continued at a rapid pace. Shotcrete was beginning to be considered "technical" again by many in the industry, because it is. The evolution of concrete pumps in the general construction market contributed to the development of machines that were also efficient for spraying wet-mix concrete, and the world has never looked back, except to learn from those who went before. Concrete technology, including chemical admixtures and supplementary cementing materials such as silica fume and fiber reinforcement, has become an integral part of the process for both wet- and dry-mix shotcrete. The bar has been raised considerably for the equipment and materials producers and suppliers, and for the knowledge and skill required of today's shotcreter.

Truly, shotcrete was in a recovery mode during these redevelopment years of the '70s and indeed, has gone beyond many expectations. Sprayed concrete (as it is known in many parts of the world) has not only achieved technical status, it sometimes reaches exotic levels of mixture technology and construction performance. The underground proving ground provided for the development of many product and equipment innovations such as fiber reinforcement, silica fume, high-performance admixtures, and mobile robotic equipment. Pumpable concrete made equipment perform more efficiently, and more efficient equipment made concrete applications in vertical and overhead arenas more effective and economical. Each improvement led to another as challenges were met in many aspects of construction. It is quite safe to say that more progress and change has taken place in the shotcrete process during the last 15 years than in the previous 75 years of its history.

Where are we today? Are the skills no longer with us? Is shotcrete relegated to cosmetic classification and shunned by the engineer? Have we abandoned the gunite process that has had such a long and successful history and turned to wet shotcrete as a panacea? Hardly!

Wet machines are available for projects ranging from "dental work" to high-production, heavy-construction applications. And the double tank is still produced. Mixtures can be designed, packaged, and delivered to meet any need—site-batched, in a bag, or in a truck. Ironically, the success of wet-mix shotcrete has been achieved by combining modern material and equipment technologies with the patented basics of the original invention. Sound, well-graded materials combined as a concrete for placement at high velocity to achieve sufficient compaction to perform at levels above similar cast materials. And the neat thing is, you can place it upside-down if you like. Today, it is possible to achieve similar results in all phases of shotcrete construction with both wet- and dry-mix shotcrete methods. Properly understood, they are a screwdriver and a wrench. Which one is better? Depends on the task. What's really important

High-volume wet shotcrete with large aggregate is evident in the texture of the material already placed

Automated wet shotcrete for a geotech application

is education, training, information sharing, and understanding. Shotcrete has become a sophisticated method of placing concrete and requires credentials suited to the task.

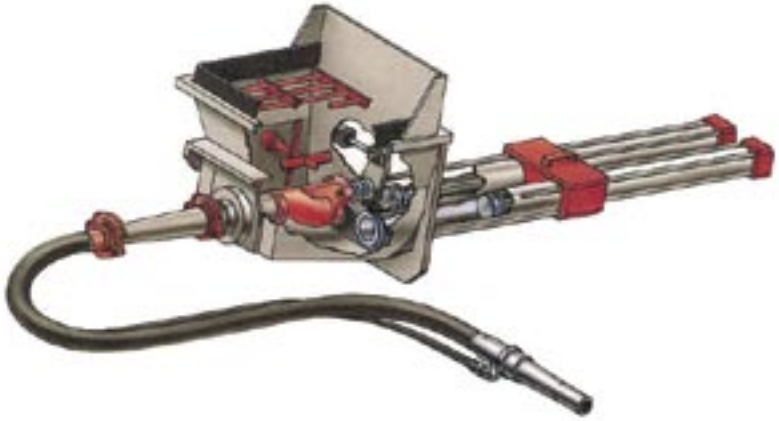
The industry has not only recovered, but has also taken giant steps forward. We are no longer forced to defend our position with only the pages of ACI 506. The engineering community is embracing shotcrete as the viable structural construction method it has always been, and is meeting modern building challenges with effective designs. Documentation and information describing successful design and construction experiences are abundant. Standards, specifications, and guidelines are available from industry sources from leading nations around the world to provide the owner, designer, and constructor with the information necessary to deliver a proper project. Contractors are becoming educated, trained, and certified to accepted levels of practice for today's requirements. Organizations such as ASA provide the opportunity for the industry to meet and exchange experiences and information vital to the health and growth of the process.

The basics from Akeley, the direction from Collier, and the hard work and dedication of many who followed still apply. Quality components, high-velocity application, proper technique, controlled water-cement ratio, clear understanding of the process, sound concrete practice, and discipline blended with modern materials and equipment allows nearly endless opportunities.

Recovery, complete!

Future, bright!

Tunnel construction provided a proving ground for new materials and equipment



Development of the swing tube concrete pump made wet shotcrete practical

Message from former ASA Publications Committee Chair Marc Jolin

There is certainly more to the story, and many of the details of each year or decade can shed light on why we do things the way we do, what works, and what doesn't. We continue to share those experiences through our association with one another in this diverse and growing industry each day that we do work, and through the recording and reporting of what is experienced. Get involved! Let us know what you're doing. These pages allow for the sharing of experiences—yours!

***George D. Yoggy** has been directly involved in shotcrete and concrete applications for more than 40 years. Yoggy retired from Master Builders in 2000 and is a consultant to the tunnel and shotcrete industries. He lectures at various training programs on the use of shotcrete, is an approved ACI examiner, and serves on several technical committees for ACI, ASTM, ASA, and the American Underground Construction Association. He continues to be an active participant and respected leader in industry initiatives.*