History of Wire-Wrapped Circular Prestressed Concrete Tanks

By Lars Balck and Daniel McCarthy

Circular wire-wrapped prestressed concrete tanks and "gunite" (dry-mix shotcrete) evolved together early in the 20th century. The flexibility and economy of the shotcrete process facilitated development of the early prestressed circular water tanks (Fig. 1). One of the engineers that developed gunite also developed prestressing for cylindrical concrete tanks. Thus, the two technologies (shotcrete and wrapped prestressing) are, on some level, sister technologies.

SHOTCRETE, AKA GUNITE

Shotcrete is the process of pneumatically accelerating concrete to high velocity to compact the concrete material upon impact. The process of conveying a dry mixture of sand and cement through a hose, with water being added at the nozzle at the end of the delivery hose, was coined "gunite" by an early equipment manufacturer. The term "gunite" is often used today, but because it was a proprietary trade name, the American Concrete Institute (ACI) has adopted the term "dry-mix shotcrete." Additionally, the process of shooting already-mixed concrete, using concrete pumps with air added at the nozzle to accelerate the mixture, was designated as "wet-mix shotcrete."

Fig. 1: Early prestressed shotcrete storage tank—circa 1936—in continuous maintenance-free service for more than 70 years

A crude form of "shotcrete" is early masons hand-throwing mortar into place. In 1907, Carl Akeley, a naturalist looking for a way to make durable models, devised a method to spray a dry sand-cement mixture with water being added at the nozzle (gunite). The machine was able to place mortar with sufficient velocity to compact the mortar, which is a characteristic not achievable with hand-thrown mortar. In addition, mechanizing the process allowed for greater production.

Akeley's invention quickly drew the attention of investors who saw the invention's potential, and for 4 years they tried to market the cement gun with Akeley. Samuel Traylor of Traylor Engineering and Manufacturing; a munitions manufacturer who had done well due to World War I, also realized the potential of the cement gun and in 1916, when Akeley's group failed, he bought all rights and started the Cement Gun Company.

Traylor saw the gun's potential was not just in manufacturing guns, but in construction. He immediately started the construction company, Traylor-Dewey Contracting, that specialized in the newly trademarked "gunite" construction using the cement gun. Traylor upgraded the gun by improving the manufacturing process, and with assembling a skilled placement crew, thus controlled the complete process. The Cement Gun Company went on to publish engineering articles about the success of the projects they undertook, and of the superior properties of gunite, which attracted the attention of engineers and helped gunite construction expand along with increased production of the cement guns.

PRESTRESSED CONCRETE

Concrete developed by the Romans over 2000 years ago was only used in gravity compression structures such as columns and arches. Later, around 1850, European engineers produced and developed a major technological improvement, "reinforced concrete," by at first adding iron chains and, in further development, steel bars. The addition of steel allowed a concrete member to take some tensile stresses along with the compression stresses.

Reinforced concrete permitted a structural member such as a beam to resist bending, and beams could be used in bridge and building construction. In a simply supported beam, the top of the concrete beam is in compression while the bottom is in tension. Reinforcement is placed in just the bottom portion of the beam to carry the tensile forces. To increase a beam's capacity, more steel can be added, but then even more concrete must also be added, causing an increase in the beam's dead weight. The full capacity of both the concrete and steel is not being used, but the reinforced concrete design improved the application and versatility of concrete in structures.

In the early 20th century, the development of prestressing concrete became the second major advancement in concrete technology. In a prestressed member, the full concrete cross section is in compression by pretensioning high-strength steel in the member. Prestressed concrete allows for the full use of the properties of both concrete and steel. Prestressed concrete has allowed designers to build a wider range of concrete structures using less material and often reducing costs.

Compression of a circular vessel is an old idea. For 2000 years, wood wine barrels have been manufactured with wood staves and compressed together with steel rings. Early gun barrel manufacturers wrapped the barrels with wire to help contain the expansive pressures produced in gun barrels.

With the development of high-strength steel wire, engineers began applying the same "hoops around a barrel" principal to the circumferential compression of concrete tanks for liquid storage for three reasons:

1. **Crack resistance**. By keeping concrete subject to tension in compression, cracks are minimized or eliminated. Concrete cracking and the resulting leakage due to hoop tension from outward hydraulic forces of non-prestressed concrete water-retaining structures has long been a problem for engineers.
2. **Durability**. Concrete has demonstrated long-term durability in environments with constant exposure to water, wastewater, and other liquids.
3. **Cost savings and sustainability**. Because prestressing uses concrete in compression and steel in tension better, prestressed concrete tanks require fewer materials (40% less concrete and 60% less steel) than equivalent form-and-pour concrete tanks. Fewer materials result in significant cost savings.

Successful prestressing of concrete began with Eugene Freyssinet in Europe in the late 1920s. Freyssinet, in 1933, published an article, "New Ideas and Methods,"[1] which outlined "conditions for the practical use of prestressing"—the basis of prestressed concrete that included compressing high-strength concrete by tensioning high-strength steel. At that time, American engineers were suspicious of European engineers; however, some Americans realized the potential of prestressed concrete. One engineer was W. S. Hewett.

While Freyssinet was working on linear prestressing to build bridges in Europe, W. S. Hewett, an American bridge builder in the United States, began building circular prestressed tanks using rods and turnbuckles. Hewett felt concrete (because of its durability) was the best material for construction of hydraulic structures. He also understood that the existing relatively low-strength steel rods didn't have sufficient strength to apply the force required to keep the concrete wall in compression due to the shortening of the concrete (shrinkage) and relaxation (elongation) of the steel.

J. M. Crom, an American engineer and associate of Hewett, picked up where Hewett left off and thus escalated the connection between shotcrete and prestressing.

In 1918, Crom was a salesman and manager for the Chicago, IL, office of Traylor's Cement Gun Company. Crom sold cement guns for 4 years and was one of the top salesmen. After a disagreement with the Cement Gun Company, he moved to Texas and started a gunite firm, Crom & Lindberg, where he shot gunite drainage canals along the Rio Grande. He even patented equipment to improve the efficiency of placing canal linings. Crom was a prolific inventor and had at least 40 patents mostly for shotcrete application and prestressed tanks (and one for an automatic baseball machine).

In 1929, Crom, along with John H. Hession and Andrew Lindberg, started a new company, National Gunite Corporation, for gunite construction, based in Boston, MA. Of course, the Great Depression hit in 1929, and consequently was not a great time to start a new company. But they prevailed and were successful in renovating buildings with gunite.

Early on, they became interested in prestressed concrete tanks due to Hewett's work and formed a second firm, The Preload Company, for building prestressed tanks using gunite. Because of Freyssinet's and Hewett's work, Preload started an intensive research program in 1933 in conjunction with the Massachusetts Institute of Technology (MIT) and other prominent scientific institutions in the United States and Canada to understand shrinkage, creep, and relaxation of high-strength prestressing steel. By the 1940s, with the knowledge gained from research and the availability of high-strength wire, they were confident they could build a prestressed concrete tank. All that was needed was a machine to place the high-strength wire.

Preload built a machine to continuously wrap fully tensioned prestressing wire in a helical pattern around the circular shotcrete tank. In 1941, Preload built the first wire-wrapped circular tank in Indian Head, MD. The high-strength wire allowed the application of sufficient force to overcome the wall shortening due to shrinkage and creep of the concrete and relaxation of the steel, while keeping the concrete in compression to fully resist the outward pressure of the contained water. Crom, through Preload, ultimately patented the complete tank building system.

Crom also developed a patented composite wall system for construction of watertight tanks. The composite system involved encasing a continuous steel shell with gunite to form a watertight tank wall and provide vertical reinforcement. With these patents, Preload soon advertised crack-free, watertight concrete tanks.

The early circular prestressed tanks were often built completely with gunite: floors, walls, and dome. But that should be no surprise. Both Crom and Hession were gunite contractors and at that time gunite strengths—regularly 8000 psi (55 MPa) or more—were significantly greater than typical 1-2-3 concrete mixtures yielding 3000 psi (20 MPa). Additionally, gunite delivery through a flexible hose provided an easy method of conveying a concrete mixture to the placement location.

The 1940s were a wild time for Preload. Preload had successfully built what engineers had tried to achieve for a long time: a truly prestressed tank. Of course, there was World War II. Steel for the war effort (battle tanks and munitions) was in great demand, so the government purchased concrete water tanks instead of steel water tanks, further increasing the demand for the new prestressed concrete tanks.

Soon, the rapid success of prestressed tanks caught the attention of investors such as John A. Roebling of Roebling & Sons Corporation in 1947, whose business sold prestressing wire. Roebling acquired controlling interest in late 1951, which they held through 1953. For the next several years, the company undertook a domestic and international licensing program. Negotiations during this period resulted in the sale of Preload to the Holly Corporation in 1956.

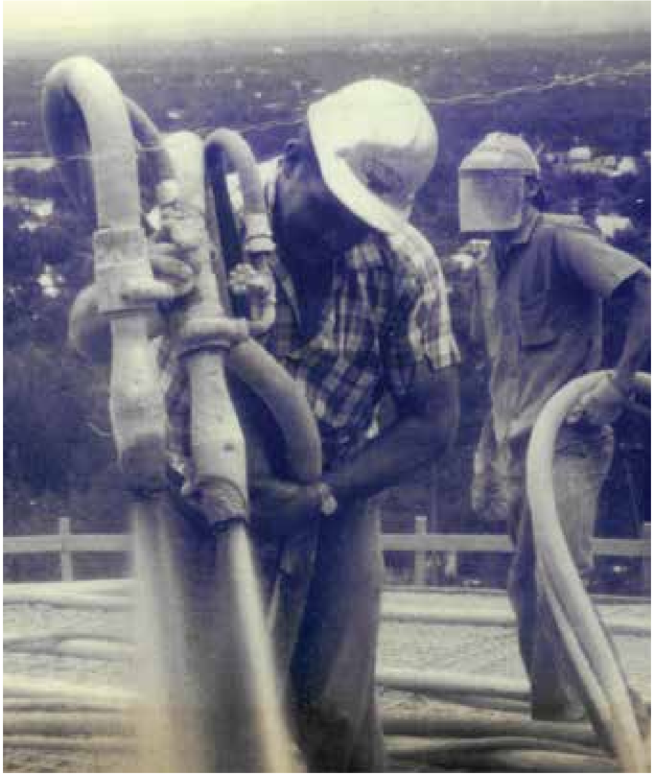

Fig. 2: Placing dry-mix shotcrete using dual nozzles to increase production when shooting a free span 3 in. (76 mm) thick dome circa 1965

One of the problems in the early tanks was early deterioration of some of the gunite domes. Prestressing the dome ring at the top of the wall allowed for the construction of a highly efficient and economical free-span concrete dome. Placing dry-mix shotcrete on a horizontal surface is difficult. Rebound and overspray is easily trapped when shooting at your feet and sand lenses can form, permitting water from both rain on top and condensation from the underside of a dome to accumulate in the sand lens. This led to deterioration of the gunite domes shot by lesser-experienced nozzlemen in freezing-and-thawing environments. Even though the majority of gunite domes never experienced problems, several domes required expensive repair. Experienced, diligent nozzlemen, with the proper technique, usually had good success (Fig. 2). In the 1970s, with the availability of concrete pumps, domes could be cast in a day or two rather than taking weeks to shotcrete, so it became much more economical to cast rather than shoot the concrete domes covering the circular tanks.

The 1950s brought further change. John Hession, the cofounder of Preload, resigned in 1950 as President. Hession still owned National Gunite and, in 1955, partnered with Preload engineer Francis Crowley to start a new company, Natgun, as a subsidiary to National Gunite to build prestressed tanks. Soon, the general gunite business was dropped in favor of focusing on tank construction. Hession financed the new company while Crowley, who "didn't have two nickels to rub together," ran the company. Together they created a successful tank company. In 1991, when Crowley passed away, his two sons took over running the company.

At nearly the same time that Hession resigned from Preload, the other cofounder, J. M. Crom, retired from Preload and moved to Florida, where in 1953, with his sons Ted and Jack, formed The Crom Corporation to specialize in building of composite prestressed concrete tanks. Crom retired a second time in 1957 and his two sons took over the business from their father. However, the two sons split the company into two separate firms in 1961, with Ted operating on the East Coast and Jack on the West Coast.

There were other changes in the 1950s. After Hession retired, Curzon Dobell, a Canadian, became President of Preload. Max Dykmans (who was a Japanese prisoner of war for 4 years) joined Preload in 1952 in New Zealand and in 1957 moved to New York to became Vice President of Engineering and Operations. Dykmans left Preload in 1961, moved to California, and established BBR Prestressed Tanks. Dykmans was another prolific inventor with over 50 patents, primarily for equipment to prestressing tanks and concrete nuclear containment vessels. Dykmans' sons would start DYK Prestressed Tanks in the early 1980s. Interestingly, in 2010, the sons of both DYK and Natgun, who had been fierce competitors for years, merged to form a new prestressed tank company, DN Tanks.

After the Holly aquistion in 1956 of Preload, the domestic licensing program was halted, and the company began to reconsolidate. The company, which had designed and built the first prestressed concrete bridge in North America in 1950 (Walnut Lane Bridge in Philadelphia, PA) and many similar bridges, turned focus back to circular tanks. In 1961, Andy Tripp and Jack Hornstein, both long-time employees of Preload, bought Preload from the Holly Corporation. They would go on to expand Preload's work from water tanks to include large and complex liquified natural gas (LNG) storage tanks, building off their earlier 1955 invention of cryogenic storage tanks for liquid oxygen. Andrew E. Tripp Jr., son of Andy Tripp, still serves as Preload's President today.

TODAY

Shotcrete continues to be an integral part of wrapped prestressed tank construction. Although floors and domes are generally cast concrete, all the prestressed tank builders use shotcrete for embedment and protection of the highly stressed prestressing wire or strand. Cement-rich shotcrete provides excellent corrosion protection to the steel, and easily accommodates the curved surfaces without formwork. A couple of tank builders use shotcrete for construction of the entire vertical prestressed concrete wall using an embedded steel diaphragm for liquid tightness. These tanks are massive structures, ranging from a capacity of under 100,000 gal. (380,000 L)[1] to over 30,000,000 gal. (110,000,000 L).[1] Diameters range up to 350 ft (100 m) and with wall heights up to 70 ft (20 m).

Today, five companies specialize in the construction of prestressed tanks and have built over 8000 prestressed concrete tanks worldwide over the past 75 years. Although equipment and construction techniques have certainly been refined and productivity increased over the last 75 years, the circular wrapped prestressed ground storage tanks built today are basically using the same design principles initiated by the Preload Company in 1941.

References

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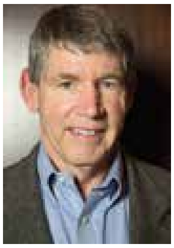

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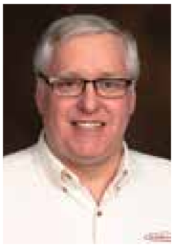

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