Shotcrete and Prestressed Composite Tanks

by Lars Balck

Circular prestressed vessels have been utilized throughout time. Wood stave barrels used since medieval times are an early example of prestressed vessels. Wrapping gun barrels with wire is another variation of circular prestressing. The design of circular prestressed concrete tanks has been evolving for decades.

Shotcrete and prestressed tanks were both developed about the same time. They grew up together. In the early 1930s, J.S. Hewitt developed shotcrete (originally called gunite) to build large-scale models of animals. It was soon being utilized for a variety of commercial applications. At the same time, prestressed tanks were being constructed using a cast-in-place concrete core wall. These tanks were prestressed by wrapping the walls with steel rods connected together by turnbuckles.

One of the important benefits of prestressing is that it reduces cost by reducing the amount of material required. In the 1940s, J.M. Crom, Sr., an inventor, began building water storage tanks with shotcrete (gunite) core walls and high strength wire for the prestressing elements. He preferred shotcrete because he could taper the prestressed tank core wall and save material.

Tanks can have tapered walls because the load varies. Stresses in circular tank walls (ring tension), increase with depth. To counter ring tension a greater amount of prestressing is needed at the base of the wall than at the top. Since the amount of prestressing varies, a thicker wall is needed at the base than at the top of the wall. Cast-in-place walls have a uniform thickness. (Building a tapered cast-in-place wall is possible but expensive). Due to it's versatility, shotcrete saves material which makes it the most economical method of building a prestressed tank wall.

For a number of years water tanks were built with shotcrete core walls. In the 1950's J.M. Crom further improved tank construction by developing the composite system. He added the shotcrete encasement of a steel shell diaphragm to provide a positive method of making the tank wall watertight. Encasing a cylindrical steel shell in poured concrete is difficult. Because shotcrete needs only one formed side, it can easily encase a steel shell of any size. The steel shell in a tank wall is important for three reasons: it serves as a form for the shotcrete, it provides a positive watertight barrier, and acts as vertical reinforcement.

A circular prestressed tank wall has two parts, the core wall which is the portion inside the prestressing wires that is compressed and the covercoat which is the shotcrete cover over the prestressing that is not compresses (see sketch). The steel shell is in the core wall. To encase the steel shell the nozzleman will shoot a thin 1/2 inch thick layer of shotcrete over the entire steel shell. A cement rich mix of 1 part cement to 3 parts of sand is used for encasement of shell and reinforcement. The wall is built out by shooting multiple layers. Subsequent layers are between 1 and 2 inches (25 and 50 mm) thick and the mix is changed to 1 part cement to 4 parts of sand. These are the only two mixes used.

The core wall theoretically does not need conventional reinforcement since it is in ring compression. But some horizontal reinforcement is usually provided as well as vertical reinforcement. In constructing a tank reinforcement is placed as the wall is built out so that it can be easily encased. Reinforcing bars are placed just prior to encasement so the shotcrete nozzleman does not have to shoot through a curtain of steel. When bars are lapped they are separated to ensure complete encasement.

The prestressing wires provide the strength that holds the tank together. Protection of the prestressing wires is vital. Wires are not allowed to touch so that each wire, along its entire length, can be completely enveloped in a cement rich coating of shotcrete. When several layers of prestressing are needed a coating of shotcrete separates each layer.

To construct a tapered wall, shooting wires with a fine diameter are stretched to the full height of the wall. The shooting wires are tensioned to provide a gage for the nozzleman. After shooting, finishers come behind the nozzleman and cut off material that extends beyond the shooting wires. The nozzleman then places additional shotcrete in the low areas. This process is repeated several times until the shotcrete wall fills out to the wires. A smooth curved exterior finish is achieved by spacing shooting wires closer together, making more passes and stoning the wall (rubbing the wall with stones to remove burrs) between shotcrete applications.

Because shotcrete should always be placed perpendicular to the receiving surface, specially designed scaffolds with elevators, which roll around the tank, allow nozzleman to shoot shotcrete perpendicular to the wall. Rebound, which accumulates at the base of the wall, is cut away. (Rebound and overspray are thrown into the work road).

From 1952 until the late '80s double chamber dry-mix guns were used. Sand and cement were mixed on the job. During that time concrete pumps improved and wet-mix shotcrete became more reliable. Ten years ago The Crom Corporation began using wet-mix shotcrete exclusively. Truck mixed concrete is delivered to the job. As with dry-mix, the wall is built up by applying multiple thin layers. With wet-mix shotcrete four times as much material is delivered through the same size hose in a given period of time. To apply thin vertical layers, large holes were installed in the air ring to provide more air volume at the nozzle. More air volume was needed since there was more material than with dry-mix shotcrete. The increased air volume provides sufficient impact velocity to ensure proper encasement of reinforcement. Sometimes the concrete truck will tow the concrete pump around the tank and a short length of hose is used. Sometimes concrete is pumped to a central hub and out to the shooting scaffold. Volumetric mixers also work well with a central hub configuration.

The wet-mix shotcrete process used in tank wall construction provides better assurance of material quality control. In order to pump a concrete mix through a small line there must be a high enough cement content so that all the aggregate particles are coated. In addition, additional cement is needed in the mixture to lubricate the pump line allowing the concrete mixture to slide easily through the pump line. While a mix with a high water to cement ratio (w/c) can be pumped through a small line such mixtures are not likely to stick to a vertical surface. Any wet-mix shotcrete mixture that can be pumped and will adhere to a vertical surface will typically have sufficient cement content and a low enough w/c ratio to easily achieve a minimum compressive strength 4,000 psi (28 MPa) at 28 days in the construction of prestressed shotcrete tanks. Typically wet-mix shotcrete compressive strengths range from 6,000 psi to 8,000 psi (41 MPa to 55 MPa) at 28 days.

The finish texture and line of the exterior exposed tank wall is important. Many tanks are judged solely on their aesthetic appearance. The curved shotcrete wall has a soft texture, which is aesthetically pleasing. Shotcrete allows for the addition of economical architectural enhancements such as pilasters and raised logos. The Crom Corporation has won numerous architectural excellence awards because of shotcrete made architectural enhancements.

For over 50 years shotcrete has been the preferred material for prestressed tank wall construction. Because of its versatility, shotcrete provides material and construction cost savings. Shotcrete also provides superior life-cycle costs compared to conventional cast-in-place reinforced concrete tank construction because with its high cement factor and low water/cement ratio it provides greater corrosion protection to prestressing and reinforcing steel and improved permeability and long term durability.

Prestressed Composite Wall