Concrete for Environmental Structures

Post-tensioning and special detailing prevents vertical shrinkage cracks in tank walls

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The versatility, economy, watertightness, and long-term durability of post-tensioned (PT) concrete make it ideal for environmental structures. Environmental structures are classified as those used for wastewater treatment and potable water treatment and storage. PT concrete can be cast into tanks of any shape required to fit the site or the process. PT concrete's higher strength allows for thinner tank floors, walls, and roofs. Furthermore, the high recoating costs that are periodically required for steel tanks are unnecessary when using PT concrete. Construction joints, particularly those in the tank floor, can be eliminated, ensuring maximum watertightness. Another benefit is that PT concrete can be made shrinkage-crack free, which helps protect the conventional reinforcement. Also, waterproof plastic ducts, sheathing, and coatings make water exposure, and therefore corrosion of the prestressing steel, virtually impossible.

Because of these and other advantages, PT concrete is gaining popularity among owners and engineers who are interested in new solutions to an old problem—leaking, maintenance-laden tanks. This article describes a number of environmental structures designed using PT concrete by Jorgensen & Close Associates, Inc. (J&CA) of Denver, CO.

Until recently, PT concrete tanks were only circular. We have designed 125 circular PT concrete tanks, ranging from 100,000 to 10 million gal. (400 to 40,000 m^3) capacity, in five countries, since 1964. They are mostly used for potable water storage, and wastewater clarifiers and digesters.

In this article, we will also discuss the PT concrete environmental structures built in China as part of a relationship with the Northeast Public Works Design and Research Institute (NPWD&RI) in Changchun. NPWD&RI uses key structural drawings from J&CA and has directed the final design drawings and construction of 22 PT concrete environmental structures totaling nearly 130 million gal. (500,000 m^3) capacity in the last 4 years.

CIRCULAR TANKS

The technology for applying circumferential post-tensioning to circular tanks has advanced from wire wrapping with thin shotcrete cover, to fully encapsulated mono- and multi-strand internal tendons. Crack-free concrete cover combined with waterproof plastic ducts (or sheathing) and rich cement grout (or grease) coating create triple corrosion protection of modern tendons.

The two-way PT flat plate roofs that cover circular PT concrete tanks have occasionally been used for tennis

Fig. 1: Ten million gallon (40,000 m³) potable water tank in Arvada, CO. Its post-tensioned roof doubles as tennis courts for visitors to the Alice Sweet Thomas Park

Fig. 2: The Hap Creamean Water Treatment Plant in Columbus, OH uses six post-tensioned concrete clearwells totaling over 48 million gal. (200,000 m³)

Fig. 3: A rectangular PT concrete tank with rounded corners at the White River Water Treatment Facility in Indiana

courts and other recreational purposes. A 10 million gal. (40,000 m³) potable water tank was built in the Alice Sweet Thomas Park in Arvada, CO (a suburb of Denver), in 1975 (Fig. 1). It received the Grand Award for Design Excellence in 1975 from the Colorado Chapter of the American Consulting Engineers Council. The Bicentennial Commission also recognized it as one of 200 outstanding community projects across the U.S. in 1976.

The circumferential tendons inside the walls of circular tanks are usually anchored at pilasters (also known as buttresses). We use a minimum of two, and a maximum of six, pilasters on tanks we design. Because the primary source of friction loss in multi-strand tendons is from their curvature, not their length, adding more pilasters does not significantly reduce the number of circumferential tendons required, even on very large tanks.

Circular PT concrete tanks were already being used occasionally in China prior to our involvement there. Nevertheless, the design details were improved, and the floors have been made more watertight with the adoption of our details and monolithic PT floor placement techniques. Eight circular PT concrete clarifiers and potable water tanks, totaling nearly 12 million gal. (50,000 m³), have been built in China between the summer of 2001 and the summer of 2003.

RECTANGULAR TANKS WITH ROUNDED CORNERS

We were retained to do the structural design of six PT concrete clearwells, with a total capacity of 48 million gal. (200,000 m³), for the Hap Cremean Water Treatment Plant in Columbus, OH (Fig. 2). When retained to design the tanks in 1993, we presumed they would be circular, as nearly all PT concrete tanks had previously been. We soon discovered that there was not sufficient room on the site to make the tanks circular—they had to be rectangular. After a little brainstorming, we realized that this situation wasn't very different from an oblong oxidation ditch we had recently designed for the Hillsdale Powell Utility District in Kentucky.

By rounding the corners of the rectangular tank, we could use the same pilaster details that were common on circular tanks. This concept turned out to be so versatile that two of the tanks at the Hap Cremean site were made five-sided to accommodate large pre-existing pipe lines. The corners are rounded to a 32 ft (10 m) inside radius. Rounded corners not only prevent wall cracking, they help prevent roof cracking, as the roof can expand and contract freely over the self-supported rounded corners, which do not require lateral support at their tops from the roof.

Figure 3 shows a 7 million gal. (30,000 m³) rectangular PT concrete tank with rounded corners that is part of an expansion and upgrade to the Indianapolis Water Co.'s White River Water Treatment Facility. It was built to aid

Fig. 4: A rectangular PT concrete tank with rounded corners under construction in Harbin, China

Fig. 5: This open-top post-tensioned aeration was built for the Bayport Wastewater Treatment Plant in Pasadena, TX

in treatment upgrades and provide additional storage. This design-build tank has horizontally and vertically post-tensioned walls. It also has a monolithically placed, flat plate mat foundation that is PT in two directions and designed for 4 ft (1 m) of water uplift. Monolithically placing and post-tensioning the two-way flat plate roof also helps prevent possible water contamination. The tank is fully buried, with 2 ft (600 mm) of backfill over the roof. The corners are rounded to a 40 ft (13 m) inside radius.

This rectangular-with-rounded-corner concept has become very popular in China. Six tanks of this type were built there between the spring of 2002 and the summer of 2003, totaling nearly 44 million gal. (170,000 m^3) of potable water storage capacity. Figure 4 is a photo of a pair of rectangular tanks with rounded corners under construction during the summer of 2003 in Harbin, China. The concrete floor was placed using four slick lines. Fifteen or 20 workers were at the end of each slick line. It took 30 h to place the concrete in this 90 x 121 m, 150-mm-thick floor. The concrete set was retarded 10 h to prevent cold joints.

Open top rectangular tanks

PT concrete is particularly well suited to very large, open top, rectangular wastewater treatment structures. These structures are used as aeration basins and sequencing batch reactors. These structures are sometimes over 300-ft-long (90 m) on each side. We always place the floors of these tanks monolithically—without any construction joints, expansion/contraction joints, or crack-control joints—yet they never crack. This is possible through special anti-friction detailing and prestressing forces applied in stages as the concrete gains strength. Similarly, the walls are placed in very long segments and post-tensioning is combined with special details to prevent vertical shrinkage cracks. This system maximizes the liquid-tightness of the tank.

Designing this 13.4 million gal. (51,000 m^3) open-top PT concrete aeration basin was particularly challenging because of its intended use (Fig. 5). The basin was built for the Bayport Wastewater Treatment Plant in Pasadena, TX. The cast-in-place rectangular PT concrete basin had to be "bottle tight" (which is a direct quote from the performance specifications for this design-build project). The aeration basin provides the primary containment for industrial wastes generated by petroleum refineries tributary to the plant. A heavy PVC membrane below the floor slab provides secondary containment, as required by ACI 350.2R-97. Monolithic concrete placement and special details and post-tensioning procedures were used on the floor and walls to eliminate cracking and maximize watertightness. The PT membrane floor has integral wall footings, and the walls are all horizontally and vertically post-tensioned.

Open top rectangular PT concrete tanks have become very popular in China. Six tanks of this type have been built there between the summer of 2000 and the summer of 2003, totaling over 78 million gal. (300,000 m^3) capacity. The first PT concrete tank we constructed in China was a 16 million gal. (60,000 m^3) aeration basin constructed in Changchun, the capital of Jilin Province, in the northeast.

Although multi-strand tendons are available in China, all the tanks built to date in China have used mono-strand tendons. The mono-strand tendons available there are not fully encapsulated, as they are in the U.S. Therefore, their tendons don't have the extra corrosion protection in the vicinity of the anchorages required in the U.S. Nevertheless, they do have a heavy plastic extruded sheathing, which allows the tendons to serve their intended usage very well.

DOUBLY CURVED STRUCTURES

One of the authors was the Division Engineer for VSL Corp.'s Western Division in 1977 when the Terminal Island, Los Angeles, CA, egg-shaped digesters (ESDs) were being

Fig. 6: Terminal Island egg-shaped digesters built in Los Angeles, CA *(Photo courtesy of VSL)*

designed and built (Fig. 6). He participated in the design and detailing of the post-tensioning tendons for the ESDs. The plywood covered horizontal blockouts were for an in-line "Z" anchor stressing system. The vertical tendons were looped such that all anchorages were located at the top of each wall placement.

The Terminal Island ESDs were formed with an elaborate gang-forming system. Some more recent ESDs have been formed with wood blocking between curved wide-flange steel beams. This same forming system can be turned "inside-out" to form elevated water tanks. Although common in Europe, no concrete elevated water tanks have been constructed in the U.S. in recent years, to the authors' knowledge. This option, of elevated PT concrete tanks, however, should be considered seriously in the U.S. as well. These structures would not have to be taken out of service frequently, for several months at a time, for repainting.

PT FOR ALL ENVIRONMENTAL STRUCTURES

In conclusion, PT concrete is very well suited to many kinds of environmental structures. Versatile PT concrete can be formed into shapes from simple rectangular tanks to doubly curved ESDs and, potentially, water towers. PT concrete tanks are economical, compared to all other types of environmental structures, especially when the high recoating costs of steel tanks are considered. The virtually crack-free properties of PT concrete and triple corrosion protection of the prestressing steel make for maximum long-term durability. Because all floor construction joints can be eliminated, no matter how large the structure, and all other joints and wall surfaces can be inspected, the watertightness of PT concrete tanks is fully ensured.

Selected for reader interest by the editors.

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