Design-Construction of Glennaire Water Tank No. 2

Discusses the functional requirements, planning, design considerations, production and erection aspects involved in the construction of a 1 million gallon (3.785 million liter) precast, prestressed concrete water tank in Spokane, Washington. A major feature of the structure is the combination of single pie-shaped tees for the roof and single tees with exposed aggregate flanges for the circumferential wall. A synthetic liner is used on the inside of the tank to ensure the structure is watertight. It is expected that this tank will provide the community with a long, safe and maintenance-free service life.

This elegant precast, prestressed concrete water tank, perched on a picturesque hillside (see Fig. 1) overlooking the City of Spokane, Washington, has a capacity of 1 million gallons (3.785 million liters).

The tank has an inside diameter of 75 ft (22.86 m) and a 30 ft (9.14 m) height of water. The roof area is 5080 sq ft (472 m²) and the wall area is 7943 sq ft (739 m²).

The roof of the tank is composed of 33 tapered (pie-shaped) single tees supported at the center by a single 36 ft (11 m) high precast concrete column and a 47 sq ft (4.37 m²) precast concrete column cap.

The outside walls are comprised of 33 single tees with exposed aggregate flanges that support the wide end of the roof single tees. Around the perimeter, just beneath the roof, 11 precast concrete radial beams provide the restraint at the top of the walls caused by the water pressure head. Also, around the perimeter at the base, a cast-in-place ring beam furnishes the required restraint at that location.

To ensure that the tank is watertight, a 45-mil Hypalon® liner is used over a geotextile fabric pad. Stainless steel hardware is used to attach the liner to the single tee walls and pinch the liner around the center column and other penetrations.

The purpose of this article is to discuss the planning, design, production and erection highlights of the tank structure from the perspective of the owner-engineer and precast concrete manufacturer. Further, it is shown that a precast, prestressed concrete solution fulfilled the project requirements, thereby producing a functional, aesthetic and economic structure that is expected to have a long, safe and maintenance-free service life.
The Problem

Browne’s Mountain, located near the southeast section of the City of Spokane, was experiencing a rapid population growth in the late 1980s. During this period, the area was served by a single 150,000 gallon (567,750 liter) water tank situated on a small site about halfway up the mountain. The existing tank, a cast-in-place, partially buried concrete structure with an exposed roof, was the only tank serving the system.

Because of the recent housing boom, the tank had quickly become inadequate to serve the Glennaire system in the excellent manner that the citizens of Spokane have come to expect from their Department of Water and Hydroelectric Services (DWHS). Additionally, the tank needed repairs, and because of the constant high demand for water, scheduling the work remained an elusive task.

Because of these concerns, the DWHS determined that a new, 1 million gallon (3.785 million liter) tank should be constructed, to serve in parallel with the existing tank, operating at the same overflow elevation. The much-needed capacity would facilitate management of the system both from an operational and a maintenance standpoint. After construction of the new tank, the existing tank could then be easily scheduled for repairs.

Site Restrictions

The existing tank site was originally sized to accommodate a future tank. However, the site is not well suited for this purpose, sloping at approximately 24 percent. Consequently, in order to place a second tank on the existing site, it was initially thought that a concrete structure would most likely be required, and that it would have to be built into the hillside, remaining partially exposed due to the impracticality of total burial.

A complicating factor was that the size of the site limited the usable diameter of the new tank. A size of 75 ft (22.86 m) diameter by 30 ft (9.14 m) overflow depth was finally determined to be the most practical and buildable for the site.

Aesthetic Considerations

An important issue confronting the design engineers was that the tank site is highly visible. The fact that the new structure could not easily or practically be buried meant that the tank would itself be very conspicuous. In recognition of the impact that the new structure would have on the surroundings, it was decided to involve the local neighborhood architectural committee members, soliciting their input during the initial phase of the project. Involving them early in the process, and in a meaningful way, was instrumental in promoting neighborhood harmony and acceptance of the project.

Selection of the System

The required sidewall height lent itself well to a system proposed by the precaster, whereby precast, prestressed concrete single tees would be used to span vertically, stems out, for the wall members, secured at the top and bottom by conventionally reinforced ring (or radial) beams. A precast concrete column placed at the center of the tank would support a precast, prestressed...
concrete single tee roof system. Since the tank would not be post-tensioned, a synthetic liner was proposed to prevent water leakage.

Because the City of Spokane has in its recent history been called a “steel tank town,” it was decided to also investigate the feasibility of constructing a steel tank. However, due to the steep slope of the site, a steel tank could not be built without constructing a sizable cantilever retaining wall. Otherwise, the tank would have to be partially backfilled, which was a situation the City of Spokane would not tolerate. The constricted site necessitated the base of the wall to be fairly close to the existing tank and well below the existing tank’s base slab elevation.

Construction of such a wall would have been prohibitively expensive and might have even required partial dewatering of the existing tank during construction. This situation would adversely impact the construction operation, especially if construction were to extend into the normal hot weather period.

Construction cost estimates were prepared for both a steel tank and a concrete tank, and the present value of future maintenance costs were calculated to provide an estimate of the life cycle costs for each system. The future maintenance costs were considered by assuming tank lives of 80 years, liner replacement at 40 years for the concrete tank, and painting of the steel components of both tanks at 20 years. Cranking out the numbers, it quickly became apparent that a steel tank would not be practical for this installation.

General Details

Because the City of Spokane had no recent experience with concrete tanks for potable water, either with a conventional design or with the envisioned not-so-conventional design, an open-graded gravel drainage blanket was placed immediately below the base slab, with the subgrade sloped to a drain pipe in order to convey any major leakage to the containment basin. This will allow inspectors to monitor the performance of the liner, albeit probably not for minor leakage. This scheme was factored into the life cycle costs for the concrete tank when comparing the steel and concrete systems for viability.

The hillside was regraded against the back portion of the tank at a depth of about 16 ft (4.88 m). It slopes uniformly around to the front of the tank, where the tank base is essentially at ground level. An asphalt concrete perimeter service lane was constructed around the tank, and is located immediately adjacent to the stems of the wall elements.

Of some concern was the requirement for compaction of the backfill between the projecting stems. It was finally decided to place rounded drainage rock in the space between the stems, and to utilize conventional backfill in the area outside the stems. By doing this, two concerns were addressed:

• It would no longer be a labor-intensive task to compact the backfill because the rounded drainage rock requires very little effort to consolidate and the conventional fill materials would be readily accessible for compaction using normal methods.

• The drainage rock would act as a vertical drainage medium, thus eliminating any possibility of additional unbalanced loading due to ground water effects.

Concrete closure slabs, 4 in. (102 mm) thick, were then poured on top of the drainage rock, in the area between the projecting stems. These slabs were constructed on 2 percent grades away from the tank, and intercept any water running down the side of the tank, directing the water to the drainage

Fig. 2. Panoramic view of Imax Theatre which was built for “Expo ’74.”
ditch at the periphery of the asphalt concrete service lane.

The use of precast concrete components meant that an architectural treatment could be easily incorporated in the exposed surface of the wall panels. We chose to provide a rustic appearance by exposing the aggregate on the walls, on what would be the underside of the tee flanges. The exposed areas were produced in small panelized areas delineated by vee grooves and were later coated with a gloss sealer.

In Retrospect

It is always gratifying to “see a plan come together.” The ease of construction for this tank was evident. Indeed, my first reaction when we discussed the possibilities of a tank of this type was that it looked like it would be simple — simple to design, simple to draw-up and simple to build. My experience has been that, if something is easy to lay out and draw, then the chances are that it will be easy to fabricate and erect, and this was further verified on this project. It was also nice to see that the tank holds water without any signs of leakage!

The use of the precast concrete single tees has provided the striking visual effect we thought was possible, and the simple use of exposed aggregate truly provides the “icing on the cake.”

Perhaps the only visual treatment we would change would be to expose the outer surface of the top ring beam. The basic approach, though limited to some extent by the realities of the structural system, is ideal. We have already discussed the possibility of providing intermediate post-tensioning in order to raise the allowable wall height of this system.

Precaster's Perspective

As a typical manufacturing company, Central Pre-Mix Prestress Co. (CPPC) is always looking for new uses of standard products as well as ways to apply a newly developed product in a new market. In 1974, Spokane, Washington, was host to a world exposition called “Expo ’74.” As a part of this exposition, and to be a permanent landmark to this event, an Imax Theatre (see Fig. 2) was constructed.

This unique structure uses precast, prestressed concrete single tee members arranged radially to form a circular structure. Hence, since 1974, there has been a highly visible example of a circular structure using single tees in the Spokane area. Our thought process continued over the years, extrapolating from this structure that a circular water tank could be built using this same concept.

By using the analogy of barrels built using staves and bands, the single tees could be used as staves and the bands could be concrete ring beams constructed at the top and bottom of the structure, tying into the single tees. A liner would then be used as a “bladder” to contain the water.

CPPC had constructed several other structures using similar concepts. Hence, some of the details used successfully on these projects could readily be adapted to the single tee system. One of the other projects using this same concept was two acid tanks of 55 ft (16.76 m) diameter and 15 ft 6 in. (4.72 m) height done for Cominco, Ltd., of Trail, British Columbia, Canada. These tanks used a prestressed solid SpanDeck wall panel with a fiberglass liner. Ring beams were cast-in-place at the top and bottom.

Another project with similar details was a project done for Cominco, Ltd., at Phosphate, Montana, where a double tee wall system was used on a rectangular building to contain powdered phosphate.

The size of this building is 60 x 40 x 32 ft (18.29 x 12.19 x 9.65 m) tall, with a steel roof system. The handling process for this powdered phosphate uses air to liquify and move the material, resulting in a fluid lateral pressure on the double tee walls. Both of these structures have been in service for several years; hence, there was a confidence and familiarity with their details and performance.

Therefore, when the City of Spokane Public Works Department contacted CPPC to enquire if there was any interest in assisting them in the development of the 1 million gallon (3.785 million liter) Glennaire No. 2 reservoir, a single tee system immediately came to mind.

Some reasons for this choice were:
1. Previous successful experience with similar concept structures.
2. Highly visible structure (Imax Theatre) serving as an example to complement the appearance of the proposed new structure.
3. The City of Spokane was uncomfortable with using a nonlinear system due to having to demolish several older reinforced concrete tanks because of leakage and deterioration. Use of a Hypalon liner, with which they were familiar, increased their confidence level.
4. Pie-shaped single tee roof segments combined effectively with sin-
Fig. 4. Interior view of center column and cap with radiating pie-shaped single tees.

Fig. 5. Closeup view of reinforcement of trough beams at center of roof.

The cost bid for the reservoir was $250,239 erected, or about $0.25 per gallon. The overall project cost was $486,000, or $0.49 per gallon. This figure included the nearby valve vault in addition to considerable sitework and piping. Of the five bids received on the project, Hoffman Contractors, Inc., of Spokane, Washington, was the low bidder.

The details and construction sequence followed by the contractor and subcontractors were as follows:

1. The general contractor prepared the site and poured the outside perimeter footing (see Fig. 3) to the heights shown and poured the bottom slab in a single pour. No waterstop or special construction techniques were needed because a liner would be used to achieve watertightness.

2. CPPC moved on site and began erection. In order to not confuse responsibilities and to ensure that the system would be assembled as conceived, CPPC chose to bid the tank erected. All aspects that correlated with the tank’s integrity were included in the price given to the general contractors.

A scope letter was issued prior to bid listing inclusions and exclusions. Wall tees were set, plumbed, welded and braced. The center column and center column cap were set, plumbed and braced (see Fig. 4). The column cap was connected to the column using high strength 1 in. (25.4 mm) diameter Dywidag bars.

3. The roof single tees were set and connected to the wall tees with grouted dowel connections. The precast radial trough beams were set on the single tee stems and the connection made between single tee and beam. At both base and top, the decision was made to use mild steel reinforcement in the ring beams rather than post-tensioning, to withstand the tension forces. For this small diameter structure, post-tensioning losses were high, and construction of buttresses to jack from would have added cost to the structure.

4. Reinforcing bars were placed in the trough beams and at the center of the roof (see Fig. 5). Concrete was pumped for placement in these two areas.

5. Inside the tank, a rolling scaffold was erected and strips of 20 gauge galvanized steel were attached to span the single tee wall joints. This would prevent the liner from protruding at the joints and ensure that vandalism to the liner could not occur.

The roof seal was installed. Initially, the roof seal was conceived to be stainless steel strips bedded in mastic and attached with mechanical fasteners. However, this did not work because some areas of mastic did not bond tightly enough to the stainless steel and allowed leakage. To remedy this problem, a 45-mil EPDM strip was applied at the joints with the spec-
ified adhesive and caulked along its’ edges according to the manufacturer’s instruction. The stainless steel protection strips were then reinstalled.

6. As soon as the inside of the tank was ready, the liner subcontractor, Northwest Linings of Kent, Washington, mobilized. After initially drilling in anchors around the perimeter, a 4 ounce (227 grams) geotextile pad was hung, followed by the white 45-mil Hypalon liner (see Fig. 6). A stainless steel pinch ring secured the pad and liner at the top.

The geotextile pad was used on both walls and roof to ensure that the liner had a soft surface to bear against and that any protrusions would be “softened” enough so that repeated filling and emptying would not eventually wear through the liner. The liner subcontractor used standard stainless steel pinch rings around all internal piping, the center column and the two manholes.

7. The general contractor then remobilized, finished threading the reinforcement at the footing, and made the second footing pour. The vent, roof hatches, roof handrail and ladders were installed. Caulking and sealer were applied to the wall tees. The two shell manholes (see Fig. A5) were installed. Backfill and other site completion items were completed, and the project was turned over to the owner for testing. To date, all visual inspections of the tank have shown that there has been no water leakage.

In retrospect, several comments can be made about the construction of the project. From a precaster’s viewpoint, the following are advantages:

• Responsibility for watertightness of the tank is shifted to the liner subcontractor.
• The components of the tank are all standard and the erection of the structure is routine. No special construction techniques or sophisticated procedures are necessary.
• The single tee wall element offers many possibilities for different architectural treatment.
• Use of standard components keeps the system cost-effective.
• There are also disadvantages:
• Reliance on the capabilities of the liner subcontractor to keep the tank watertight.
• Cost of the liner is an additional expense.

Many compliments have been received about the tank’s attractiveness and how it blends well with the expensive homes. Exposed aggregate on the flanges of the single tees (see Fig. 7), combined with contrasting smooth concrete surfaces (see Fig. 8), give the structure an attractive visual appearance.

The structure was completed in spring 1991 and the facility has been in service since June 1991. During the past 18 months, the water tank has been operating with total satisfaction. The structure is much admired by the public and has become a distinguished landmark in the Spokane area.
Fig. 8. Partial view of finished water tank showing exposed aggregate flange of tee.

Credits

Owner: City of Spokane, Spokane, Washington
Engineer: City of Spokane Public Works Department, Spokane, Washington
Liner Subcontractor: Northwest Linings, Kent, Washington
Precast, Prestressed Concrete Manufacturer: Central Pre-Mix Prestress Co., Spokane, Washington
Fig. A1. Footing plan of tank with detailed sections.
Fig. A2. Typical cross section of tank showing single tee wall and joint sections.
Fig. A3. Roof plan of tank showing detailed sections.
Fig. A4. Beam plan of tank showing typical roof single tee and detailed sections.
Fig. A5. Elevations, sections and details of shell manholes.