Precast Prestressed Concrete — Solution of Choice for Lincoln Heights Water Tanks

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This article discusses the functional requirements, planning, design considerations, and erection aspects involved in the construction of two 10 million gallon (37.9 million liter) precast, prestressed concrete water tanks in Spokane, Washington. The tanks were designed to replace a two-basin, 5-acre open-type reservoir. A major feature of the structures 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 interior of the tank to ensure the structure is watertight. The authors describe the design and construction process from the perspectives of the project engineer, the owner, and the precast concrete manufacturer.

Since 1911, the drinking water storage at Lincoln Heights, Spokane, Washington, consisted of a five-acre reservoir (swimming pool style). A floating cover was placed on the reservoir in 1981 and, like the cover for a swimming pool or hot tub, wore out with time. The natural aging process was compounded by the neighborhood ducks who populated the many puddles left on the cover after rains. The aging of the cover and the real and imagined threats to the city's drinking water posed by the duck population prompted the City of Spokane Department of Water and Hydroelectric Services to search for a more permanent and duck-proof cover.

From an engineer's viewpoint, this was an easy task.

Fig. 1. The Lincoln Heights water tanks in Spokane, Washington, fit aesthetically into their environment.

That is, until the city added a further stipulation: "It must fit aesthetically into the environment and be reasonably priced" (see Fig. 1).

David Evans and Associates, Inc. (DEA), Spokane, Washington, was retained to evaluate the economics of several alternatives. The success of this project can be traced back to the cooperation of the design team during the preliminary design phase. The team, made up of Spokane city staff, DEA personnel, and Central Pre-Mix, Spokane, Washington, studied various alternatives including concrete, wood, and steel covers over the existing reservoir and various circular storage tank systems. The precast water tank option proved to be the optimal choice for the Lincoln Heights site. The new water tanks combine strength, beauty, and economics. Each tank holds 10 million gallons (37.9 million liters) of pure drinking water.

It is a common misconception that only steel or cast-in-place concrete systems will provide acceptable economics for such tanks. Ordinary single tee beams were used for the wall panels. These were placed in a circular pattern with the flanges oriented towards the outside. This arrangement developed the vertical flutes that define this type of tank. By installing exposed aggregate on the bottom side of the flanges, an attractive visual contrast was developed. A flexible plastic liner was installed on the inside of the tank to hold water. Utilizing standard precast shapes for the walls saved considerable money.

The roof system is also constructed from tee beams. They are pie-shaped so that they could be placed in a radial pattern. The roof tees are supported by a column at the center of the tank. The other end of the tees are supported by the wall panels.

Substantial cost savings and enhanced appearance were achieved by partially burying the new tanks. This allowed the site to be graded at a slope that matched the original topography, giving the project a natural look and aesthetics.

As a bonus, the soil placed around the tanks was used for structural support of earthquake forces. The utilization of soil as a structural element allows for smaller precast members and further cost savings.

The height of soil backfill was balanced against the need for the walls to bend due to the pressure of the water on the walls as the reservoir fills and drains.

To obtain the desired ground layout, and provide adequate flexibility, a soft, loose fill material was installed in the upper portion of the backfill. Finally, topsoil was installed over a filter fabric to protect the soft backfill. Grass was planted to protect the ground from erosion.

Redding Construction Company, the project's primary constructor, became a member of the team through the construction phase. The project was designed and built within budget, on schedule and without interruption of the water supply to the Lincoln Heights neighborhood. The end result is an award-winning project that provides drinking water storage at a very reasonable cost.

Fig. 2. The existing Lincoln Heights reservoir with deteriorating floating cover.

CITY OF SPOKANE'S PERSPECTIVE

Located near Ray Street and 23rd Avenue in Spokane, Washington, the original Lincoln Heights Reservoir, a rectangular open-type facility with two basins, was constructed in 1911 to create a water storage facility for the City of Spokane. The reservoir measured 534 x 319 ft (163 x 97 m) and had a capacity of 24 million gallons (95 million liters) when full. Until 1981, the facility was operated as an open reservoir that required extensive maintenance over the years by the Water Department.

The open basins were an attraction to waterfowl as well as to airborne contaminants — a concern in terms of water quality. Then in 1981 after the eruption of Mount St. Helens, the city installed a liner in the basins to ensure that the reservoir was sealed from leakage and installed a floating cover to protect the quality of the drinking water from water fowl and airborne pollution.

Although the floating cover was an improvement over an open reservoir, it did not prove to be a cure-all. The cover was subject to rips and tears, which needed patching. The problem of rips and tears became more frequent as the cover deteriorated with age.

By 1990, the floating cover had reached its useful lifespan.

The reservoir was a vital facility in the water system for providing water service for essentially the entire southern portion of the city — an area from 5th Avenue south to Browne's Mountain. It was apparent that the Water Department needed to develop a plan to provide a more permanent solution for protecting the drinking water — something better than another floating cover (see Fig. 2).

The construction of steel water tanks within the basins of the open reservoir was initially considered and then quickly set aside as an unacceptable option due to the resulting lack of aesthetics offered by this option. It was felt that a "tank farm" setting would be unacceptable in a residential community.

Another option considered was to construct a concrete roof over the open basins and install landscaping over the "lid" to provide a park-like setting. After some initial preliminary design, it became apparent that this option would be quite expensive. In addition, it did not seem practical to install an expensive lid over an old structure with a limited remaining life. This option was subsequently set aside.

After examining numerous other alternatives, the Water Department became particularly interested in the option of constructing two 10 million gallon (37.9 million liter) concrete tanks, each 240 ft (73 m) in diameter and 35 ft (11 m) high, within the basins of the existing reservoir. The Water Department had recently constructed a similar concrete tank, although much smaller [1 million gallons (3.79 million liters)], known as the Glennaire Reservoir No. 2 (see the article "Design-Construction of Glennaire Water Tank No. 2" in the January-February 1993 PCI JOURNAL, pp. 28-39) and was quite pleased with the aesthetics of that structure.

The Opportunity

The construction of two 10 million gallon (37.9 million liter) concrete tanks within the basins of the existing reservoir presented the best permanent solution considering the life of the facilities, cost, aesthetics (avoiding the "tank farm" look), compatibility with the neighborhood, and protection of the drinking water.

The existing open basin reservoir was constructed with a low center wall dividing the reservoir into two basins. This design allowed one-half of the reservoir to be drained for maintenance while the other half remained in service. This allowed the city to construct the new tanks within the existing basins. One tank (the first tank) was scheduled to be constructed within the west basin while maintaining the east basin in service. Then, upon completion and filling of the first tank, the east basin could be drained to allow the start of construction of the second tank.

Obviously, the simultaneous construction of both tanks was not possible. It is also important to note that the construction of the first tank had to be scheduled during the fall, winter and spring months because the east basin contains insufficient storage to support the water system through the heavy water demands during the summer. During the summer, it is typical to have 30 million gallons of water per day move through this corridor of the water system.

The Tanks

The tank shell consists of 78 prestressed, single tee concrete beams approximately 9.5 ft wide by 35 ft long (2.9 x 11 m) and weighing approximately 47,000 lbs (21320 kg) each.

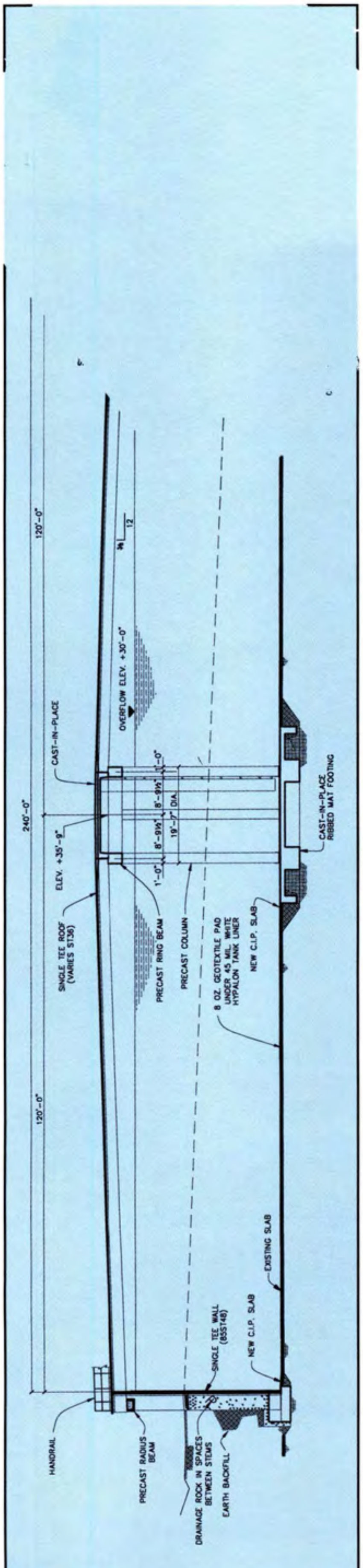

Fig. 3. Typical cross section of tank.

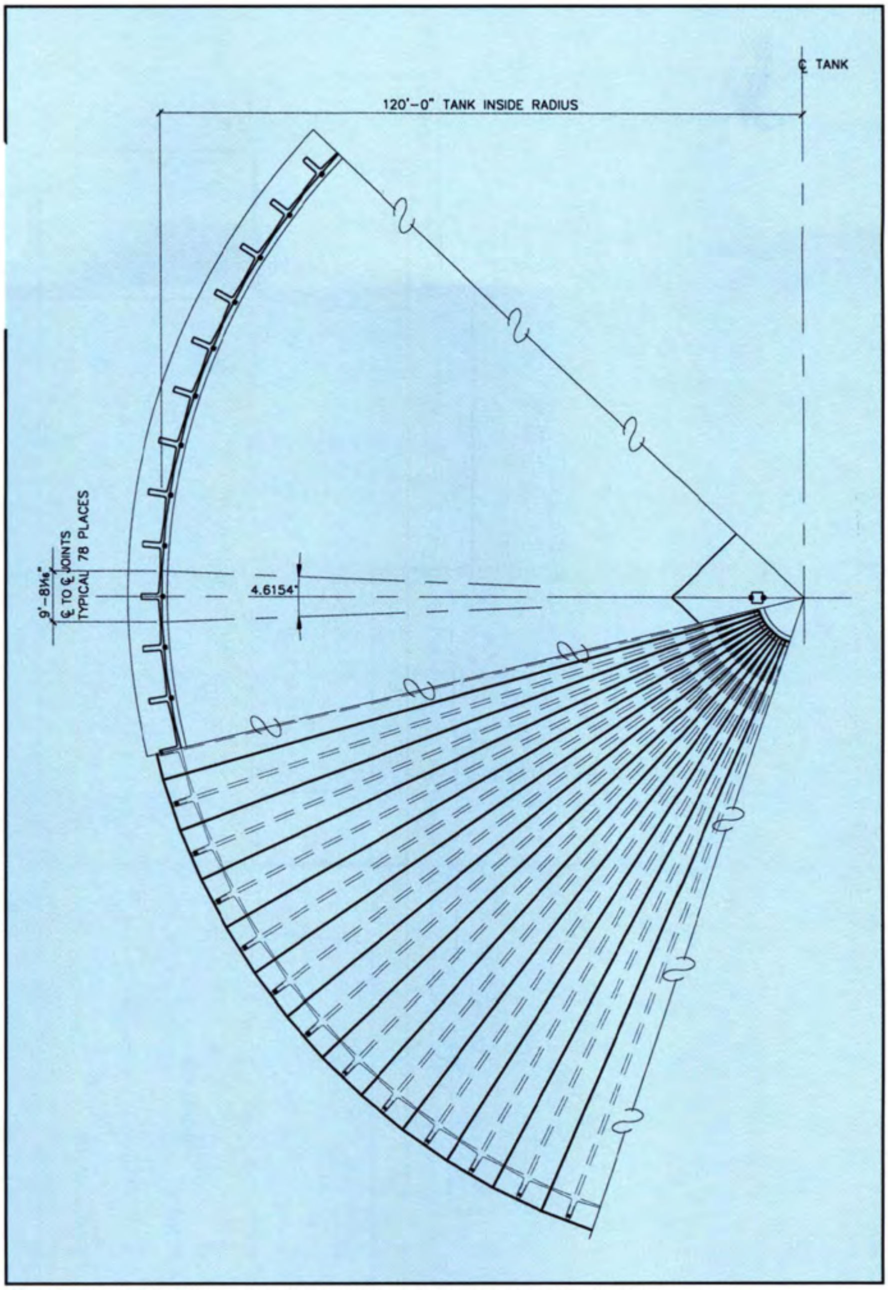

Fig. 4. Partial footing plan (top) and partial roof plan (bottom).

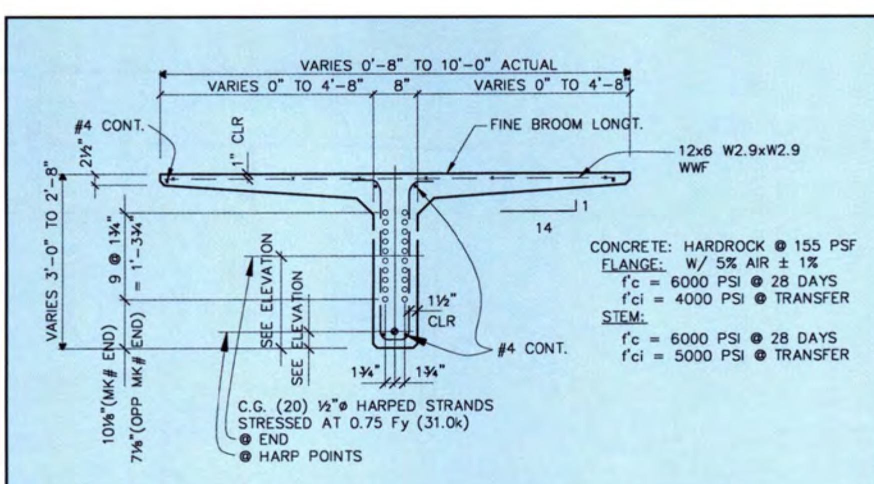

Fig. 5. Typical roof cross section.

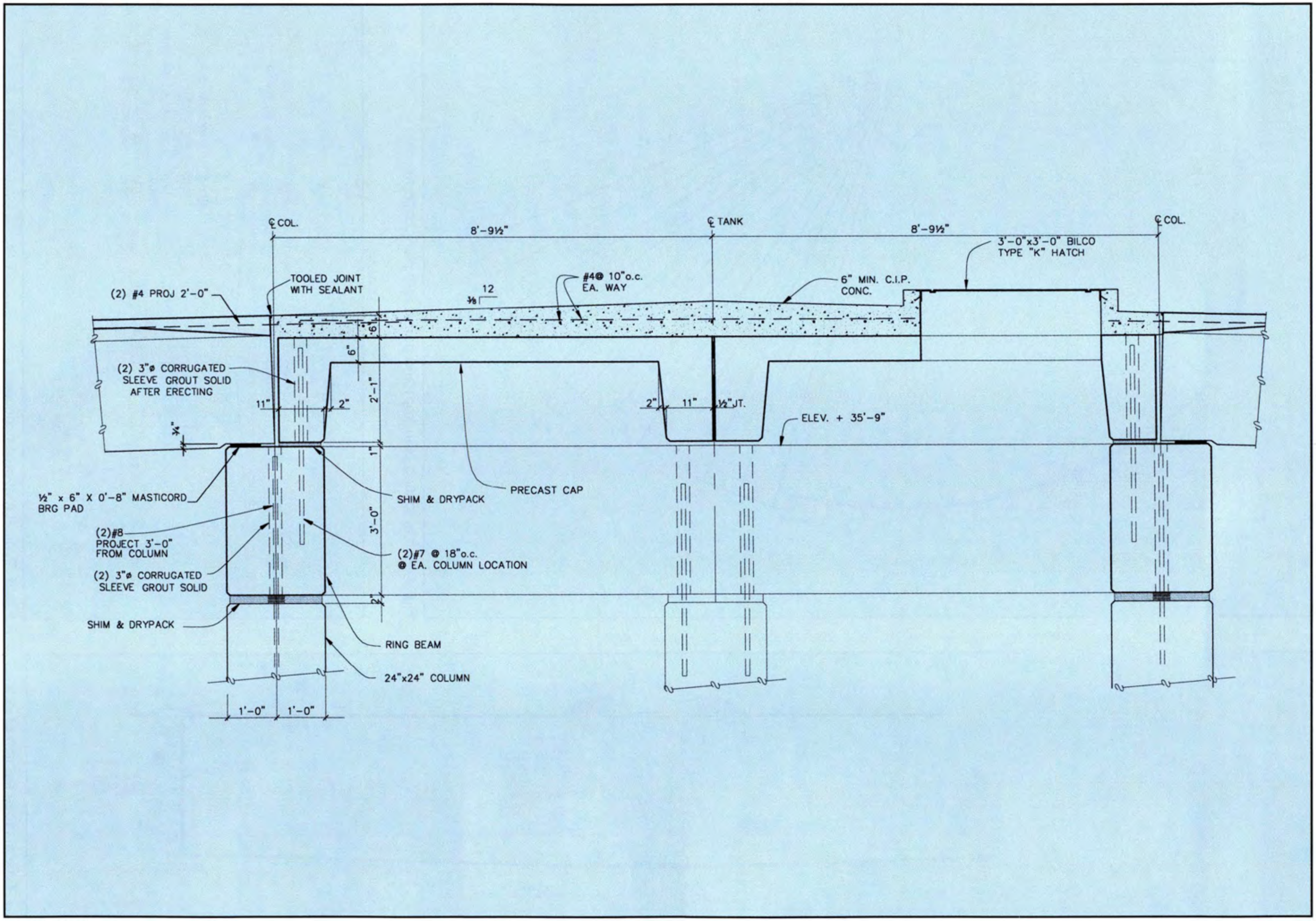

Fig. 6. Center ring cross section.

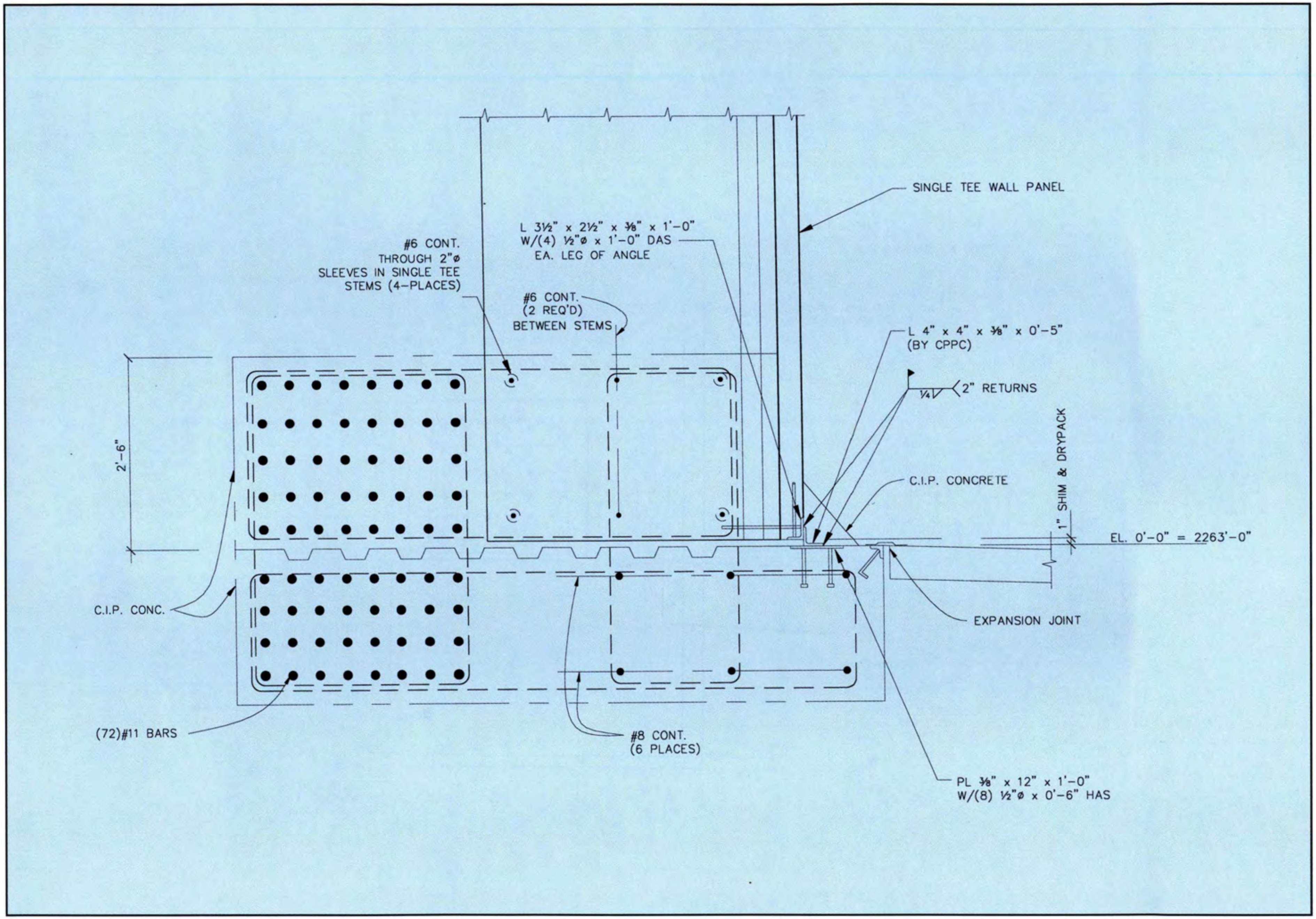

Fig. 7. Wall section at footing.

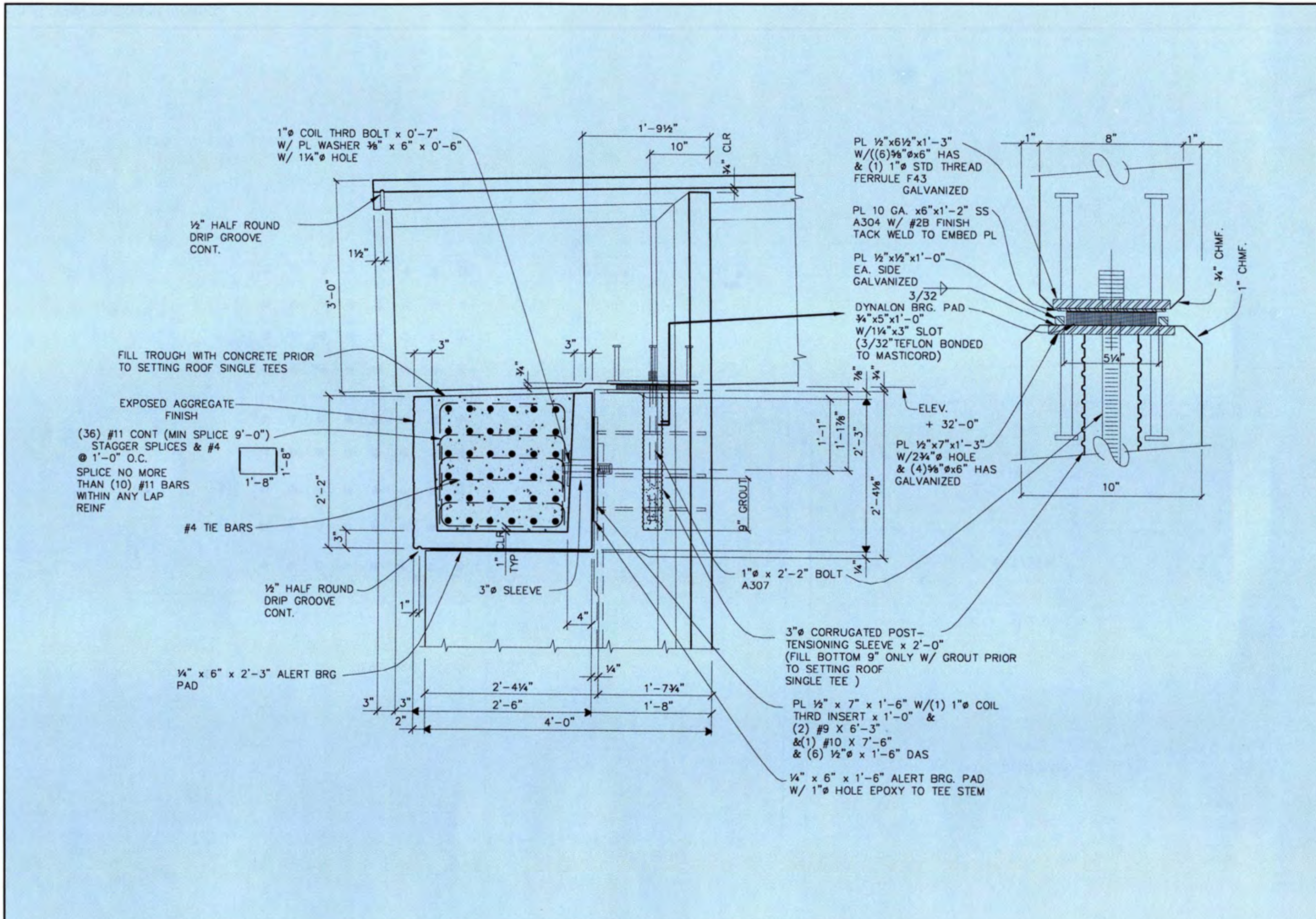

Fig. 8. Wall section at roof.

An exposed aggregate surface was incorporated into the beams' flanges for aesthetics. The tank roof consists of 78 prestressed, tapered single tee concrete beams approximately 115 ft (35 m) long and weighing approximately 67,000 lbs (30390 kg) each. The tanks were sealed against leakage by an interior 45-mil reinforced polypropylene liner on the walls and floor.

The lateral hydrostatic loads on the tank shell tee beams are transferred to each end of the beams where they are transferred and resisted by top and bottom reinforced concrete ring beams. These forces are typically known as hoop stresses or loads.

The roof beams are supported at one end by the tank shell and at the other end by a center concrete ring beam mounted on four concrete columns. For night-time aesthetics, floodlights were incorporated into the upper ring beam to shine down on portions of the tank shell exterior.

When the tanks were completed, the site was regraded, partially burying the tanks and providing a smaller profile for the structures. Finally, extensive landscaping with lawn, shrubs, and trees completed the project into a world-class finished facility.

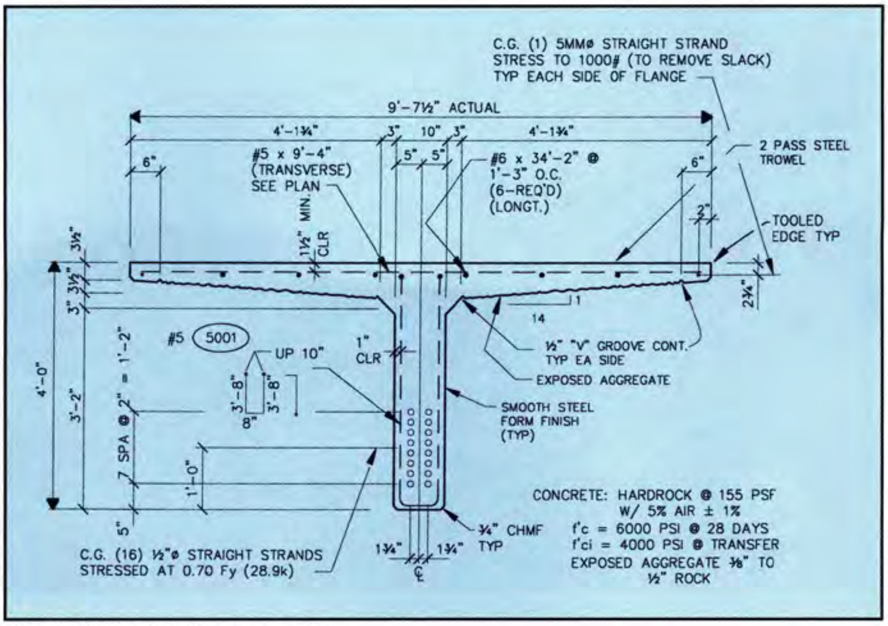

Fig. 9. Typical wall cross section.

PRECASTER'S ROLE

Central Pre-Mix Prestress Co. (CPPC) had been talking with the City of Spokane Public Works Department about subsequent water tanks or other projects since constructing two tanks in 1990 and 1991. CPPC had been discussing the city's intentions for Lincoln Heights reservoir because it was evident that the floating cover was failing (see Fig. 2). Initial conversations with the city revolved around covering the entire existing open reservoir.

Covering this large area with double tees or hollow-core slabs, supported by precast beams and columns, made sense to CPPC and seemed logical to the city as well. When it came time to proceed, due to the size of the project, the city decided to bring a consulting engineer on board. The engineer selected was David Evans & Associates (DEA).

DEA formalized the process of reviewing reservoir covering options that the city had begun. The first option pursued was covering the entire basin with precast concrete, but by this time a park was envisioned on the deck with a soil load. The weight of the soil added many beams and columns and required a heavily reinforced double tee along with an expensive waterproofing system. The cost estimate for this option exceeded the budget. After reviewing several other options, it was decided to construct two tanks, one on each side of the center dividing wall in the existing reservoir basin.

Initially, it was proposed that steel tanks be used. CPPC went back to DEA and the city to discuss using prestressed concrete tanks. Among the advantages of using prestressed concrete discussed with DEA and the city were: reduced maintenance, cost effectiveness, attractive aesthetics, and the ability to restore the site to the original contours with backfill against the concrete walls. DEA and the city recognized the benefits of using prestressed concrete and chose that option.

Other tanks had been successfully constructed in the Northwest using precast elements with a liner to contain water. Liner suppliers felt that without exposure to ultraviolet light, their liners would last indefinitely. The city also felt more comfortable using a liner to contain water as opposed to the concrete itself providing the tanks' watertightness. In this case, with a successful 1 million gallon tank built with this type

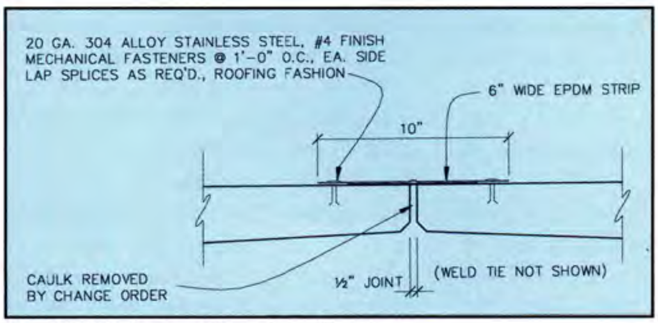

Fig. 10. Typical section at roof joint.

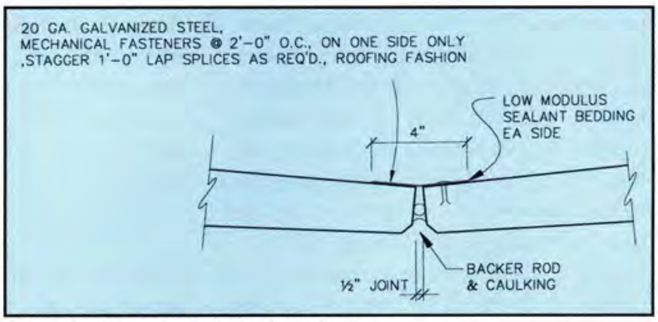

Fig. 11. Typical section at wall joint.

Fig. 12. Placement of reinforcing bars in footings.

Fig. 13. Ring beam shoring for roof tee placement.

of construction and the city's stated preference to use this type of tank, that became the concept promoted.

The liner system uses an NSF-approved white 45-mil reinforced polypropylene liner over a 4-oz. geotextile pad. The pad is used to protect the liner from any sharp projections. All the hardware used to attach the liner to the tank wall or boot around pipes is stainless steel. Northwest Linings from Kent, Washington, was the lining subcontractor. The cost for the liner, installed, was \$0.01 per gallon.

CPPC's help was requested in preparing designs and specifications for bidding. It was agreed that CPPC would assist DEA in the design of the footings and base, and that DEA would show the agreed upon details on their design drawings for general contractors to bid. CPPC would design the tanks, DEA would review the design, make comments, and incorporate what was deemed appropriate into the bid documents. The project was bid September 30, 1993, and CPPC received notice to proceed on November 1, 1993.

The low bid from the general contractor, Redding Construction Co. of Spokane, Washington, was \$4,777,484 (approximately \$0.24 per gallon). Bid cost for CPPC's portion of the project was \$2,640,470 (approximately \$0.13 per gallon). Some modification of prices occurred as all parties were requested to identify ways to save money. Several changes were made that resulted in cost savings. One area of savings was to remove the caulking requirement between the roof single tees and rely on the EPDM strip to provide the weather seal, protected by the stainless steel covers. This had been done on the previously constructed tank of this type.

This was a quick job, with \$2500 per day liquidated damages. The preconstruction meeting was held November 5, 1993, engineering began immediately, production setup started mid-November, with actual production beginning November 22. Erection of the first tank began January 24.

Winters in Spokane can be very harsh so it was important to expedite all phases of the work to meet the schedule required by the city — the first tank had to hold water by April 15 and the second tank had to hold water by July 15. Particularly tight was the window between filling the first tank, emptying the other half of the reservoir, demolishing the center wall, and pouring footings to allow erection of the second tank to begin May 23. This would allow erection of the tank and liner to conclude July 5, leaving 10 days for the general contractor to complete his work and water test the tank.

DESIGN FEATURES

The first objective was to define the geometry of the tank. The tank itself was designed with the same approach CPPC used when designing a similar type one million gallon tank constructed in 1991. Design assumptions used were: 30 psf (1.44 kPa) roof live load, soil weight of 120 pcf (1922 kg/cu m) with $k = 0.33$, and seismic zone 2B.

The single tee bed that CPPC had was adjustable in width of flange up to 10 ft (3 m); web width and web depth could also be adjusted. By setting the maximum width of the roof single tees to 10 ft (3 m) and working backwards, wall panel width and center ring beam radius could be calculated. Water height and tank capacity were supplied by the city and DEA along with required freeboard above overflow. This enabled CPPC to set the tank diameter and wall height (see Fig. 3).

The roof circumference of 779.11 ft (237.5 m) set the number of roof and wall tees at 78 pieces each per tank (see Fig. 4). The flange of the roof single tees was formed to vary from the stem width of 8 in. (203 mm) at one end to 10 ft (3 m) at the other end. Due to the taper of the underside of the flange, the tee depth varies from 2 ft 8 in. (0.8 m) at the narrow end to 3 ft (0.9 m) at the wide end (see Fig. 5).

This depth was determined to be adequate to resist the handling and roof live loads. Because the roof members had varying section properties and tributary width, a computer program was written that could check section properties and stresses at various nodes along the length of the tee. This then enabled CPPC to determine strand quantity and centroid distances as well as stirrup spacing.

By determining the size circle needed to support 78 roof stems of 8 in. (203 mm) width plus tolerance, the center ring beam diameter was set at 19 ft 7 in. (6 m). Because this was too large to haul, it was cast in two pieces and spliced at the jobsite. The center ring beam was elevated to provide a $^3/_8$ in. (9.5 mm) per foot roof slope toward the outside. Total load to the ring beam and, hence, to its supports was approximately 2642 kips (11750 MPa). For stability, it was decided to use four columns to support the ring beam.

Column size to support the load with this column length dictated 2 ft (0.6 m) square columns. Using four supports enabled CPPC to design the ring beam for positive and negative moments, shear, and torsion applied by the roof single tees. As a form for a cast-in-place closure pour tying the ends of the roof tees to the center ring, a separate precast piece was designed to share bearing on the ring beams with the roof stems (see Fig. 6).

Design of the walls for the imposed loads from soil or water gave reactions to be resisted by the top and bottom ring beams (see Figs. 7 and 8). These large forces could be resisted either by using post-tensioning or mild steel reinforcement. Comparing the costs, led CPPC to use the less expensive mild steel reinforcement. Apportioning mild steel to resist the ring tension gave the required quantity of circumferential bars. Forming of the upper ring beam was done using a precast trough beam — essentially just a form for the cast-in-place concrete infill. This seemed to be a good way to build an elevated beam without doing any forming in the air.

Fig. 14. Steering trailers were used to deliver roof tees to the jobsite.

Fig. 15. A stainless steel sliding plate was welded across the joint in the bottom slab between the footing and floor.

Shear forces dictated the stem depth and width of the wall single tees. The walls were designed to resist a 30 ft (9.1 m) height of water pressure outward or a 20 ft (6 m) height of soil pressure inward. Because there could be times when the tanks would be empty or have no backfill, worst case scenarios were used to develop forces to the single tees. High base shears required use of a 10 in. (254 mm) wide stem.

Flange thickness to resist lateral bending stresses required a minimum thickness of $3^1/_2$ in. (89 mm) at the outside edge. The single tee flange has a 1:14 slope so the flange was 7 in. (178 mm) thick at the flange-to-stem fillet intersection. Mild steel was designed to resist the lateral bending due

Fig. 16. Placement of geotextile material and tank liner.

Fig. 17. A hanger and trolley system was used to position roof members.

to soil or water loads (see Fig. 9).

Thermal stresses and moments were checked. Top ring beam change in length gave a lateral movement at the top of the wall tee that was a design factor. Thermal movement of the roof was large, so a sliding teflon bearing detail was used. A pinned connection was used in a slot to provide shear wall/diaphragm action between the walls and roof.

Special attention was given to the details of the roof and wall joints (see Figs. 10 and 11). As discussed later, this is because galvanized steel strips were placed over the wall units to keep the liner from protruding through the joints.

The center column footings individually became so large, that it was decided to use a single mat footing for all four column supports. This footing and the perimeter footing were cut and cast through the existing slab. The center footing used a ribbed mat with ribs 3 ft 6 in. (89 mm) wide and 4 ft (1.2 m) deep. The perimeter footings were cast at a fixed elevation. The existing reservoir bottom was sloped, so a closure pour slab was used to provide a transition between the two elevations. Expansion of the bottom ring beam necessitated a sliding expansion joint between the slab and the footing. DEA designed a stainless steel plate and rubber cover that could slide as movement occurred.

Overall tank stability was checked to determine the effect of differential soil loading from one side of the tank to the other. Seismic resistance was checked for the sloshing action of water that would occur in an earthquake using a method from API 650 Appendix E and from the Uniform Building Code. Structure uplift under seismic conditions was also checked. Connections were designed for the wall to ring beam, the wall to roof connection, the roof to center assembly, and the center ring beam to columns.

PRODUCTION DETAILS

CPPC, like many prestress plants of its age, had a single tee form. Since double tees became less costly to produce than single tees, the single tee form had seen very limited use in recent years. CPPC had been getting closer and closer to scrapping that form and putting in a bed to do other types of products. Since 1990, CPPC has been doing round water tanks using this form. In hindsight, it is a good thing the form was not scrapped!

Following erection needs for the tanks, casting began November 22 with walls being fabricated at a rate of four per day. It would have made sense from a production standpoint to cast walls for both tanks before switching to roofs, but that would not work with the erection schedule.

Roof tees for the first tank were cast at the conclusion of walls for the first tank at a rate of two per day. Roof tees for the second tank were next followed by walls for the second tank, with production concluding in early June, just in time for erection to begin on the second tank.

Wall tees incorporated an exposed aggregate finish on their flanges, which was laid down prior to casting the remainder of the tee. Steel bulkheads were used to form the ends of the single tees because a high degree of precision was needed to allow the tees to fit their intended use.

Curved trough beams were cast by pouring the sides, setting them upright, and pouring the bottom between them as a secondary pour. Exposed aggregate was used on the vertical face of the exterior on the trough beams. To achieve a uniformly dense appearance, the decision was made to cast these sides with the exposed side "down in form." Casting of the other side was done on a similarly curved form. Casting these pieces, setting them up, and casting the trough bottom quickly became an assembly line type of operation.

Spokane's 1993-94 winter weather was mild, which made both erection and production much less of an ordeal than would have been the case had the weather been more harsh.

Fig. 18. EPDM placed at roof joints.

CONSTRUCTION AND ERECTION HIGHLIGHTS

Construction began on November 8 with the city draining one side of the reservoir. Redding Construction began removing the existing liner, saw-cutting and removing the existing slab at the perimeter and center footings. Footings were excavated, reinforcing bars were placed, perimeter footings were poured to the construction joint elevation (see Fig. 12), and the center footing was poured. An access road was constructed through the existing reservoir's sidewall to bring in materials and the new tank components.

CPPC envisioned about 30 days erection per tank. There was considerable discussion between Redding Construction, the CPPC erection crew, and Northwest Linings regarding phasing of work. All crews had to overlap to meet the schedule. The CPPC erection crew set several wall tees, then set trough beams so Redding could place reinforcing bars for the secondary footing pour at the base.

Once troughs were set, reinforcing bars were placed in them and roof erection began. Single tee roof members weighed 66,300 lbs (30070 kg) each. Setting several pieces together on the ring beam put too much load in one quadrant, so the ring beam was shored until all roof pieces were placed (see Fig. 13). Wall tees, weighing 37,000 lbs (16780 kg) each, were delivered one per truck, erected on shims, and braced to the inside of the tank. Roof tees were delivered on steering trailers (see Fig. 14).

Two cranes were used to erect the roof, a 50-ton (45 t) hydro crane at the narrow end and a 62-ton (56 t) conventional crane at the wide end. Walls, columns, ring beam, trough beams, and center cap were erected with the 62-ton (56 t) crane. Redding and

Fig. 19. The completed Lincoln Heights water tanks.


Fig. 20. Night-time view of Lincoln Heights water tanks with floodlights in place.

CPPC poured trough beams and cast secondary footing pours as erection progressed.

Concrete was placed at the wall base to form a fillet to be sure the liner did not have a sharp transition between the walls and floor. The stainless steel sliding plate was welded across the joint in the bottom slab between footing and floor (see Fig. 15). After welding, the stainless steel was covered with two layers of wax impregnated paper and a strip of used conveyor belting.

When approximately 75 percent of the walls were erected, Northwest Linings began hanging the geotextile and liner. By leaving the tank open, manlifts could be used to hang the sheets, which was much quicker than working from ladders or scaffolding (see Fig. 16).

When it was time to pull out the temporary access road and erect the last of the roof single tees, a challenge presented itself to the CPPC erection crew. The last roof pieces could not be set with two cranes because the crane in the center had to come out. Bringing in a crane large enough to set a single tee from outside the tank would have been cost prohibitive.

To solve this problem, a hanger and trolley apparatus was designed to lift the narrow end of the closure roof members from their stockpiled position on top of previously set roof members (see Fig. 17). A crane outside the tank hoisted the wide end of the roof members as they were rolled into place.

As the roof pieces were set in place, their weld ties were welded and grouted. A 6 in. (152 mm) wide 45-mil EPDM strip was bonded to the concrete and a protective stainless steel cover was attached over the EPDM. Galvanized steel strips were placed over the wall joints to keep the liner from protruding through the joint (see Figs. 10, 11, and 18).

Due to a mild winter, an excellent working relationship between all parties, and a little luck, all project dates were met. The tanks were completed, backfilled, and landscaped. Comments from all parties, including the public, have been very positive. CPPC is very proud to have been a member of the team for construction of this attractive, cost effective project (see Figs. 19, 20 and 21).

POSTSCRIPT

In retrospect, it is appropriate to comment on what did not work well and what would be done differently if the project were done again. We know special attention needs to be paid to

Fig. 21. Panoramic view of Lincoln Heights water tanks surrounded by attractive landscaping.

the liner where it boots around pipes and manholes. Several callbacks to fix minor leaks have been annoying and point to the need for doing a better job the first time around.

The EPDM roof seal has allowed some minor leaks to drip into the tank when it rains. Investigating the cause has been difficult, but it appears that the cement used to bond the EPDM to the concrete does not create a tight enough bond to prevent water from coming through in some locations. As a solution, it was agreed among all parties to caulk between the flange edges of the roof, doing the work from inside the tank on a raft floating on the water.

One tank has been completed at this time, the second will be done next spring. It appears the caulking has eliminated all but a few leaks, which will be identified and repaired. In hindsight, caulk at the roof should have been left in the original contract and been done before the EPDM strip was adhered, or a different joint sealant system should have been used.

CREDITS

Owner: City of Spokane Public Works, Water and Hydroelectric Services, Spokane, Washington

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Contractor: R. Redding Construction Co., Spokane, Washington

Prestressed Concrete Manufacturer: Central Pre-Mix Prestress Co., Spokane, Washington