Reinforced Concrete Tank Design

By Mark W. Holmberg, P.E.

Reinforced concrete tanks have been used for water and wastewater storage and treatment for decades. Structural engineers are asked to design a variety of square, round, and oval reinforced concrete structures that may be above, below, or partially below ground. Design of reinforced concrete tanks requires attention not only to strength requirements, but also to crack control and durability. The challenge for the structural engineer is to design concrete liquid containing structures that will resist the extremes of seasonal temperature changes and a variety of loading conditions, and remain watertight.

Design and construction of the Bear Creek Waste Water Treatment Plant (WWTP) Expansion located in Hampton, Georgia and the Commerce Georgia WWTP are used to illustrate code requirements, tank analysis, design details, and construction of liquid containing reinforced concrete tanks.

Code Requirements

ACI 350-06 *Code Requirements for Environmental Engineering Concrete Structures* extends the basic ACI 318 *Building Code Requirements for Structural Concrete* with additional serviceability requirements for crack width control due to flexure, shrinkage of concrete, and temperature movement. The commentary of ACI 350 makes it clear that ACI 318 requirements alone will not produce watertight structures. ACI 350 serviceability requirements include:

- Reduced working load stresses, and requirements for size and spacing of reinforcement
- Increased minimum reinforcement for temperature and shrinkage movement, which is dependent on the grade of reinforcing steel and the length between shrinkage dissipating joints
- Waterstop requirements at all joints
- Concrete mix design requirements
- Increased cover requirements compared to ACI 318
- Commentary suggestions for use of shrinkage compensating concrete per ACI 223

Properly designed, specified, and detailed structures applying the requirements of the ACI 350, along with engineering judgment and quality construction, should have a useful life of 50 to 60 years.

Analysis

Analysis of reinforced concrete slabs and walls is a complex finite element exercise. ACI 350 suggests three design aids that can simplify the analysis of liquid containing tanks:

- *Rectangular Concrete Tanks*, Portland Cement Association, 1994
- *Circular Concrete Tanks Without Prestressing*, Portland Cement Association, 1993
- *Concrete Manual*, U.S. Department of Reclamation, 8th edition, 1981

The two Portland Cement Association (PCA) publications include coefficients for calculating moments, shears, tension, and deflection for a variety of aspect ratios and end conditions of plate and circular elements. Engineering judgment of the designer is required to select the proper design tables, detail sections to resemble the boundary conditions selected and recognize that ideal boundary conditions are rarely achieved in the field. In addition, the engineer must recognize conditions, beyond the limitations of the PCA data, that require special analysis.

Liquid containing tanks often support heavy equipment requiring special design of equipment support and surrounding walls. The structural engineer must obtain vertical and vibration loads of equipment, and design for possible restraint of temperature movement of supporting concrete.

Figure 1 is an example of equipment that restrains or induces temperature movement in the reinforced concrete structure.

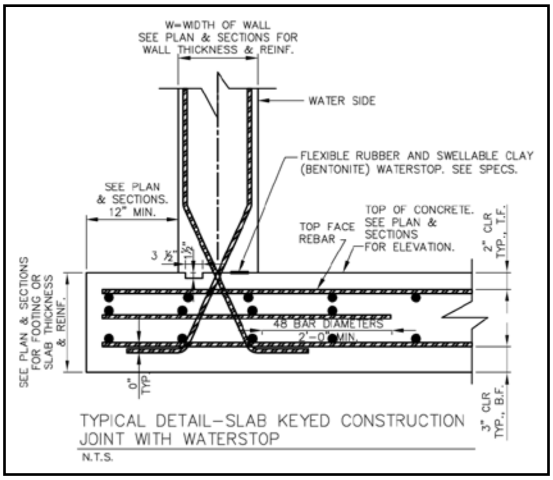

Figure 2: Hinged Base Detail.


Figure 1: Commerce WWTP Aeration Screen, Walkway and Hoist Bridge.

Details

Proper detailing of reinforcing and joints has as much to do with durability of a liquid containing structure as properly applying the provisions of ACI 350 and correctly analyzing the structure. End fixity of a section affects location and magnitude of maximum moments, and joint location affects the amount of minimum shrinkage and temperature reinforcing required. The PCA design tables include both fixed and hinged base conditions. The commentary states that either extreme is rarely achieved in the field. The detail in *Figure 2* is typical for a hinged base condition and was used in several of the Bear Creek WWTP structures. A compression type waterstop was installed near the inside face of the wall. A PVC bulb type waterstop is not practical at this location due to the location of slab reinforcing.

Prior to completing the Bear Creek WWTP structures wall details, it was determined that the maximum allowable length between construction joints would be 50 feet, and that Grade 60 reinforcing steel would be specified. *Figure 3*, from the PCA Circular *Concrete Tanks Without Prestressing* noted above, is a useful aid for proportioning shrinkage and temperature reinforcing based on joint spacing. ACI 350 notes that concrete sections over 24 inches thick must have shrinkage reinforcing at each face based on a 12-inch thick section.

Concrete

Specifying and supplying a concrete mix that minimizes shrinkage is critical to the durability of liquid containing structures. Concrete shrinkage is dependent on several factors, including cement content and aggregate. To insure that design assumptions are valid, the engineer should specify shrinkage requirements (0.04% to 0.03%), and that the concrete supplier provide shrinkage test results prior to approving the mix design. Where large tank walls or slabs are required

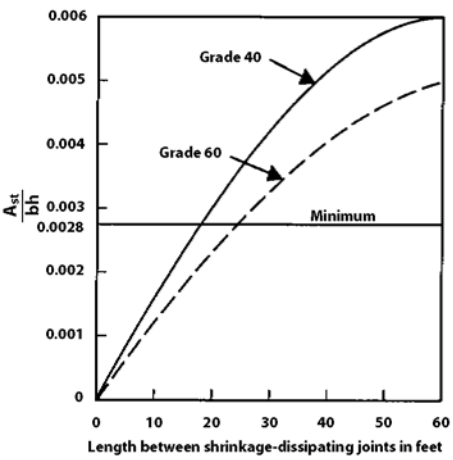

Figure 3: Minimum Temperature and Shrinkage Reinforcement.

without expansion joints, shrinkage compensating concrete may be specified; however, the structural engineer must account for concrete expansion movement.

ACI requirements for hot and cold weather concrete placement must be specified because construction of a large project can take place over a year or more. One concrete mix design will not be adequate for all pour conditions.

Construction

Formwork, concrete placement and curing are obviously critical to the quality and durability of the structure. Almost all form systems require through-wall form ties that create potential for leaks, and weak planes where cracks may occur. Proper concrete mix design and appropriate add mixtures will assure that concrete is easily consolidated. Proper curing of concrete will reduce the potential for shrinkage cracking.

Figure 4 shows small temperature/shrinkage cracks in the Bear Creek WWTP Aeration Basin Tank wall located at form tie holes. The contractor injected the cracks and applied a specified waterproofing membrane to the inside of the tank walls.

Conclusion

Proper application of ACI 350 design requirements, appropriate structural details, properly specified and supplied concrete, and quality construction will assure long life for reinforced concrete tanks that will be subjected to harsh environmental and use conditions. The structural engineer and the contractor must work together to produce reinforced concrete liquid containing tanks that are as watertight as possible.▪

Figure 4: Tank Wall Cracks at Tie Hole.

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