Concrete Restoration of Three Underground Water Storage Tanks

Boston, Massachusetts

Submitted by Gale Associates, Inc.

The water storage tanks are located three stories below-grade beneath a 10-story building in the center of Boston, MA. Each tank has inside measurements of 58 ft long x 22 ft wide x 24 ft high (17.7 m long x 6.7 m wide x 7.3 m high) and has an approximate capacity of 225,000 gal. (851,700 L) when filled. Constructed in the mid-1980s, the tanks consist of concrete walls, base slab, and midheight level concrete beam grids. The tanks are semi-segregated into an upper level and a lower level by concrete grid beams. Three structural steel wide-flange columns, which support the building floor loads, are embedded in two circular and one square concrete shell, and penetrate the tanks near their midpoints.

The tank lids, or tops, are composed of precast concrete planks that span the entire width of the tank. According to original structural drawings, each of the three storage tanks is separated by a 2 in. (50 mm) ± void space, which has been infilled with rigid insulation. The tanks are bound on two to three sides by the building's slurry wall foundation.

Problems that Prompted Repair

Historically, the tanks had been used to store clean water for use within the building's mechanical air-conditioning equipment. Each of the three tanks was leaking thousands of gallons each day, causing concern about the possible undermining of the structures, the potential to damage mechanical equipment, and the cost of replenishing the tanks on a daily basis. In the mid-1990s, attempts at repair using crystalline parge coat waterproofing were ineffective in stopping leakage.

Examination of the tank interiors revealed delamination of the crystalline parge coat applied during the earlier repair attempt. The coating was flaking off the surface of the concrete and falling off the walls. Reflective cracking through the waterproof coating was widespread. Exposed wire mesh reinforcement was observed at column and beam locations. Along with honeycombing of the concrete, cracking of the surface was also widespread, with multiple spalls and delaminated concrete at structural steel wide-flange columns. A cementitious paste appears to have leached from the bottom of several wall cracks.

The inner surfaces of the concrete tank walls were observed to have the following accelerated deficiencies:

- A large number of "bugholes" and surface "holidays" at surfaces of the concrete, presumably as a result of poor vibrating or placing of the concrete during original construction. Some of

Leaking water tank

Front of tank showing major leaks

Corroded reinforcement showing through deteriorated concrete

Close-up view of "soft" deteriorated concrete

these recesses were not protected by a waterproof coating, allowing an unprotected pathway for moisture absorption into the concrete substrates;

- Areas of original waterproof coatings were blistered, delaminated, or loosely bonded to concrete substrates. These areas of deteriorated coatings were easily removed with light scraping of a fingernail or claw hammer. Coatings appeared to have been applied thin and to have lost their effectiveness;
- In general, in the areas where no visible waterproof coatings were observed to be intact, honeycombing and soft "punky" concrete was encountered;
- Surface cracks, which project through the coatings, were extensive, with some cracks leaching out a cementitious paste; and
- The inner surface of concrete (just beneath waterproof coatings) was deteriorated; up to 1/8 in. (3 mm) of soft "punky" concrete was easily penetrated at numerous areas and removed by moderate tapping with a hammer.

Typically, pipe hanger supports, trays, and related hardware within each tank appeared to be corroded. The building envelope engineer also observed heavy mineral deposits and rust exfoliation covering many steel support components, with some experiencing near complete section loss due to corrosion.

Inspection/Evaluation Methods

The building envelope engineer's inspection/evaluation methods included reviewing all available documents relating to the structure, including original drawings, previous reports, and maintenance records. Access into the tanks was difficult; the existing building's floor structure, coupled with a network of sprinkler system piping, contributed to limited headroom in the access areas. The engineers had to crawl on their hands and knees under the building's floor structure, climb over sections of sprinkler piping, and then crawl below large steel support beams to access the hatch of each tank.

The building envelope engineer used the claw of a small hammer to check concrete "softness" at spot locations. The hammer was also used to "sound" the concrete at suspect areas and surfaces directly adjacent to cracks, for audible detection of substrate delaminations and possible evidence of corroded reinforcing steel. An electric coring drill in combination with a small electric hammer drill was used to obtain concrete core samples.

The building envelope consultant submitted six test cores at various elevations to a petrography laboratory for testing.

Test Results

- Overall quality of the concrete in the examined samples was fair to good;
- Cement paste was found to be moderately soft and porous with the paste/aggregate bond considered fair to poor;
- Some macro-/micro-cracking at surface areas was evident with carbonation depths varying as irregular, especially nearer to macro/micro-cracked sections;
- Surface micro-cracking appeared to be the result of drying shrinkage, with no evidence of alkali-aggregate reactions;
- Although some of the examined concrete appeared purposefully air entrained, a white acicular ettringite partially to completely filled most void spaces throughout the noncarbonate paste; and
- Both coarse and fine aggregates were fairly graded with good overall uniform distribution throughout the examined specimens.

Causes of Deterioration

Inadequate vibration and placement of the concrete, insufficient concrete coverage over reinforcing steel, inadequate waterproofing of the interiors of the tanks, and lack of maintenance over the years all contributed to accelerated deterioration of the concrete walls of the tanks.

Repair System Selection

Based on the results of the field investigation and laboratory testing, the following repair guidelines were developed:

Concrete ready for epoxy injection

- Perform hydrodemolition to interior surfaces of the tank walls, basin slab, and column encasements to remove existing waterproof coatings and the soft carbonated, micro-cracked layer of underlying concrete;
- Repair cracks via high-pressure epoxy injection and repair spalls with reinforced mortar patches; provide supplemental reinforcing steel as required;
- Apply a high-performance fiber-reinforced resurfacing mortar via the shotcrete method to replace the removed deficient layer of concrete;
- Apply a monolithic cycloaliphatic epoxy waterproof coating (reinforced with fiberglass fabric as required) to the interior of the tank; and
- Replace all internal piping and replace existing pipe hanger support components with new stainless steel components.

Site Preparation

Site safety was of utmost concern due to access to tanks and the fact that the work required all personnel to "confined entry certifications." Air intake compressors were in operation at all times. Dewatering and debris removal required in-depth planning and sequencing on the part of the contractor.

Demolition Method

Demolition methods used hydrodemolition to prepare all surfaces for the application of surface coatings, protectorants, shotcrete, and waterproofing coatings.

Repair Process Execution

Surface preparation included initial removal of loose coatings, delaminated concrete, and corrosion using hydrodemolition. Prior to application of shotcrete, all cracks were repaired using high-pressure epoxy injection, concrete spall repairs, and installation of supplemental reinforcing steel.

Due to the amount of surface loss to the concrete, it was decided to apply resurfacing mortar to the entire surface of the tank interior.

Finished repair

After surface preparation using hydrodemolition crack and spall repairs, a fiber-reinforced resurfacing mortar was applied using the shotcrete method over which a reinforced epoxy coating was applied.

Team Approach to Challenges

Access limitations, including "confined access" requirements, presented logistical and manpower issues that were addressed jointly between the engineer, owner, and contractor. The application process required coordination between various disciplines and trades. A variety of different products required a contractor experienced with several different waterproofing techniques. The success of the project has been highlighted by no loss of water and was only achievable by having a team concept between the engineer, owner, and the contractor.

Three Underground Water Storage Tanks

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