Hyperbolic Cooling Tower Column and Lintel Beam Protection

By Kraig Tarou and Stan Boshart

Used in large power generation plants, hyperbolic natural draft cooling towers are known for their distinct shape. Although eye-catching in form, the distinct shape serves a functional purpose by cooling the water at a much lower operating cost than mechanical draft cooling towers. The purpose of the cooling tower, by means of a closed loop system, is to cool water utilized to condense the steam under the generating unit's steam turbine as well as secondary plant cooling water systems. Water is pumped from the towers basin (through the turbine's steam condenser) and secondary system heat exchangers, and returned to the tower. The water enters the tower through a single riser and ultimately makes its way through a series of flumes, distribution headers, spray nozzles and packing, then back to the 3 million gallon holding basin. The natural draft of the tower, by design, generates a significant on-rush of air up and through the packing, thus allowing the air to absorb the heat (BTUs) contained in the water as it falls back to the holding basin. The water in the basin is returned to the 235,000 GPM pump pit and the process repeats.

While this process is extremely effective, practically all surfaces in the basin are subject to "immersion" conditions. The columns and lintels are in a "splash zone" environment subject to intermittent wet and dry conditions. As a result, these towers are extremely susceptible to corrosion-induced deterioration. Construction of new hyperbolic natural draft cooling towers, however, represents a large capital investment, so maintaining existing towers is crucial.

Such was the case for the Unit No. 2 Hyperbolic cooling tower located at St. John's River Power Plant in Jacksonville, Fla. This particular cast-in-place tower, in operation since 1987, is 450 feet tall and 360 feet in diameter. It was constructed using traditional formwork for the columns and lintel beams, and slip-form construction for the veil (shell).

The owners, a joint venture between Jacksonville Electric Authority (JEA) and Florida Power & Light (FPL), first noticed deterioration on the veil, 80 perimeter legs (support columns) and lintel beams in the form of severe damage of concrete surfaces. Visual inspections noted concrete cracking, spalling, rust staining and delamination. Damage to the concrete is the result of corrosion of the embedded steel reinforcement.

This problem is not unique to these towers. It exists in most concrete structures exposed to salts and moisture. The rate of reinforcing steel corrosion is directly dependent on the original design specifications. Appropriate specification parameters for cover over reinforcement and concrete porosity can delay the onset of corrosion if properly executed during construction.

This tower utilizes brackish make-up water from the St. John's River, which contains a high volume of chlorides. Prevailing winds from the nearby Atlantic Ocean and St. John's River carry high levels of chlorides that deposit on the structure's surfaces. Variable wind patterns around the tower expose it to wet and then dry operating periods. These factors contribute to accelerating the corrosion process.

Relevant ACI Standards

ASCE 11-09 Guideline for Structural Assessment of Existing Buildings

ACI 201.1: Guide for Making a Condition Survey of Concrete in Service

ACI 228.2: Nondestructive Test Methods for Evaluation of Concrete in Structures

ACI 311.1: Recommended Practice for Concrete Inspection

ACI 224.1: Causes, Evaluation, and Repair of Cracks in Concrete Structures

ASTM C 1218: Standard Test Method for Water-Soluble Chloride in Mortar and Concrete

ASTM C876: Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete

During operation, practically all surfaces in the basin are subject to "immersion" conditions. Columns and lintels are in a "splash zone" environment.

Inspection Method and Cause of Deterioration

Because of the progressive nature of the corrosion-induced deterioration, understanding the root cause, the consequences and associated costs was essential. As such, a condition evaluation was conducted. A visual and hands-on inspection by trained professionals formed the investigation's focus. Given the logistical challenges of gaining access, the inspection addressed the lower 50 feet of the massive structure. The data gathered by the owner through visual inspection was augmented with the following data, gathered and analyzed by the owner's engineer.

- Review of existing plans, specifications and records.
- Measurement and documentation of geometry, deflections, displacements, cracks and other damage.
- Extraction of samples and testing for chloride concentrationat various depths.
- Corrosion Potential Mapping.
- Continuity testing.
- Depth of cover testing.

The testing, conducted in accordance with the American Concrete Institute (ACI) standards, showed the lintel beam and columns to be in poor condition as they exhibited heavy cracking and spalling. Chloride testing results, which exceeded the chloride threshold value of 2.2 pounds per cubic yard at all measured depths, indicated that active corrosion of the reinforcement was the cause of the deterioration.

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Repair Recommendation

Repairing corrosion-induced deterioration typically involves removal of deteriorated concrete, undercutting around the reinforcing steel, cleaning and protecting the reinforcing steel, and re-establishing the original concrete section. However, the investigation team also understood that repair was not the only objective. The project scope also included the prevention of a reoccurrence of the existing situation. The team recognized the importance of installing a protection method, and recommended a sacrificial cathodic protection system for the affected concrete structural components. The cathodic protection system for the perimeter columns and lintel beam consisted of encapsulating zinc mesh anodes within a stay-in-place fiberglass form filled with cementitious grout. The zinc mesh is connected to the existing reinforcing steel by means of an insulated copper wire attached to the zinc mesh in the factory. This cathodic protection jacket utilizes the principles of galvanic corrosion to cause the zinc anode to corrode preferentially to the steel. The process ensures that the corrosion of the steel is mitigated for a long time after the repairs are completed. Because the system is self-regulating, easy-to-install, maintenance-free and cost-effective, it was ideal for this application.

A specialty concrete repair contractor was selected to install the cathodic protection system. The project started with pre-project planning activities involving a site visit by all of the team's leadership. The team gathered for more than a week to determine schedules, logistics, jacket-lifting system design, temporary formwork design, delegation of responsibilities and more. The next step involved a detailed submittal process. Satellite images of the site were utilized to identify the lay-down and staging areas, the location of temporary facilities and the flow of work – an important factor considering the tight working conditions with other contractors.

Located at St. John's River Power Plant in Jacksonville, Florida, the Unit No. 2 hyperbolic cooling tower is 450 feet tall and 360 feet in diameter.

The scope of the repair project included installation of 120 lintel beam jackets and 240 column jackets for a total of 34,000 square feet of jacketing. Procedures included removing delaminated concrete with pneumatic chipping guns, profiling concrete surfaces to a minimum ICRI Surface Profile Number 3 and cleaning the corroded reinforcing bars utilizing 35,000 psi ultra-high pressure water blasting equipment and pneumatically rotated handguns prior to placing and grouting the fiberglass jackets.

Design Challenges

Although the tower was originally built to withstand a 110 mph wind load, the engineering firm hired by the owners performed an evaluation of the tower's stability to ensure that the tower, when subjected to the design lateral forces of a 110 mph wind load as well as 72 mph wind load, could meet the design criteria for the non-hurricane season repair. The total weight of the tower and the static pressure on each column also was determined. Utilizing the collected data, the tower was recreated using a three-dimensional structural engineering computer program. The software included model generation, static, dynamic, p-delta and non-linear analyses. First, the tower was modeled under its original design criteria of a 110 mph wind load. Next, the structure was modeled under its demol-

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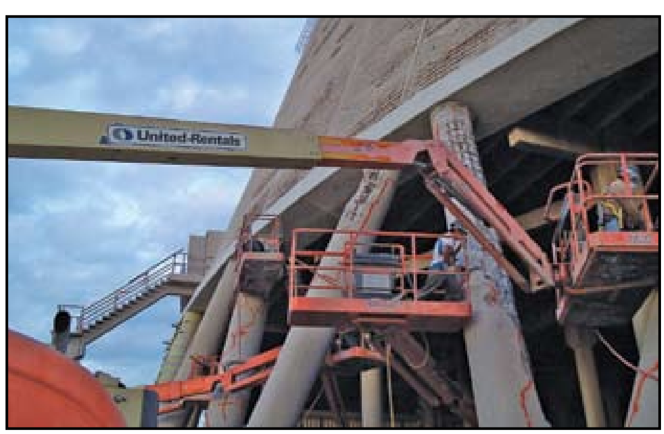


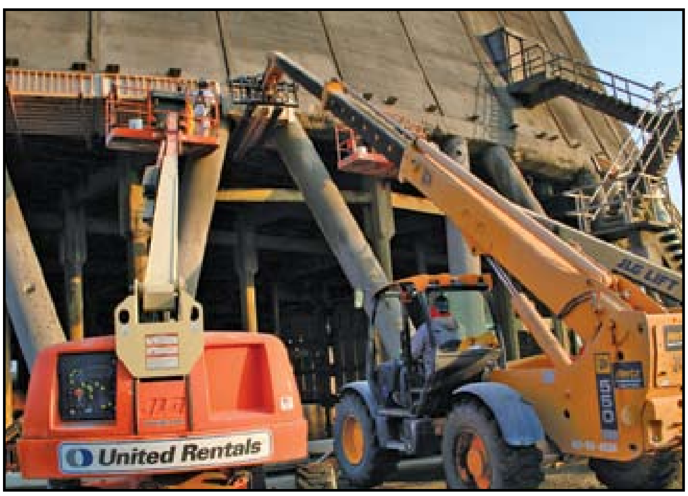
The repair included installation of 120 lintel beam jackets and 240 column jackets.

ished state with a 72 mph wind load. Based on hand calculations and computer models, it was determined that concrete could be safely removed from all lintel sections, and 40 of the 80 columns of the tower at one time. Additionally, the lintel beams and columns could be stripped of 3 inches of concrete on all faces.

Since the lintel jackets were an odd shape and size, the specialty contractor had to determine how to lift them into place and support them while grouting. Several methods were considered, and all but one were determined to be too cumbersome and time-consuming for the project. The method chosen involved building a grillage in which the jacket would be placed prior to mounting, keeping it in place and fastened to the structure until the grout cured. For this method, structural steel brackets were first mounted to the interior and exterior of the tower and were utilized, along with steel rods, to suspend the grillage formwork and jacket. First, however, the grillage had to accommodate the locations for installing the permanent stainless steel fasteners that hold the jackets in place. Because the final placement of the fastener was important for aesthetic reasons, the grillage had to allow space for them to be installed at precise locations. Using an aerial lift, the jackets were attached to the lintel beam and 4,000 psi cementitious grout was pumped through ports on the back face of the jackets.

Jacket installation on the columns was challenging because of the compound angle of the columns. To address this concern, the specialty contractor designed and fabricated a lifting bracket that, once lifted off the ground, was at the correct angle to slide the jacket into place. For each column, the jacket was divided into six pieces – two pieces each for the bottom, middle and top. Placement started at the bottom with the two pieces resting on the foundation and subsequent pieces supported by the ones below. Each section of the jacket was lap-spliced and held in place with stainless steel fasteners. Brackets held up the jackets through the grout port-holes, and the jackets were held open with straps attached to the lifting bracket. Once the jacket was around the column, the strap was released and the jacket closed around the column. Next, ratchet straps were wrapped around each section of jacket to increase hoop strength and to keep the jackets from warping during grouting. Grouting was performed through ports built into the jacket at 2.5-foot vertical intervals, alternately placed on either face of the column.

Gaining access to the repair areas was a significant challenge. Nearly all of the work on this project was done off of aerial lifts. A total of 16 articulating aerial lifts and two 4x4 scissor lifts were required to provide access. Since this type of activity was new to most of the crew, the specialty contractor arranged for instructors to come to the jobsite and perform onsite field and classroom training. In addition to giving the crews the opportunity to practice operating the lift, these sessions taught the crews the dangers involved in using this equipment and what needed to be checked daily before using the lift. The crews also engaged in safety courses highlighting communication and the safe use of such large equipment in tight quarters.



Using an aerial lift (above), the jackets were attached to the lintel beam and 4,000 psi cementitious grout was pumped through ports on the back face of the jackets (left).

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"Outage" Schedule

Because the cooling tower had to be shutdown for this project, work was scheduled for a five week period during an outage. An unforeseen delay, however, occurred to accommodate a chemical cleaning of the internal tower "fill" or "packing" media. The result was an eight day loss in an already tight schedule. In response and with plant management's approval, the specialty contractor proceeded with a 24/7 work week to accommodate the client's aggressive deadline.

Adding to the scheduling challenges were three other contractors working on the tower during the same period. One was working inside the structure cleaning and replacing some of the fill, using Bobcats and other machinery below the work area. Two other contractors were working on the veil of the tower – one performing hydro-demolition and the other applying zinc mesh and shotcreting an overlay above the specialty contractor work. Both had multiple 120-to 150-foot aerial lifts that required constant vigilance to avoid mishap.

With this incredibly busy work environment, coordination and communication were essential. Daily meetings with the owner project/contact management team and other contractors were invaluable. Coupled with the skill of the crew of 35 putting in more than 16,000 hours with no injuries, these challenges were successfully addressed and the client's aggressive schedule met.

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Project Success

The entire project team is very proud of meeting the tremendously challenging schedule despite many interruptions, complications, cold weather and constant changes. Completing this project, which happens to be the largest cathodic protection system installation on a hyperbolic concrete cooling tower in North America to date, successfully opens the door for applications of this technique on other cooling tower projects.▪

View of installed lintel beam and column jackets.

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Understanding Cathodic Protection

In a corrosion cell, the areas of a metal discharging current to the environment (anodes) corrode, while the areas receiving current from the environment (cathodes) do not corrode. Thus, if the entire exposed metal surface could be made cathodic, it would collect current and not corrode. Cathodic protection systems operate by causing a direct current to flow from an external source to the metal structure to surfaces of the structure. When the current is adequate and properly distributed, corrosion is mitigated and the structure is cathodically protected.

For a cathodic protection system to be effective, current must be discharged to the electrolyte from an anode. In discharging current, the anode corrodes. Galvanic or sacrificial cathodic protection systems use materials that when coupled to steel corrode preferentially and become the anode in the corrosion cell.

Cathodic protection does not eliminate corrosion; it merely transfers it from the structure being protected to a less expensive, consumable, non-dangerous, known location – specifically, the anode. There are basically two methods of applying cathodic protection, although there are numerous variations of these methods. The basic methods are sacrificial or galvanic and impressed current.

Sacrificial Cathodic Protection

A cathodic protection system is a corrosion cell in which the structure to be protected is the cathode. Sacrificial or galvanic systems are corrosion cells of the differential metal type. Sacrificial anode systems use a material that will develop a more negative voltage when coupled with the structure of concern. Typical sacrificial anode materials include aluminum, magnesium, and zinc. When any of these anode materials is coupled to steel, they behave anodically and discharge current, which is picked up by the structure, arresting the corrosion process on the structure.

Galvanic cathodic protection systems are typically used where the total current requirement is low, and the total circuit resistance allows the small voltage differential between the anode and the cathode to generate the protective current. Galvanic systems are designed by adding sufficient metal to reach the desired life. These systems also have the advantage that they require little maintenance and incur no operating costs, other than preventive monitoring and maintenance.

Impressed Current Cathodic Protection

Impressed current systems use an outside source of power to drive the current from the anodes to the cathode. This source can be solar power, batteries, DC generators or 60 Hz alternating current (AC) converted to DC via a rectifier or other device. The most common impressed current systems consist of an anode cluster (also called a "ground bed"), which can be in one location or distributed around the protected structure, powered by rectified AC power.

There are many different materials to choose for impressed current anodes. Early applications used old railroad steel rails buried in the ground for the protection of buried pipelines. Anode materials include graphite rods, silicon-iron alloys and lead-silver alloys. More recent technology includes platinized titanium or niobium rods and disks, conductive graphite impregnated polymer wires, conductive paints and grouts and mixed metal oxide coatings on titanium substrates of various shapes. The latest anode technology incorporates thermal sprayed zinc and thermal sprayed titanium. These are used particularly on concrete substrates as surface conforming anodes.

Impressed current systems are commonly used where the current requirements for corrosion protection are high and where the driving voltage is greater than what can be obtained with galvanic systems. These systems are more accurate and can be controlled to deliver just enough protective current to the structure. Their disadvantage lies in that they require more maintenance and consume power.▪