Corrosion Mitigation and Column Strengthening at the Atalaya Towers Condominium

By J. Christopher Ball, Alan J. Schweickhardt, and C. Robert Thaxton

Atalaya Towers is a 16-story oceanfront condominium located in Garden City Beach, SC, approximately 20 miles south of Myrtle Beach. Built circa 1985, Atalaya Towers was constructed with reinforced concrete columns, shear walls, and concrete floor slabs with an exterior that is clad with brick veneer and stucco.

In December 2003, a structural engineering consultant was contacted to assess visible concrete spalling on the ground floor of the structure. At that time, the engineer visited the site to conduct a visual survey. The primary focus of the visual inspection was to determine the extent of concrete damage and to make recommendations for repair.

Initial Survey Findings

During the survey, evidence of concrete deterioration and corrosion of the reinforcing steel was observed at the ground floor 12 and 24 in. (30.5 and 61.0 cm) square and rectangular columns and 12 in. (30.5 cm) shear walls throughout the structure. Several sections of concrete came off the structure when sounded with a hammer, and there was concrete damage and rusting of the reinforcing steel. Due to the proximity of the structure to the Atlantic Ocean, the engineer believed that the concrete damage was caused by corrosion of the reinforcing steel due to water, salt (chloride), and oxygen intrusion into the concrete through hairline cracks, diffusion through the concrete, or a combination of both.

Corrosion of reinforcing steel in concrete is a long-term process that only becomes visible when there is sufficient corrosion of the reinforcing steel to result in expansive stresses in the concrete that cause the concrete to crack or spall. Only a small amount of corrosion is necessary to cause concrete spalling.

During the field survey, the engineer also noted that a smaller 12 x 24 in. (30.5 x 61.0 cm) ground floor concrete column at the southeast corner of the structure had significantly spalled concrete and corroded reinforcing steel. The vertical steel and ties were exposed, and the deterioration extended around the column and down below the sand line, beneath the wood frame deck that was built around the column.

Strengthening Considerations

Calculations completed by the engineer indicated that removal of the deteriorated concrete on the

Significant concrete damage on 12 x 24 in. (30.5 x 61.0 cm) column

Typical concrete damage on ground floor columns

12 x 24 in. (30.5 x 61.0 cm) column had significantly reduced the capacity of the column. The existing axial loads (primarily dead loads) had redistributed through the remaining concrete section. There was a concern, however, that the column would be overloaded under full live load combined with a lateral wind or seismic load. To restore the axial and lateral load capacity, the structural engineer determined that structural strengthening was necessary.

Several methods of strengthening the column were considered, including section enlargement. Column section enlargement would consist of installing a new column directly adjacent to the existing column to provide additional structural capacity. This procedure, however, would be disruptive to the owners, take up valued oceanfront deck space, and significantly change the appearance of the structure.

Carbon fiber strengthening, which has become more commonplace in recent years, was deemed to be a more practical solution from an installation standpoint. For these reasons, the engineer recommended that the column be strengthened using externally bonded carbon fiber sheets wrapped horizontally around the column using the wet lay-up process. The carbon fiber design was performed using the manufacturer's engineering guidelines and ACI 440.2R-02, "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures." The design requirement was four layers of a 0.015 in. (0.038 cm) thick unidirectional carbon fiber fabric, field laminated using epoxy. The corners of the column were rounded to a 2-1/2 in. (6.35 cm) radius to meet the design parameters.

This procedure was deemed to be the preferred method to provide the necessary structural upgrade, and was much less disruptive to the owners compared to building a new column. After the new coating was applied, the column with the strengthening system would be similar in appearance to the other columns.

While isolated areas with concrete damage and exposed reinforcing steel were noted during the visual inspection, the magnitude and extent of the steel corrosion was not fully known. This was of particular concern for the column that was to be strengthened because the long-term performance of the carbon fiber strengthening is dependent upon bonding to sound concrete. If corrosion continued under the carbon fiber sheets, it could affect the performance of the strengthening system over time.

Corrosion Evaluation

Prior to making final repair recommendations, the structural engineer determined that a more comprehensive corrosion evaluation was warranted and requested the services of a corrosion specialist. The specialist was to conduct a survey to determine the location and extent of the corrosion activity on the ground level columns, beams, and brackets.

Condition surveys that include a corrosion evaluation are one step in the overall concrete repair process. Experience has shown that investing in concrete rehabilitation without an understanding of the underlying cause of the deterioration can result in underperforming repairs and dissatisfied clients. The information gathered during a corrosion survey can be useful in designing a repair and corrosion protection strategy that meets the client's objectives.

In February 2004, two corrosion technicians performed the field evaluation over a 3-day period. The evaluation included conducting a corrosion potential survey, taking concrete samples for determining the level of chloride contamination, determining the concrete cover over the reinforcing steel, and noting existing damage through concrete sounding and visual inspection. The evaluation was performed on 22 columns, three balconies, two corridors, and eight beams/brackets, which were chosen by the engineer and corrosion specialist to provide a sample of the various levels of damage and exposure conditions.

The testing was conducted as follows:

- Physical condition: The location of visible defects, sample locations, field measurements, and delaminations detected beneath the concrete surface (identified in accordance with ASTM D 4580-02) were recorded on the field drawings of each element tested.
- Chloride content: To determine the level of chloride contamination in the concrete, concrete powder samples were taken from each element being tested. Each sample location was tested at three depths (0 to 1 in., 1 to 2 in., and 2 to 3 in. [0 to 2.5 cm, 2.5 to 5.1 cm, and 5.1 to 7.6 cm]) to provide a chloride profile. Testing was completed in accordance with AASHTO T260.
- Corrosion potentials: To determine the probability of active reinforcing steel corrosion, a corrosion potential survey was completed as per ASTM C 876-91 using a using a copper-copper sulfate half-cell.

Test Results

The visual survey indicated that concrete delamination, cracks, and spalling were generally isolated. Physical damage beyond that which was already visible in the beams or columns was minor.

Approximately 20% of the samples taken from the columns tested above the threshold level for initiating corrosion (approximately 1.2 lb/yd^3 [19.2 kg/m^3]). The samples that were above the chloride threshold were from the east or ocean-facing side of columns or from the bottom half of the columns. The overall chloride profile analysis showed moderate levels of contamination at the level of the steel.

The half cell potential survey indicated that nearly 30% of the readings were in the active range, suggesting a greater than 95% probability of active corrosion in the area tested. These active readings were found mainly at the base of the columns, which consistently showed higher corrosion potentials than the upper sections of the columns. While visible damage was not evident in most of these areas, active corrosion potential readings generally indicate a level of corrosion activity that will lead to future damage and repair.

Higher corrosion potential readings on the ocean-facing columns could be easily explained by their proximity and exposure to the Atlantic Ocean. The higher corrosion potentials on the lower half of each first floor column was thought to be due to salt water saturation from frequent storm surges.

In summary:

- The lower half of most of the first floor columns tested showed a higher corrosion potential and higher chloride levels then the upper section.
- Of the balconies and corridors tested, nearly all were in the passive range for corrosion potentials and showed moderate levels of chloride contamination.
- Of the beams and brackets tested, only the areas with visible spalling showed high corrosion potentials and/or chloride levels indicating that the corrosion activity was generally isolated.

Repair System Selection

Armed with a better understanding of the current corrosion problem and the risk of future corrosion damage, the engineer recommended a four-step process for the building rehabilitation consisting of concrete patch repair, targeted corrosion mitigation, column strengthening, and barrier protection.

Concrete Patch Repair

All spalled and delaminated areas in the columns were repaired in accordance with ICRI Guideline No. 03730, "Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion." Concrete removal was completed with 15 lb (6.8 kg) chipping hampers to minimize microcracking and bond failure of the repair material.

The area of concrete removal continued until clean steel was encountered. Concrete was also removed from around the full circumference of the exposed steel and the steel was sand blasted to remove all corrosion by-products and cement paste that is likely chloride-contaminated. If more than 25% of the bar diameter was lost to corrosion, supplemental reinforcing was provided by splicing in new steel. By following these industry recommended procedures, the areas with the most advanced corrosion activity were addressed.

Concrete patch repair

Locating reinforcing steel prior to galvanic anode installation

Decking removed and sand excavated for access to column below sand line

Holes drilled prior to anode installation

Installation of carbon-fiber strengthening system

Close-up of anodes and reinforcing bar connector

Anodes installed into column on staggered grid pattern

Targeted Corrosion Mitigation

Galvanic protection was targeted to control the corrosion activity in the bottom 4 ft (1.3 m) of each column in the three rows of columns closest to the ocean, an economic approach to extend the overall service life of the structure. Galvanic corrosion protection systems provide a naturally generated electrical current to the embedded steel to mitigate corrosion activity. Compared to impressed current systems, they do not require an external power source or system monitoring and are generally maintenance-free over their design life.

The spacing between the individual cylindrical-shaped anodes was determined based on the density of steel to be protected (steel: concrete surface area ratio). Based on this information, three galvanic anodes were installed into the face of each column with a vertical spacing of approximately 16 in. (40 cm) between anodes. The anodes were staggered such to provide a more even current distribution, especially to the steel in the corner of the columns, which are particularly vulnerable to corrosion damage. Where wood decking concealed a portion of the columns above the sand line, the wood decking was removed and the anode installation started approximately 8 in. (20 cm) above the sand line. The anodes were grouted into 2 in. diameter x 4 in. deep (5 x 10 cm) holes and individually connected to the reinforcing steel.

Strengthening

After the galvanic anodes were installed, the carbon fiber sheets were bonded to the column with epoxy using a wet-layup method.

Protection

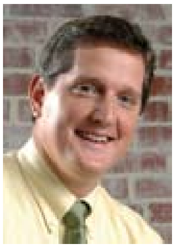
To protect from further chloride contamination, a chloride-resistant acrylic coating was applied to all repair areas. The coating was color-matched to the existing façade coating to provide overall color consistency and enhanced aesthetics.

Teamwork for Success

The Atalaya Towers Condominium project presents an excellent case study of the various steps of concrete repair process. The entire project team worked closely throughout the process from initial identification of concrete deterioration, analysis to determine the cause and magnitude of the problem, to the selection of repair methods to meet the owner's objective.

It is also worthwhile to note that all members of the project team are active members of ICRI.

***J. Christopher Ball** is Vice President, Sales and Marketing, Vector Corrosion Technologies, Inc., in Tampa, FL. Ball has over 13 years of construction industry experience, with a specialty in concrete rehabilitation and corrosion protection systems. He previously held the positions of Senior Market Development Manager and Concrete Repair Product Manager for Master Builders, Inc., and Concrete Repair Product Manager for Fosroc Inc. Ball earned his BA and MBA in business administration from Bellarmine University, Louisville, KY, and is a member of ICRI, the American Concrete Institute (ACI), and the National Association of Corrosion Engineers.*



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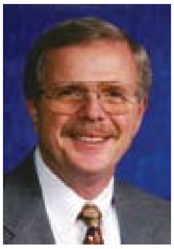

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Owner
Atalaya Towers Condominium Association
Garden City Beach, SC

Project Engineer
Applied Building Sciences, Inc.
Charleston, SC

Repair Contractor
Carolina Restoration & Waterproofing, Inc.
Creedmoor, NC

Material Supplier
Vector Corrosion Technologies, Inc.
Tampa, FL