Cathodic Protection and Concrete Repairs at Sound of the Sea II Condominiums

Assessment after a decade indicates long-lasting success

by David G. Tepke, Clement A. Firlotte, and Stephen P. Robinson

Constructed in 1984, Sound of the Sea II is a six-level reinforced concrete condominium building with 36 individually owned units. It is on the 0.75 mile (1.2 km) wide Bogue Banks Island within a few hundred feet of the Atlantic Ocean in Emerald Isle, NC, USA. It includes exterior common access corridors (walkways) on the front side of the building and private balconies for each unit (Fig. 1).

The location of Sound of the Sea II makes it highly susceptible to chloride penetration from ocean-borne salts and associated corrosion-related distress of embedded steel. Deck coatings were reportedly installed on corridors and balconies circa 1999. These deck coatings did not effectively arrest corrosion, as was evidenced by the formation of subsequent delaminations. Given the cost, inconvenience, and impact on renter and owner occupancy associated with capital repair projects, the owners commissioned a comprehensive repair project in 2007/2008 to address corrosion-related concrete distress, including preservation of existing concrete with cathodic protection (CP). The repair project, totaling approximately $1.2 million, was completed in December 2008 and included:

- Structural concrete repairs;
- Impressed current cathodic protection (ICCP) on balconies;
- Localized galvanic cathodic protection (GCP) in corridors and roof parapet repairs;
- Steel stair repairs;
- Improved drainage; and
- Protective coatings.

Fig. 1: Sound of the Sea II condominiums: (a) viewed from the beach; and (b) viewed from the front parking lot in 2019 (more than 10 years after repairs)

Evaluation

Evaluation of the structure prior to design included review of previous testing and assessment reports, on-site assessment, and sample collection by the design team. The design team reviewed and used information from a preliminary durability assessment report and a delamination survey report prepared by a testing and consulting firm in 2006. The reports were provided to the design team by the management company for review and included results and general recommendations. The reports indicated generally low reinforcing steel cover, chlorides at reinforcing steel depth in sufficient concentrations to initiate corrosion (approximately 500 to 1500 parts per million in some locations), significant delamination, and evidence of corrosion based on half-cell potential testing. Considerably more delaminations were identified on balconies as compared to corridors.

In 2007, excavations were made as part of the design effort to review embedded steel and structural conditions. Core samples were extracted from one corridor area and one balcony for resistivity testing by a third party. Resistivity was found to be relatively low and thus conducive for active corrosion for both samples. Of note, the balcony sample (4800 ohm-cm as received; 3000 ohm-cm after 12 hours of saturation and removal from bath) had about 60% the resistivity of the sample taken from the corridor (7700 ohm-cm; 4700 ohm-cm). Excavations revealed significant reinforcing steel corrosion (Fig. 2).

Design

Budget was of the utmost importance to the owners. Thus, it was necessary to evaluate repair/preservation options that would extend service life but not be overconservative and cost prohibitive. The designers discussed the merits of global ICCP and GCP with the owners. Given the spatial differences in exposure, identified differences in magnitude of distress, budgetary constraints, and the owners' directives, two separate approaches for repair and protection were adopted. Concrete repair—an alternate for ICCP—and cementitious deck coatings were specified for balconies where distress was more severe. Limited concrete repairs, urethane deck coatings, and an alternate for localized GCP were specified for corridors where distress was more sporadic and exposure somewhat less severe. Alternates were provided in the bid for CP to provide flexibility for the owners. A general overview of primary repairs to the corridors and balconies is summarized in Fig. 3.

As required by the owners, sliding glass doors remained in place during balcony repairs and existing embedded guardrails were not replaced. Ability to remove, store, and reuse guards to conduct repairs required special approval from the code official.

The design included a performance specification with additional prescriptive requirements for ICCP, including a 10-year no-corrosion warranty. Repair materials compatible with localized GCP and the global ICCP were specified.

Construction

General

The owners elected to accept the alternates for ICCP for balconies and localized GCP for corridors and roof parapets.

Fig. 2: Example of test excavation during 2007 assessment

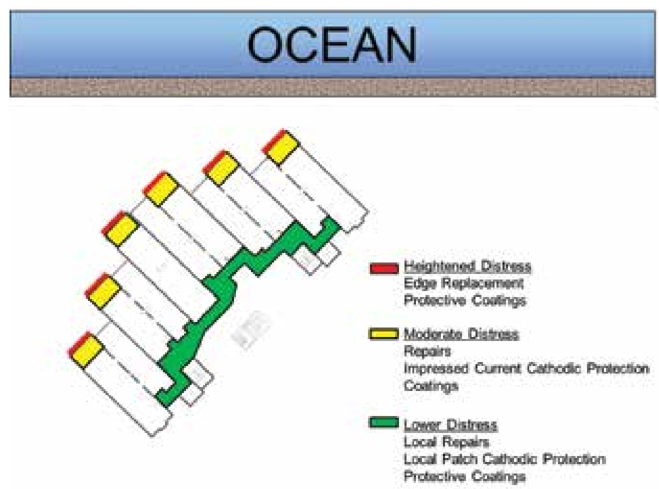

Fig. 3: Schematic showing tower position and final repair strategy

The Notice to Proceed was issued in October 2007. The project was substantially complete for all items except corridor coatings by December 2008, with completion of coatings following within a few months.

Repairs included horizontal, full-depth, vertical, and overhead orientations and were more substantial on balconies as compared to corridors. Repairs were completed by saw-cutting surfaces at repair extents, chipping deficient concrete, preparing surfaces via sandblasting, and conditioning to achieve a saturated-surface dry condition. Prepackaged portland cement-based repair materials were used for all repairs. Pre-extended repair mortars were used for deeper repairs. Repairs were moist-cured after installation.

All horizontal surfaces were shotblasted and coated with cementitious (balconies) and polyurethane (corridors) deck coatings after concrete repairs. Overhead and vertical surfaces were prepared and coated with a breathable acrylic coating where required.

Fig. 4: Balcony repairs: (a) general construction access with visible swing stage; (b) extent of distress; and (c) one of the more severely distressed balconies requiring shoring. Note demising walls at balcony sliding glass doors

Balconies

Swing stages were used for balcony access (Fig. 4 (a)). Due to project logistics and the amount of uncovered distress (Fig. 4(b)), it became immediately evident that the most efficient and cost-effective manner to address slab edges was to remove the entire slab edge. Although some sound concrete was removed, this method was less complicated and allowed for more efficient installation of supplemental reinforcement to address severely corroded reinforcing steel. It also allowed for effective coordination and installation of drip edges and guardrail posts after repairs. A significant challenge to the project was to minimize damage to guardrails during removal, storage, and reinstallation, and to make sure that slab edge installation was coordinated with new precisely located post pockets.

In general, less concrete removal than typical was necessary due to the use of ICCP. However, some balconies required full-depth repairs over substantial areas that required temporary support (Fig. 4(c)). Finite element analysis was used during the project to evaluate conditions for making field decisions. Mechanical splices and adhesive anchors were used where severely corroded reinforcing steel or inadequate steel was encountered and limited space was available for lap splicing. This also allowed for reduced quantities of concrete removal.

Balcony repairs required protection of sliding glass doors. Repairs generally terminated at the doors; however, distress at a limited number of areas required that repairs continue under thresholds into units. This required careful and well-planned execution of concrete repairs, as well as rapid cure repair materials to minimize impact to interiors and occupants.

Concrete repairs and reinstallation of guardrails were coordinated with the ICCP system. Reinforcing steel was tied together at repair areas to reduce the potential for stray current corrosion. Reinstalled aluminum guard posts were placed in polyvinyl chloride (PVC) pockets filled with epoxy to provide a dielectric barrier between guards and concrete subjected to ICCP. Textured, breathable cementitious deck coatings were installed at balconies for aesthetics and functionality.

Corridors and other areas

Lift and foot access were used on corridors. Repairs at corridors (Fig. 5(a)), columns, and walls were less frequent and generally smaller than those at balconies. Repairs at roof parapets (Fig. 5(b) and (c)) were variable. Commercially available alkali-activated galvanic zinc anodes were embedded in patch repairs to help prevent incipient anodes directly outside repair areas and associated distress. Anodes were tied to reinforcing steel within patches and all reinforcing steel and anodes within patches were confirmed electrically continuous. Reinforcing steel was coated with a cementitious/epoxy anticorrosion bonding agent. This had the likely added effect of diverting current from the anode to the existing substrate concrete.

Flood testing was conducted to identify ponded areas. Additional drains to address significant ponding and a urethane

Fig. 5: In-progress repairs: (a) exposed reinforcement in corridor; (b) exposed reinforcement in parapet; and (c) GCP and formwork installed at parapet repair

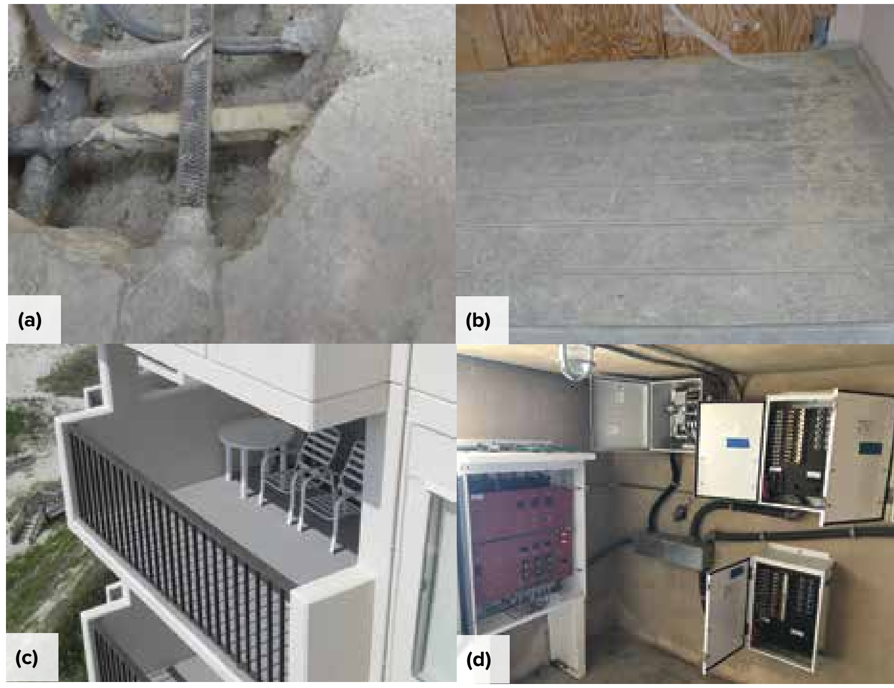

Fig. 6: ICCP system features: (a) anode and isolation from low-cover reinforcing bar; (b) grouted anode slots; (c) balcony deck as finished with vertical conduit (photo taken 2010); and (d) control and power system components (May 20, 2019)

deck coating were installed as water management and waterproofing measures. Deck coatings extended up the wall with mesh reinforcement at the transition.

Balcony ICCP system

The ICCP system (Fig. 6) was designed by the manufacturer to meet project and contract requirements during the project and was installed by an experienced specialty contractor. It includes 3/8 in. (10 mm) wide titanium/mixed metal oxide (MMO) mesh ribbon anodes with a current rating of 0.85 mA/ft (2.79 mA/m) grouted into 9/16 in. (14 mm) wide and 1/2 in. (13 mm) deep slots spaced approximately 12 in. (305 mm) on center and connected to 1/2 in. wide titanium headers. Testing was conducted to confirm continuity of reinforcement and separation of reinforcement from anodes. Embedments were grounded to the system negative. Where anodes and reinforcement were found to be continuous, they were isolated. System negative and anode connections were led through concrete to a junction box at each of the 36 balconies and then to the constant voltage transformer/rectifier in the mechanical room at the roof via PVC conduits painted to match the building.

Circuitry was split into three cathodic protection zones, each with 12 units over two vertical balcony stacks. Wiring for each balcony was connected to the assigned zone through a variable resistor for individual balcony control. Each zone included four embedded Ag/AgCl/KCl reference electrodes (silver/silver chloride reference electrodes immersed in a potassium chloride solution) for depolarization testing, commissioning, and future monitoring. Remote monitoring equipment and a modem were installed that allowed for system review.

The system was commissioned and adjusted in September 2008 with approximately 60 mA current delivered to the average balcony (approximately 0.73 $mA/ft^2_{steel, design}$ [7.86 $mA/m^2_{steel, design}$]; 0.48 $mA/ft^2_{concrete}$ [5.17 $mA/m^2_{concrete}$]; 0.41 mA/ft_{anode} [1.35 mA/m_{anode}]). Depolarization testing per NACE Publication 35108[1] over a 4-hour period was used to evaluate the system, with 100 mV depolarization being considered effective protection. Depolarization data during commissioning are shown in Fig. 7.

Overall Repair Totals

The final project cost was approximately $1.2 million. About 830 ft^2 (77 m^2) of horizontal concrete repairs, 275 ft^2 (26 m^2) of overhead repairs, and 30 ft^2 (3 m^2) of vertical repairs were conducted. Approximately 4660 ft^2 (430 m^2) of balconies are protected by ICCP.

Recent Site Visits and Closing Remarks

The management company has communicated that no major repairs associated with the work conducted in 2007/2008 have been needed and that only a minimal amount of maintenance has been necessary. This contrasts with other nearby properties requiring much more extensive repair and maintenance. Guardrails were reportedly replaced subsequent to the project in 2015; however, concrete repairs, coatings, and cathodic protection installed as part of the 2007/2008 project generally have performed well and are in serviceable condition, even withstanding a number of hurricanes over the past 10+ years in the very harsh, chloride-rich environment.

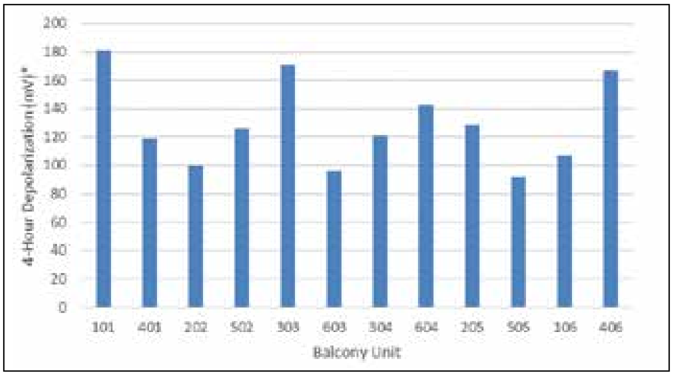

Fig. 7: Four-hour depolarization (September 25, 2008) (Note: Unit 505–97 mV at 6.25 hours; Unit 603–102 mV at 5.25 hours)

Fig. 8: Typical balconies and corridor area as of May 20, 2019

Table 1:
Summary of 2008 and 2019 depolarization data

ICCP depolarization*	September 2008	May 2019
Average 4-hour depolarization of reinforcing steel, mV	130	182
Average depolarized potential of reinforcing steel, mV†	−269	−199

*Based on 12 embedded Ag/AgCl reference electrodes
†Converted to CSE

During visits in 2019, it was observed that critical ICCP system components were functioning to protect reinforcing steel within the original design parameters. While some small discrete corrosion stains and one small delamination were observed on balcony soffits, likely associated with discontinuous steel embedments, no major concrete distress was observed on balconies repaired and protected with ICCP in 2007/2008. The remote monitoring device had its backup battery replaced as part of routine maintenance, and the site-monitoring device and wiring conduits on the roof required maintenance after a recent major hurricane; however, these items have not affected protection. Guardrail anchorages in the concrete from the 2015 guardrail replacement project had variable connectivity, demonstrating the need for coordination of all repairs to concrete subjected to ICCP. Some concrete distress was observed on walkway areas and roof parapets where ICCP was not installed, and some isolated deck coating damage was observed, but installed repairs and coatings generally have performed well. Balconies and corridor areas as of May 2019 are shown in Fig. 8.

Table 1 contains a comparison between data collected and reported by the System Designer in 2008 and 2019. After 11 years, the average depolarization increased and the average depolarized potential decreased, reaching, on average, a level of passivation (more positive than −200 mV versus a copper-copper sulfate reference electrode [CSE]) per NACE Publication 35108.[1] This project serves as an example of how ICCP can provide long-term service-life extension and shows that strategically selecting different preservation strategies on a building can provide economic, effective, long-term benefits.

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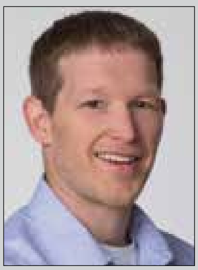

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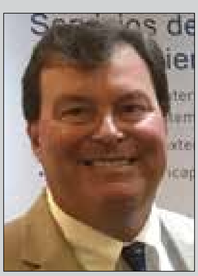

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