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ICRI
CONCRETE REPAIR
Restore | Repurpose | Renew
35th
YEAR
ANNIVERSARY

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ON THE COVER: Image from technical article "Design for Longevity: A Look Back at Concrete Rehabilitation and Preservation at Shipyard Village Condominiums" on page 16.

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Design for Longevity: A Look Back at Concrete Rehabilitation and Preservation at Shipyard Village Condominiums

by David G. Tepke, Nicholas B. Tribble, and Stephen P. Robinson

Fig. 1: 2023 photos: courtyard side of Building A (left) and ocean side (right)

INTRODUCTION

A repair project totaling approximately $8.5 million was undertaken 2009-2011 at Shipyard Village Buildings A and B in Pawleys Island, South Carolina, including concrete repair and replacement, cathodic protection (CP), coating installation, guardrail replacement, and fenestration replacement. Repairs and preservation strategies were primarily conducted to address corrosion-related distress that resulted in significant structural deficiencies and to extend service-life in the harsh coastal environment. Figure 1 shows pictures of Building A from the courtyard and ocean side.

STRUCTURAL SYSTEM

Shipyard Village Buildings A and B are five story, forty-unit beachfront sister condominiums constructed in the mid 1980s. The ground level beneath the building serves as an open parking area. The structural system includes prestressed hollow-core panels (PHCP) with topping slabs supported by load bearing concrete masonry walls and reinforced concrete beams. Both buildings are comprised of three structures joined by walkways with expansion joints at the separations between the structures.

The buildings are oriented such that the central portion, with two units in plan, is parallel with the coastline and the north and south towers, each with three units in plan, are angled away from the coast. Balconies for each unit are approximately 20 feet long by 6.5 feet deep and are generally separated and supported by load bearing privacy walls. Balconies in the center tower were supported by tapered cantilever beams on one side. Large tapered concrete haunches at Level 1 support the load-bearing masonry balcony walls above.

Walkway panels are supported on load-bearing masonry walls and reinforced concrete beams, including tapered 16-inch deep cantilever beams that support panels at the center tower and portions of the end towers.

CAUSE OF DISTRESS

While no original construction drawings were available for review, a condition assessment was performed that included review of previous test reports, visual observations, and corrosion-related testing to evaluate cover, chloride contents, and distress at selected representative locations. Heightened chloride levels were characteristic

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at the level of reinforcing and prestressing steel at various locations, particularly at ocean front locations and at the walkway areas adjacent to the separations between the structures. Areas with high chlorides coincided with areas of visually observed distress in varying quantities. Windy conditions were characteristic of the walkway locations near the building separations, indicating that the increased chloride levels were likely from increased exposure to airborne salts.

Chloride levels at walkway areas away from the separations were mixed; however, reduced amounts of distress were observed in these areas. Distress was also variable at slab edges supporting curtain walls (Fig. 2). Shoring and supplemental supports (Fig. 3) were necessary in some locations to make conditions temporarily safe for occupant use prior to commencement of the repair project.

GENERAL REPAIR METHODOLOGY

The ownership was interested in exploring available technologies for addressing damage and proactively addressing future corrosion for extending service-life. Given the economic climate in 2009 during the Great Recession and associated competitive nature of construction costs, the project cost of $8.5M (likely about $13M to $15M in today's dollars and construction climate) was a considerable investment by the owners. From the beginning, communication of needs and wants from the owners and technical possibilities from the engineering team were key.

To determine an appropriate repair methodology, the design team reviewed the data, distress patterns, and general costs for various approaches. The complexity and time associated with intricate repairs on the thin section, hollow core panels was a key consideration. It was decided to remove and replace panels in areas with heightened observed distress and/or elevated chloride levels (ocean-side balcony panels and courtyard-side panels in the central portion of the condominiums) and implement limited repairs and a preventative protection strategy at remaining panels with a thermal spray CP system.

Refer to Figure 4 for a schematic repair strategy. Costs associated with removal and replacement of cantilever beams with variable amounts of distress at walkway and balcony locations and slab edges supporting curtain walls on the ocean-side were also favorable compared to widespread implementation of individual concrete repairs and CP strategy at these areas. Ocean-side haunches were patched and galvanically protected with patch zinc anodes. Fenestrations were also replaced during the repair project and coatings were installed at vertical and horizontal components. The buildings were unoccupied during the renovation work. Work was primarily conducted between September and May of successive years (2009-2010, 2010-2011), with much of the concrete replacement and repair being conducted in the months of December through March.


Fig. 2: Corrosion damage: prestressed hollow core panels at Level 1 walkway soffit (top left), balcony prestressed hollowcore panel during construction demolition (top right), balcony cantilever beam (bottom left), and walkway beam (bottom right)

Fig. 3: Example of supplemental supports prior to project to make conditions temporarily safe

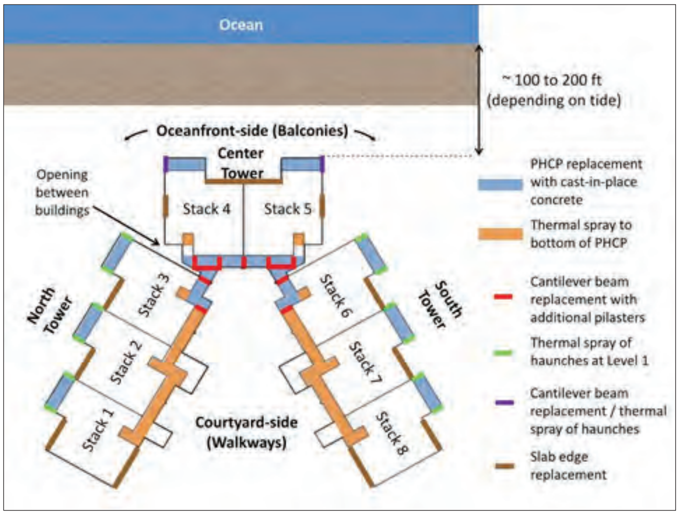

Fig. 4: Schematic plan view of buildings showing proximity to ocean and general repair methodology

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SLAB EDGE REPLACEMENT

Swing stages were utilized for slab edge replacement (Fig. 5). Slabs were demolished approximately 6 to 8 inches to remove contaminated concrete and provide clearance behind reinforcing steel bars for replacement. The variation in existing alignment in both horizontal and vertical planes required specific attention to placement tolerances. Surfaces were prepared using an abrasive sandblasting. Horizontal reinforcing steel bars were spliced or doweled into existing grout-filled masonry walls, as necessary. Existing reinforcing steel that served as anchors between the PHCP topping slab and slab edge were re-used when possible. Due to the condition, placement and limited amount of existing reinforcing, dowels were adhesively anchored into the hollow core sections at the end of the slabs. Tensile testing was conducted at representative anchors to verify anchor installation.

Pre-packaged repair materials were used in replacement. Draped protection and radiant heat from distanced lights were used to maintain the concrete at appropriate temperatures during cold weather. Coatings and new curtain walls were installed after the slab edges were placed and cured.

CONCRETE SLAB REPLACEMENT AT BALCONIES AND WALKWAYS

Cast-in-place ready-mix concrete was used to replace the PHCP due to access, code requirements, and general control in the durability of the mixture properties and installation afforded by ready-mix concrete. There were several technical challenges with PHCP removal and installation of ready-mix concrete, including:

1. achieving access,
2. providing support to a new slab without compromising aesthetics,
3. reducing cracking tendency in the 20 ft long, fully restrained balcony sections and up to 60 ft long walkway sections with re-entrant corners and no control joints,
4. achieving total weight comparable to the PHCP and topping so that the structure is not overloaded, while still achieving adequate stiffness to resist deflections,
5. constructing components with similar thicknesses and elevations to meet existing components to remain,
6. providing adequate slope from working points to properly drain water, and
7. requirements to meet provisions of the current code, including loading.

New slabs were approximately 7 to 8 inches thick with two mats of reinforcing, and were tied into existing components, including supporting cantilever beams and privacy walls, as applicable. Specifications for concrete permitted the use of performance requirements or prescriptive alternates. Specifications were developed to provide concrete with low shrinkage, low chloride-ion penetrability, increased chloride threshold or both, resistance to freezing and thawing, resistance to alkali-silica reactivity, reduced unit weight to limit additional dead load, adequate strength and adequate elastic modulus to maintain acceptable deflections. Refer to Table 1 for specification requirements and proportions.

At the balconies, existing PHCP slabs acted to laterally brace the structure; therefore, temporary braces were needed at each level prior to removal of the slabs to prevent out of plane buckling of the walls. Slabs were removed by demolition onto installed scaffolding below or removed by crane. Scaffolding was constructed full height to provide access for trade work. At balconies, three pockets 8 to 12 inches wide, 8 inches deep and the thickness of the slab were excavated into the wall on each side of the balcony that was approximately 7 feet wide. The tabs were reinforced to transfer loads from the slab to the load-bearing wall. A beam was formed at the sliding glass door to form the header and threshold for the door installation. Balcony slab removal and replacement was sequenced to reduce impact to project schedule. Figure 6 shows lateral bracing during construction and balcony slab reinforcement.

Where cantilever beams supported the slabs (limited locations at the balconies and most locations on the walkways), they were placed integrally with the slabs. Where hollow cells were observed at the locations where con-

Fig. 5: Replacement of balcony slab edges from swing stage (left), example of corrosion of reinforcing steel during demolition (center), and example of thermal control (right)

nections were made to the masonry walls, or at other locations as necessary to transfer loads for the repair, they were grouted. At walkways, supplemental steel supports were installed at the limited locations where existing panels were supported by the walls and the new cast-in-place concrete required a bearing surface.

Concrete was pumped into place. Emphasis was placed on ensuring that concrete was well consolidated in the bearing tabs at balconies and at cantilever beams and pilasters at walkways, as described below. Fresh concrete testing was conducted from samples obtained at point of placement for all batches delivered on site. A sample

Table 1: Specification Requirements for Lightweight Concrete Slabs and Implemented Mixture

Required Properties	
Min Comp. Strength	5,000 psi at 28 days
Maximum w/cm	0.40
Equilibrium Density	108 to 112 lbs/ft^3
Nom. Max. Aggregate Size	0.75 inches
Air Content	5%
Slump	4 inches
Corrosion Alternatives	ASTM C 1202 (mod curing): 800 Coulombs max at 28 days or 30% fly ash + 7% silica fume or 25% fly ash + 5% silica fume + Corr. inhibitor to increase cl$^-$ threshold to 7.5 lbs/yd^3 or Corr. inhibitor to increase the cl$^-$ threshold to 15 lbs/yd^3
Shrinkage Alternatives	ASTM C 157 (mod curing): 300 microstrain max at 35 days (7 days curing followed by 28 days drying) or Max cementitious materials: 660 lbs/yd^3; w/cm between 0.35 and 0.4; and use of commercially available shrinkage reducer to reduce long-term shrinkage by 50%
Min Elastic Modulus	2,800,000 psi at 28 days
Alkali-Silica Reactivity	ASTM C 1260 or ASTM C 1567: 0.1 percent max at 16 days
Submitted and Implemented Mixture Proportions	
Type I/II Cement	465 to 500 lbs/yd^3
Class F Fly Ash	165 lbs/yd^3
Silica Fume	30 lbs/yd^3
Lightweight Coarse Aggregate	925 lbs/yd^3
Normal Weight Fine Aggregate	1208 lbs/yd^3
w/cm	0.40
Calcium Nitrite Corrosion Inhibitor	2.5 gal/yd^3
Shrinkage-Reducing Admixture	0.5 to 1.5 gal/yd^3

Fig. 6: Lateral bracing necessary for removing balcony slabs (left) and reinforcing layout at balcony (right). Note tabs at privacy wall used to support the new slab. Not easily visible in the figure is the tab nearest the threshold

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of compiled quality assurance data for strength and unit weight for all lightweight concrete used in beams, slabs and pilasters is provided in Figure 7. Slabs were fogged with an atomized fogger as necessary to resist plastic shrinkage cracking. Slabs were broom finished and immediately wet cured for a minimum of seven days. Heat and insulating blankets were used to maintain appropriate curing temperatures in cold weather. New exterior concrete masonry walls were installed on the concrete curbs and beams. Slabs were coated with a breathable cementitious coating after work was completed. Figure 8 shows general replacement operations at a typical central walkway area and balcony.

CANTILEVER BEAMS AND PILASTERS

Cantilever beams were replaced where the PHCP were replaced on the walkway-side and where present on oceanfront-side balconies. To replace the beams, the beams were either cut and reinforcing steel later mechanically spliced with shear wedge and screw splices, or concrete demolition was conducted around the bars, thus preserving them for re-use after abrasive blast cleaning. Several challenges were uncovered in reworking the beams, including:

1. many of the cantilever beams had low or no cover to the steel from the reinforcing cages not being properly supported during the original construction,
2. top bars in the cantilevers were lower than appro-

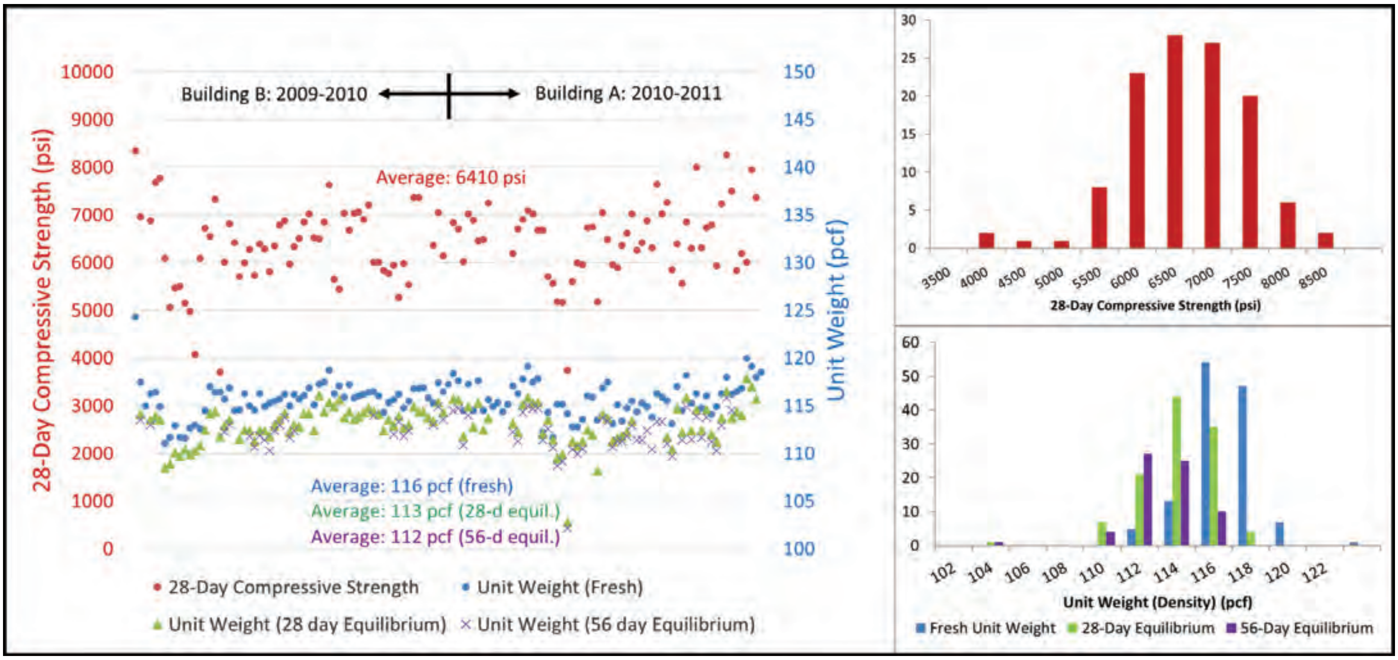

Fig. 7: Quality assurance data for 28-day compressive strength and unit weight (density) for batches of concrete delivered to site for both buildings

Fig. 8: Illustration of replacement of portion of walkway slabs (left) and balcony (right). Note the fogger at right of craftsman, used after finishing and prior to implementation of wet burlap and plastic for moist curing and insulating blankets when necessary

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priate and/or undersized for resisting code applied loads, and

3. new installations were required to meet current code provisions (increased live load).

Beams were widened where necessary and deepened where possible to increase cover. Limited opportunity to deepen beams was available due to code required minimum overhead heights. Where possible, additional reinforcing was anchored to the existing portion of the beams above existing top reinforcing steel to increase capacity to meet current code load requirements. While this was acceptable in marginal situations, the use of pilasters tied to the masonry walls to reduce cantilever span was necessary in many cases on the walkway sides.

Hollow cells were grouted at pilasters to transfer load where grout was omitted during original construction. Galvanic point anodes were installed into a pocket of low-resistivity repair material attached to the existing portion of the cantilever beam to remain. Beams and pilasters were formed and placed concurrently with the slab systems. Figure 9 shows a removed walkway cantilever beam and reinforcing, partial forming of new beam and pilaster, and finished work after installation and coating application.

THERMAL SPRAY CATHODIC PROTECTION (CP)

Thermal spray CP was chosen for application on the bottoms of PHCP on the walkway-side of the building in areas away from the building separations, where slabs were generally well protected, but exhibited variable levels of chlorides at the level of the steel. Specifications required a minimum of 12 mils thickness, or as required to provide a service-life extension of 15 to 20 years. Existing coatings were stripped from the panels. The panels were quite sensitive to coating removal and surfaces were rather rough in some places. Repairs at spot locations were completed. Excavations to the prestressing steel were made near the panel ends in a staggered fashion to make two connections per strand. An alloy of aluminum, zinc, and indium was applied to the surface by thermal spray and connected at the excavated sites by spraying into the excavations. Epoxy repair material was used to patch the excavations. A breathable coating was applied after the thermal spray was applied for aesthetics.

Haunches at Level 1 on the oceanfront-side were also protected with thermal spray galvanic protection. Steel plates were used as connections for thermal spray to reinforcing steel. A skim coat was applied in some places prior to installation, and a breathable coating was applied thereafter. Figure 10 shows thermal spray application at PHCP and current condition at haunches.

Testing associated with the galvanic systems included thickness measurements, substrate bond testing, and

Fig. 9: Walkway cantilever beam showing removed concrete, low cover to bottom of beam, excessive cover to top tension reinforcing steel, and voids (top left), partially placed and formed reinforcing steel for reconstructed beams and pilasters used to reduce the stresses in the beam (top right), and completed pilasters and beams cast integrally with the new concrete slabs (bottom). The pilaster was tied to the wall. Note the mechanical splices used to tie to existing steel for this beam.

Fig. 10: Thermal spray being applied to the PHCP soffits (left) and current condition of haunches after thermal spray and coating application (right)

Fig. 11: Test station for CP testing at panel

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monitoring stations to measure the effectiveness of the CP system during construction and in the future. These stations were installed on panels and haunches. Long-term monitoring equipment included embedded reference electrodes. Figure 11 shows a typical test station at a PHCP.

Fig. 12: Installation of self-consolidating concrete at a beam under a slab by pumping

OTHER REPAIRS

Other repairs were implemented at the project. Self-consolidating concrete was used to replace deteriorated beams at level one with limited access (Fig. 12). The Contractor submitted a mixture design and installed plastic windows in the form to verify consolidation. Testing was conducted on-site to demonstrate flowability and stability. Other repairs included replacement of PHCP at the roof level, replacement of a deteriorated stair section and installation of prefabricated panels with incorporated galvanic CP on selected beams.

PERFORMANCE SUBSEQUENT TO REPAIR PROJECT

Both buildings were reviewed in 2017 and 2023, approximately 7 and 13 years after the primary repair project. New concrete balcony and walkway slabs and beams, as well as PHCP, beams and haunches subjected to cathodic protection, generally were performing well. Cathodic protection test systems were reviewed in 2017 and showed excellent protection to the instrumented hollow-core panel. Haunches and beams generally showed at least partial

Fig. 13: Examples of current conditions: walkways (top left and right), soffit with thermal spray and coatings (bottom left) and replaced balconies with thermally sprayed haunches (bottom right)

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cathodic protection where test stations were functional, though results were more variable.

Approximately $300,000 (3 to 4 percent of the primary project cost) in maintenance and repairs were completed in 2018 to address minor issues. Of this was about $100,000 (approximately 1 percent of the primary repair project cost) for concrete and coating repairs / maintenance to address grinding some corrosion stains associated with tie wires on concrete surfaces, sealants, and concrete repairs. Concrete repairs were ascribed primarily to limited reinforcing steel that was inadvertently not connected into the cathodic protection system as well as minor stray steel. Other repairs included coatings on guardrails and typical sealant work. No significant corrosion-related damage to protected or newly installed components from 2008 was observed during a visual review in 2023. Example photos of the buildings as of 2023 are shown in Figure 13.

SUMMARY

A pragmatic approach was used to cost-effectively replace and preserve portions of the structure to extend the service-life of a coastal condominium. This included replacement at locations combined with complex repairs and protection of other members where warranted. A high-performance concrete mixture was used to provide a viable solution for replacement of PHCP. Galvanic protection was used to protect areas of the structure with limited distress. After 11-13 years, observations indicate that the 2010-2012 repairs are performing well; minor maintenance and limited localized areas of discontinuous reinforcing steel have been addressed.

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