PACIFIC MANOR PARKING GARAGE STRUCTURAL REPAIRS

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INTRODUCTION

Pacific Manor is a nine-story condominium built in the early 1970s, located in Honolulu, HI. The structure is constructed of paper-wrapped post-tensioned (PT) concrete with a suspended parking deck, lobby level deck, and recreation deck at the lower levels. The decks consist of PT slabs spanning about 20 ft to reinforced concrete beams supported on reinforced concrete walls and columns. The clear height below beams is about 6 ft 6 in. while the clear height below the slabs between the beams is 6 to 12 in. higher. Significant spalling of the suspended parking, lobby, and recreation decks that were exposed to the weather had occurred in the early 2000s due to corrosion of the embedded PT reinforcement, resulting in extensive repairs several years ago, including the installation of new PT tendons to replace fractured tendons. However, as corrosion and fracturing of the tendons and the accompanied spalling continued to occur at a significant rate after these repairs, a second design team engaged by the condominium association (AOAO) instituted immediate shoring of portions of these decks as well as closing and emptying of the pool at the recreation deck and recommended complete removal and replacement of the parking, lobby, and recreation decks. As this work would be very costly and would require that the residents vacate the condominium during the construction, further increasing costs to the unit owners, the AOAO engaged MKE Associates LLC and Vector Corrosion Technologies Inc. to investigate the cause of the continued spalling, the effect it had on the structural integrity of the decks, and to develop alternate repair and/or retrofit measures that could reduce costs.

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INVESTIGATION

Initial investigation of this project included the following items:

- Review of original project drawings to obtain information about the deck reinforcement and concrete properties.
- Field survey to visually observe and sound portions of the decks to obtain information on the extent and location of spalling and cracks, and location, size, and spacing of existing reinforcement.
- Measurement of slab deflections to confirm whether there were any excessive deflections.
- Limited reinforcing bar scanning to verify reinforcement location and spacing.
- Destructive investigation at a few delaminated areas to verify reinforcement size, spacing, cover, and extent of corrosion.
- Material testing of concrete to obtain information about the concrete quality and possible causes of deterioration.

From our initial observations, a significant number of tendons had fractured to the degree that the shoring and reducing of loads over the portions of the lobby-level deck was warranted until either deck repairs or replacement could be performed. Additional observations included the following items:

- Cracks and spalls were oriented primarily in the longitudinal (tendon) direction. At open spall areas,

Fig. 1—Galvanic couple between strands and reinforcing bar, where the strands are the anodes and corroding, while the reinforcing bar is the cathode and protected.

Fig. 2—Verifying conductivity of paper sheath, checking current flow from anodes to strands, and checking polarization of strands using a galvanic anode.

the most severe corrosion appeared largely limited to the exposed PT tendons, with the adjacent mild steel reinforcement exhibiting minor to no significant corrosion.

- No significant slab deflections were measured in the slabs, and deflections remained relatively the same over a 1-year period prior to repairs.
- Chloride ion contents exceeding the theoretical threshold for chloride–induced corrosion were observed at the top 0.75 to 1 in. (19 to 25 mm) depth of the recreation deck core sample and bottom 0.75 to 1 in. (19 to 25 mm) depth of the lobby level spalled soffit sample, which corresponded to the minimum cover for the tendons.
- The maximum depth of concrete carbonation at the bottom and top surfaces was 0.89 and 0.49 in. (22.6 and 12.4 mm), respectively, measured in the recreation deck sample.

After the previous investigation, it was decided to perform an additional investigation on the PT tendons including the following items:

- Locating tendons using ground-penetrating radar (GPR).
- Excavating inspection recesses at selected locations.
- Visually inspecting and recording the condition of the PT strand in newly excavated recesses and in previously exposed areas at concrete spalls.
- Performing screwdriver tension tests on PT strand.
- Testing electrical continuity between PT strand and any exposed mild steel reinforcement, and between PT strand themselves.
- Testing half-cell corrosion potentials: native and instant-on by the temporary anode.
- Measuring protective current flowing between PT strand and temporary anodes.
- Testing air communication along selected PT strand.
- Filling inspection recesses with mineral wool insulation and sealing with galvanized plates.

The investigation results yielded the following findings:

- The tendons are paper-wrapped strands.
- Tendon corrosion appeared to be due to the ingress of water, chloride ions, and carbonation of the concrete to the depth of the embedded strand.
- It appeared that there were galvanic couples between the strands and the reinforcing bar in which strands were corroding and protecting the reinforcing bar. (Fig. 1)
- Conductivity tests showed a significant amount of current could flow from the testing galvanic anodes to the strands through the paper sheath. Therefore, the paper sheath was found to be a good conductor that promotes corrosion of the strand (Fig. 2).
- Tendons that had fractured due to corrosion could still be in considerable tension a few feet away from the break, in some respects behaving much like a prestressed bonded tendon due to the higher friction in the paper wrap combined with surface corrosion of the strand.
- From the observed lack of transverse tension cracks at points of maximum moment in the deck, it appeared that the majority of tendons were still effective in maintaining the integrity of the decks with regard to

supporting the garage vehicular loading. Deflection measurements of the deck also indicated that many tendons were still intact, as no areas of excessive deflections were identified.

REPAIRS

After the investigation, structural analysis of the existing decks was performed, based on the information gathered about as-built conditions during our survey. Based on this analysis, a retrofit scheme was developed and implemented. Although PT tendon corrosion and concrete spalling had occurred throughout the decks, previous repairs appeared to have repaired many of the broken tendons, corrosion, and spalling. Therefore, it was believed a scheme could be developed to repair the remaining spalling and arrest future corrosion of the original strand and mild reinforcement, while providing supplemental reinforcement and steel framing that would provide adequate strength to address current and future isolated corrosion of reinforcing and broken tendons (Fig. 3). This strengthening retrofit option was found to be feasible due to the large amount of mild reinforcing steel specified in the original design for most of the decks to the degree that only a small amount of additional reinforcement would need to be added by installing them in grooves cut into the deck. For one of the parking decks where this was not the case, steel beams were added under the deck as a precaution against significant fractured tendons. As these retrofits were provided only to provide adequate strength capacity, preservation of the existing tendons was relied on to maintain the slab deflections within acceptable limits.

At the suspended pool, due to the lack of height clearance and the large pool load, these retrofit options could not be employed. Therefore, the pool walls were converted into upturn beams by adding reinforcement below the pool walls so that the span of the pool slab was greatly reduced to the point that existing slab reinforce-

Fig. 3—Installing steel beams in some local areas where there were a significant number of broken tendons.

ment was adequate to support the pool in the case of total tendon failure.

To protect the tendons against future corrosion, it was decided to install embedded zinc anodes to provide cathodic protection to the tendons (Fig. 4). It is anticipated that this protection, in addition to properly repairing all spalled concrete and re-waterproofing the top surface of the decks, will greatly mitigate future corrosion and keep the tendons largely intact.

The repairs were initiated in November 2016 and completed in October 2017. To eliminate relocation costs and as parking was not available in nearby areas, repairs were in phases so that the building could remain occupied at all times and so that the majority of parking stalls could be used during non-construction hours. We believe these repairs will protect the tendons from further significant corrosion over the expected remaining life of the building; however, if some tendons are already fractured or fracture in the future, the repairs also provide significant additional strength to compensate for any tendon failures.

The original estimated cost of these repairs was about half of the estimated cost to replace the decks. In addition, as the actual cost of the repairs was about $300,000 less than the original construction cost estimate, the condominium association is using these cost savings to implement some much-needed enhancements to improve the overall appearance of the building.

CONCLUSIONS

A comprehensive investigation to determine the existing condition and causes of corrosion was an important first step in developing a feasible repair strategy to salvage this paper-wrapped PT parking deck. Galvanic protection was a cost-effective way to mitigate the future corrosion of paper-wrapped tendons and preserve their structural integrity. The client saved considerable deck replacement costs by rehabilitating the deck through tendon corrosion mitigation retrofits and supplemental deck strengthening.

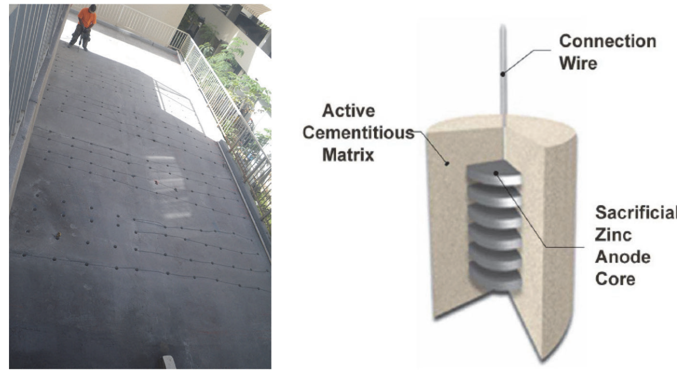

Fig. 4—Installing galvanic anodes along the tendons and connecting anodes to the steel.

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