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REHABILITATION OF O'HARE INTERNATIONAL AIRPORT PARKING STRUCTURE

Summary: The primary parking structure serving O'Hare International Airport was opened for use in 1973 with 10,000 parking spaces and over 240,000 square meters of supported slabs. The six-story concrete structure was primarily reinforced using button-head post-tensioning. A condition assessment was performed in January of 2018 and identified structural deterioration which included freeze-thaw deterioration of concrete, corrosion-related delamination and spalling, and localized eruption of failed button-head tendons. Waterproofing deterioration consisted primarily of wear of waterproofing membranes and damage and wear of expansion joint seals. The resulting multi-year restoration program to extend the service life of the parking structure began in September 2020 and was completed in September 2022. Concrete and post-tensioning repairs to the slab, beams, girders, and columns were performed throughout. Sealant and expansion joint seal replacement were also performed to address leaks. Additionally, a unique structural strengthening repair was implemented at one of the columns that supports a signature helical ramp.

Keywords: concrete deterioration, post-tensioning, concrete repair, strengthening, parking garage

SANACIJA PARKING GARAŽE NA O'HARE INTERNACIONALNOM AERODROMU

Rezime: Primarna parking garaža na internacionalnom aerodromu O'Hare otvorena je za upotrebu 1973. godine sa 10000 parking mesta i preko 240000 kvadratnih metara noseće konstrukcije. Šestospratna betonska konstrukcija je prvenstveno armirana naknadnim prednaprezanjem. Procena stanja je izvršena u januaru 2018. i identifikovana su oštećenja konstrukcije uključujući oštećenje betona od smrzavanja, raslojavanje i ljuštenje povezano sa korozijom, i lokalizovano izbijanje korodiranih kablova. Propadanje hidroizolacije se prvenstveno sastojalo od habanja hidroizolacionih membrana i oštećenja i habanja dilatacionih spojnica. Višegodišnji program sanacije za produženje veka trajanja konstrukcije počeo je u septembru 2020. godine i završen je u septembru 2022. godine. Popravke predrapregnutih kablova i betonskih ploča, greda, nosača i stubova su vršene svuda u garaži. Zamena elastomernih zaptivača i dilatacionih spojnica takođe je izvršena da bi se sprečila curenja. Pored toga, izvedeno je jedinstveno konstrukcijsko ojačanje na jednom od stubova koji nosi tipične spiralne rampe.

Ključne reči: oštećenje betona, naknadno zatezanje, popravka betona, ojačanje, parking garaža

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1. DESCRIPTION OF STRUCTURE

The elevated parking structure at O'Hare International Airport is a six-story structure (Figure 1) that was designed by C.F. Murphy Associates of Chicago, Illinois in 1968 and opened for use in 1973. The structure is located on the north side of the airport terminals, and extends between the stations for the automated transit system (ATS) at Terminal 1 on the west and at Terminal 3 on the east. In plan view, the parking structure is shaped like an arch between these two terminals for a length of approximately 325 meters along the southernmost column line and 435 meters along the northernmost column line. Along the north-south column lines, the structure is 140 meters wide. Four pairs of spiral ramps are located in the center of the garage that allow vehicular access to all levels.

Figure 1: Overall view of the south elevation of the elevated parking structure

The structural floor system for the elevated garage levels is constructed of cast-in-place lightweight aggregate structural concrete. The columns typically measure 65 cm by 80 cm. The beams along the north-south column lines and the girders along the east-west column lines are 215 cm wide with unbonded post-tensioned tendons. In between the typical column lines, there are two 30 cm wide post-tensioned concrete joists aligned in a north-south direction and three 30 cm wide conventionally reinforced concrete joists parallel to the arching east-west column lines. In the bays where the expansion joints are located, north-south post-tensioned beams, one on each side of the joint, are used in lieu of the north-south joists. The concrete floor slab located between the joists, beams and girders is approximately 11.5 cm thick and is reinforced in two-directions with deformed welded wire fabric reinforcing. The beams, joists, and girders extend 45 cm below the bottom of the slab.

2. PARKING DECK REPAIRS

The supported floor systems had experienced delamination and spalling of the slab, beam, joist, and column surfaces at many locations throughout the structure due to exposure to deicing salts and water ingress. Additionally, all expansion joint seals in the garage had failed and numerous cracks were allowing moisture and deicing salts to enter the concrete. The moisture and deicing salts reached the level of the reinforcing steel, leading to corrosion of the embedded reinforcement and resulting in concrete delaminations.

Repairs were implemented to address the concrete deterioration. The repair contractor removed the full depth of the 11.5 cm thick structural slab at areas of deterioration and performed partial depth removal at beams and vertical surfaces. Over 90,000 square meters of top surface/full depth repairs and 400 square meters of vertical and overhead repairs were performed. ACI and ICRI recommendations for best practices were followed for designing and implementing the repairs, including concrete removal around the full circumference of exposed reinforcing bars, coating of the exposed steel surfaces with a corrosion-inhibiting coating, providing new supplemental epoxy-coated reinforcement, and using replacement concrete designed to be more resistant to extreme weather exposure. Supplemental reinforcement was installed to address section loss of the existing reinforcement. An overview of one area of concrete repairs ready for concrete placement is shown in Figure 2.

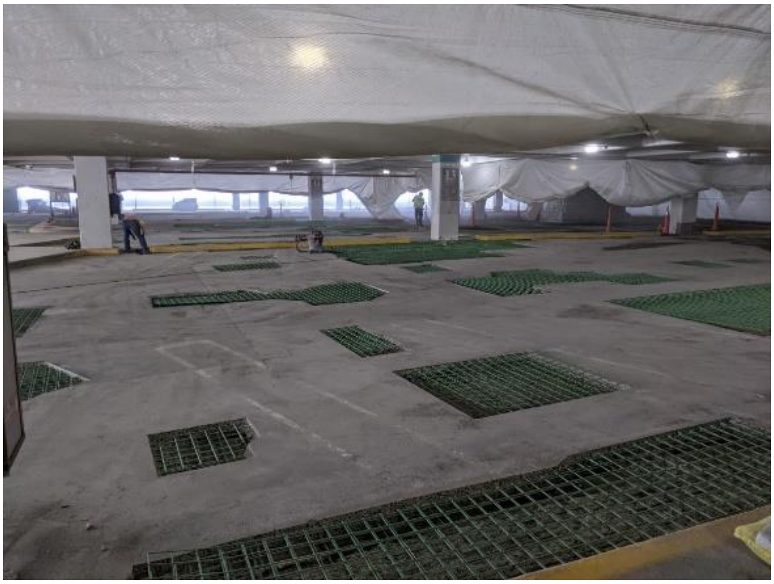

Figure 2: Full depth concrete repair openings in the work enclosure

Maintaining the schedule was critical due to operations disruption and lost income from areas removed from use. Further complicating the work, the site was very sensitive to dust, and the owner required strict dust mitigation. Enclosures were erected around work areas to provide weather protection to help maintain an aggressive construction schedule as well as for security and dust control. Wet sandblasting was utilized to further reduce dust while cleaning the concrete and exposed steel surfaces. The size of some of the full-depth slab repair areas exceed one square meter in area, creating a potential fall hazard to the floor below. Providing fall arrest protection would have slowed progress of the work. To increase the pace of repair work and lessen worker encumbrance, the existing welded-wire-reinforcement exposed within the full-depth repair areas was innovatively load tested to demonstrate the reinforcement's ability to act as an adequate barrier for personnel.

3. POST-TENSIONING REPAIRS

As the contractor performed concrete repairs throughout the garage, the engineer evaluated exposed tendons primarily in girders at repair openings, identifying tendons with various levels of corrosion-related wire loss (Figure 3). Structural analysis of the as-built configuration of the structure, including actual concrete strengths from material testing and the actual number of wires and tendons present, was used to quantify remaining structural capacity. As a result, the threshold for requiring tendon repair was refined, reducing the repair costs and expediting the repair schedule. Where tendon repairs were necessary, custom anchor plates were fabricated to allow restoration of the button-head system in-kind, reducing the amount of concrete removal required and avoiding the need for supplemental external PT systems. Replacement wire material exceeded the original specified strength, allowing the number of wires needed to be reduced. Four tendons were repaired with 50 meters of post-tensioning wire replaced. Sheathing restoration replaced the paper-wrapped sheathing with new waterproof sheathing materials to extend the life of the repaired tendons. Over 230 meters of sheathing repair was performed. After installation of the new tendons, the wires were stressed (Figure 4) and the surrounding concrete restored.

Figure 3: Fractured and heavily corroded girder tendon exposed in a concrete repair opening

Figure 4: Girder PT restressing

4. EXPANSION JOINTS

At the ends of expansion joints, a 60 cm deep concrete infill block was used to allow access to stress the exterior girder post-tensioning during the original construction. The joint seal transitioned from a winged seal to a precompressed seal at this location, as the joint split in two directions around the infill block. A number of these concrete infill blocks were displacing downwards (Figure 5) and required immediate shoring until repairs could be performed. To repair the dropping infill blocks, reduce the length of joint seal required, and to eliminate a transition in joint seal type, the infill block was removed, and the joint opening reconfigured for a uniform-width joint seal (Figure 6). At other areas, jogs in the winged expansion joint from original construction had discontinuous joint seals that perpetually leaked. These jogs were reconfigured to allow for installation of a continuous joint seal, as shown in Figure 7.

Figure 5: Dropped, rotated, and spalling concrete infill blocks

Figure 6: Dropped infill block replaced with monolithic concrete (original position of infill bock outlined)

Figure 7: Jog in expansion joint removed to allow for continuous joint seal installation

Additionally, the existing expansion joint seals had large areas of nosing failure with edge angles protruding up from the joint opening. All of the expansion joint seals in the garage were replaced with new more durable winged expansion joint seals. Approximately 4,600 meters of expansion joint seals were replaced throughout the garage.

5. HELICAL RAMPS

Each pair of spiral ramps is essentially an independent structure, isolated from the garage (Figure 8). The ramps are constructed by cantilevering four levels of sloped floor slabs from six central columns. A bonded overlay was installed over the structural ramp slab during a previous repair project. The ramps receive heavy applications of deicing salts, and no traffic coating was present. Untreated cracks and debonded overlay allowed chloride and moisture exposure to the embedded reinforcement, leading to concrete deterioration, especially at the joint between the ramps and the parking deck (Figure 9). The deterioration at the joints required shoring of the slab during reconstruction of the joint where the bearing plate was cleaned and coated with corrosion-inhibiting coating and reinforcement with complete section loss was replaced with new epoxy-coated reinforcement. Over 1,100 square meters of concrete repairs on the top surface of the ramp slabs was performed with an additional 950 square meters of concrete repair on the underside of the ramps.

Figure 8: Helical ramp structure

Figure 9: Repair of deterioration of the underside of the ramp slab at the joint between the ramp and the parking deck

6. POST-TENSIONED COLUMN STRENGTHENING REPAIR

The 18.5 meters tall central columns are cantilevered from their foundations and are reinforced with three internal vertical button-head tendons, each consisting of 42-wires. The tendons resist the significant moment imposed on the column by the cantilevered ramp floors. During the initial condition assessment, 10 broken wires were observed protruding from the top of one column (Figure 10). Failure was caused by water intrusion at the stressing anchorage on the exposed top of the column. Considering the severe exposure conditions and high potential for further deterioration, the design team recommended that the column be strengthened to alleviate reliance on the original compromised post-tensioning for strength. This approach would prevent unexpected loss of use of a critical component of a heavily trafficked structure.

Figure 10: Failed post-tensioning wires erupted from top of a helical ramp column

The strengthening concept consisted of installing new vertical, draped, external post-tensioning (EPT) tendons on the subject column. The innovative detailing and implementation of the EPT alleviated the need to shore all of the supported floors of the ramp and avoided de-tensioning the existing tendons, thereby significantly reducing the schedule and cost, and utilized modern post-tensioning systems to elegantly provide a more resilient and robust structure.

The EPT design and installation for the cantilevered column provided a unique engineering and construction challenge. The design intent was to replace the original post-tensioning design force, almost 455 tons in the 185 cm by 107 cm column, using new vertical EPT. The work had to be completed without access to the interior tendons or column foundation, and while accommodating limitations of the existing structure. EPT would replace the remaining existing post-tensioning system, which was inaccessible inside the column section, prohibiting further evaluation, repair, protection, or other direct intervention.

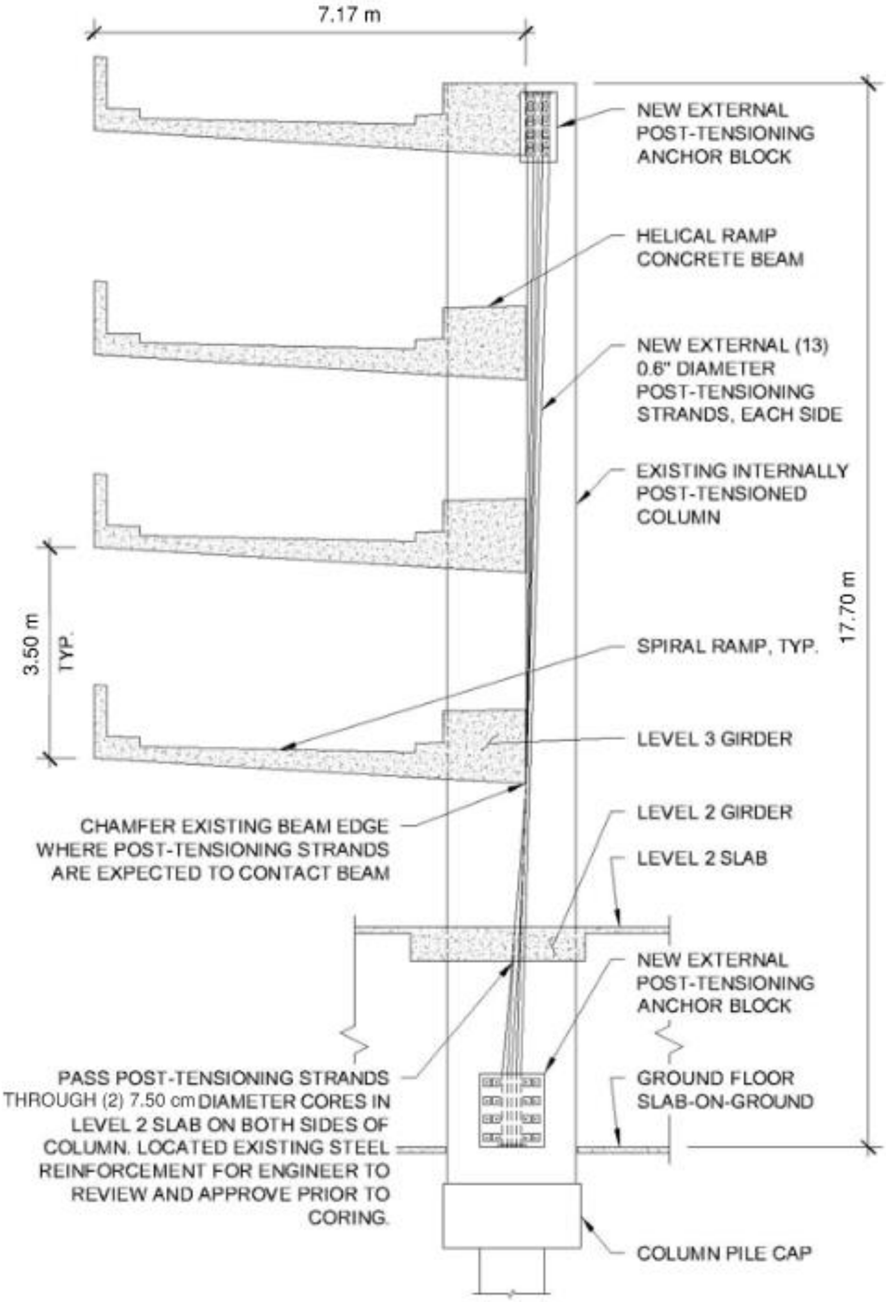

Figure 11: Elevation of the vertical external post-tensioning strengthening of a cantilever column

New vertical EPT tendons, each consisting of 13-15 mm diameter 7-wire strands, were mounted one per side to the long sides of the cantilevered column (Figure 11). The tendons were draped along the strong axis of the column to follow the drape of the original tendons. Each strand was stressed to 17,000 kg. New anchor blocks transfer all of the force from the new external tendons at the top (Figure 12) and bottom (Figure 13) of the column. The magnitude of force transfer required the use of 12-32 mm diameter, horizontal post-tensioned bars to clamp the anchor blocks to the existing column. Each bar was stressed to 25 tons. The bars were anchored on each side of the column. The final position of the post-tensioned bars was determined in the field after GPR scanning of the columns faces was complete. The new bars had to avoid the original column tendons and conventional reinforcement, while the new EPT tendons had to avoid the girder tendons and conventional reinforcement where is passes through Level 2.

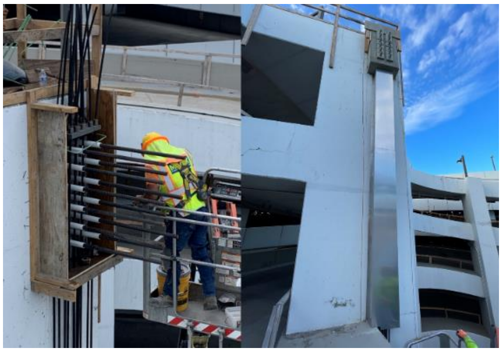

Figure 12: One new anchor block for the vertical external post-tensioning system at the top of the column

Figure 13: One new anchor block for the vertical external post-tensioning system at the base of the column

Working at the top of the column to install and stress the vertical EPT and top anchor blocks presented an access challenge during construction. Instead of constructing an expensive work platform, the contractor constructed a barrier and established fall arrest anchorages at the top of the column. They were then able to efficiently perform the required operations by using an aerial lift and working from the top column surface (Figure 14). After stressing the new EPT tendons, the broken wires at the top of the column were removed, the openings sealed, and the top of the column protected with the application of a coating system. The exposed tendons were protected with stainless steel sheet metal covers against UV degradation. The finished EPT column repair is shown in Figure 15.

Figure 14: Stressing of the vertical external post-tensioning tendons strengthening the cantilevered column

Figure 15: Finished EPT column repair (red arrows) with stainless steel cover protection against UV degradation

This construction project was successfully completed over a period of two years during the pandemic. The total cost of construction was $23 million (USD).

7. CONCLUSIONS

The large, aging, O'Hare International Airport post-tensioned concrete parking structure needed to be restored due to its extensive deterioration. Widespread damage caused by water intrusion, deicing salts, freeze-thaw exposure, reinforcement corrosion, and failed expansion joint seals was addressed through extensive concrete repairs, reinforcement replacement, selective restoration of button-head tendons and sheathing, reconstruction of deficient joint details, and replacement of expansion joint seals. Evaluation of the as-built structure and tested material properties allowed tendon-repair criteria to be refined, reducing unnecessary work while maintaining structural capacity and supporting the demanding construction schedule.

The external post-tensioning system installed on the helical-ramp column was the project's most distinctive structural repair approach. The repair system reduced reliance on inaccessible and deteriorated internal tendons without requiring de-tensioning of the existing post-tensioning or shoring of all supported ramp levels, thereby limiting cost, construction time, and operational disruption. Successful completion of the two-year rehabilitation program during the pandemic illustrates the importance of detailed assessment, adaptable repair design, field verification, and close coordination among the owner, engineer, and contractor when extending the service life of critical transportation infrastructure.

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