PARKING STRUCTURES CATEGORY

Baltimore Garage Restoration

DETROIT, MI

SUBMITTED BY PULLMAN SST, INC.

Fig. 1: Baltimore Parking Garage after repairs and showcasing a new exterior mural

OVERVIEW

Built in 1964, the Baltimore Garage is a 270,000 sf (25,084 sm) split-level button head post-tensioned (PT) garage located in Detroit's New Center neighborhood (Fig. 1). With recent revitalization of the area, including a new light rail system and construction of the Detroit Pistons practice facility, there was an influx of activity and demand for parking. New owners of the garage recognized the renewed demand and solicited design-build proposals to address years of deferred maintenance, improve the appearance, and quickly bring the restored parking to market.

The parking structure has five elevated PT concrete slabs, each approximately 60 ft (18 m) wide and 615 ft (188 m) long, with the length divided by a central expansion joint and two intermediate construction joints on each side of the expansion joint. Each slab is supported by 26 precast single-tee beams spaced at 25 ft (7.6 m). The 27 unbonded slab tendons consist of eight ¼-in (6.4 mm) diameter button headed wires, anchored at the ends of each slab and at the construction joints. Lack of maintenance at the construction joints and expansion joint allowed water and deicing salts into the slab concrete causing corrosion to unbonded tendon and anchorage hardware.

EXISTING CONDITION

The 52-year-old PT one-way slab and beam structure exhibited structural degradation, damage and under-reinforced elements, ranging in severity from immediate safety hazards to modest aesthetic concerns. The structure's PT concrete design included minimal bonded slab reinforcing steel to supplement the primary structural support provided by the slab PT tendon system, and increased the significance of the failures of the slab PT tendons. The conventionally reinforced concrete in the structure was also significantly deteriorated. The cast-in-place ramps were in poor condition with approximately 25% of the concrete floor surfaces having corrosion related damage. Extensive concrete spalling and exposed corroded reinforcing steel was visible at the underside of ramp slabs. The slab-on-grade levels were in fair condition, but some sections had up to 12 in (305 mm) of settlement. Widespread corrosion-induced deterioration was evident on concrete columns and haunches (Fig. 2). Column haunch deterioration reduced tee stem bearing at several locations that required several stories of shoring to grade. Corrosion of shallow reinforcing steel and abandoned embedded conduit caused less structurally significant damage, but produced unsightly near-surface concrete deterioration throughout the parking deck. Poor drainage and failed expansion joints and sealants significantly contributed to the concrete deterioration. Additional scope included lighting, signage, handrail replacement or repair, and upgrades to the finishes.

SLAB AS-BUILT CONDITION, ASSESSMENT AND DESIGN

The PT slabs were investigated using the drag-chain method to identify areas of concrete delamination, and scanned using ground penetrating radar to locate PT tendons. Unsound concrete regions were excavated for inspection, and it was discovered that tendons were frequently severely corroded at, or near, the end and intermediate anchorages. Section loss of each wire in a tendon was measured, and the in-situ tension in each wire was evaluated using the screwdriver penetration testing method.

The assessment, conducted simultaneously with initial repair construction, identified a much larger number of severely corroded tendons than indicated by the preliminary visual assessment (Fig. 3). Initial structural analysis also indicated less 'add tendon' reinforcing of the end spans than provided by current design practice. This condition increased the number of slab PT repairs.

To develop an economic repair plan (as construction was continuing), the slab concrete was cored and tested to determine the in-situ concrete compressive strength instead of using assumed values. Then, an elasto-plastic finite element analysis was conducted for the slab. This advanced analysis utilized moment redistribution within the indeterminate structure, resulting in a more accurate (higher) calculated capacity of the structural system than provided by typical simplified elastic examination methods. Based on the results from the advanced investigation, 234 critical corroded tendon locations in the slabs were repaired to provide sufficient capacity to support the required loads (Fig. 4). This more precise repair plan saved the owner almost US $1.2 million.

SINGLE-TEE BEAM AS-BUILT CONDITION, ASSESSMENT AND DESIGN

A total of approximately 130 precast single-tee beams are used to support the five elevated parking slabs. These beams are typically reinforced with eight ½-in (12.7 mm) diameter straight bonded prestressed strands and two draped twenty-wire unbonded post-tensioning tendons. The unbonded PT tendons exit the beam ends above the beam flange (within the concrete topping), where they connect to threaded anchorage rods that extend through the reinforced concrete columns to anchor at the outer face of the column. This anchorage system allows negative bending moment to develop at beam ends and provides structural integrity at the beam-to-column connections. The unbonded tendon ends and anchorage rods at the beam ends were encased within a shallow grout pocket, which were typically found to be cracked and debonded from the substrate (Fig. 5).

Unsound grout pockets in the beams were opened for inspection, and the unbonded wires were often found to be severely corroded, with a large proportion of wires completely failed. In-situ deflections of the beams were measured to correlate the condition of the tendons to the measured deflections of the beams. Based on the developed correlation, sound grout pockets at beams that exhibited a measured deflection exceeding the developed critical deflection threshold were opened for inspection, as well as beams that were next to slab drains (i.e. likely often exposed to ponding water), and beams that were located to adjacent distress. As a result, emergency shoring was provided for 20 beams and a total of 32 beams were repaired due to significant tendon section loss. The beam repair design was subject to multiple constraints, including structural integrity requirements at beam-column connections, fire-protection, and construction accessibility

Fig. 2: Existing condition discovered at an interior column

Fig. 3: Many beams were observed to have completely corroded through tendons

Fig. 4: Placement of new PT anchors

Fig. 5: (a) Many grout pockets on the roof were delaminated and some had vegetation growing, and (b) Grout pocket after concrete removal and cleaning

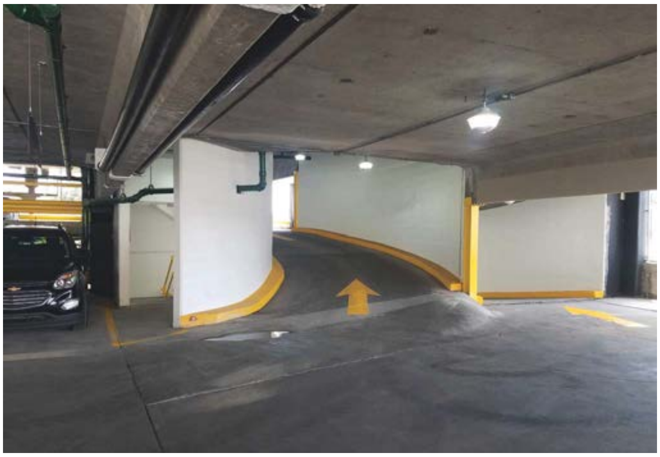

Fig. 7: Ramp and staircase area at end of construction

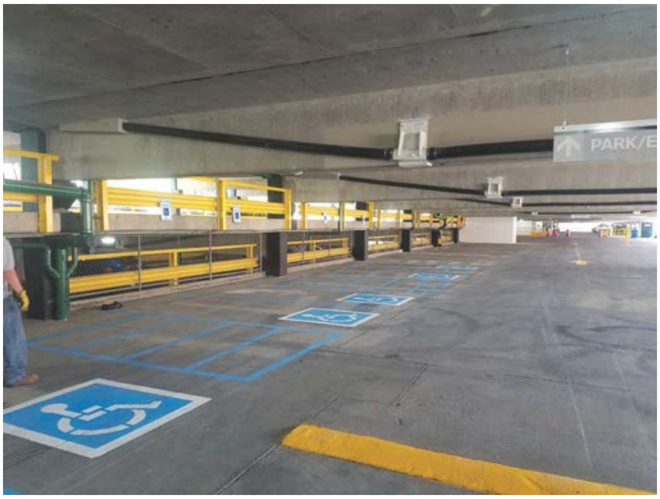

Fig. 8: Completed repairs to beams and columns, updated drainage system, and painting observed during final project walkthrough

constraints, along with financial and scheduling concerns. Evaluating many repair options, it was decided to abandon the existing failed tendons and replace them with two external draped tendons (each consisting of four 0.6-in [15.2 mm] diameter strands) placed symmetrically on both sides of the beam web. The new external tendons were connected to the existing threaded anchorage rods and post-tensioned from the top side (Fig. 6). The external tendons were also embedded in HDPE conduits that were fully grouted to comply with fire-resistance requirements. To further extend the life of the beams and structure, the water management system was repaired to ensure no standing water would occur on the concrete deck. To protect the existing and newly installed PT tendons, waterproof membranes were installed over anchorage zones.

Fig. 6: External PT beam repair prior to running tendons through conduit

DESIGN-BUILD SUCCESS

The Baltimore Garage is a showcase of what the design-build process can accomplish when the team collaborates effectively (Fig. 7 and 8). Upon award of the project, construction started concurrently with the design phase. The design-build team successfully displayed the ability to provide turnkey engineering support using the elasto-plastic finite element analysis to determine the minimum number of repairs needed to sufficiently support the deck. This process uncovered the need for over double the amount of PT slab and beam repairs than originally anticipated; however, it only added six weeks to the project. ■

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