Fountain View on the Plaza Parking Garages' Structural Strengthening and Concrete Repair and Protection

Fountain View on the Plaza in Kansas City, MO, includes two parking garages: Garage A and Garage B. Constructed in 1999, the garages are free-standing, four-story, open parking structures. Garage A is an L-shaped structure accommodating 406 cars. Garage B is a rectangular-shaped structure accommodating 248 cars.

The suspended parking decks of both garages are constructed of nominal 6.5 in. (16.5 cm) thick, two-way, cast-in-place, post-tensioned (PT) concrete flat plates (the slabs are supported directly by columns without beams between the columns). The slabs are supported on 16 in. (40.6 cm) diameter round or 16 in. (40.6 cm) square reinforced concrete columns. The slabs are PT with unbonded tendons. In one direction, the tendons are banded (closely spaced over a width of several inches) along the column lines; in the perpendicular direction, the tendons are uniformly spaced along the deck.

The suspended parking deck slabs exhibited numerous signs of distress, deterioration, and other conditions of concern to varying degrees, such as:

- Partial-depth cracks in the top of the slabs;
- Failed previous concrete repairs;
- Cracking and spalling at slab edges adjacent to banded tendons;
- Efflorescence and rust staining at grout pockets over tendon anchorages;
- Spalled and delaminated concrete on the topside and underside of the slabs; and
- Readily visible downward profile of the slabs at or near midspan.

Fig. 1: Load testing of slab using hydraulic jacks and steel frame to apply the loads. Note the computers acquiring data

The owner retained an engineering consulting firm to assess the structural integrity and condition of the suspended parking deck slabs, to identify the cause(s) of distress and deterioration, to identify remedial work necessary to repair existing distress and deterioration, and to correct structural and durability deficiencies of the suspended parking deck slabs.

In-Depth Field Investigation

The investigation to determine the condition of the PT concrete slabs included:

1. Surveying the condition of the topside and underside of the suspended parking decks to document the approximate location and extent of distress and deterioration;
2. Conducting optical level surveys of selected bays to estimate slab deflections (offsets); and
3. Using ground penetration radar (GPR) testing on the top surface of most of the garage decks to identify the as-built location of PT tendons and reinforcing bars and to measure the slab thickness. The GPR test results revealed that the uniform PT tendons were typically much further below the top of the slab than specified in the original construction documents.

Structural Evaluation

The structural evaluation included a thorough analysis and capacity check of the parking decks. The as-built slab thicknesses and locations of tendons (layout and depth) collected during the field investigation were used for a more accurate evaluation of the response of the PT slab system. The structural evaluation revealed the following structural deficiencies:

- The low placement of the uniform tendons and mild steel at columns significantly reduced the

flexural and punching shear capacities of the slab at many locations;
- The low placement of the uniform tendons and the mild steel caused cracking around columns and cracking over banded tendons that extend between columns; and
- The low placement of uniform tendons caused excessive deflection of the slabs at many locations.

In-Place Evaluation of Structural Strengthening Options

The structural analyses showed that, due to the low placement of the tendons and mild steel reinforcement, several regions of the slab near columns and slab/column intersections did not have adequate structural capacities for bending (flexure) and punching shear. Two options were considered to address these deficiencies:

- Option 1: Use of a concrete fiber-reinforced polymer (CFRP) strengthening system, externally bonded to the slab topside at areas adjacent to the columns to increase the flexural and punching shear capacity of the slabs. Recent research has shown that CFRP flexural strengthening can also increase, to a limited extent, the punching shear capacity of concrete slabs; and
- Option 2: Enlargement of the punching shear area of the slabs around the columns using concrete shear collars. The shear collars also reduce the bending stresses by reducing the clear span of the slab.

Before making the final selection of the most suitable option, mock-ups of both options were constructed and tested to confirm their effectiveness.

The load test objective was to demonstrate the feasibility of Option 1 to effectively increase the structural capacity of the slabs. A garage area showing typical overstresses (25% for flexural capacity and 30% for punching shear capacity) was selected to test both options. The load test was designed to simulate the stress condition caused by the uniformly distributed self weight and vehicular traffic load. The test loads were generated by four hydraulic jacks controlled by manual pumps, which applied the load to the slab through a steel frame (Fig. 1) and reacted against the floors above. Several sensors were connected to a computer and installed under the slab to monitor displacements and deformations of the slab during the load tests (Fig. 2).

Load testing of Option 2 was conducted first. The test simulated the presence of a shear collar using shoring posts. The load test of Option 1 occurred after installing CFRP laminates in the mock-up area. The test results demonstrated the effectiveness of Option 1. Therefore, this option was selected to strengthen areas with typical overstresses. For areas with larger overstresses, Option 2 or a combination of Options 1 and 2 were used to strengthen the slab.

Fig. 2: Underside of test slab showing sensors during load test of Option 2. Shoring was used as a safety measure (it was not in contact with the slab bottom)

Fig. 3: Slab underside strengthened with CFRP laminates

Structural Strengthening

The work began with flexural strengthening of negative bending moment regions (slab topside near columns) where the capacity was lower than required. This strengthening, at areas adjacent to interior and exterior columns, was accomplished with CFRP systems. Near-surface-mounted (NSM) CFRP bars embedded in grooves cut in the slab were used at areas where perpendicular tendons were deep enough to preclude damage when cutting the grooves in the slab. CFRP laminates were used where there was a risk of cutting tendons. In the latter case, the concrete surface was scarified to a depth of approximately 1/8 in. (0.3 cm) to recess the laminate embedded below the slab and thereby minimize the risk of damage due to wheel loads.

Flexural strengthening of positive moment regions (slab underside) was also undertaken where the slab strength was inadequate due to the incorrect placement of the tendons. This strengthening was accomplished with a CFRP laminate system placed on the bottom of the slab (Fig. 3).

There was also a need for punching shear strengthening of slab/column intersections. At interior columns, this strengthening was accomplished by installing shear collars. Shear collars strengthened the exterior/ramp edge columns with three-sided corbels doweled into the column faces (Fig. 4) or with new spandrel beams connected to the existing columns.

Concrete Repair and Protection

In addition to the structural strengthening work, several areas of the garage required concrete repair and protection work, including:

1. Repairing delaminated concrete on the topside of the slab over corroded reinforcement;
2. Repairing hollow-sounding areas of concrete and previous repairs on the underside of the slab below the banded tendons where the concrete/repairs were cracked;
3. Repairing areas of slab with horizontal cracks on the exposed slab edge (Fig. 5);
4. Repairing stressing pockets where the grout-fill had gaps and/or showed signs of leakage, and filling grout pockets that were ungrouted;
5. Injecting epoxy into column cracks resulting from the restraint of slab post-tensioning and other volume changes;
6. Repairing spalled column tops;
7. Routing and filling cracks in the topside of the slab with methacrylate resin;
8. Applying vehicular traffic-bearing waterproofing on the elevated slabs. The waterproofing was extended down the vertical faces of the exposed slab edges to provide additional protection to the ends of the tendons; and
9. Applying penetrating sealer to all the slabs-on-ground.

Fig. 4: Headed bars used in the construction of external shear collars

Fig. 5: Cracking on slab edge shown before and after repair

Fig. 6: Complete structure

Load Testing is an Important Tool

This project demonstrated the value of load testing as an important tool in rehabilitation projects. The thorough testing/evaluation process was a critical component to the success of the application. The selected solution for strengthening of slabs with deficient flexural and punching shear capacities is one of the first applications of this kind to be implemented in the field. As a result, the structure was strengthened in a manner that met both functional requirements and the owner's cost considerations.

Fountain View on the Plaza Parking Garage

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Beachwood, OH

BASF Building Systems
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