

# 100 South Gay Street Parking Garage Rehabilitation

By Robert Wychulis

The Inner Harbor Garage is a nine-level parking facility that provides parking for approximately 1300 vehicles. The parking garage is located in Baltimore, Maryland. The lowest parking level, Level 1, is a slab-on-grade reinforced with welded wire fabric. The elevated parking levels, 2 to 9, consist of both concrete precast single tee beams and two-way concrete joist slabs, or waffle slabs. All of the waffle slab concrete was cast-in-place, typically spanning 32 ft (9.75 m) between concrete columns. Spacing of the joists is typically 3 ft (0.91 m) on center each way. All waffle slabs are reinforced with conventional reinforcing bars and are not post-tensioned. The design live load for the elevated parking decks, as stated on the original structural design drawings, is 75 lb/ft<sup>2</sup> (365 kg/m<sup>2</sup>). The concrete cover over reinforcing bars specified for the elevated parking decks and walls is 3/4 in. (1.9 cm), and 1-1/2 in. (3.8 cm) for the beams. None of the reinforcing bars were specified to be epoxy coated. The cast-in-place concrete used to construct the garage is normalweight concrete with a specified minimum compressive strength of 4000 psi (27.6 MPa). The total area of elevated parking slab is 372,800 ft<sup>2</sup> (34,635 m<sup>2</sup>).

The facility was constructed in two distinct phases. The original structure was approximately 120 x 200 ft (37 x 61 m) in size with eight elevated parking decks. The structural system used in construction of the original garage was single precast tee sections 9 ft wide x 60 ft long (2.7 m wide by 18.7 m long) covered with a cast-in-place topping slab. The ground level of the original structure was an asphalt topping over a concrete slab-on-grade, or possibly an on-grade asphalt parking surface. The structural drawings of the original facility were not obtained so the actual age of the older portion of the garage is unknown.

In 1980 the facility was enlarged in both the south and west directions from a 120 x 200 ft (37 x 61 m) garage to 175 x 275 ft (53 x 84 m) in size. The addition was built using concrete waffle slab or two-way joist construction. The height of the addition matched that of the original structure. Elevated decks in the two structures were separated by expansion joints.

## Parking Garage Deterioration

The elevated parking decks were sounded via chain drag and mason's hammer to detect

delamination of concrete due to corrosion of embedded reinforcing steel. Delamination of the top surface within the garage due to corrosion of the reinforcing steel was documented in approximately 20% of the total top surface area of the elevated parking decks in both garages. In the precast single tee garage, approximately 9% of the elevated decks were delaminated, whereas in the waffle slab garage, 30% of the elevated decks were delaminated. The amount of concrete delaminations was larger in the waffle slab garage due to the greater abundance of reinforcing steel in the decks. Concrete delaminations typically occur when embedded reinforcing steel corrodes and exerts an expansive force on the concrete due to a volume increase that takes place as iron is converted to iron oxide. The expansive force causes horizontal cracking at the level of the reinforcing bar. Repair areas were estimated by sounding the decks with a chain and mason's hammer, marking repair boundaries in conformance with recommendations from the International Concrete Repair Institute (ICRI).

## Original Structure Elevated Decks, Precast Tees

### Top Surface Delaminations

The cast-in-place topping poured over the precast single tees in the original facility would typically be reinforced with only welded wire fabric. As a result, delamination of the topping slab due



Top surface concrete delaminations and spalls in the waffle slab portion of the garage. The top mat of reinforcing bars can be seen in the spalled areas.

to corrosion of embedded reinforcing steel was not as concentrated as it was in the waffle slabs. Due to the small cross-sectional area, welded wire fabric does not normally cause extensive concrete deterioration in a corrosive environment. Isolated areas of the topping have cracked and debonded from the structural precast single tee beams. In some locations the debonded topping extends from one end of the tee beam to the other.

### Top Surface Cracking

The topping slab is, however, cracked at each joint between single tees along the full length of the joint. At the top deck and isolated joints throughout the garage, the cracks have been routed and sealed. The majority of the sealed cracks throughout the garage have debonded or split opening the cracks. Open cracks and debonded sealed cracks allow water to pass through the joint between single tees staining the soffit flanges.

### Flange Shear Connectors

At various locations along the joint between the single tees, embedded plates were cast into the tee flanges to allow welding of the flanges for shear transfer across the flange edges. This embedded steel is subject to corrosion due to the water infiltration through open cracks in the topping slab above the joints between single tees. Delamination of single tee flange concrete around these plates was observed. Failure of the connectors does not allow for proper load distribution between two adjacent tee beams.

### Soffit Delaminations

Soffit delaminations can be found typically at the inverted tee concrete girders. These girders support the single precast tee sections over the turning drive lanes where columns would interfere with the traffic flow. Large delaminations were observed at the bottom of the girders where a large amount of reinforcing steel exists within the girder. Water leaking from the open cracks above in the topping slab has caused the bottom bars of the girders to deteriorate.

## Garage Addition Elevated Decks, Waffle Slab

### Top Surface Delaminations

The waffle slab construction used in the garage addition is reinforced with uncoated reinforcing bars and is, therefore, subject to deterioration due to corrosion of the embedded reinforcing steel. Large delaminations can be found throughout the garage. In some cases the delaminations extend for several bays, or 12 to 15 parking stalls in one area. The lower levels of the garage have greater corrosion-related deterioration when compared with the upper levels. In a large garage such as 100 South Gay Street, the parking turnover



*(Above and below) Large repair areas in the waffle slab portion of the garage prior to the placement of the new concrete. The wood forms are the bottom portion of the dome area of the waffle slab.*



rate is very high on the lower levels. More cars using the parking stalls allow for greater amounts of deicing salts to attack the concrete. Higher levels within the garage had lesser quantities of delaminations. For example, the lower four levels contain an average of 35% delamination in the waffle area top surface, whereas the upper levels average 15% concrete deterioration.

### Top Surface Cracking

Throughout the waffle garage, minor cracking was observed. All of the construction joints were not sealed. The majority of cracking on the top surface is located within delaminated concrete. Isolated cracking was also apparent around columns where the concrete has not yet delaminated. Open cracks and construction joints allow salt-laden water to penetrate easily



through the slab. As the saltwater passes through the concrete, the salts corrode the embedded unprotected steel reinforcement.

### Soffit Delaminations

Delamination of soffit concrete is caused by corrosion of the bottom reinforcing bars in the elevated parking decks. Water penetration through unsealed top surface cracks and failed expansion joints allow the water and salts to reach the bottom mat reinforcing bars. The delaminations are common to almost all of the construction joints. Small isolated flat slab portions of the soffit were delaminated. Primarily the deterioration has occurred on the bottom portions of the ribs at the construction joints.



*A close-up picture of an existing reinforcing bar spliced with new epoxy-coated bars. Note the section loss on the existing bar due to corrosion.*



*Newly placed concrete in repair areas and along the existing expansion joint. The block out seen in the picture is for the wings of the new expansion joint seal.*

### Expansion Joints

Each level has an expansion joint separating the two garage types. All of the expansion joints are in poor condition and appear to be leaking. The expansion joint seals that bridge the waffle slab and precast tees have become loose in some areas and have an abrupt transition from one structure to the other. Deterioration in the joint seals was observed in the joints between two of the waffle slabs as well.

### Repairs and Construction

#### General

All of the deficiencies listed previously were repaired by a specialty repair contractor. Demolition of the concrete was completed by jackhammering. The repairs were completed within enclosed phase areas of no more than 260 parking spaces or 20% of the garage capacity. The contractor began the concrete repairs on the roof waffle slab portion of the garage and worked downward. After all levels of the waffle slab were repaired, they began the concrete repairs on the roof level precast elements and also worked downward. New floor drains were installed in the phase areas as required to alleviate standing water. Overhead concrete repairs, such as waffle rib, flat slab, inverted tee beam, and signal tee stem repairs, were completed during the transition period between the placement of ready mix concrete and the membrane application. After all concrete repairs were completed and cured for a minimum of 28 days, a waterproofing membrane was applied to all of the elevated decks. The phase areas of the membrane application mirrored the same areas for the concrete repairs. Every top surface joint in the precast portion of the garage was routed and sealed prior to the membrane application. New steel brackets were installed at the expansion joints between the waffle slab and precast tee beams. The new brackets help stiffen the precast tee beam to minimize the live load deflection when a vehicle would drive from the stiffer waffle slab to the more dynamic tee beam.

#### Materials

All the new concrete placed in the repair areas was from a mixture proportion of 5000 psi (34.5 MPa) with a 0.4 maximum water-cement ratio ( $w/c$ ). Four gal./yd<sup>3</sup> (19.8 l/m<sup>3</sup>) of corrosion inhibitor was added to the mixture. Also added was 1 lb/yd<sup>3</sup> (0.6 kg/m<sup>3</sup>) of micro fibers to control shrinkage cracks during curing. New hot-dipped galvanized shear connectors were installed where existing connectors failed due to corrosion. All newly placed reinforcing bars were epoxy coated to replace deteriorated existing bars. The urethane membrane system applied has a minimum dry film thickness of 40 mils in the parking stalls and 52 mils in the drive lanes. All the precast

single tee beams were coated with flint aggregate for traction.

## Quantities and Schedule

During the bidding of the project, a total of six qualified concrete repair contractors were invited to submit pricing and scheduling. The contractor submitted an initial unit price bid of \$2,300,800 to be completed within 168 days. The next closest competitor submitted a unit price of \$2,223,773 and 364 days. The contractor completed the entire restoration project on time. The following is a list of the repairs completed with their associated quantities:

Top surface partial depth repairs—15,500 ft<sup>2</sup>  
(1440 m<sup>2</sup>)

Waffle dome repairs—44,800 ft<sup>2</sup> (4160 m<sup>2</sup>)

New floor drains—58 each

Floor drain piping—1600 linear ft  
(490 linear m)

Precast shear connectors—405 each

Topping slab repair—17,000 ft<sup>2</sup> (1580 m<sup>2</sup>)

Waffle rib repairs—420 LF (130 linear m)

Slab and beam soffit repairs—985 ft<sup>2</sup> (91 m<sup>2</sup>)

Wall and column repairs—200 ft<sup>2</sup> (19 m<sup>2</sup>)

Rout and seal cracks—35,600 linear ft  
(10,850 linear m)

Expansion joint installation—1500 linear ft  
(460 linear m)

Expansion joint brackets—64 each

Membrane application—372,800 ft<sup>2</sup> (34,635 m<sup>2</sup>)

As one can see, the sheer volume of the repair made communication between all parties critical, and the project was completed on time and within budget.

## 100 South Gay Street Parking Garage

### Owner

PDL Pratt Associates, LLC  
Greenwich, Connecticut

**Project Engineer/Designer**  
Smislova, Kehnemui & Associates, P.A.  
Rockville, Maryland

**Repair Contractor**  
Restoration East, Inc.  
Baltimore, Maryland

**Material Suppliers**  
LaFarge  
Towson, Maryland

Construction Specialties Group  
Springfield, Virginia



*Robert Wychulis, Project Manager, Smislova, Kehnemui & Associates, P.A., is a registered professional engineer in the state of Maryland. He received his master's of science in structural engineering in 1998 from the University of Virginia and a bachelor's of science in 1992 from Pennsylvania State University.*



*This is a picture of the finished product in the garage. The waterproofing membrane has sealed and protected the new repairs and original concrete from additional chlorides entering the slabs.*