# 400 North Capitol Street Parking Garage Rehabilitation

**By Robert Wychulis**

The 400 North Capitol Street parking garage is a four-level, below-grade facility constructed in 1973, located in Washington, DC. The lowest parking level, Third Cellar, is primarily a slab-on-grade reinforced with welded wire fabric. An 8.0 ft (2.4 m) wide strip of mat slab reinforced concrete is located along two sides of the foundation walls of the Third Cellar level. The elevated parking levels, Ground Floor, First, and Second Cellars, consist of concrete flat slabs. All of the concrete was cast-in-place, typically spanning 21 ft (6.4 m) between concrete columns. The flat slab system is 7 in. (18 cm) thick. A service loading dock is located in the rear portion of the garage, not connected to the garage. The loading dock slab is 10 in. (25 cm) thick. All 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$^2$ (3.6 kPa), and 300 lb/ft$^2$ (14.4 kPa) at the service loading dock. All the design loads meet or exceed the BOCA code requirements for live load capacity in parking facilities both currently and at the time of construction. The concrete cover over reinforcing bars specified for the elevated parking decks and walls is 3/4 in. (1.9 cm). None of the reinforcing bars were specified to be epoxy coated. The concrete used to construct the garage is normalweight concrete with a specified minimum compressive strength of 3500 psi (24 MPa). The total area of elevated parking slab is 212,900 ft$^2$ (19,800 m$^2$).

There is a box culvert located on the Third Cellar level. The bottom of the culvert sits on grade, is two bays wide, and runs along two sides of the garage. The 12 in. (30.5 cm) thick top slab of the culvert supports a portion of the Second Cellar level parking. The inside of the culvert was inaccessible. The condition of the culvert soffit concrete was, therefore, unknown. Due to the inaccessibility of the culvert, the existing structural capacity of the culvert slab and the extent of corrosion damage could not be determined. Only the top surface concrete located on the Second Cellar level above the culvert was surveyed and documented. Because of the inaccessibility of the culvert, repairs were begun on the top surface concrete first.

*Typical top surface delamination with exposed reinforcing bars*

## Condition Survey of Garage

### Top Surface Delaminations

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 reinforcing bars was documented in approximately 28% of the total top surface area of the elevated parking decks. Concrete delaminations typically occur when embedded reinforcing steel corrodes and exerts an expansive force on the concrete due to a volume increase, which takes place as iron is converted to iron oxide. The expansive force causes horizontal cracking at the level of the reinforcing bar. The slab-on-grade areas were, as expected, found to be sound. The 8 ft (2.4 m) wide section of mat slab was sounded on the Third Cellar level. Minimal concrete delaminations were found on the reinforced foundation mat.

Approximately 9 years ago, concrete patching was conducted in the garage. The majority of delaminated concrete, both original and repair concrete, found in the garage was visually apparent; however, large areas of delaminated concrete were also detected only by sounding the concrete. Repair areas were estimated by sounding the decks with a chain and mason's hammer, temporarily marking repair boundaries in conformance with recommendations from the International Concrete Repair Institute, and measuring the areas inside the markings.

### Top Surface Cracks

Throughout the garage, numerous top surface cracks were found in many areas of the garage. The

past garage repair included routing and sealing open concrete cracks. Top surface cracking either continued over the last 9 years or all cracks were not sealed during the repair. Generally, the crack sealant was in fair to poor condition. Splits and debonding of the existing caulk were typically apparent. Construction joints in the elevated parking decks were found to be unsealed. Typically, the cracks were more closely spaced at the negative moment areas in the slabs. Negative moment areas are located at the slab areas around supports such as columns, beams, and walls. Cracks propagate in all directions away from the columns and longer cracks extend from column to column. Open cracks and construction joints allowed salt-laden water to penetrate easily through the slab. As the saltwater passed through the concrete, the salts corroded the embedded, unprotected steel reinforcement. Water leakage can be seen throughout the garage on the soffits, or ceilings, of the slabs. The quantity of cracking noted in the quantity summary reflects only the estimated quantity for cracks >1/16 in. (0.16 cm) width as all smaller cracks would be bridged by the waterproof membrane.

### Soffit Delaminations

Delamination of the soffit concrete was caused by corrosion of the bottom mat of reinforcing steel in the elevated parking decks. Water penetration through unsealed top surface cracks allowed water and salts to reach the bottom mat reinforcing bars. Delamination of the soffit concrete was found to cover 10% of the elevated deck areas.

The past soffit concrete repairs can be seen extensively throughout the garage. Typically, almost every bay has soffit repairs or new delaminations. The soffit patching conducted in the past was not in conformance with the proper repair procedures that are being used today. Apparently, the contractor just removed the surface delamination and applied a trowel-applied material back in the void over an unsound substrate. A few important steps were not completed in the soffit repairs such as not properly exposing and cleaning the reinforcing steel and leaving feathered edges around the patch perimeters. A portion of the repair area was easily removed to reveal the improper techniques used in the past.

### Floor Drain Installation

After observing the garage after rain and snow storms, poor drainage of top surface water was apparent throughout the structure. In many areas of the garage, low spots were observed in the center of the bays, both drive lanes and parking stalls. These low spots often led to concrete deterioration as the standing water kept the concrete below saturated and exposed to large amounts of saltwater. Top surface cracking located within the low spots also allowed saltwater to easily penetrate into the slab. Large soffit delaminations were typically found under all low spots in the garage. Floor drains should be installed where these low spots are located.

*Typical top surface negative moment cracking around column due to low top surface steel location*

*Typical previously repaired soffit patch. Note the old patch was not properly repaired—the reinforcing bars were not undercut*

*Typical ponding of water at low spot in center of bay*

## Repairs and Construction

All of the deficiencies listed above were repaired by a specialty concrete repair contractor. Demolition of the concrete was completed with hydrodemolition. The repairs were completed within enclosed phase areas of no more than 200 parking spaces. The

contractor began the concrete repairs on the highest elevated slab level, Ground Floor Level.

During the first phase of the project, it was observed that the top mat of steel reinforcement was significantly lower in the slab than specified on the original structural drawings. The original drawings specified 3/4 in. (1.9 cm) cover over the top mat. It was observed that the top mat of steel had anywhere from 1 to 5 in. (2.5 to 12.7 cm) of cover.

The location of the top mat immediately caused structural concerns. The project engineers conducted a slab analysis to determine the severity of the misplaced bars. The slab was initially designed for 75 psf (3.6 kPa). The current BOCA code requires a minimum of 50 psf (2.4 kPa). The slab analysis applied the 50 psf (2.4 kPa) to the existing slab geometry and amount of reinforcing steel. The engineer then determined the maximum cover that can be provided to meet the current BOCA code live load requirements. A maximum cover of 2.75 in. (7.0 cm) was determined from the analysis.

The amount of full-depth repair areas within the garage grew significantly as a result of this deficiency. During hydrodemolition, undercutting the top mat No. 6 bars in both directions by 3/4 in. (1.9 cm) and providing 2.75 in. (7.0 cm) of cover left only 2 in. (5.1 cm) of concrete below the top mat. Such a thin amount of concrete could not be salvaged. In areas where the top mat of steel had more than 2.75 in. (7.0 cm) of cover, the entire bar was disengaged from the slab and raised up to the point of 1.5 in. (3.8 cm) of cover. Due to the extensive amount of full-depth repair areas around the columns, a large number of lateral braces were required to shore the structural elements during the demolition.

Observing the location of the top mat of reinforcing during demolition answered questions such as why there was such extensive cracking in the negative moment areas (top surface of the slab) and ponding of water in almost every bay. The slab was deflecting and cracking until the top mat of bars engaged to resist the induced stress. Basically, the top 2.75 in. (7.0 cm) of the slab was unreinforced, free to deflect and crack. During the repairs within the garage, the majority of the top mat was around the 2.75 in. (7.0 cm) level of cover. If the BOCA code did not change the live load requirement from 75 psf (3.6 kPa) to 50 psf (2.4 kPa) over the decades, the large garage repair could have been a large garage replacement program.

*Top mat of reinforcing steel with 4-3/4 in. of cover. Note the top bar was actually tied to the bottom mat of steel*

*Full depth repair. Note the depth of the top mat located at the left side of the picture. The top mat is depressed to mid-depth of the slab*

*Full depth repair area. Note the deflected top bars, from original concrete pumping operations and additional epoxy coated bars were installed due to the lack of amount of bottom steel*

*Full-depth repair at a crane opening*

New floor drains were installed in the phase areas as required to alleviate standing water. Due to the large amount of concrete removed, entire bays were resloped to new floor drains. All of the concrete repairs were completed prior to the application of a corrosion inhibitor treatment (CIT) and a waterproofing membrane system. After all concrete repairs were completed and cured for a minimum of 28 days, the CIT was applied just prior to the waterproofing membrane on all elevated decks. The phase areas of the CIT and membrane application mirrored the same areas as the concrete repairs.

## Materials

All of the new concrete placed in the repair areas had the following mixture design: 5000 psi (34.5 MPa) with a 0.4 maximum water-cement ratio. Four gal./yd$^3$ of (19.8 L/m$^3$) of corrosion inhibitor was added to the mixture. One lb/yd$^3$ of (0.59 kg/m$^3$) of microfibers was also added to the mixture to control shrinkage cracks during curing. All newly placed reinforcing bars were epoxy coated to replace deteriorated existing bars. A urethane membrane system was also installed at this point. The system applied has a minimum dry film thickness of 40 mils in the parking stalls and 52 mils in the drive lanes. All of the drive lane ramps were seeded with flint aggregate for traction.

## Quantities and Schedule

The original contract was bid at $2,528,230. The project was completed on July 23, 2003, with a final cost of $3,787,511.75. The increase in the project cost was due to the unknown location of the top mat of reinforcing, substantially increasing the quantity of full-depth repairs. The following is a list of the repairs completed with their associated quantities:

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| Top Surface Partial Depth Repairs | 21,887 ft$^2$ (2033 m$^2$) |
| Full-Depth Repairs | 54,570 ft$^2$ (5070 m$^2$) |
| Soffit Repairs | 330 ft$^2$ (31 m$^2$) |
| Plaza Soffit Repairs | 90 ft$^2$ (8.4 m$^2$) |
| Wall and Column Repairs | 50 ft$^2$ (4.6 m$^2$) |
| Foundation Wall Crack Repairs | 250 linear ft (76 m) |
| Rout and Seal Top Surface Cracks | 25,000 linear ft (7620 m) |
| Waterproofing Membrane Application | 212,900 ft$^2$ (19,779 m$^2$) |
| Floor Drain Installation | 173 EA |
| Floor Drain Piping | 7540 linear ft (2298 m) |
| CIT Application | 212,900 ft$^2$ (19,779 m$^2$) |
| Lateral Brace Supports | 152 EA |
| Corrective Bar Installation | 1532 lb (695 kg) |

This project was quite unique due to the unknown complications caused by the depressed location of the top mat of reinforcing steel bars. The original repair project cost increased 50% but could have escalated to a full slab replacement if the top mat of steel was 1/4 in. (0.6 cm) lower on average in the garage. It is also notable that the building owners remained engaged and informed, and they ultimately understood the reasons for the project cost overrun. Options such as leaving a portion of the garage to be repaired in the future to meet the original budget were explored, but after discussion and evaluation of the options, the funds were allocated and the project was completed.

*The finished garage. The battleship gray waterproofing membrane has sealed and protected the new repairs and original concrete from additional chlorides entering the slabs. The entire garage was painted and new lighting was installed*

## 400 North Capitol Street Parking Garage

**Owner**
Trammell Crow Company
*Washington, DC*

**Project Engineer**
Smislova, Kehnemui & Associates
*Rockville, Maryland*

**Repair Contractor**
Restoration East, LLC
*Baltimore, Maryland*

**Material Suppliers**
Aggregate Industries
*Greenbelt, Maryland*

Construction Specialties Group, Inc.
*Manassas Park, Virginia*

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