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Corrosion of Galvanized Steel Floor Slab Reinforcement

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ABSTRACT

A 17-year-old parking facility in metropolitan Detroit is experiencing floor slab deterioration. An investigation was performed to determine the nature and extent of deterioration and identify probable restoration alternatives. The investigation involved visual observation, materials testing, a chain drag delamination survey, and determination of concrete cover to slab reinforcement. The structural frame consists of a 12-in.-thick flat plate floor slab system spanning in two directions supported by columns approximately 30 ft on centers. Floor slab reinforcement in the top and bottom slab sections are galvanized reinforcing steel bars. The floor slab and ceiling deteriorated from corrosion-induced spalling. Chain drag and coring surveys indicate that approximately 26 percent of exposed floor surfaces and 5 percent of ceiling surfaces are delaminated or spalled to a depth of about 2 in. Clear concrete cover is generally good, with a low cover of about 1.25 in. and an average cover of about 2.25 in. The chloride content of the concrete, determined within the top 3 in. of the slab, ranged from 25.2 to 8.5 lb/yd^3 of concrete. The average concrete compressive strength of the floor slab is about 5,670 psi. The average air content of the concrete was determined to be 2.3 percent. Slab concrete pH ranges from 9.93 at the deck surface to 10.82 at the 3-in. depth. Reinforcement section loss of upwards to 20 percent was noted at isolated areas.

The objective of this paper is to provide a report on the field performance of a 17-year-old parking structure with galvanized floor slab reinforcement.

The case study is for the Kennedy Square Parking Garage in Detroit. The parking facility, built in 1965, consists of a slab on grade and two supported levels of parking. The parking levels are located directly beneath a pedestrian plaza, complete with plantings and a wading pool. The structural system for the supported level consists of a conventionally reinforced flat slab with drop panels and circular columns. The slab has galvanized steel reinforcing bars in the top and bottom mat of slab reinforcement. Typical slab reinforcement is shown in Figure 1.

Concern with the structure developed because of observed concrete spalling and cracking. An engineering investigation into the physical condition of the parking facility was completed in June 1982. The investigation objective was to determine the physical condition of the structures and to recommend appropriate repair procedures. The scope of the work included evaluating the parking facility through

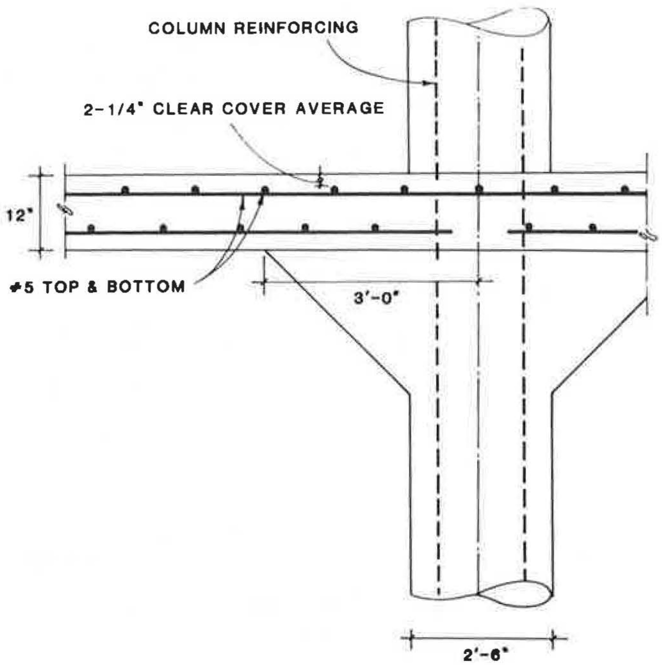

FIGURE 1 Floor slab section at column.

visual examination, nondestructive testing, and materials testing.

CONDITION APPRAISAL AND DISCUSSION

The condition appraisal of the structure was separated into three tasks: a visual examination; field surveys; and materials testing. A complete visual examination of all accessible floor slab surfaces, ramps, columns, and walls was performed. Materials testing involved chloride ion analysis, compressive strength testing, and determination of the air content of concrete. Field surveys consisted of taking pachometer readings and performing chain drag surveys.

Floor Slab Surface

Visual examination indicated that the floor slab was experiencing widespread spalling. A chain drag survey also indicated the presence of floor slab delaminations. Concrete cores were removed at selected locations to verify the chain drag survey results.

Spalls and delaminations were concentrated around columns and along column lines. The extent of surface delaminations determined were observed to range from several to hundreds of square feet and were typically 2 to 3 in. deep. Approximately 31,000 ft^2 (26 percent) of the supported floor surface was determined to be spalled or delaminated (see Figure 2, which is a field survey sheet).

Examination of the cores and open spalls indicated that much of the deterioration was caused by reinforcement corrosion. This corrosion had proceeded to the point of causing humps in the floor surface. Cores removed from the floor slab exhibited fracture planes 2 to 3 in. beneath the exposed surface. At isolated locations, 20 percent section loss of embedded reinforcing steel was observed. The most significant section loss was observed in the column capitol region.

Patterned floor slab cracking was frequently observed throughout the parking facility. The most common cracking was circumferential around the columns and radial extending out from column capitols. Random full-depth slab cracks were also frequently encountered, as were restraint cracks near perimeter walls and elevation breaks. Many of the surface cracks penetrated through the slab and caused significant salt contamination and leaching below.

Ceilings

The ceilings of this structure exhibited frequent full-depth leaking cracks, spalling, and delaminations. Delaminations ranged between 2 and 30 ft^2 in surface area and averaged between 1 and 2 in. in depth. The plaza level ceiling showed the most leaking cracks, as there are sidewalks and soil areas above. Spalls and delaminations frequently coincided with leaking construction joints or cracks.

Floor Slab Control and Construction Joints

Control and construction joints were often observed to be leaking. This contributed to corrosion of the

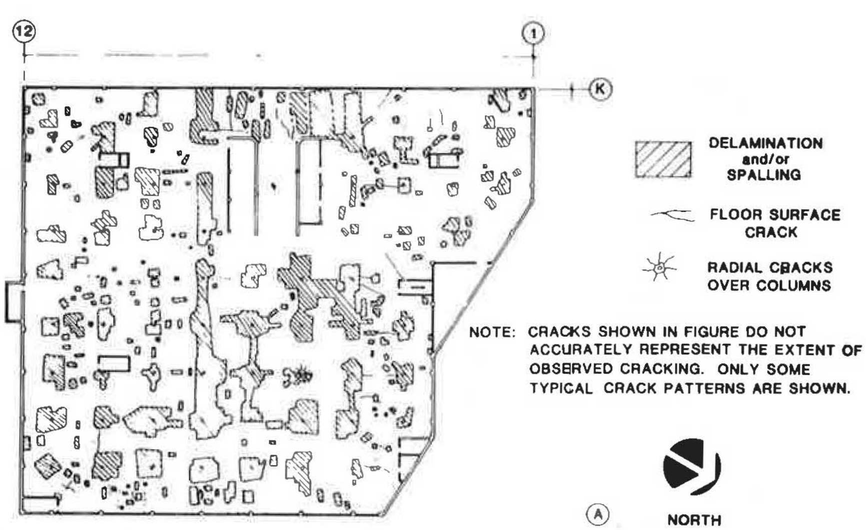

FIGURE 2 Second level plan view.

bottom mat of the floor slab reinforcement and subsequent delamination and spalling of the ceilings below. Ceiling repairs were estimated to be approximately 5 percent of the total surface area. There was no indication that these joints were previously sealed, and it is likely that normal concrete shrinkage and the lack of building expansion joints (coupled with considerable restraint from the perimeter walls) were the principle causes of crack movement and leaking.

Columns

The columns in this structure were in satisfactory condition. Occasional minor spalls and delaminations were noted above the floor surface. The columns did not appear significantly impaired, and observed spalls were usually less then several square feet in surface area and less than 2 in. deep.

RESULTS OF MATERIALS TESTING

Concrete Chloride Ion Analysis

Chloride sampling was performed at 17 locations throughout the structure. Samples were taken from random parking bays and drive lanes by using the dry (Roto hammer) sampling method. Test results indicated high concentrations of chloride within the first 3 in. of the concrete. Concentrations ranged from 25.2 lb/yd^3 of concrete in the top 1 in. to 12.4 lb/yd^3 of concrete at the 3-in. increment of the first supported tier.

Results from the second supported tier, or upper parking level, had somewhat lower chloride concentrations, ranging from 18.6 lb/yd^3 of concrete in the top 1 in. to 8.5 lb/yd^3 of concrete at the 3-in. increment. Results of chloride ion content testing are shown in Figure 3, which indicates significant chloride contamination of concrete at the level of reinforcing steel. However, the corrosion threshold level for galvanized reinforcement is not known. For plain black steel the threshold level is indicated to be 1.1 to 1.6 lb/yd^3 of concrete (1).

For cover measurements, pachometer readings were taken at 30 locations on each supported tier. Clear cover measured over the top reinforcing steel mat ranged from approximately 1.25 to 4 in. and the average concrete cover was determined to be approximately 2.25 in.

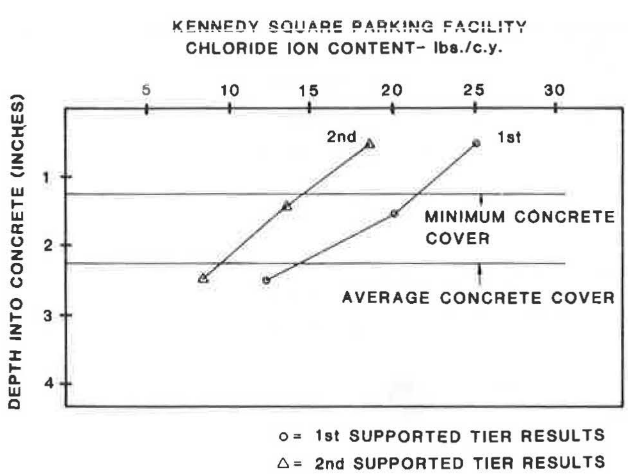

FIGURE 3 Chloride ion content versus depth into concrete.

Concrete Compressive Strength Testing

Compressive strength tests were performed on eight concrete core samples. Core compressive strengths ranged from approximately 4,500 to 6,600 psi. The average compressive strength, approximately 5,700 psi, was greater than the 3,000-psi specified design strength.

Determination of Air Content of Concrete

A microscopic examination of concrete core samples was performed to determine the air void characteristics of the concrete in accordance with ASTM C 457-80. Results of the examination indicated that the average air content of the concrete was approximately 2 to 3 percent. This value is significantly below the acceptable range of 4 to 8 percent, which indicates that the concrete is only marginally durable against freeze-thaw exposure in the presence of deicing agents.

This deck, however, is partly protected from rapid freeze-thaw cycling by its earth containment (underground design). Scaling was not observed to be a significant deterioration mechanism, as the floor surface exhibited only isolated surface erosion from freeze-thaw action.

During the microscopic examination a cursory inspection of the polished section of concrete revealed the presence of a gel formation, which suggested the possibility of alkali-aggregate reactivity. Further tests to confirm the presence of alkali-aggregate reactivity were recommended but have not been performed.

pH Testing

Concrete powder samples were collected from the floor slab and subjected to pH testing. Samples were extracted incrementally beginning at the surface and stopping at 3 in. One-inch increments were obtained to allow pH determination as a function of depth.

Test results indicated the average pH of the concrete to be 9.83 at the surface increment and 10.82 at the third increment. These values are considered lower than would be anticipated for conventional concrete, which is typically 12.5 or more. Values lower than 11.5 are believed to create a corrosive environment, even without the presence of chloride (2). It is further evident that the effect of high chlorides in low pH concrete would cause an unusually harsh and aggressive environment, given the presence of moisture and oxygen (3).

CONDITION APPRAISAL CONCLUSIONS

Based on visual observations, materials testing, and nondestructive tests performed, observed concrete deterioration was determined to be primarily caused by corrosion of embedded steel reinforcement. Materials tests indicated that corrosion of steel could be attributed to the high chloride content of the concrete at the level of embedded steel reinforcement and low concrete pH. It is evident that concrete delamination and subsequent spalling are progressive and will continue to seriously affect the existing structural integrity and serviceability of the parking facility.

Although further recommended petrographic examination was not performed, it is the authors' opinion that the presence of alkali-silica gel was probably caused by localized reactions in the open cracks. Evaluation of crack patterns observed in the structure suggests that cracking is probably a result of restraint and normal concrete shrinkage. Close examination of core crack pattern and characteristics failed to detect evidence of polygonal cracking, which is considered typical when alkali-silica reactions are a predominant deterioration mechanism. Thus it is not believed that alkali-silica reaction is a serious problem in the subject structure.

DISCUSSION OF RESULTS

There is considerable controversy concerning the advantages of using galvanized reinforcement in concrete slabs exposed to harsh environments such as bridges, decks, parking structures, or marine structures. Some researchers have maintained that zinc provides adequate corrosion protection for the reinforcing steel embedded in concrete slabs exposed to periodic deicer or seawater exposure.

Several laboratory and field studies have been performed in connection with galvanized reinforcement in concrete (4-6). The studies frequently contradict one another, and evaluation of data generally results in differing opinions regarding measurable and anticipated performance of galvanized reinforcements. Some studies indicate that under conditions of high chloride concentrations at the embedded steel, substantial corrosion of zinc can occur, followed by corrosion of steel (7,8).

A meaningful estimate of long-term performance can only be obtained by actual field evaluation of structures constructed with galvanized reinforcement. To date, several long-term studies related to bridge decks have been performed (4), but none related to galvanized reinforcement in parking decks has been reported.

During investigations of similar facilities with conventionally reinforced uncoated reinforcing bars, approximately equivalent deterioration was recorded during the 12th year of service. This suggests that the galvanized coating delayed the corrosion initiation by roughly 5 years when compared to black steel.

It is generally agreed that significant study would be required before implementation of remedial actions to restore the structure. Candidate systems identified for study and possible use at the subject facility are special concrete overlays, both conventional and polymeric; polymer impregnation by deep grooving; and traffic bearing membranes.

SUMMARY AND CONCLUSIONS

The condition appraisal of Kennedy Square Parking Garage represents a long-term performance of galvanized reinforcement in parking decks. Results of the evaluation indicate that although galvanized reinforcement was used, floor slab spalling and delamination are widespread. The field condition appraisal consisted of visual examination, chain drag delamination survey, determination of chloride content of concrete, determination of air void characteristics of the concrete, and compressive strength of core samples.

Although various laboratory and field studies elsewhere may suggest the beneficial effects of zinc in reducing reinforcement corrosion, the condition appraisal of the Kennedy Square Parking Garage indicates that concrete slabs under long-term exposure to chloride salts have deteriorated because of corrosion of galvanized reinforcement. Extensive corrosion of zinc has occurred, followed by corrosion of steel. Although chloride concentrations around embedded steel are somewhat higher than may be considered typical for bridge decks, they are not considered abnormally high.

Restoration of the subject parking facility has been delayed because of budget considerations, but interim measures are being taken to maintain structure serviceability. Periodic maintenance is being performed along with regular monitoring, inspections, and testing. The restoration alternatives are being evaluated carefully to ensure that the most cost-effective solution is selected when restoration proceeds.

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