Field investigation of spalling in partial-depth precast concrete bridge decks using nondestructive testing

Kandi R. Spraggs, Lesley H. Sneed, Abdeldjelil Belarbi, and Neil L. Anderson

Precast, prestressed concrete panels are commonly used in bridge construction and repair to speed the construction of concrete bridge decks. Precast concrete members are often more durable and more uniformly constructed than their cast-in-place concrete counterparts because of the controlled fabrication environment and stringent quality control in precast concrete production plants. Two types of precast, prestressed concrete panel systems are commonly used on bridge decks: full-depth and partial-depth panel systems. It was recently observed that some bridges with partial-depth panels have experienced spalling of concrete and corrosion of embedded steel reinforcement.1–4 Spalling of concrete compromises composite action and protection of embedded reinforcement. This paper discusses the results of a comprehensive field investigation to determine the mechanism of spalling observed in bridge structures containing partial-depth precast, prestressed concrete bridge deck panels.

Background

Bridge deck description

Partial-depth precast concrete deck panels are thin, prestressed concrete panels that span between girders and...
serve as stay-in-place forms for the cast-in-place concrete deck. Typical geometries of panels are 3.0 in. to 3.5 in. (75 mm to 90 mm) thick, 8 ft (2.4 m) long in the longitudinal direction of the bridge, and wide enough to span simply supported between the girders in the transverse direction of the bridge, though their geometries vary from state to state. The panels are pretensioned with prestressing steel strands at middepth in the transverse direction of the bridge. Panels are placed adjacent to one another along the length of the bridge and typically are not connected to one another in the longitudinal direction of the bridge. The joint between two adjacent panels in the longitudinal direction of the bridge (the direction of traffic) is referred to in this paper as a panel joint. After the panels are in place, the top layers of reinforcing steel are placed and the cast-in-place concrete portion of the deck (typically 5.0 in. to 5.5 in. [125 mm to 140 mm] thick) is placed on top of the panels. The cast-in-place concrete and stay-in-place panels act as a composite deck slab. Panels are typically constructed with a roughened top surface to transfer horizontal shear, and the prestressing strands in the panels serve as the bottom layer of reinforcement in the bridge deck.

Problem description

Recently it was observed that several bridges with partial-depth precast, prestressed concrete panel bridge decks have experienced spalling of the concrete at the bottom of panel joints. Bridges investigated as part of this study are located in the Midwest region of the United States and were constructed between 1985 and 1990. In each case, the panels are supported on continuous steel plate girders spanning two to four spans. Figure 1 shows examples of the spalling observed. Spalling has resulted in exposed prestressing tendons as well as mild reinforcing at the ends of the panels. The tendons exhibit a large degree of corrosion, in some cases to the extent of rupture. This study was aimed at determining the causes of the spalling.

Field investigation

Objective

To fully comprehend and accurately define the cause of the spalling, investigations were conducted on five bridges within the same geographical region and constructed with the partial-depth precast, prestressed concrete paneling system. Investigations of the first four bridges involved a brief visual inspection to identify the nature and extent of the spalling. These investigations also served as the basis for establishing the protocol for the comprehensive investigation conducted on the fifth bridge. The objective of the comprehensive investigation was to gain information on the in-place bridge deck properties and to determine the mechanisms of spalling in the precast, prestressed concrete panels.

Techniques used

To determine the causes of spalling, the following information was sought: the reason that the deterioration in the cast-in-place concrete was more extensive in some locations than in others along the deck, the mechanism by which water and chlorides were progressing through the cast-in-place concrete topping and into the panels, and the location of corroded tendons within the panels. A brief visual inspection was conducted on four bridge decks. Various techniques to examine each side of the bridge deck were selected for comprehensive investigation on the fifth bridge to gain a full understanding of the deck and its deterioration. The fifth bridge deck was investigated on the upper and lower surfaces by conducting an in-depth visual inspection.
inspection and using other nondestructive techniques, including ground-penetrating radar (GPR). Cores were also taken from the cast-in-place concrete topping.

During the visual inspection, cracking in the cast-in-place concrete portion of the deck was measured and mapped. Incongruities, including spalling, efflorescence, water stains, and exposed tendons in the panels and panel joints, were mapped alongside the core locations and GPR data.

GPR was selected for this investigation because of its ability to detect delaminations, voids, and reinforcement corrosion. GPR uses reflected pulses of electromagnetic radiation to locate and qualitatively assess the condition of reinforcement embedded in concrete by relating position to arrival time and condition to both arrival time and reflection amplitude.\(^5\) The GPR antenna transmits short bursts (pulses) of high-frequency electromagnetic radiation into the concrete slab. Some of this radiation is reflected or diffracted from embedded reinforcement or other discontinuities in dielectric properties and returned to the antenna, where the arrival time and amplitude are recorded. The velocity at which electromagnetic energy travels through a material depends on the material dielectric constant, or dielectric permittivity. The permittivity of the material is influenced by the temperature, moisture content, and salt content of the material as well as the material pore structure and the electromagnetic energy pulse frequency.\(^6\) As the dielectric constant of the material increases, the velocity at which electromagnetic energy propagates through the given material decreases.\(^7\) Hence, variations in the velocity of the concrete (or attendant variations in the apparent depth to reinforcement) generally indicate variable concrete integrity. Degraded concrete also attenuates propagating electromagnetic energy more rapidly; hence variations in the amplitude of the energy reflected or diffracted from reinforcement often indicate changes in the integrity of the concrete overlying the reinforcement.

GPR measurements were taken from both the top and bottom surfaces of the bridge deck using a 1.5 GHz antenna (Fig. 2). GPR data are typically not acquired from the bottom surface of bridge decks due to the inconvenience of having to couple the GPR antenna to the bridge deck surface. The reason for taking measurements from both surfaces was to obtain a better image of the cross section because the deck consists of two layers of concrete and multiple layers of reinforcement within each layer.

In addition, it was of particular interest to image the bottom surface to examine the condition of the prestressing tendons, which are critical to the load-carrying capacity of the deck. Reinforcement is best detected from GPR data acquired perpendicular to its axial orientation. Therefore, data were acquired along longitudinal traverses on the bottom surface of the deck (Fig. 2) with a special apparatus consisting of a small survey wheel and antenna attached to an extended handle.

Data were acquired at the panel ends next to the girders as well as in the middle of each panel. On the top surface of the deck, data were acquired in 24 in. (600 mm) intervals in both directions using a cart and a survey wheel (Fig. 2). The longitudinal scan was performed to locate delaminations within the cast-in-place concrete and panel interface and to determine the location of corroded prestressing...
significantly affect the structural performance of the deck slab; however, such cracks may accelerate deterioration by permitting the ingress of moisture and chloride ions to the reinforcement.

In the comprehensive investigation of the fifth bridge, visual inspection of the top surface included identification and mapping of all crack locations. In the cast-in-place concrete topping over nearly every panel joint, transverse cracking stretched in a diagonal zigzag across the bridge deck and extended to the concrete barriers at the edges of the deck. No longitudinal cracking over the girders was observed in the bridge deck.

Of the 116 total panel joints on the fifth bridge, 15 (13%) showed spalling, and an additional 19 cracked at the panel edges parallel to the tendons. Spalling was limited to one side of the bridge, panel lines C and D (top of Fig. 3). Panel line D included nine of the spalled joints, and panel line C included six spalled joints. The top of Fig. 3 shows a full bridge deck bottom surface view of the spalled panel joints (spalled joints are circled in the figure). Prestressing tendons were exposed in 14 of 15 spalled joints and exhibited conditions ranging from rusting to rupture (Fig. 1). Panel cracking was observed in panel lines A, C, and D. Cracking was limited to the panel joint locations. The bottom of Fig. 3 shows the locations of panel joints with cracking but no spalling (circled in the figure).

Efflorescence tended to be less prevalent in the panels in the middle and at the ends of the bridge deck. The same is true for water stains observed at the joints with the exception of the middle and at the ends of the bridge deck.
bar in immediate proximity to panel joints. Both features normally indicate concrete degradation. In addition, the arrival time (apparent depth) of the reflection from the base of the concrete slab is anomalously long, presumably because of deterioration of the concrete. These interpretations are consistent with the visual inspection data. As described previously, reflective cracking was observed in the cast-in-place concrete portion of the bridge deck, and water stains and cracking were observed in the precast, prestressed concrete panels of the bridge deck in these locations.

Figure 5 depicts GPR data acquired in the longitudinal direction from the top surface of the bridge deck over panel line C. The graph to the right of the profile depicts pulse magnitude along the horizontal axis and travel time along the vertical axis. The wavelet encircled by a solid line in the top of Fig. 5 is the reflected signal from the bottom of the bridge deck in the middle of a panel with little to no visible evidence of degradation. In comparison, the bottom of Fig. 5 shows the GPR reflection from the bottom of the bridge deck near a panel joint that shows evidence of degradation. The relatively low pulse amplitude indicates that degradation is occurring near the joint.

To determine the deterioration inside the bridge deck, data acquired from the top and bottom surfaces were compared. Figure 6 shows data acquired from the top and bottom surfaces of the bridge deck in the longitudinal direction over a length of 8 ft (2.4 m). The data from both the top and bottom surfaces show increasing apparent depths to reinforcement near the edges of the data (panel joint locations) indicating degradation. Visual inspection data confirmed the GPR data that both panel joints experienced slight spalling.

Figure 7 shows the varying degree of degradation from one panel line to the next. This figure shows GPR data...
taken in the longitudinal direction from the top of the bridge deck in the four panel lines at the same location measured along the length of the bridge. The solid lines indicate the GPR representation (apparent location) of the bottom of the bridge deck in that area away from the presumed deterioration. When data for the four panel lines are compared, varying apparent reinforcing bar depths and apparent concrete thicknesses are observed. As expected, apparent reinforcing depths and apparent concrete thicknesses are greatest on panel line D because it is the most deteriorated according to the visual inspection data.

Additional graphical representations of deterioration were depicted in contour maps of the bridge deck. Using commercial GPR interpretation software, reinforcing bar reflection signals were used to create contour maps of the reflection amplitudes and travel times in the bridge deck. Figure 8 shows the contour map of the reflection amplitudes from the upper mat. The map of reinforcing bar reflection amplitudes, based on data obtained in the transverse direction, shows that relatively high amplitude signals were detected near the ends of the bridge deck, as well as in localized areas within the middle of the deck near the girder support location. The amplitude of the signal indicates dielectric permittivity contrasts between the concrete and the reinforcing bar and is recorded in decibels (dB). Smaller amplitudes (bottom of Fig. 5) indicate areas of increased deterioration. According to the amplitude contour map in the middle part of Fig. 8, less deterioration occurred at the ends and localized areas within the middle portions of the bridge deck.

A contour map of the signal travel times to the upper mat of reinforcing steel was also developed. The bottom of Fig. 8 shows the time travel contour map, which represents signal travel times to the upper mat in nanoseconds. As explained previously, the velocity at which electromagnetic energy travels through a material depends on the material’s dielectric constant or dielectric permittivity. Normally, longer travel times would indicate more severe deterioration in the system. According to the time travel contour map, the deterioration is less severe near the middle of the bridge.

Ten cores obtained on the shoulders of the bridge deck were used to correlate GPR data by determining reinforcement depths and chloride ion concentrations in the cast-in-place concrete topping. The top of Fig. 8 shows the core locations. These cores were intended to penetrate the cast-in-place concrete topping only and not the precast concrete panels. Table 1 summarizes the core data obtained. Chloride ion contents were determined at different depths using AASHTO T-260 (water-soluble method) to examine the penetration of chlorides in the concrete. The corrosion threshold for reinforcing steel in concrete is generally taken as 1.0 lb/ft³ to 1.5 lb/ft³ (0.6 kg/m³ to 0.9 kg/m³). However, the onset of corrosion varies with concrete properties and exposure conditions. This range was used as an indicator of whether the chloride ion content measured in the bridge deck was high enough to break down the protective passive film on the reinforcing steel. Only three of the cores, C-2, C-3, and C-10, had chloride ion contents above 1.0 lb/ft³. Cores C-2 and C-3 were acquired.
adjacent to a panel joint, and core C-10 was acquired directly over a panel joint and reflective crack.

**Discussion of results**

**Deterioration of concrete** The visual inspection findings indicated that an uneven distribution of deterioration occurred in the panels of the bridge decks. Spalling was limited to panel lines D and C (Fig. 3), and the panels in the middle of the bridge deck had little to no evidence of deterioration. Reasons for the varying deterioration were determined by correlating the GPR with visual inspection data.

GPR data obtained on the top surface of the bridge deck in both the longitudinal and transverse directions indicated areas of less deterioration in locations similar to those observed in the visual inspection data. Data obtained in the longitudinal GPR scans show an anomaly in the middle of the bridge deck. This anomaly is due to the presence of additional longitudinal reinforcement in the cast-in-place concrete topping in areas of higher negative moment in the bridge girders. Construction documents indicate that reinforcement in the cast-in-place concrete topping in the longitudinal bridge direction is spaced at 5 in. (130 mm) over the abutments and 15 in. (380 mm) in the remainder of the deck. **Figure 9** shows the beginning and ending of an anomaly in the GPR data of panel line C. This anomaly represents the upper layer of reinforcement in the slab, and the anomaly appears as a white fill located above the peaks of the uppermost hyperbolas in the left part of the figure. The apparent depth of the reinforcement in the anomaly, indicated by the dashed line, is less than the apparent depth of the reinforcement hyperbolas, indicated by the solid line. The panel joint, located to the right of the anomaly in the right part of Fig. 9, shows an area of more degradation than the joints located under the anomaly. Areas under this anomaly appear less degraded, which is likely the result of lower chloride concentrations because this additional reinforcement provides improved transverse crack control.

Less severe degradation of concrete within the anomalous region is confirmed with the GPR scan in the transverse direction. **Figure 10** shows the variation in apparent reinforcement depths in scan lines 45 and 47 in the transverse scan. Line 45 is located just outside the anomalous region, and line 47 is located just inside it. The figure shows a decrease in apparent reinforcement depth as the spacing of the reinforcement decreases. Cores C-7 and C-8 were taken in locations similar locations to lines 45 and 47 and showed that the actual reinforcement depth was similar in both cases; therefore, the decrease in apparent reinforcement depths indicates less severely deteriorated concrete.
Regions of the deck with additional reinforcement in the cast-in-place concrete topping slab also exhibited decreased spalling, efflorescence, and water staining noted during visual inspections. Figure 11 shows photos taken from the bottom surface of the bridge deck of panel lines C and D beneath the transition between 15 in. (380 mm) spaced reinforcement and 5 in. (125 mm) spaced reinforcement in the cast-in-place concrete topping slab (panel lines are defined in Fig. 3). Panels in the bottom left corner of the photo on the left are shown in the middle and right photos. The topping slab reinforcement spacing transition occurs in the middle of these panels, resulting in different conditions above each panel joint. Cast-in-place concrete topping slab reinforcement is spaced at 5 in. (125 mm) over the panel joints at the tops of the middle and right photos and is spaced at 15 in. (380 mm) over the panel joints at the bottoms of the photos. It can be seen clearly that for these panels, the panel joint at the bottoms of the photos is significantly more deteriorated than the panel joint at the tops of the photos. In general, mapping the

<table>
<thead>
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<th>Core identification</th>
<th>Core depth, in.</th>
<th>Reinforcement depth, in.</th>
<th>Core bottom surface type</th>
<th>Sampling depth, in.</th>
<th>Cl–, lb/yd³†</th>
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<td>C-1</td>
<td>4.5</td>
<td>4.5</td>
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<td>3</td>
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<tr>
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<td>0.224</td>
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<tr>
<td>C-3</td>
<td>6.1</td>
<td>None</td>
<td>Smooth</td>
<td>3</td>
<td>2.610</td>
</tr>
<tr>
<td>C-4</td>
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<td>3.1</td>
<td>Broken</td>
<td>2</td>
<td>0.643</td>
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<tr>
<td>C-5</td>
<td>6.5</td>
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<td>Broken</td>
<td>3</td>
<td>0.257</td>
</tr>
<tr>
<td>C-6</td>
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<td>3.9</td>
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<td>3</td>
<td>0.100</td>
</tr>
<tr>
<td>C-7</td>
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<td>4.8</td>
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<td>3</td>
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<tr>
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<td>4.5</td>
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<td>Broken</td>
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<td>C-10</td>
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<td>Broken</td>
<td>3</td>
<td>5.393</td>
</tr>
</tbody>
</table>

*Sample thickness = ___ in.
†AASHTO T 260 water-soluble chloride content
Note: AASHTO = American Association of State Highway and Transportation Officials. 1 in. = 25.4 mm; 1 lb/yd³ = 0.593 kg/m³.
locations of spalled and water-stained joints throughout the entire deck showed that more widespread and severe deterioration is occurring in areas with the decreased cast-in-place topping slab reinforcement. Even though many of the panel joints located under the decreased reinforcement areas are not yet significantly deteriorated, eventual progression of cracking and ultimately spalling may occur given adequate moisture and chloride concentrations.

Figure 9. These screen shots show the anomaly in ground-penetrating radar data in panel line C. Note: 1 in. = 25.4 mm; 1 ft = 0.305 m.

**Delamination locations** Results from the previous section show that areas of the bridge deck with less reinforcement crossing the transverse cracking in the cast-in-place concrete topping are more prone to panel joint deterioration; however, more information was needed to determine how water and chlorides were progressing through the deck once inside the cast-in-place concrete topping. Because delaminations occurring within the bridge deck cross section at the
precast, prestressed concrete–cast-in-place concrete interface cannot be seen, GPR and core data were used to locate them.

Figure 8 shows two contour maps that were created from the GPR data to display possible areas of deterioration and delaminations. Figure 8 shows the GPR interpretation of deterioration in the bridge deck through the reinforcement reflection amplitude and signal travel time contour maps versus the visual inspection results from the bottom side of the bridge deck. The circled portions of each contour map correspond to locations with the most severe spalling and cracking observed on the underside of panels on the bridge deck. These areas should presumably correspond to the worst delaminating area in the cast-in-place concrete topping because chlorides migrated through cracks in the topping slab in these locations.

GPR data gathered in the area of the dashed circles located on the east side of the bridge correlate well with visual inspection data. The amplitude map shows lower areas of reinforcement reflection amplitudes (lighter sections), and the travel time map shows longer travel times (darker sections) in the circled area, especially close to the east end of the bridge deck. There is, however, a strip of darker area in the reinforcement reflection amplitude map located inside the circle, indicating less severely deteriorated concrete. This darker area is directly over the midwidth of a panel and not near a panel joint. This confirms that most of the deteriorated concrete is over the panel joints alone and that there are no additional delaminations between the panel joints in cast-in-place concrete topping.

GPR data on the west side of the bridge deck show excessively long travel times in the signal travel time map, indicating deterioration, and some areas of lower reinforcement reflection amplitudes in the amplitude map. Again, the amplitude map includes strips of relatively high amplitudes. The sinkhole areas of longer travel times in the signal travel time map likely correspond to the reflective cracking in the cast-in-place concrete topping over the panel joints observed during the visual inspection. Scan lines in the west portion of the deck appear to have acquired data over the reflective cracking occurring over panel lines B and D, and scan lines acquired in the east portion of the bridge deck appear to have acquired data over the reflective cracking occurring over panel line C.

In some areas, such as just west of the eastern circle, the maps complement each other. The amplitude map shows higher amplitudes, and the travel time map shows shorter travel times, both of which indicate less severely deteriorated concrete. In contrast, the two contour maps produce some contradicting results, particularly at the outer ends of the bridge deck. The reinforcement reflection amplitude map shows higher amplitude signals at the ends of the bridge deck, indicating less severe deterioration. The travel time contour map, however, shows longer travel times at these same locations, which are an indication of deterioration if the thickness of the concrete and the depth of the reinforcement are the same throughout the entire bridge deck. Varying reinforcement depths and concrete thicknesses may explain this discrepancy.

Cores C-2 and C-3 had smooth bottom surfaces when extracted from the topping slab. These cores were easy to extract from the concrete deck, which suggests failure at the cast-in-place concrete topping–precast, prestressed concrete panel interface with little or no bond between the two surfaces. As mentioned previously, cores C-2 and C-3 also had high chloride ion contents relative to other cores.

The shortest smooth bottom core obtained was 5.5 in. (140 mm) long, which is the cast-in-place concrete topping thickness specified in the construction documents. The longest smooth bottom core obtained was 6.5 in. (165 mm) long, but the longest broken bottom core obtained was 7.1 in. (180 mm) long (precast, prestressed concrete panel thickness was measured to be 3 in. [75 mm]). A broken
bottom surface suggests that either the core stopped significantly short of the precast, prestressed concrete panel or that the bond strength at the cast-in-place concrete topping–precast, prestressed concrete panel interface was greater than the tensile strength of the cast-in-place concrete topping, resulting in tensile failure during extraction. Core lengths tended to increase toward the middle of the bridge deck. Variations of thicknesses in the cast-in-place concrete topping may have been used to achieve a level bridge deck or to create a crown in the bridge deck cross section.

GPR data obtained in the longitudinal direction from the top and bottom surfaces of the bridge decks were also correlated with findings from core C-7, which was taken in the middle of a spalled panel. Core C-7 was taken in close proximity to a crack in the cast-in-place concrete topping. Figure 6 shows the location of core C-7 with respect to the GPR data (indicated by the position of the black arrows) from the upper and lower deck views. This core had a smooth bottom surface and included reinforcement (Table 1). Some delamination may be occurring in the area as indicated by the smooth bottom surface of the core, though measured chloride ion content was low in the cast-in-place concrete portion of the deck. This suggests that other factors may be contributing to the cause of delamination. Apparent depth of reinforcement and apparent slab thickness shown on the GPR data obtained on the top surface of the bridge deck correlate well with the core data, which indicate little to no delamination; however, little information pertaining to the cast-in-place concrete portion of the cross section of the bridge deck could be obtained from the bottom surface GPR data due to the close spacing of the tendons (4 in. [100 mm] spacing).

For additional comparison, each core was plotted on the amplitude contour map. Figure 8 shows the core locations with respect to the amplitude contour map created from the transverse scan GPR data. The amplitude value for each core location was then compared with the highest chloride ion content in each core. GPR data did not always correlate with the chloride ion contents. For example, core C-10 had the highest chloride ion content but was not in an area of the lowest amplitude. Core C-10 was taken directly over a reflective crack, which would allow more chloride ingress into the concrete at that location. GPR data, however, indicate concrete integrity in a given area, and the concrete area around core C-10 may be very sound.

A closer look at core C-10 on the GPR data obtained in the longitudinal scan provided better correlation to the core data. Core C-10 exhibited the most severe deterioration because it was taken directly over a panel joint. As expected, the chloride ion content was highest in this core. The panel joint at the location of core C-10 had no spalling and minimal water stains, but the GPR data in the longitudinal scan indicated some degradation. Figure 12 shows the screen shot at the location of core C-10. As indicated in the figure, there is slight degradation, indicated by a change in anomaly depths, at this location. This demonstrates that GPR can be used to locate areas of degradation before spalling occurs.

**Deterioration of precast, prestressed concrete panel reinforcement** Investigation of tendon deterioration was needed to determine whether chlorides had reached the middle tendons as well as the outer tendons on each panel. Unfortunately, because of the apparatus used to acquire the GPR data from the bottom surface of the bridge deck and difficulty in maneuvering the lifts, the antenna was not always directly coupled to the surface of the panel, resulting in changes of the angle of the antenna with respect to the panel. Much of the data obtained was unusable in comparing panel-to-panel deterioration, but the general relationship of the data proved useful.

Through the use of commercial GPR interpretation software, the amplitude of each tendon reflection was acquired for all panels selected for the GPR data acquisition located in panel line D, which exhibited the worst case of spalling. Figure 13 shows the average amplitudes recorded for each tendon reflection acquired on selected panels. Many of the panels had varying amplitudes, but most showed the general relationship of lower amplitudes at the panel ends near the joints and higher amplitudes in the middle of the panels. Data were often not obtainable at the edges of the panels due to the sampling wheel configuration. Lower amplitudes at the joints indicate that more deterioration is occurring in tendons at the edges than in those near the middle of the panels.

**Conclusion**

This study involved field investigation of spalling in several partial-depth precast, prestressed concrete bridge decks using nondestructive testing. GPR was used to assess the condition of concrete throughout the deck to identify areas of cracking and corrosion as well as the condition of prestressing tendons in the precast, prestressed concrete.
panels. To identify areas of delamination at the interface between the precast, prestressed concrete panels and cast-in-place concrete topping, data were acquired from both top and bottom deck surfaces and specialized data interpretation techniques were used. Core samples and visual inspection were used to interpret and validate the GPR data. The following conclusions are based on the findings:

- Spalling observed in the precast, prestressed concrete panels is the result of corrosion associated with the penetration of water and chlorides through reflective cracking in the cast-in-place concrete topping to the interface between the cast-in-place concrete topping and the precast, prestressed concrete panels, then through the precast, prestressed concrete panels to the prestressing tendons located near the panel joints.
- Visual inspection results from the bottom surface of the bridge deck indicated an uneven distribution of deterioration in the bridge deck panels. GPR results indicate that panels located under the area with increased negative moment reinforcement (that is, girder interior supports) were less deteriorated; therefore, concrete integrity increased with increased cast-in-place concrete topping in the bridge longitudinal direction because such reinforcement serves as transverse crack control and thus delays the onset of spalling.
- For the fifth bridge included in this study, GPR showed that most deterioration in the cast-in-place concrete topping occurred near the area of reflective cracking and not over the middle of the panels.
- Smooth bottom cores, acquired at various locations along the panels, indicate that some delamination may have occurred at the interface between the cast-in-place concrete topping and precast, prestressed concrete panels despite the roughened precast, prestressed concrete panel surface.

Figure 13. Average tendon reflection amplitudes acquired on panels located in panel D. Note: 1 ft = 0.305 m.
Acknowledgments

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References


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Abstract

This study involved field investigations of spalling in several partial-depth precast, prestressed concrete bridge decks through nondestructive testing. Ground penetrating radar (GPR) was used to assess the condition of concrete throughout the deck to identify areas of cracking and corrosion, as well as the condition of prestressing tendons in the precast, prestressed concrete panels. Particular techniques were used to identify areas of delamination at the interface between the panels and cast-in-place concrete topping. Core sampling and visual inspection were used to interpret and validate GPR data. Findings indicate that transverse reflective cracks at the panel joint locations played a key role in spalling. Combined data analyses showed that the spalling observed results from penetration of water and chlorides through reflective cracking in the cast-in-place concrete topping at the panel joints to the cast-in-place concrete topping and precast, prestressed concrete panel interface, then through the panels to the prestressing tendons. Concrete integrity increased with increased cast-in-place concrete topping reinforcement in the bridge longitudinal direction because such reinforcement serves as transverse crack control and thus delays the onset of spalling.

Keywords

Bridge, corrosion, deck, GPR, ground-penetrating radar, spalling.

Review policy

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