Bridge Deck Condition Assessment using Ground Penetrating Radar

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ABSTRACT - Ground Penetrating Radar (GPR) is an accepted electromagnetic evaluation technique used for the transportation infrastructure and a variety of other applications including concrete inspection, utility detection, geology and archeology. A well-established and accepted application of GPR is the accurate condition assessment of bridge decks as well as other reinforced concrete structures. Traditional bridge deck inspection methods include hammer soundings, chain dragging and visual inspection. The interpretation of these familiar techniques is subjective, is operator dependant and may produce highly variable results. Significant advantages of using GPR for bridge deck assessment include the non-destructive nature of the technique, the ability of GPR to be used without requiring the removal of an existing asphalt overlay and to provide a quantitative record independent of operator interpretation. The most accurate bridge deck condition assessments using GPR have been performed using high frequency (1.5 GHz) ground-coupled antennas. The high frequency ground-coupled antenna provides excellent resolution of the reinforcing steel. Geophysical Survey System’s BridgeScan is a convenient cart-based ground penetrating radar system for non-destructive bridge inspection and analysis. In a collaborative effort between Geophysical Survey Systems and the Maine Department of Transportation, the BridgeScan GPR system was used on April 13th, 2005 to evaluate the condition of an asphalt overlaid bridge deck located in Lewiston, Maine known as the Ramp D from Main Street over Maine Central Railroad. The GPR data was collected along the bridge deck in lines parallel to the direction of traffic. The profile lines were perpendicular to the transverse direction of the upper-most rebar. GPR data lines were acquired at two foot spacing by simply manually walking the BridgeScan cart-based system along the bridge deck. The data collection process was completed in less than one hour. The GPR data was processed using GSSI’s RADAN software program with the corresponding Bridge Assessment Module. The results were used to produce a color coded deterioration map of the bridge deck. The deterioration map from the GPR data was compared with the visual data from the top-side and bottom-side visual inspections. The comparisons of the GPR data with top and bottom side visual inspection data demonstrated excellent correlation. Based on all data, it was determined that over 50% of the Ramp D bridge deck was significantly deteriorated. The Maine DOT later removed the asphalt overlay and conducted a chain drag of the deck and comparing these results with the GPR data demonstrated excellent correlation. Excavating the concrete for bridge repair provided actual confirmation of the validity of the GPR method.

INTRODUCTION

The American Society of Civil Engineers reported that as of 2003, 27.1% of the nation's bridges (160,570) were structurally deficient or functionally obsolete (ASCE, 2003). The Federal Highway Administration's (FHWA's) strategic plan states that by 2008, less than 25% of the nation's bridges should be classified as deficient.
Traditional bridge deck inspection methods include hammer soundings and chain dragging. These familiar techniques rely on the ability of an operator to correctly and consistently interpret acoustical feedback to determine good and bad areas of concrete and produce an overall condition assessment of the deck. Existing asphalt overlays must be removed prior to using acoustical methods, and results can vary depending on the operator’s technique and determination of results. Assessment data normally consists of areas of the deck marked simply as good or bad.

Ground Penetrating Radar (GPR) is an accepted electromagnetic evaluation technique used for the transportation infrastructure and a variety of other applications, including concrete inspection, utility detection, geology and archeology. An established application of GPR is the accurate condition assessment of bridge decks as well as other reinforced concrete structures (Parrillo and others, 2005; Romero and others, 2000; Schongar, 2004; Romero, 2003).

Hundreds of bridge decks have been evaluated using GPR. The most accurate bridge deck condition assessments using GPR have been performed using high frequency (1.5 GHz) ground-coupled antennas. The high frequency ground-coupled antenna provides excellent identification and resolution of the reinforcing steel. When performing a condition assessment of a bridge deck using GPR, it is common to use the relative reflections from the reinforcing steel (rebar) to produce deterioration maps and determine the extent of deterioration. GSSI’s BridgeScan system includes a SIR-3000 Windows CE based portable GPR data collection system with 1.5 GHz ground-coupled antenna. The 1.5 GHz antenna has a depth of penetration of approximately 18 inches in concrete, which is more than adequate to accurately locate the top layer of rebar. An optional small hand-cart configuration is available and allows the 1.5 GHz ground-coupled system to be used for applications where the 3-wheeled push cart may not be appropriate due to size limitations (i.e. condominium balconies). Ground-coupled antennas may also be towed behind a vehicle at slow speeds. Dual channel GPR data collection systems, such as GSSI’s SIR-20, may be used to collect two paths (channels) of data simultaneously to reduce data acquisition time.

In a collaborative effort between Geophysical Survey Systems and the Maine Department of Transportation, the BridgeScan GPR system was used on April 13th, 2005 to evaluate the condition of an asphalt overlaid bridge deck located in Lewiston, Maine known as the Ramp D from Main Street over Maine Central Railroad Bridge. Ramp D is a portion of the Veterans Memorial Bridge which crosses the Maine Central Railroad and the Androscoggin River (See Figures 1 & 2).
Constructed in 1971, the deck is a 9 inch reinforced structural concrete slab and measures approximately 32 feet wide by 180 long. A 2 inch concrete cover was specified above the reinforcing steel. The hot bituminous wearing surface was replaced in 1991. A variety of repairs were performed and some are evident as patches in the deck surface (see Figure 3). The Maine DOT suspected the deck was considerably deteriorated and had scheduled the bridge for repair. Consequently, this particular bridge deck presented the DOT with an excellent opportunity for evaluating the GPR technique.
In addition to collecting GPR data, visual inspections were performed on both the topside and bottom-side of the bridge deck. The locations of cracking and patching on the topside and locations of cracking, rusting and efflorescence on the bottom-side were recorded. This data was used to create top-side and bottom-side maps of the defects for comparison with the GPR data (see Figure 4).

Figure 4. Bottom Side Pictures

DATA COLLECTION

For a bridge deck condition assessment project, GPR data is typically collected in the direction perpendicular to the upper most rebar orientation. Thus, if the upper rebar orientation is transverse, then the data would be collected in the direction of traffic. If the orientation of the rebar is unknown, it can easily be determined with by acquiring sample GPR data in both directions and then simply comparing the arrival times of the rebar reflections in the data.

Mechanical drawings for the Ramp D bridge deck indicated that the upper rebar was in the transverse orientation. This was quickly confirmed by using the BridgeScan system to acquire data in both directions and comparing the arrival times of the rebar targets.

GPR data along the bridge deck is normally collected in parallel lines approximately 2 feet apart. Since the upper rebar was transverse, 14 data files were collected in lines parallel to the direction of traffic starting 4 feet from the edge of the bridge deck (2 feet from the traveling lane curb) and continuing to 30 feet from the edge of the bridge deck (28 feet from the traveling lane curb) (see Figure 5).
Data was collected at a density of 24 scans per foot or one scan every half inch. This data density was sufficient to clearly image the individual rebar locations, which varied from 6 inch spacing to 1 foot spacing and back to 6 inch spacing along the width of the bridge deck. The data collection process was completed in less than one hour.

Rebar appear in the GPR data as small hyperbolas. These hyperbolas occur because the antenna transmits energy in a conical pattern, and consequently, receives reflections from the rebar at decreasing two-way travel times as it approaches the rebar, then increasing two-way travel times after the antenna passes over the rebar. Rebar locations were evident in the unprocessed data as well as obvious areas of deterioration where rebar reflections were weak. Areas of the bridge deck exhibiting weak reflection amplitude values are typically indicative of deterioration. These weaker reflections can be due to several factors, including elevated chloride content, concrete degradation or corrosion of the rebar, which all attenuate the radar signal (see Figure 6).
It should be noted that the bottom of the bridge deck is also visible in the GPR data and appears as a white-black-white horizontal band that can be seen at approximately 7.5 ns in the unprocessed data shown in Figure 6.

**DATA PROCESSING**

Following data collection, the individual GPR data files were transferred from the BridgeScan’s SIR-3000 system to a PC for processing. Using the RADAN Bridge Assessment Module, the 14 individual 2D GPR files were combined into a single file. Each data point in the file is position-referenced relative to known bridge features, such as the traveling lane bridge curb and starting joint. There are three processing steps involved in creating a deterioration map from the 3-D file. The first processing step, implemented in a semi-automated manner, performs time-zero correction, migration, and rebar reflection mapping. The next step is interactive interpretation. The last step is the presentation of the deterioration data in the form of a contour map. From start to finish, the GPR data processing time for the Ramp D bridge deck was less than two hours. Each important task performed during the data processing is described below.

**Time-Zero Correction**
The first step in data processing is to shift each scan of data so that the top of the scan corresponds to the surface of the bridge deck. This step is typically referred to as the time-zero correction.

**Migration**
Migration is a mathematical hyperbolic summation process that collapses hyperbolic diffractions associated with the rebar locations and focus on their subsurface position (see Figure 7).
Automatic Rebar Reflection Mapping

The migration process provides data containing rebar reflections that are typically easily detected using automated algorithms. The algorithm implemented for deterioration mapping locates each rebar reflection and records its spatial location in the bridge deck and the amplitude of the rebar reflection. These values are written to an ASCII comma-separated value (CSV) file.

Interactive Interpretation

The user will normally want to view the performance of the automatic rebar reflection-picking algorithm. In many instances, the rebar reflection picks will need to be edited. This may occur, for example, when the bridge deck is very deteriorated and the reflections from the rebar are very weak. During the interactive interpretation process, circular markers overlain on top of the GPR data indicate the located rebar reflections (see Figure 8).
Contouring
Using a contour mapping program, such as Surfer® from Golden Software, the X, Y, and reflection amplitude data for each rebar location were imported from the ASCII file and used to create a color-coded contour map of the bridge deck. Weaker rebar reflections were mapped as “hotter” colors to indicate the areas of the bridge deck suspected of greater deterioration (see Figure 9).

![Figure 9. Deterioration Map of Bridge Deck](image)

Visual data from both the top-side and bottom-side inspections were recorded into an Excel spreadsheet with rows used to represent the locations along the width of the deck and the columns used to represent locations along the length of the deck. Each row or column represented 1 foot. This data was then also imported into the Surfer contour mapping software and used to create top-side and bottom-side maps (See Figures 10 and 11).

![Figure 10. Topside Map](image)

![Figure 11. Bottom-side Map](image)

ANALYSIS AND INTERPRETATION

The weaker rebar reflections indicated by the “hot” colors observed in Figure 9 can be due to several factors including elevated chloride content, concrete degradation and/or corrosion of the rebar, which all attenuate the radar signal. Areas of moderate to severe deterioration
are visible in raw GPR data as it is being collected. This was clearly evident on the Ramp D bridge deck as the GPR data was acquired near the center line of the deck.

However, it is important to note an estimate of the amount of deterioration should not be determined by merely considering colors on the contour map. Indeed, a GPR evaluation of a new bridge deck will contain some range in rebar reflection amplitudes that are associated with rebar at different depths. It is more important to consider the total range of rebar reflection amplitudes when assessing the quantity of deterioration on a bridge deck.

As the bridge ages, deterioration mechanisms selectively attack portions of the bridge deck that are subjected to mechanical, chemical and/or thermal stress. Mechanical stress could be associated with loading and unloading from traffic; chemical stress from chloride infiltration; and thermal stress from freeze-thaw cycles. Thus, the onset of deterioration is often localized to areas of the bridge-deck subject to the most stress. These areas may grow in dimension as the bridge ages. The rebar reflection maps produced from GPR data are useful in locating these areas. The areas of weakest rebar reflections in the rebar reflection map shown in Figure 9 do not possess sharp boundaries. Rather, there is a gradational change in amplitude. For this reason, it is difficult to clearly state where deterioration stops and starts from inspection of deterioration maps produced from GPR data alone. It is preferable to use the GPR deterioration maps as a tool for classifying maintenance action level required on the bridge and to determine the sections of the bridge deck requiring repair.

The bridge maintenance action-level decision typically incorporates information from a number of sources, including inspection of the bridge deck surface, inspection of the bridge deck underside (if possible), deterioration maps produced by GPR (or other techniques such as corrosion potential, chain drag or chloride analysis), traffic control requirements for different types of rehabilitation, man-hour costs and budget constraints. It is in the context of determining a maintenance action level that the GPR deterioration maps from the Ramp D bridge deck are examined.

The green, yellow and red colors in the deterioration maps shown in Figure 9 along the center of the bridge correspond to significant cracking in the asphalt layer on the surface of the bridge and evidence of cracking and corrosion from the underside inspection map. In addition, all of the yellow and red areas associated with other sections of the bridge deck can be correlated to topside or bottom side cracking or corrosion. It is clear that the bridge deck is significantly deteriorated beneath the cracked sections of asphalt and in many cases the deterioration extends through the bridge deck.

MAINE DEPARTMENT OF TRANSPORTATION VERIFICATION AND CONCLUSION

Following the GPR evaluation, the Maine DOT removed the bituminous wearing surface and performed a chain drag to verify and complement the GPR results. The chain drag indicated deterioration in the same areas as the GPR deterioration map thus demonstrating very good correlation (see Figures 12 and 13).
Figure 12. Removal of wearing surface

Following the chain drag the Maine DOT excavated the concrete at the suspected areas of deterioration (see Figure 14). The deteriorated deck concrete was removed, one half of the bridge at a time, allowing traffic to continue. Rusted steel was cleaned or replaced if deterioration was over 20% of the cross-sectional area. The deck concrete was replaced along with replacing the wearing surface with concrete.

Figure 13. Surface deterioration map constructed from chain drag on one side of bridge after stripping asphalt layer.
The GPR data and analysis was helpful to the Maine DOT in estimating the scope of work and the treatment required. If little or no deck was deteriorated, the membrane would have been repaired and the bituminous wearing surface would have been replaced. Since significant deck deterioration was indicated (50%), the entire membrane was deemed useless and in need of replacement.

GPR data is valuable to the Maine DOT in that the degree of deterioration can be determined prior to opening up the bridge. This information can help determine the scope of work and even the type of repair that is most effective. Schedule and budget can be more accurately determined, decreasing the likelihood of claims and overruns (of time and money).

GPR technology is extremely valuable to Maine DOT’s Bridge Management system, and the Maine DOT intendeds to use GPR again.
References


