GPR SURVEYS TO HELP DETERMINE CONDITION OF A CONCRETE BRIDGE DECK

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Abstract

Ground-penetrating radar (GPR) surveys were conducted as part of an investigation to evaluate the condition of a bridge across the Missouri River between Nebraska and Iowa. The bridge, constructed about 50 years ago, has a concrete bridge deck with asphalt overlay. Stay-in-place steel forms were used during construction. Missing and deteriorated concrete could be seen from below in some areas where the steel forms had rusted away and exposed the concrete.

The GPR surveys were performed to obtain reflections from the upper layer of steel reinforcement (rebar) within the concrete deck. Variations in rebar reflection amplitude have been shown by others to represent variations in concrete quality. The GPR data were collected along lines spaced two feet apart and 2000 feet each in length. The results suggested that the majority of the concrete was deteriorated, a finding supported by the results of the laboratory testing performed by others. Our work also suggests that variations in rebar depth should be considered when evaluating GPR anomalies.

Background and Methodology

The GPR method is in wide use for mapping rebar in concrete, locating voids beneath concrete slabs, and evaluating pavement. A number of state transportation agencies have accepted GPR as a valid method for helping determine the condition of asphalt and concrete pavements. Both air-coupled and ground-coupled antennas are in use for this purpose. Air-coupled antennas allow data acquisition at higher speeds while ground-coupled antennas collect higher resolution data at a slower speed.

The use of GPR to evaluate concrete bridge decks is a relatively recent application and is based on evaluating the amplitude of reflections from the upper layer of rebar. Although variations in GPR reflection amplitude can be due to other factors, including variations in moisture content and variations in the rebar diameter, work by others has shown that GPR surveys can provide an accurate estimate of the percent of deteriorated concrete (Cardimona, et al, 2002). Guidelines have been developed for conducting and interpreting GPR surveys to evaluate concrete bridge decks (e.g., AASHTO TP36-93 and SHRP Product 2015).

Ground penetrating radar technology is based on the propagation and reflection of a high-frequency electromagnetic energy pulse. Reflections are obtained from subsurface changes in dielectric permittivity that occur between materials of contrasting physical properties. The energy pulses are emitted at a high rate, allowing the data to be collected while the GPR antenna is pulled across the surface of the ground or structure. For bridge deck surveys, the data are collected along parallel lines spaced a few feet apart and oriented perpendicular to the orientation of the upper rebar mat. Location control during the survey is very important; a survey wheel is typically used that allows survey line distances to be recorded with the digital GPR data.

GPR reflection data is displayed and recorded in two-way travel time for each individual scan. The data can be converted to an approximate depth by using the arrival time for the reflection of an object at a known depth, or the dielectric constant can be estimated for the particular material. For a bridge deck survey, the GPR pulse is typically reflected from the top of the asphalt overlay (ground surface), from the interface between the asphalt and the concrete, and from steel rebars within the concrete (Figure 1). A high frequency antenna is used that typically does not provide data below the top rebar mat. Reflections may also be obtained from such features as voids and aggregate within the concrete, although these are typically much lower amplitude and do not affect the data analysis.

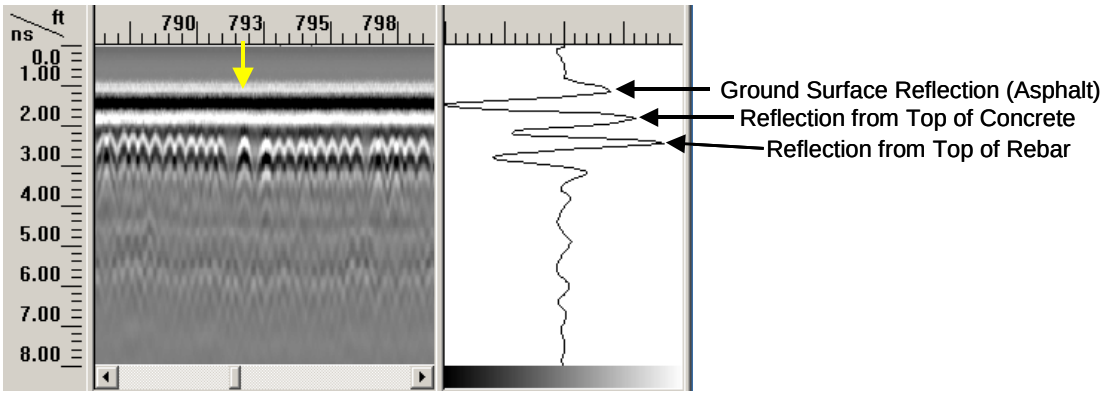

Figure 1 *– Example GPR data from bridge deck survey showing typical trace for one scan (on right) for location marked with yellow arrow on data record. Arrows on right point to reflection peaks. Actual start of reflection is considered to be at the zero crossing amplitude before peak.*

The strongest reflection beneath the top of the concrete is usually the reflection from individual rebars. When all other factors (depth, size, etc.) are equal, variations in rebar reflection amplitude should indicate some deterioration of the concrete. Variations in reflection amplitude are measured in decibels (dB) and typically displayed as plan view contour plot. Work by others has shown that rebar amplitude reductions of about –14 dB should be used as a threshold for deterioration of concrete (SHRP Product 2015). However, site-specific evaluations should be performed by obtaining cores from a range of anomalies and conducting tests to establish the threshold value for a specific concrete deck. It is also possible that the threshold values could vary within a specific bridge for different concrete mixes, placement methods, and ages.

Bridge Deck Survey

Data Acquisition

The GPR data were acquired on the Missouri River bridge on July 8, 2003 using a GSSI SIR-2000 GPR system with a 1500 MHz (1.5 GHz) antenna (Figure 2). The antenna was towed behind a vehicle at a very slow rate of speed along 10 east-west trending parallel lines spaced 2 feet apart and located 2 feet to 20 feet from the south curb of the bridge. Each survey line was 2000 feet in length and covered the western approach span (Nebraska side), the bridge span, and the eastern approach span (Iowa side).

The data were collected at a rate of about 18 vertical scans per foot (about 60 scans per meter). Each vertical scan consisted of 256 samples and the record length in time of each scan was 8 nanoseconds. Filters used during acquisition were 250 MHz high pass and 3000 MHz low pass.

A counter wheel was used for approximate distance control during the survey. Lines painted across the bridge at 100-foot stations were used as location control for the data collection. When the antenna passed over each 100-foot station, a marker was generated by hand in the GPR data. Short paint marks were used to indicate the location of each survey line at each 100-foot station. These short paint marks were used to adjust the position of the antenna by calling out directions to the vehicle driver. Through this method, the antenna was kept within about plus or minus 0.5 feet of the planned survey line.

Data Analysis

The raw data were reviewed to determine the rebar spacing and assess the general reflective character of the rebar. Areas of diminished amplitude were easily recognizable in the raw data and included areas on either side of the expansion joints (Figure 3). In addition, the bridge deck reflection amplitudes were generally higher than the two approach spans. The rebar spacing was variable and was

more closely spaced on the outside lines than on the interior lines. The rebar spacing also varied along each line from about 4 to 10 inches.

Figure 2 *- Photograph of data acquisition showing towing arrangement for 1500 MHz antenna (left).*

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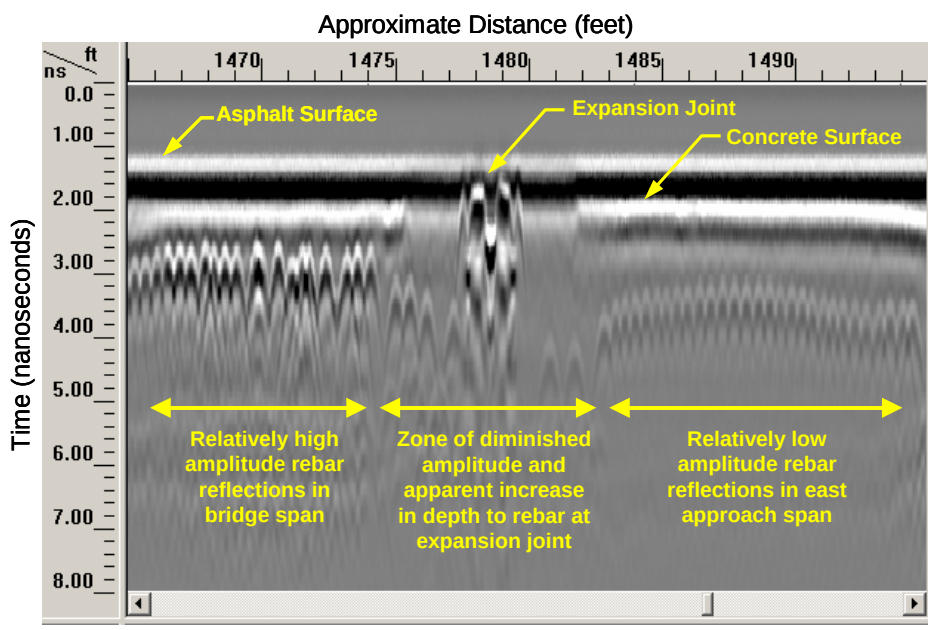

Figure 3 *– Example GPR data showing contrast between typical reflection amplitudes from bridge deck (left) and approach span (right). Example also shows the typical reduction in amplitude and increase in apparent depth at expansion joint (middle).*

The data were evaluated using the Bridge Assessment Module of the software program RADAN, version 5.0 (copyright 2003 GSSI, Inc.). This software module includes an automatic picking routine that attempts to select the maximum amplitude associated with each rebar reflection. The automatic picking routine accounted for most of the rebar reflections. The automatic picks for each line were reviewed and corrected where needed, then additional picks were added using the manual picking option. Examples of the rebar picks are shown in Figure 4. A total of 48,521 rebar picks were selected for an average of about 2.4 rebars per foot.

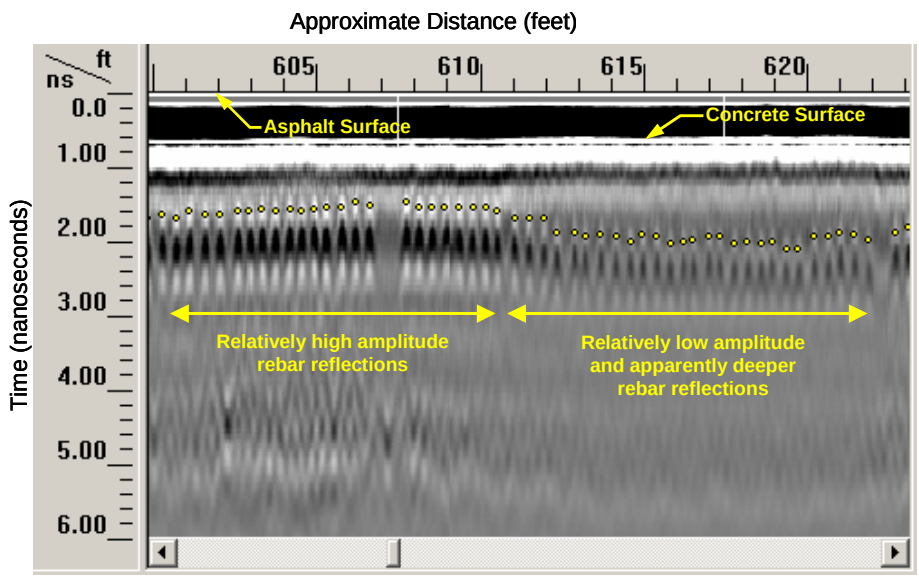

Figure 4 *- Example GPR data (migrated) showing peak rebar reflections initially selected by the automatic picking routine of the Bridge Assessment Module of RADAN and then adjusted manually, as needed.*

The output data from RADAN were imported into an Excel spreadsheet (copyright 1985-1999 Microsoft Corp.) for further review. The output data included X (distance in feet along each line from Station 00+00), Y (line number in feet from south curb), Apparent Depth (inches), and Amplitude (in normalized decibels, dB). Due to variability in slope, surface roughness, and other factors, the distance generated by the counter wheel caused some errors to accumulate in the data. The manual marks generated in the data at each 100-foot station were used to correct the X-coordinate. The final X-coordinates were checked by comparing the calculated location of the six expansion joints with the locations of the joints as measured in the field. The calculated locations were found to be within about plus or minus one foot of the actual stations.

Discussion of GPR Results

The reflection amplitudes of the upper rebars in the bridge deck concrete were contoured using a standard contouring package (Surfer, copyright 1993-2002, Golden Software, Inc.) to show areas of high and low values. In general, the results show that the reflection amplitudes of the bridge deck are higher than those of the western and eastern approach spans (Figure 5). The results also show a number of low amplitude anomalies within each of the three spans, including anomalies in the vicinity of the expansion joints. Approximately 97 percent of the area surveyed has reflection amplitudes below the suggested threshold of –14dB that is used to indicate concrete deterioration.

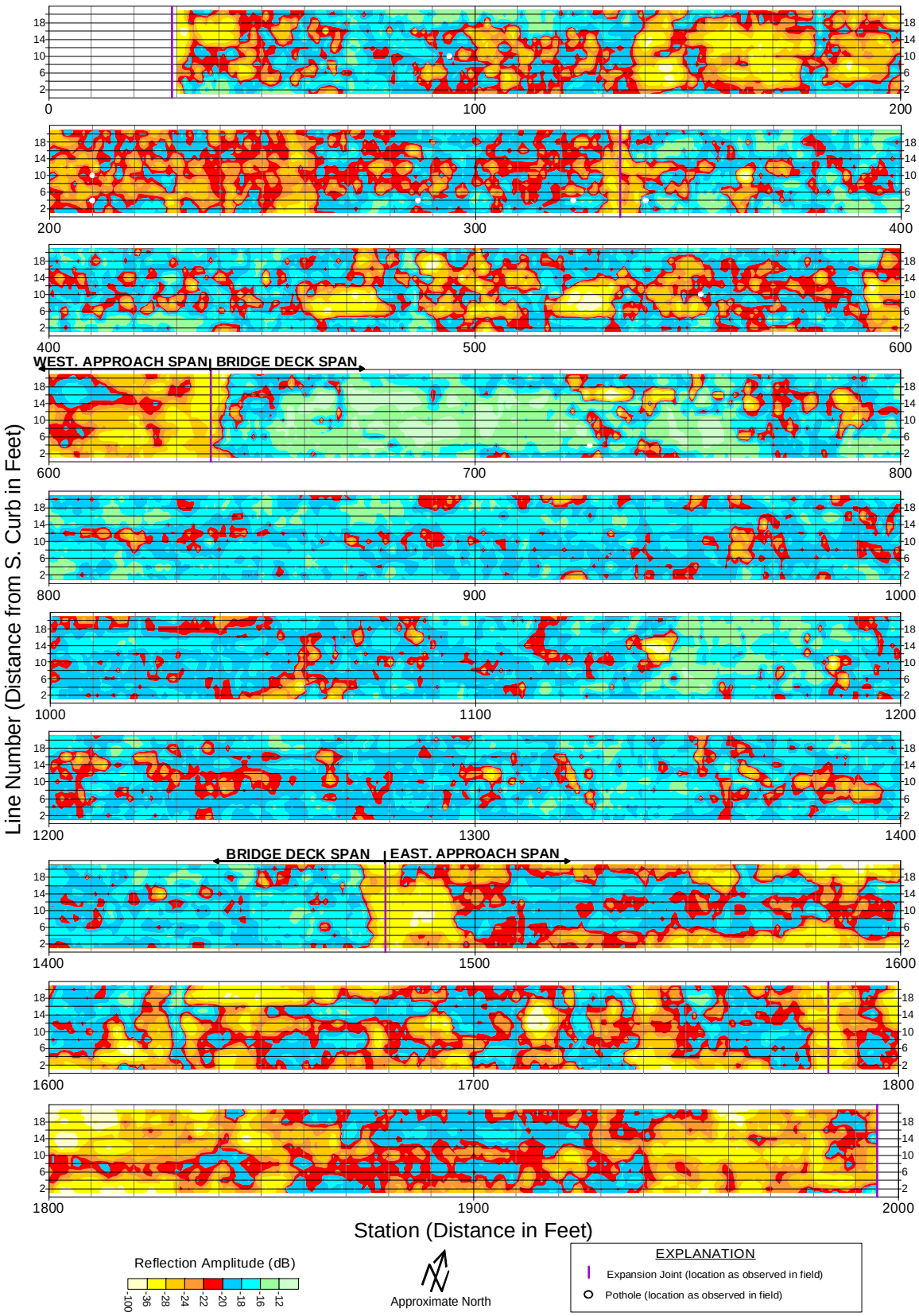

Figure 5 *– Contour map of GPR reflection amplitudes for upper rebar course in concrete bridge deck.*

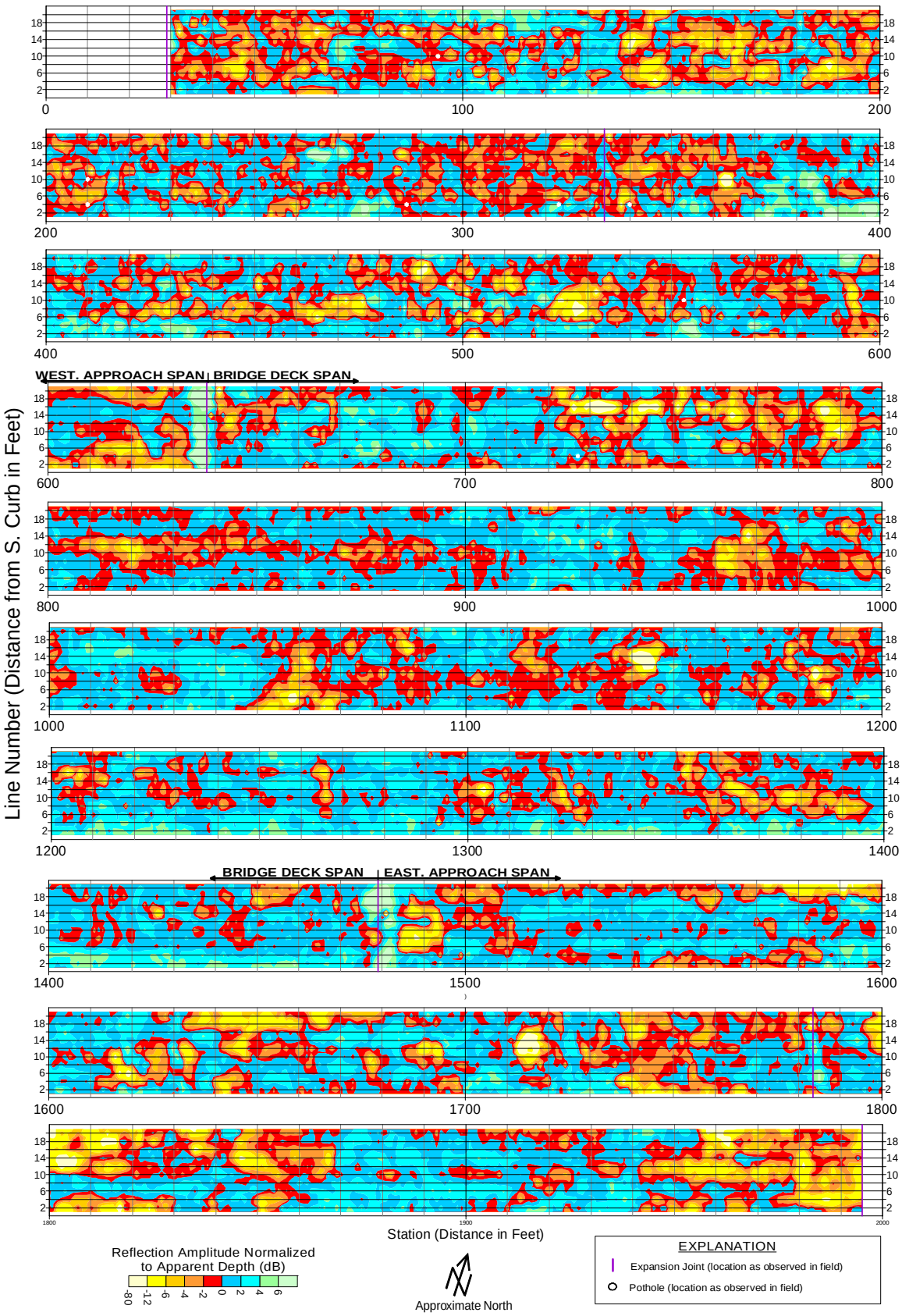

Figure 6 *– Contour map of GPR reflection amplitudes normalized to apparent depth.*

Areas of relatively low reflection amplitude may indicate areas of relatively poorer quality concrete between the surface of the concrete and the top rebar course. However, variations in reflection amplitude may be caused by other factors such as differences in depth to the rebar, variations in rebar diameter, and variable moisture content of the overlying asphalt. For example, the large-scale difference in reflection amplitude between the bridge span and the two approach spans may be due to differences in the rebar depth during construction.

The apparent depth to the peak reflection amplitude of the top rebar was calculated during processing by dividing the reflection time by an assumed constant velocity of the concrete. The actual velocity of the concrete in the bridge deck will vary depending on the concrete quality. Therefore, the apparent depth to the top rebar will vary depending on the condition of the concrete.

Since variations in the apparent depth of the rebar can be due to either variations in actual depth or changes in concrete condition, we also examined the data with the effect of the apparent depth removed. Figure 7 shows all the rebar amplitude data plotted as a function of apparent depth, with a best-fit trend line superimposed. The amplitude data were then normalized to apparent depth by removing the trend shown in Figure 7. While this process may have diminished or removed some amplitude anomalies that are caused by variations in concrete condition, low amplitude anomalies that remained after apparent depth normalization were considered high confidence, in terms of indicating possible areas of relatively poorer quality concrete. The process of normalization to apparent depth also removed much of the amplitude difference between the bridge span and the two approach spans and most of the low amplitude anomalies associated with the expansion joints (Figure 6).

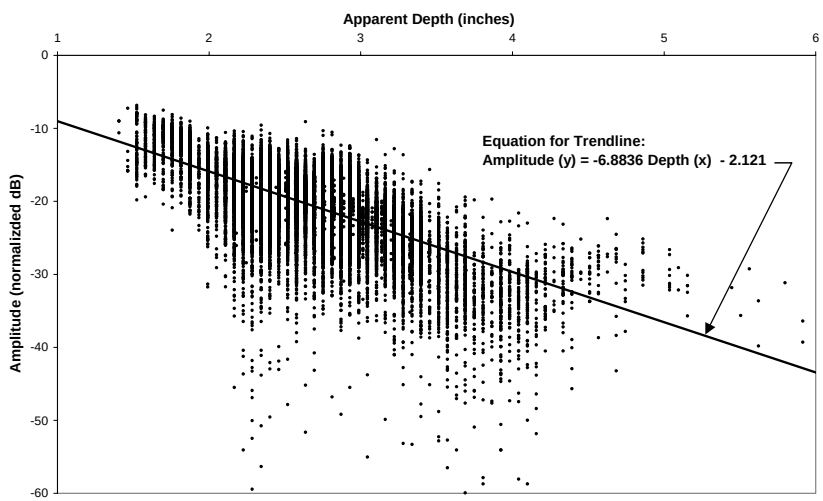

Figure 7 *- All GPR rebar reflection amplitude data plotted as a function of apparent depth with best-fit trend line superimposed.*

As was discussed previously, approximately 97 percent of the concrete may be deteriorated, using the suggested threshold of –14dB. After normalization to apparent depth, the area of concrete below 0dB is 45 percent. This suggests that a blanket use of a threshold may overestimate the percentage of deterioration, if variations in depth of rebar are not considered.

Concrete Testing

Forty concrete cores were obtained by others from selected GPR anomalies on the bridge deck and approach spans. The observations and tests made by others on the concrete cores included macroscopic examination, Petrographic Examination (ASTM C856), Rapid Chloride Permeability (ASTM C1202), Chloride Ion Test (ASTM C1218 – Water-Soluble Chloride), Density (Unit Weight – ASTM C138-Modified), and Compressive Strength (ASTM C42). At this time, the specific results of the testing were not

available for correlation with the GPR data. In general, the results of the testing were reported to indicate that the condition of the concrete in the bridge deck is poor.

Conclusions

It appears that the blanket use of a threshold amplitude value may overestimate the percentage of deterioration. As much as 97 percent of this concrete bridge deck could be deteriorated using the recommended threshold value of –14dB, if variations in depth of the rebar are not considered. However, once the data are normalized to apparent depth, about 45 percent of the bridge deck concrete can be classified as deteriorated. This probably represents a minimum percent deterioration since normalization to apparent depth can remove some actual low amplitude anomalies. However, this work does show that variation in rebar depth should be considered for specific anomalies.

The specific results of the coring and testing were not available at the time of writing to establish a correlation between the range of reflection amplitudes and the actual concrete condition. However, the general conclusion of the laboratory testing that the condition of the concrete is poor supports the results of the GPR survey.

References

AASHTO Designation TP36-93, 1996. Standard Test Method for Evaluating Asphalt-Covered Concrete Bridge Decks Using Pulsed Radar.

Cardimona, S., B. Willeford, J. Wenzlick, and N. Anderson, 2002, Investigation of Bridge Decks Utilizing Ground Penetrating Radar, Proceedings of Geophysics 2000, Dec. 11-15, 2000, St. Louis, MO.

SHRP Product 2015: Ground-Penetrating Radar for Bridge Deck Evaluations, FHWA, Office of Technical Applications, Washington, D.C.