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Data acquisition and processing parameters for concrete bridge deck condition assessment using ground-coupled ground penetrating radar: Some considerations

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ABSTRACT

Ground penetrating radar (GPR) is a non-destructive geophysical technique that is widely used to determine the relative condition of reinforced concrete. This paper presents case studies from Missouri, USA, where a ground-coupled GPR system was used to assess the condition of eleven concrete bridge decks. The main goal of this paper is to develop appropriate acquisition and processing parameters in order to conduct rapid, efficient, and cost-effective assessment of bridge decks. To accomplish this goal, the GPR data sets were collected with slightly different acquisition parameters and processed using different parameters. The quality of the results and the time required for each bridge deck survey are analyzed. Additionally, several experimental data sets were collected across a 12th concrete bridge deck to examine the influence of weather conditions on reflection amplitude values, since amplitude analysis is used in this study. Based on the authors' experience and findings, appropriate GPR acquisition and processing parameters are suggested and described for use of the ground-coupled GPR method for bridge deck assessment.

1. Introduction

Bridges are a significant part of the transportation system, allowing roads to cross over most obstacles. Due to harsh conditions such as exposure to deicing salts, temperature fluctuations, and heavy traffic, bridge decks tend to deteriorate over time. Corrosion of the internal reinforcing steel is a major cause of concrete bridge deck deterioration. Corrosion byproducts cause the steel to expand and crack the surrounding concrete, allowing for increased deterioration rates (Belli et al., 2013). To prevent and delay significant damage, bridge deck monitoring is essential. Nondestructive techniques, in particular, can be used to identify deterioration at early stages, and the results can help guide decision makers in determining the need for bridge deck rehabilitation or even replacement.

Ground penetrating radar (GPR) has recently been determined to be an effective and efficient technology for bridge deck inspection (Gehrig et al., 2004; Barnes and Trottier, 2004; Tarussov et al., 2013). GPR is a nondestructive tool that uses electromagnetic (EM) signals to penetrate into the medium and measure amplitude and two-way travel time of reflections from the boundary of materials with different electric properties (Shin and Grivas, 2003). GPR is an effective technique for the evaluation of reinforced concrete because of the significant dielectric contrast between concrete and steel. Two types of GPR have been used in bridge deck evaluation: air-launched GPR and ground-coupled GPR. An air-launched GPR antenna is useful to acquire data at higher speed with lower resolution measurements, while the use of a ground-coupled GPR antenna provides higher resolution but lower speeds of data acquisition. Since lane closures are generally required during bridge deck surveys with ground-coupled GPR, such survey needs to be completed rapidly while providing good quality data sets for further processing and interpretation.

As part of this study, eleven concrete bridge decks in Missouri, USA, were surveyed using ground-coupled GPR to assess the condition of the bridge decks. The details of each bridge are discussed in detail elsewhere (Sneed et al., 2014). The data sets from the eleven investigations were obtained using different acquisition parameters and then processed using slightly different processing parameters. The objective of this paper is to design, develop, and validate appropriate acquisition and processing parameters for concrete bridge deck GPR surveys on the basis of the eleven bridges investigated in this study and supplemented with additional test surveys conducted on a 12th concrete bridge deck.

2. Acquisition parameters

Prior to a GPR survey, care must be taken to select appropriate acquisition parameters to achieve an appropriate balance between cost and data quality. The main acquisition parameters include antenna

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frequency, number of scans per unit of distance, dielectric constant, range, number of samples per scan, transmit rate, antenna filters, gain, and traverse spacing, all of which are described in the paragraphs that follow. Important aspects in planning and preparation, as well as conditions during data collection, are also discussed in this section.

2.1. Antenna frequency

Investigation of a concrete bridge deck using ground-coupled GPR is frequently performed with the use of one or more high-frequency antennas (greater than 900 MHz) to provide an optimum balance between depth and resolution of imaging (Gehrig et al., 2004).

In this study, the bridge deck investigations were performed using a GSSI SIR System-3000 unit coupled with a 1.5 GHz antenna and mounted on a compact hand-pushed cart. Based on the authors' past experience, this GPR system has proved adequate for shallow, high resolution investigations, as it provides high quality data and is easy to operate. GSSI states that a 1500 MHz antenna can image to a depth of 18 in.; a 900 MHz antenna can image to a depth of 36 in. (GSSI, 2006). In most investigations, the objective is to image the uppermost layer of reinforcing steel. This was also the objective of the surveys conducted in this study.

2.2. Number of scans per unit of distance

The number of scans per unit of distance is a function of EM pulse repetition and acquisition speed. This parameter affects both lateral resolution and acquisition speed.

In an attempt to optimize this parameter for the equipment utilized in the field investigations in this study, a survey was carried out to determine the time required to acquire ground-coupled GPR data that allows clear imaging of individual pieces of rebar for a different number of scans per unit distance. Data were acquired along the same 20 ft long traverse of a concrete slab using a high-frequency (1.5 GHz) GPR antenna, and the resulting graph is presented in Fig. 1. Fig. 2 shows the GPR data collected at the same location using a different number of scans per distance.

For the same traverse, the influence of numbers of scans per distance on amplitude values was also studied and is shown in Fig. 3. A very minimal effect on amplitudes is observed, which is likely caused by slightly different rebar peak locations as expected, as the amplitudes are picked manually.

As seen in Fig. 1, the parameter of 12 scans/ft allows for collecting data more rapidly. However, using such coarse scan spacing may limit data visibility in the field and cause inaccurate manual adjustments of peaks when processing (Fig. 2a). Conversely, 24 scans/ft is found to be sufficient to image a single piece of rebar for detailed amplitude analysis and can be used to significantly increase data acquisition speed and obtain good quality data for further amplitude analysis. However it should be kept in mind that if other field estimates are required (e.g., selecting a site for coring, locating an individual steel bar, imaging of the lower layer of transverse steel), a denser scan spacing is recommended to improve visibility of GPR scans as they are being collected. Clearly, if identifying anomalies in the field is necessary, more care must be taken to investigate those areas.

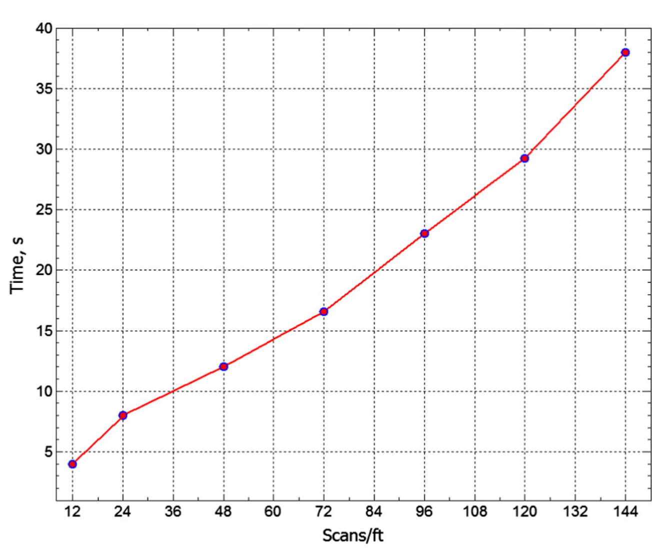

Fig. 1. Number of scans per foot vs. acquisition time recorded per 20 ft of distance.

2.3. Weather conditions & dielectric constant

Weather conditions should also be taken into consideration and documented. Changing weather conditions can cause variations in the moisture content in the bridge deck, and as a consequence alter the dielectric constant of the medium investigated. Small cracks and fractures in concrete tend to hold water increasing both the dielectric constant and conductivity of the material (Tarussov et al., 2013). However, the conductivity of concrete may not be uniform throughout the entire deck due to varying moisture and chloride content. Moisture and chloride content decrease the propagation velocity and reflection amplitude. Fundamentally, propagation velocity υ is a function of the dielectric constant ε ($\upsilon = c/\sqrt{\varepsilon}$, where c is the speed of light), and EM velocity decreases with increasing dielectric constant. Similarly, signal attenuation might affect reflection amplitude as the signal penetrates through conductive concrete, weakens, and strikes reinforcing steel with less energy (Barnes et al., 2008).

To investigate the influence of weather conditions on the reflection amplitude values, a study was carried out in which reflection amplitude values were measured along a given traverse on a solid reinforced concrete bridge deck (Fig. 4) during different weather conditions. Measurements were carried out using the same GPR antenna with the same acquisition settings over a time period of 6 months (from December 2012 until May 2013). Fig. 5 shows the reflection amplitude results from four different scans corresponding to the following: 1) December 5, 2012, 0.98 in. of rain reported within 35 h prior to the investigation, temperature range of 33–57 °F; 2) February 19, 2013, no precipitation within 24 h prior to the investigation, temperature range of 24–35 °F; 3) May 19, 2013, no precipitation within 24 h prior to the investigation, temperature range of 68–87 °F; and 4) May 20, 2013, 0.60 in. of rain reported within 10 h prior to the investigation, temperature range of 60–75 °F. Results from scans 3 and 4, which were acquired within 24 h of each other, clearly illustrate a difference in reflection amplitudes at each location along the traverse. Since it is reasonable to assume that the bridge deck did not deteriorate significantly within a single day, the differences in results from scans 3 and 4 can be attributed to differences in weather. Comparing the reflection amplitudes from scans 1–4, it can be observed that the values from scan 4 are larger (less negative) than those of scans 2 and 3. Under the same conditions, these results would suggest that the bridge deck actually improved with time. However, this cannot be the case since no intervention was carried out on the bridge deck within this time period. Therefore, the weather conditions to which the bridge deck was exposed can be assumed to have influenced the results. Additional study is currently underway by the authors to further study this issue. However, these results illustrate that in practice, it is important to complete a GPR survey within one day with no significant weather changes so that the range of reflection amplitude values is consistent. The test data also indicate that the absolute value of the reflection amplitudes is a less critical consideration than relative differences in reflection amplitude.

The dielectric constant should be set using core control for calibration purposes. If this is not possible, bridge plans (rebar embedment depth or deck thickness) should be used for calibration purposes. If this is not