On the Use of Ground Penetrating Radar for Bridge Deck Assessment

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ABSTRACT

Many transportation agencies require the condition assessment of concrete bridge decks as part of scheduled maintenance programs. Traditional bridge deck inspection methods include: hammer sounding and chain drag techniques. The interpretation of such techniques' results depends on the operator and may produce highly variable results. Ground Penetrating Radar (GPR) has been extensively used and become an invaluable technique due to its high level of accuracy, being Non-destructive testing (NDT), low cost and simple operation. GPR technique is used for detecting the steel rebars embedded in the concrete, determining the concrete slab thickness, the asphalt layer thickness as well as developing a corrosion map for the steel rebars. This study presents the recap of using GPR technique in inspection of a bridge deck located in El-Kobba suburban in Cairo. A clear methodology for the data collection, processing and analysis of collected raw data is presented. Data is first processed, then Numerical amplitude method is used in the analysis. The study also clearly shows how to determine: 1) the slab thickness, 2) asphalt layer thickness, and 3) the arrangement of steel rebar of the slab. Thus, GPR technique can be used to make structural assessment and obtain the structural information without destruction to the element as well as structural checks and analysis can be performed for the bridge decks.

INTRODUCTION

Non-destructive testing (NDT) methods have become an effective and reliable way for characterization, diagnosis and monitoring of concrete structures. Continuous diagnosis assists proactive timely management of any infrastructure assets specifically highway bridge decks. The implementation of the NDT methods implies the evaluation of different parameters such as the presence and condition of cracks, voids and delamination. When evaluating existing concrete structures, knowledge about inner structural condition is essential. Particularly, the diagnosis of concrete condition state comprises several parameters and factors: estimation of the element thickness, detecting the location of the reinforcing bars, and the location of the voids, if any, chloride content, delamination, cracking, and corrosion. NDTs gain popularity due to their various advantages including; providing a high level of safety for the labor staff, time saving, providing high rates of production in comparison to traditional methods. Ground Penetrating Radar (GPR) is a widely-used technique in the different aspects such as archeological excavation, detection of the embedded pipes in soil, and the
determination of the glaciers thickness. GPR is an electromagnetic evaluation technique used in the transportation infrastructure and a variety of other applications, including: concrete inspection, utility detection, geology and archeology. GPR has been proven as a successful condition assessment technique by numerous authors particularly for the condition assessment of bridge decks [1, 2, 3, 4]. The study shows the application of using GPR for the structural assessment of a bridge deck in Egypt. The GPR scan is analyzed to obtain the concrete thickness, reinforcement bars count and configuration in addition to the asphalt layer thickness.

DATA COLLECTION

El-Kobba bridge deck was scanned using GPR to obtain the arrangement and the positions of the steel rebars of the slab, slab thickness, determine the asphalt layer thickness and getting the corrosion map of steel rebars. El-Kobba bridge passes over the Great Cairo metro at the El-Kobba suburban. The bridge system is composed of steel girders on the steel pillars with a reinforced concrete deck. The bridge deck condition assessment using the GPR was performed using high frequency (2.00 GHz) ground-coupled antennas, which provides an excellent identification of the reinforcing steel. GPR data along the bridge deck is normally collected in parallel and orthogonal lines approximately 1 meter apart. A strip of approximately 20 meters length and a lane width of 3 meters was scanned parallel to the direction of traffic. There are 21 scans in the transversal direction, and 3 scans in the longitudinal directions which results in a total of 24 scans. The scanning process is depicted in Figure 1. A plan of the scans is shown in Figure 2.

Figure 1. GPR data collection for the bridge deck.

Figure 2. A plan of the scanned paths.
The GPR system, RIS MF Hi-Mod with an array of 2 antennas (2000 and 400 MHz) is used through this study. The 2000 MHZ antenna is utilized because of its high-resolution capability. Moreover, the concrete bridge decks don’t need a high exploration depth. Traverse spacing must be chosen depending upon the objective of investigation. A coarser traverse spacing requires less survey time but decreases spatial resolution of mapping, which could lead to inaccurate results especially when small embedded objects should be clarified. The grids spacing in both directions were taken to be 1.0 m. In this setting, we have a strip of 3.0 m width and 21.0 m length.

MODEL DEVELOPMENT

Rebar positions appear in the GPR raw data as small hyperbolas. These hyperbolas occur due to the conical pattern in which antenna transmits energy, 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 clear in the raw data as well as obvious areas of deterioration where rebar reflections were weak. Areas of the bridge deck having weak reflection amplitude values are typically indicative of the deterioration. These weaker reflections can be due to several factors, including high chloride content, concrete deterioration or corrosion of the embedded steel rebar, which all attenuate the radar signal. After making data collection, we have radar signal amplitudes for both antennas, 400 and 2000 MHZ. The spacing in both the longitudinal (3 scans), and the transversal direction (21 scans) is one meter.

Each scan contains thousands of reflected amplitudes of radar signal and represents a strip of 1.00 m. Following data collection, the individual GPR data files (A-scan) are transferred to a PC for processing. Using the software IDS GRED HD, the 1D data files are analyzed to get the 2D images (B-scans). The raw data gathered through GPR scanning is just amplitudes (Volts) versus the horizontal distance along the scanning path. Processing data means converting the raw data into a readable information.

Thermal drift, electronic instability, cable length differences and variations in antenna airgap can cause ‘jumps’ in the air/ground wavelet first arrival time (usually referred to as the time-zero point) as reported in [5,2,6]. Therefore, traces require the adjusting to a common time-zero position before applying processing methods. This is usually achieved using some particular criteria (e.g., the air wave first break point or first negative peak of the trace) and is often done automatically by the processing software. The first step in data processing is to shift each scan of the data so that the top of the scan corresponds to the surface of the bridge deck as shown in Figure 3.
The proposed model develops a corrosion map that is extensively based on the clustering algorithms. The proposed model assumes that there are four categories for the condition of the bridge deck which are: “very severe”, “severe”, “medium”, and “good”. i.e., three thresholds. The GRED HD software is used to extract the amplitudes of the top reinforcement rebars. The X,Y, and the reflection amplitude data for each rebar location were exported in a XLS format. Clustering is the process of grouping objects that have the similar information together. RapidMiner® 7.5 software [7] is used as a platform to perform the clustering algorithm based on the Excel files. There are different clustering algorithms such as K-means clustering, expectation maximization cluster, fuzzy C-means clustering, X-means, Fast K-means, K-medoids, hierarchical agglomerative clustering, etc. The proposed model utilizes expectation maximization algorithm to partition the amplitude values because of its capability to generate compact and well-separated clusters. Surfer 12 [8] is a plotting and mapping software that is utilized to develop the corrosion map for the bridge decks. Finally, a Corrosion Index (CI) can be calculated as follows.

\[
CI = \frac{\sum_{i=1}^{4} q_i \times W_i}{\sum_{i=1}^{4} q_i}
\]

Where; \(q_i\) represents the quantity of a bridge element in category \(i\). \(W_i\) represents the weighting factor for a bridge element in category \(i\). The weighting factors for the “good”, “medium”, “severe”, and “very severe” categories are assumed 100%, 70%, 50%, and 20%, respectively.

Several precautions are considered during the operation and processing processes. For the thermal drift, the scanning process was performed at night 2:00 am to overcome the internal heating of the equipment during the operation process. The antenna air gap is removed by moving the profile start time to the asphalt layer. For the dielectric constant of the material (concrete in our case), the wave length of the electromagnetic waves decreases as they encounter higher dielectric material. The utilized GPR is equipped with two antennas. The utilized GPR is equipped with two antennas which are: 2000 and 400 MHZ. Consequently, in case the electromagnetic waves fail to reach the desired penetration depth, the lower frequency (400 MHZ) is utilized.
DATA ANALYSIS AND RESULTS

Data analysis was performed using the IDS GRED HD data analysis software. The software provides a two-dimensional (2D) tomography of the underground layers. It also presents the automatic detection of the data traces (hyperbola) and allow transferring to AutoCAD. Before analysis, some basic options were set as time zero correction, background removal and many filtering algorithms to get the B-scans clear. Figure 4 represents the B-scan image for the longitudinal direction, the first scan path in the VV configuration (antennas are parallel to the scanned paths).

![Figure 4. B-scan depiction of a section cut of the concrete floor slab.](image)

As indicated in Figure 4, the yellow and red boxes represent the weak reflections due to existence of expansion joint at the start and end of the scan path. The signal attenuation areas that indicate unclear rebar returns are indicated. The green box indicates good and clear rebar reflection that can be easily distinguished. This also represents the concrete that is in a good case. The brown line represents the approximate concrete slab depth as it is noisy beneath this line. This scan indicates also that the bridge deck has one bottom layer of steel rebar which is approximately 20cm. The top region represents the air gap between the antenna box and the surface and is cut-off using time zero correction algorithm. The asphalt layer thickness is 10cm based on the profiles.

Figure 5 shows the lines representing steel rebar forming a grid for the transversal and longitudinal directions. Using AutoCAD, the lines are drawn along the positions of hyperbolas representing the steel rebar. From this step, the arrangement and positions of steel rebar are known. For the longitudinal direction, it is found that in a distance of 16m clear reflections of rebar, there are about 102 bars which mean the one meter has about 6.4 bars with average spacing 15.6cm. On the other direction, it is found in a distance of 2.33m, there are about 14 bars which mean that one meter has about 6 bars. The figure shows the bottom mesh of the slab. Also, the steel rebar reflections are positioned at about 0.20m from the top which is considered the slab thickness.
The developed clustering model using the RapidMiner platform is shown in Figure 6. The corrosion map for El-Kobba bridge is depicted in Figure 7 where 4.56% of the bridge is a “very severe” condition, 14.11% of the bridge is in a “severe” condition, 61.83% is in a “medium” condition, and 19.5% is in a “good” condition. Based on Equation (1), the Corrosion Index is 70.76% which means that the bridge deck is in the “medium” category. The amplitude thresholds are expressed in volts and they are shown in Figure 7. There is significant amount of corrosion at the center lane because of the dense traffic. Moreover, the bridge is located in the center of Cairo which means that it is subjected to heavy traffic loads.

CONCLUSIONS

This study presented applications of GPR technique in structural assessment for bridge deck. With the presented study, the following information can be collected:

1. Bridge deck overall thickness and concrete cover where there is a noisy region representing air beneath the deck bottom.
2. Asphalt layer thickness which is considered a different material and the in-between distance can be represented in a different color.

3. Position, number and arrangement of steel reinforcement as the hyperbolas represent the steel rebar and the bars are picked. This helps making future structural checks and determining the structural capacity for the bridge deck.

4. Corrosion map for the steel reinforcement of the bridge deck.

Different acquisition parameters were discussed. The obtained results can be used in a wide range for structural assessment for concrete elements.

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REFERENCES


