APPLICATIONS OF GROUND PENETRATING RADAR IN BRIDGE HEALTH MONITORING AND ASSESSMENT

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Abstract

The development of bridge systems is an area of significant engineering investment and has been a feature of human progress. This is primarily because any failure in bridge and highway maintenance is likely to lead to increased deterioration with known consequences such as accidents and closures with significant economical impact. Bridges are constantly subject to different loading conditions (dynamic and static loading) as well as being susceptible to the full impact of natural and environmental events such as flooding and earthquakes. They are also subject to a natural process of deterioration of construction materials. In one short sentence bridges are an important part of the infrastructure asset and the heritage of any society. They require care and should be the subject of any planned maintenance mechanism adopted by the owners. Employment of new technology in bridge health monitoring and assessment has taken momentum in recent years. Applications of Ground Penetrating Radar systems have proved to be effective in detecting and assessing certain aspects of a bridge’s structural components. This paper presents and discusses the adopted methodology and the results of a case in which GPR was used in monitoring and assessing a bridge in Chatham, Kent. It focuses on the effectiveness of using the “correct” tool and data processing in the understanding of possible defects on a very busy bridge.

Keywords: GPR; IBIS-S; Bridge; Monitoring; Non-destructive

Introduction

Bridges are assets and are vital to human life in terms of economy, mobility, environment and development of communities. No doubt assets should be harnessed and looked after, but not in a dispersive and disorganised manner. It should be part of a robust planned monitoring and maintenance mechanism within the context of the life cycles of structures. In this day and age, it is imperative that any assessment and monitoring method adopted should be “cost effective”, efficient and fit for purpose.

Depending on types and needs of bridge, different approaches should be adopted in order to generate relevant and useful information (data) accordingly. Most bridge health assessment theories emphasise that it is important to know how each technique and method works and is applied, what exactly it is anticipated to achieve and how it is achieved.

Different types of NDT (non-destructive testing) techniques are commercially available within the context of bridge health monitoring and assessment. Naming a few, accelerometers, smart total station, vibration measurement sensors, wireless network systems, and GPR have proved to be of great service to the industry if and when they have been adopted appropriately. It is known within the community that no NDT technique on its own can produce complete answers to all questions in terms of bridge condition survey, but they all have been proven successful in certain applications. Each NDT technique provides different information about the bridge structure. Therefore each NDT technique can be used to assess different conditions and problems of the structure. It is needless to emphasise that it is of paramount importance to choose the right NDT technique related to bridge health monitoring needs (Annan et.al., 2002) and ((Parrillo & Roberts, 2006).

Applications of GPR have been widely appreciated by different professionals and have been successfully implemented and adopted to solve complicated engineering and science based problems. Recent developments in GPR technology (equipment and software) and awareness of scientists and engineers of its effectiveness and varied applicability have boosted GPR's credibility and utilisation extensively in recent years (Scotta et. al., 2003), (Soldovieri et. al., 2006) . Nowadays Civil Engineers and NDT Archaeologists, Geologists, Geotechnical Engineers, Glaciologists, Forensic Investigators, Environmental Scientists and Hydrologists amongst others utilise GPR in one form or another to find solutions for challenging engineering and scientific problems.

The application of Ground Penetrating Radar in structures including highway / road infrastructures such as assessment and monitoring of bridges and tunnels is not a new concept. GPR has been used successfully to monitor bridge decks within the context of identification and integrity assessment of rebar, rebar cover length, depth of cracks, settlement, ingress of moisture and delamination, layers of materials, cavities, location of rebar and other structural features (beams and columns) as well as bridge abutments (leakage, cracks and settlement) (Parrello and Roberts 2006), (Benmokrane et.al, 2004), (Rhazi et.al., 2003), (Lubowieckaa et. al., 2009), (Fujun et. al., 2011) and (Helwany et. al., 2003).

As described by the EuroGPR web site, www.eurogpr.org, *"ground penetrating radar (GPR) is an advanced, non-invasive sub-surface imaging technique that typically uses short pulses of electromagnetic energy to 'see' into the ground. GPR can image through soil, concrete, tarmac, rock, wood, ice and even water. It is quick, easy to use and inexpensive in comparison to other investigation methods. It is capable of probing down to a few tens of metres (depending on the system type & ground conditions) and provides the user with a 'cross-sectional' image of the sub-surface"*.

GPR uses electromagnetic waves (pulse) to identify underlying features in solid structures. The typical technique uses a source antenna (transmitter) to generate waves that then interact with and reflect from subsurface features. A receiving antenna measures the reflected waves. The return signals are then analysed to identify underlying features.

This paper presents a full case-study of applying GPR in assessing the actual condition of the "Pentagon Road Bridge" in Chatham, Kent, England. This study is part of a larger study which considers other NDT methods in conjunction with each other in order to produce a clearer picture of the health of bridges.

Site Description

Pentagon Road Bridge (Fig. 1) was constructed in 1975 and carries an access road from Rope Walk to the Pentagon Shopping Centre in Chatham, Kent. The bridge is believed to be a four span simply supported concrete deck of beam and slab construction. At the west, high end, the bridge links the access road to the rooftop car park of the shopping centre. The end support is a leaf pier that is shared with the access road. There is a lower access road for buses that is a brick faced concrete abutment at the east, low end of the bridge. At the east end there was a pedestrian walkway beneath the deck but it has been removed. The bridge foundations are spread footings.

The Pentagon Road Bridge

The Pentagon Road Bridge is located in Chatham (SE UK) and forms the entrance to the Pentagon Shopping Centre car park.

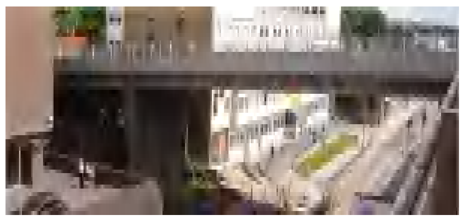

Figure 1 – (A) Pentagon Road Bridge in Chatham, Medway, England.

The figures 2 and 3 depict a plan view and the 3D model of the bridge respectively.

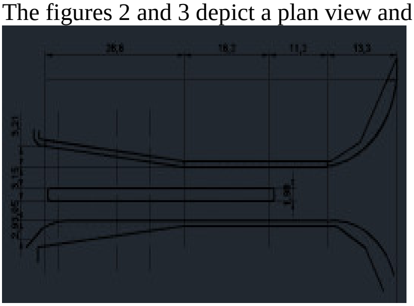

Figure 2 – Plan of the Pentagon Road Bridge

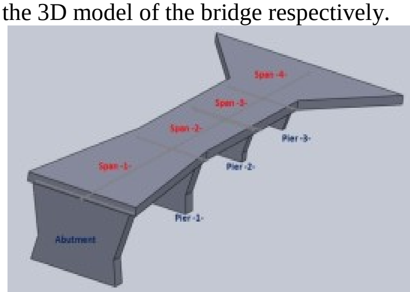

Figure 3 – 3D Model of the Pentagon Road Bridge

Visual Inspection

Previously, a visual inspection was carried out with a camera, Leica Disto laser height measuring instrument, crack gauge, hammer, torch, ladder, and a 22m ascendant telescopic hoist in 2009 by Jacobs Engineering U.K. Limited. From the report, the faults and recommendations are a number of known defects on the bridge with the rebar visible in some places due to concrete deterioration. Concrete repairs are required to the West End Leaf Pier Support, Piers 1 and 2 and all of the deck spans. The transverse beam at the west end of Span 4 is in very poor condition and requires an assessment of its adequacy prior to any remedial works being carried out. The surfacing on the deck is nearing the end of its life with areas of reinstatement, some in poor condition, potholes and fretting. All of the bearings to the main spans that could be seen were in a poor condition. The fixed bearing at the east of the north deck of Span 1 has a broken bottom plate/shell and needs to be replaced. The report recommended that all of the bearings need replacement. The transverse joints and the longitudinal joint have faults that indicate that there is leakage at each. The joints should be replaced. The parapets are damaged with areas of corrosion and require repair and painting.

The above inspection and subsequent report did not cover any sub-surface investigation and assessment of the bridge structure. The first author's research team at the University of Greenwich requested access to the bridge via the highway engineering department of Medway City Council (the owners of the bridge) in order to carry out a full survey of the bridge using their Ground Penetrating Radar system. For that purpose the following objectives were set:

- To locate the position of the upper rebar
- To estimate the depth of rebar cover throughout the bridge deck
- To locate the position of the lower rebar
- To identify posible areas of moisture ingress below the deck surface
- To identify any other structural features and / or defects

The Equipment

The GPR survey was carried out on 20th January 2011. The weather was dry and sunny and the temperature was recorded as 10˚C. This survey was carried out with the full support of the Medway City Council's Highway division and their subcontractors. This survey was also carried out in collaboration with IDS-UK. It was necessary to introduce a traffic control system on the day as the bridge is heavily used by members of the public. Full access to the bridge was required, from time to time, during the survey.

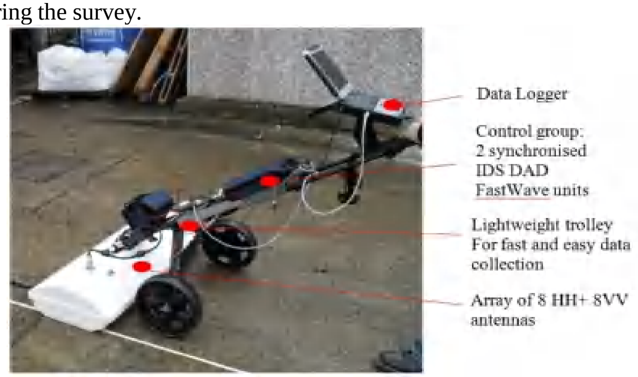

Figure 4 –Full view of the GPR system RIS Hi-Bright

The Ground Penetrating Radar (GPR) survey was performed using the RIS Hi BriT. Designed specifically for the inspection of bridge decks, this high frequency array is lightweight and maneuverable yet provides high quality, densely sampled data. Denser sampling produces higher quality tomography and 3D images which assist considerably in the interpretation of data.

The system is composed of an array of eight horizontally polarized 2GHz channels spaced at 10cm, mounted on a lightweight and highly maneuverable trolley and powered by a large, 24Ah 12V battery. The acquisition is controlled by K2 Fast-wave software, which runs on a standard ruggedised laptop. The RIS Hi Bright was specifically designed to work in conjunction with advanced software processing allowing the detection of shallow features and the condition of materials within structures. It was particularly intended for concrete assessment on bridges to detect thickness of layers, shallow utilities and drainage, location and spacing of rebar, and moisture penetration and delamination.

The Survey

GPR survey was performed by marking a grid on the ground using chalk or temporary paint and pushing the radar across the grid in straight lines. The location of the grid is referenced by recording the coordinates with respect to a fixed location. Because the RIS Hi Bright hardware has eight antennas at 10cm spacing, in order to maintain a regular interval of scans the ground must be marked at 80cm intervals. The process of referencing is very important and should be carried out with care and diligence in order to map the survey area accurately. Due to the frequency of the antennas and the size of the array, it was recommended that multiple surveys be performed covering moderate areas, rather than one large survey. For optimum results it is recommended to push the radar in both the Transversal (T) and Longitudinal (L) axes. The GPR test was performed on bridge deck covering an area around 7m x 60m approximately.

Over the bridge deck, a total of 54 longitudinal and 182 transversal array scans were cautiously collected using 2GHz, RIS Hi Bright system antenna.

Results and Data Processing

Data processing procedure

The data processing was performed using the IDS GRED data analysis software. The software provides a 2D tomography of the underground layers and a 3D view of the surveyed volume. The capability of merging on the same tomographic map of datasets collected along both longitudinal and transversal scans considerably increases the reliability of the results of the analysis.

The process involves the following steps:

data filtering, estimate of the propagation's velocity on EM waves in the structure through hyperbolic fitting and migration such as focusing.

The processed data sets run the automatic extraction of the shallower layer of rebar, the analysis of rebar backscattered signal and manual extraction of the deeper layer of rebar. Acquired radar data is saved as raw data and is processed to display as a ‘B-Scan’ that represents a vertical slice through the surveyed area.

Due to the scale of the operation and for the sake of accuracy, it was decided to divide the deck surface into 8 separate but interconnected zones and carry out GPR survey separately. This also was necessary to allow the traffic to flow at certain intervals. Figure 5 depicts the proposed zone configuration of the bridge for survey purposes:

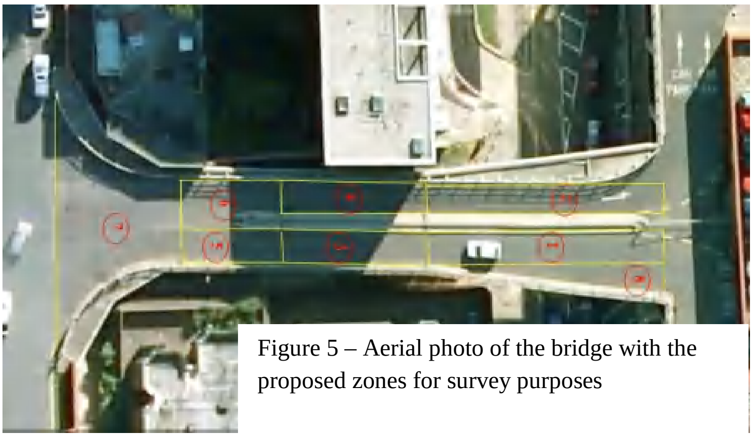

Figure 5 – Aerial photo of the bridge with the proposed zones for survey purposes

Figure 6 depicts a set of vertical sliced data at depths of 6, 16, 26, 38 and 50 cm from the surface of the deck respectively. Certain consistent features and their respective appearances have also been highlighted (red circles). These features then have been superimposed on a computer model depiction of the bridge in order to demonstrate their scales in 3D.

A possible explanation for the appearance of the highlighted features could be ingress of moisture through the surface of the deck. These features associate with surface cracks that were observed during the visual assessment of the bridge. Recommendations have been made to the owners of the bridge to expose one of the highlighted areas in order to verify the suggested moisture presence and possible delamination of the concrete at lower levels of the bridge structure. This feature is compatible with other case-studies and laboratory experiments that the team has carried out previously.

A large quantity of data was obtained and processed in order to address the set objectives of this work but for obvious reasons it was not possible to present them all in this paper. However, for the purpose of this paper a selected number of data have been chosen to highlight the effectiveness of the GPR in assessment of bridge structures in identifying possible defects that otherwise are not easily identifiable by adopting conventional methods. To this effect this paper has presented results (processed data and interpretation) concerning the identified Zone 5 of the bridge, see figure 5.

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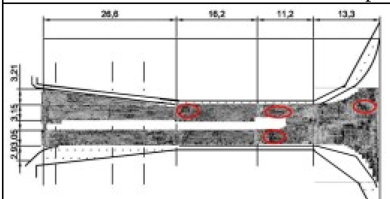
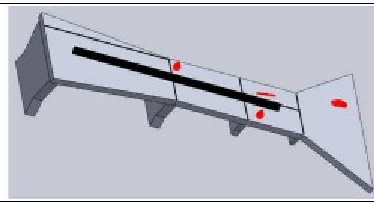
<tr><td></td><td></td></tr>
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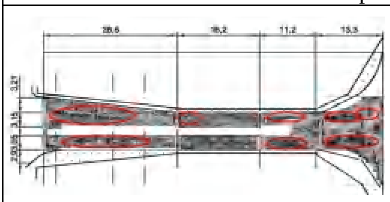
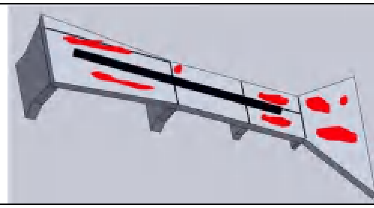
<tr><td></td><td></td></tr>
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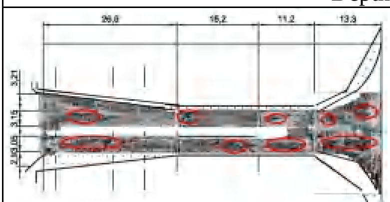
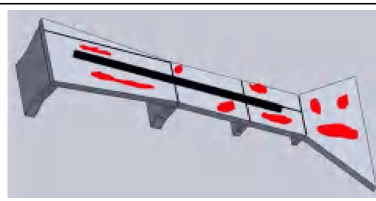
<tr><td></td><td></td></tr>
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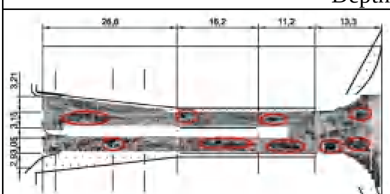
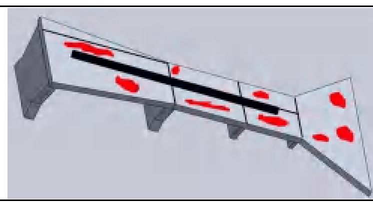
<tr><td></td><td></td></tr>
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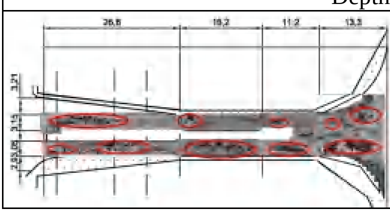
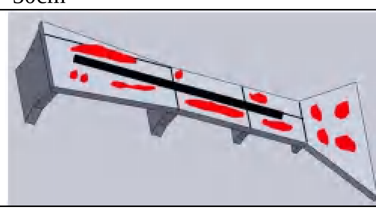
<tr><td></td><td></td></tr>
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Figure 6 – Vertical Sliced processed data (left) and computer modelled depiction of possible moisture ingress (right)

The processed data and the subsequent interpretations are rather conclusive in terms of the identified structural features and components. Figures 7 and 8 illustrate clearly the locations of the upper rebar as well as the lower rebar with possible areas which may have been affected by moisture ingress. Figure 8 also depicts the lower structural features (at around)

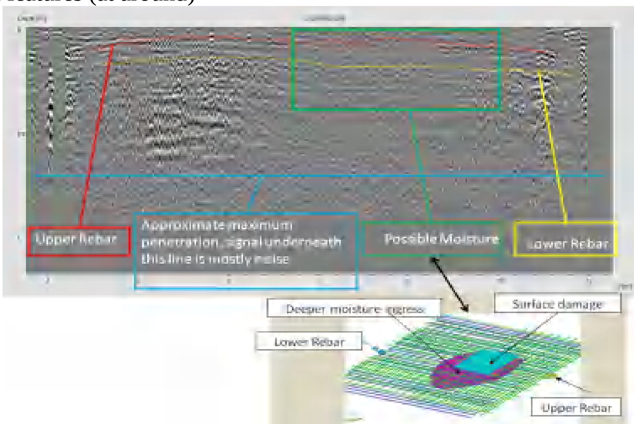

Figure 7 – Processed data and possible explanations (interpretation) on one of the survey lines within Zone 5 of the bridge

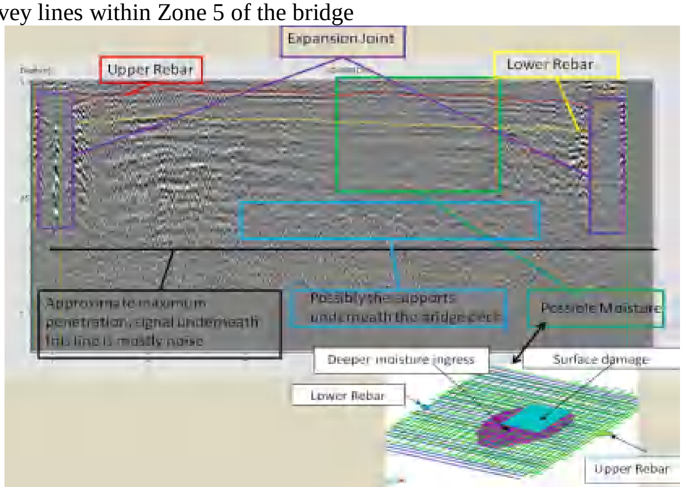

Figure 8 - Processed data and possible explanations (interpretation) on another survey lines within Zone 5 of the bridge with deeper penetration

Conclusions

In terms of achieving the set objectives of this investigation, the presented results are pretty conclusive. As result of diligent and careful planning, survey (referencing), data acquisition, data processing and interpretation it was possible to obtain the required answers to a number of challenging questions. Results of this investigation in conjunction with other non-destructive testing methods (IBIS-S with interferometric capabilities) produced vital information within the context of structural integrity of the bridge. Once more it was demonstrated that if the "right" equipment and trained staff are employed there is a high chance of success in achieving challenging objectives. No doubt, Ground Penetrating Radar is effective and conclusive if it is used correctly and appropriately.

Acknowledgement

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