Non-destructive assessment of a historic masonry arch bridge using ground penetrating radar and 3D laser scanner

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# Non-Destructive Assessment of a Historic Masonry Arch Bridge Using Ground Penetrating Radar and 3D Laser Scanner

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*Abstract* – **Applications of non-destructive testing methods such as ground penetrating radar (GPR), 3D laser scanners, accelerometer sensors and vibration detecting sensors amongst many others have been used to assess and monitor masonry arch bridge spans (brick and stone) in the past few years. This paper reports the application of high to low frequency GPR antenna systems (2000 MHz, 600 MHz and 200 MHz) and a 3D laser scanner on a historic masonry arch bridge (the Old Bridge, Aylesford - 860 years old) located in Kent, England. The position of different layers of the deck structure was established with the identification of the original stone base of the bridge and location of a number of structural ties (anchors – remedial work carried out previously). Results of the 3D laser scan of the bridge were crucial to initiate long-term monitoring of the structure.**

## I. INTRODUCTION

There exist approximately 70,000 masonry arch bridge spans (brick and stone) in the UK with tens of thousands more throughout Europe. A significant number of these bridges are still in operation and form part of the road and rail network systems in many countries. Many of these structures are in desperate need of repair and maintenance [1]. To keep these assets operational in the future it is necessary to provide effective management and maintenance as well as to understand adequately their special needs [2]. Applications of non-destructive testing methods such as ground penetrating radar (GPR) [3, 4], 3D laser scanners [5], accelerometer sensors and vibration detecting sensors [6] amongst many others have been recently used to assess and monitor such structures. GPR can provide information on the subsurface; hence the structure can be assessed and the interventions planned on purpose. The use of a 3D laser scanner allows for an accurate measurement of the dimensions of the entire bridge as well as for recording the position of all the features (mm accuracy) for future reference.

## II. AIMS AND OBJECTIVES

The main aim of this research was to provide structural detailing of the bridge deck in order to install spotlights flush within the upper layer of the pavement without any intrusion on to the historic stonework of a masonry arch bridge. To achieve this aim, the main objectives (pursued using a 2000 MHz GPR system) were:

- to assess the depth of the upper layer of asphalt and its uniformity throughout the surface of the deck;
- to assess the depth to the historic stonework.

A secondary aim of this project was to model the bridge (including the location of reinforcement bars) and initiate the long-term monitoring of the whole structure. To this purpose, low-frequency GPR systems (200 MHz and 600 MHz), tape measuring and a laser scanner were used.

## III. THE SURVEY SITE

The Old Bridge at Aylesford (UK) dates from around 1250. The bridge is made of local "ragstone" (Fig. 1). It underwent a major alteration in 1811. The bridge is closed to cars and motorbikes, although it remains in use for pedestrians, cyclists and horses. It is a scheduled ancient monument under the control of the English Heritage. There is currently no lighting system on the bridge and potential installation was considered in this paper. To this purpose, lights and power cables could be installed within the upper layer of the asphalt without any intrusion to the historic bridge stonework.

*Fig. 1. The Old Bridge at Aylesford in Kent, UK.*

## IV. EQUIPMENT & SURVEY METHODOLOGIES

### *A. 2000 MHz antenna system*

Data were acquired using the IDS RIS Hi-BrigHT GPR antenna array. The system consists of two rows of eight double polarized 2000 MHz antennas with 10 cm spacing and allows scanning with a footprint 80 cm wide. The bridge deck was surveyed using four scans spaced equally, performed along the length of the bridge. For data management purposes, the survey was divided into three 'Zones' (Fig. 2).

### *B. 200 MHz & 600 MHz dual frequency antenna system*

Four scans were performed using the TR Dual-F 200 MHz and 600 MHz antenna system (penetration of 1.5 m and 2.5 m, respectively) from the IDS RIS MF Hi-Mod. The existing reference points (high frequency survey) were exploited and the same data acquisition as the high frequency survey over the three areas was carried out.

### *C. Manual measurements*

A multi-stage procedure was followed to approximately locate the positions of the X frames in depth with respect to the bridge deck, and distance with respect to the scar in the tarmac. A folding ruler was used to calculate the depth of the targets $D_T$ as follows:

$$D_T = D_1 - D_2 \tag{1}$$

where $D_1$ was the depth of the centre of the X reinforcement (measured from the top of the wall) and $D_2$ was the height of the wall above the tarmac.

### *D. Laser scanner*

A laser scanner Leica P20 was used for the investigation. The high resolution scan was made placing the reference targets on the bridge in locations that were visible from multiple measurement positions.

## V. MAIN RESULTS AND CONCLUSION

Results from the 2000 MHz antenna system enlightened that the average thickness of the upper asphalt layer was 7 cm. The average total depth from the bridge surface to the historic stonework was 41 cm (Fig. 3). There was considerable variation in the thickness of both layers (e.g., Fig. 4), due to the bridge's construction and the large areas of resurfacing. With regards to the location of the ties and the modelling of the whole structure, the 200 MHz and 600 MHz dual frequency antenna system was able to identify the reinforcing bars (Fig. 5a). Location was confirmed by the modelling made using the laser scanner (Fig. 5b).

*Fig. 2. The Aylesford Bridge: the survey zones.*

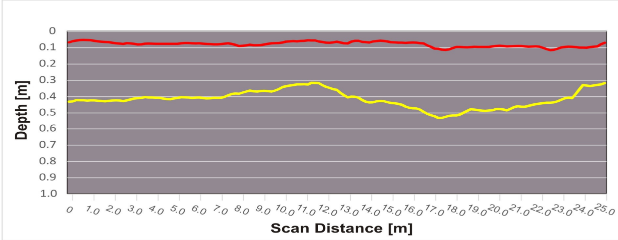


*Fig. 3. Average total depth of asphalt (red line) and base layers (yellow line) within the bridge deck area.*

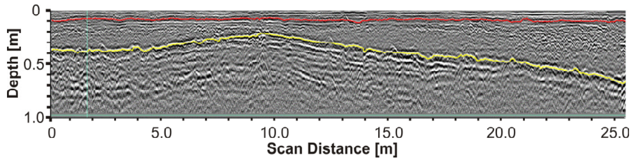


*Fig. 4. Layering of the asphalt (red line) and base layers (yellow line) within one scan in Zone 2.*

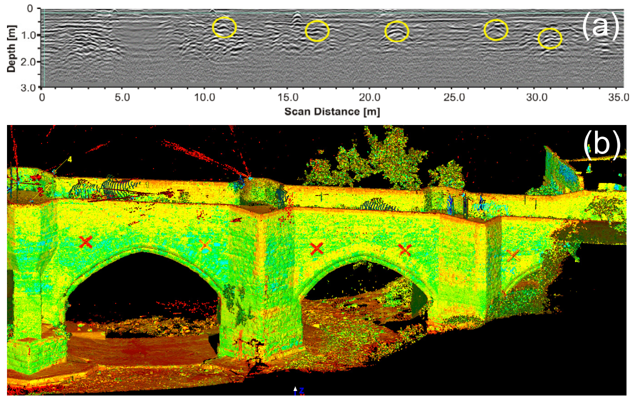


*Fig. 5. Reinforcing bars identified by (a) the 600 MHz GPR (circles) and (b) the laser scanner (red crosses).*

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