Road foundation detailing using ground penetrating radar systems with different frequencies

Alani, Amir, Tosti, Fabio ORCID: https://orcid.org/0000-0003-0291-9937, Bianchini Ciampoli, Luca and Benedetto, Francesco (2017) Road foundation detailing using ground penetrating radar systems with different frequencies. In: 9th International Workshop on Advanced Ground Penetrating Radar - IWAGPR2017, 28-30 Jun 2017, Edinburgh, UK.

http://dx.doi.org/10.1109/IWAGPR.2017.7996096

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Assessment of the Underground Construction Details of a Road Pavement Using GPR Antenna Systems with Different Frequencies

A.M. Alani[1], F. Tosti[1], L. Bianchini Ciampoli [2], F. Benedetto[3]

[1]School of Computing and Engineering, University of West London (UWL)
St Mary's Road, Ealing, W5 5RF, London, UK
Amir.Alani@uwl.ac.uk; Fabio.Tosti@uwl.ac.uk
[2]Department of Engineering, Roma Tre University
Via Vito Volterra 62, 00146 Rome, Italy
luca.bianchiniciampoli@uniroma3.it
[3]Signal processing for Telecommunications and Economics Lab., Roma Tre University,
Via Vito Volterra 62, 00146, Rome, Italy
francesco.benedetto@uniroma3.it

***Abstract*—This paper reports on the assessment of the underground construction details of a road pavement using different frequency ground penetrating radar (GPR) antenna systems. In addition to this, the possible presence and location of an underground watercourse was investigated in this work. The existence of the latter problem was perceived due to reoccurrence of longitudinal and traversal road surface cracking as well as subsidence at a particular location of the road. Reoccurrence of this damage was interpreted and related to the possible existence of an underground watercourse. The original design and the construction of the road were as such to prevent this movement. Therefore it seemed necessary to perform a GPR survey to investigate and confirm the underground construction details of the road. To this purpose, the identified area was surveyed using high to low frequency antennas with 2000 MHz, 900 MHz, 600 MHz and 200 MHz central frequencies of investigation. The results were conclusive in terms of construction details provided and evidence of subsidence within the road identified. The maximum depth of penetration achieved by the use of the 600 MHz and the 200 MHz antennas (maximum of 3 m) did not allow to identify or confirm the existence of any underground watercourse.**

Keywords—underground consruction details; road pavement; ground penetrating radar (GPR); antenna frequency

I. INTRODUCTION

The assessment of the underground construction details of a road infrastructure is a problem of great concern in highway engineering [1]. The case becomes complicated especially when damages reoccur after carrying out remedial surface maintenance and repair works over the life cycle of the infrastructure [2]. The challenge becomes exacerbated at the presence of underground watercourses, such that the geotechnical stability of the entire road structure could be threatened [3].

In this respect, ground penetrating radar (GPR) has been recognised and accepted as one of the most effective non-destructive testing (NDT) techniques that could be employed in identifying the cause/s of such problems. The recent advancements and developments made in the field of GPR hardware as well as the current level of understanding of the applications and processing techniques of the GPR data have immensely added to the reliability in the utilisation of this tool in variety of subsurface investigation projects.

The origin of GPR can be traced back to the nineteen fifties [4] with first major usage in demining operations [5]. Due to its high flexibility of employment it is now used in a wide range of disciplines, spanning planetary explorations [6], civil and environmental engineering [1, 7], geology [8], archaeology [9], forensic and public safety [10], agricultural and forestry sciences [11, 12].

In highway engineering, GPR has been widely used for the assessment of the underground construction details of road pavements. These information are usually implemented within mechanistic models for the assessment of the pavement performance during its life cycle [13]. Among the main pavement features investigated, we can cite the assessment of the layer thicknesses [14], damage in hot mix asphalt (HMA) layers [15], load-bearing layers and subgrade soils [16], the monitoring of concrete structures [17], and the assessment of the strength and deformation properties of roads [18].

II. AIMS AND OBJECTIVES

In this study, GPR antenna systems with different frequencies were used. The main objectives of the research were to provide an effective assessment of the underground construction details of a road pavement. In addition to the above objective, it was investigated the possible presence and location of an underground watercourse.

III. THE SURVEY SITE

The investigated road is located in close proximity to the westbound entrance of the Medway Tunnel (Fig. 1). This tunnel passes under the River Medway and links Strood with Chatham in Kent, England.

The original design and the construction of the road were as such to prevent subsidence at a particular location of the road. Indeed, the existence of a possible underground watercourse was perceived due to reoccurrence of longitudinal and traversal road surface cracking as well as subsidence at a particular location of the road.

Figure 2 shows the expected construction details of the road in the investigated area. As it can be seen from the figure, the two concrete sections have been designed to allow movement between the tunnel section, which is piled into the bedrock, and the road section. This was reasonably due to avoid any cracking of the road surface.

IV. METHODOLOGY

In view of the reoccurrence of longitudinal and traversal road surface cracking as well as subsidence at a particular location of the road, it seemed necessary to perform a GPR survey to investigate and confirm the underground construction details of the road. To this purpose, the identified area (Figure 3) was surveyed using high to low frequency antennas with 2000 MHz, 900 MHz, 600 MHz and 200 MHz central frequencies of investigation.

The scans were performed at ≈1m intervals in the direction of the road starting from the identified T-axis, which is located 5 m behind the drain at the side of the road, and continued in the +L direction. Figure 4 shows the location of the scans (survey grid) within the survey area.

Fig. 1. Bird's-eye view of the survey area.

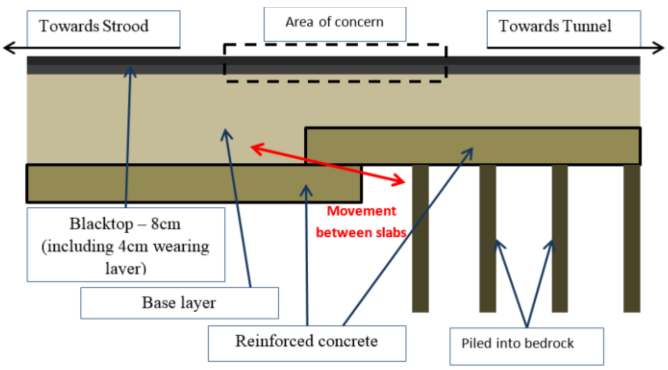

Fig. 2. Road details as expected by the original design and the construction of the road.

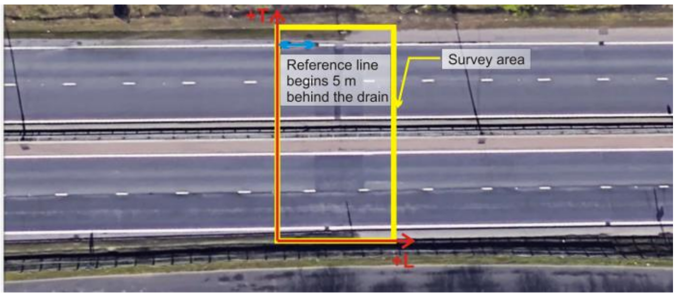

Fig. 3. Plan view and reference details for the survey grid of the investigated area.

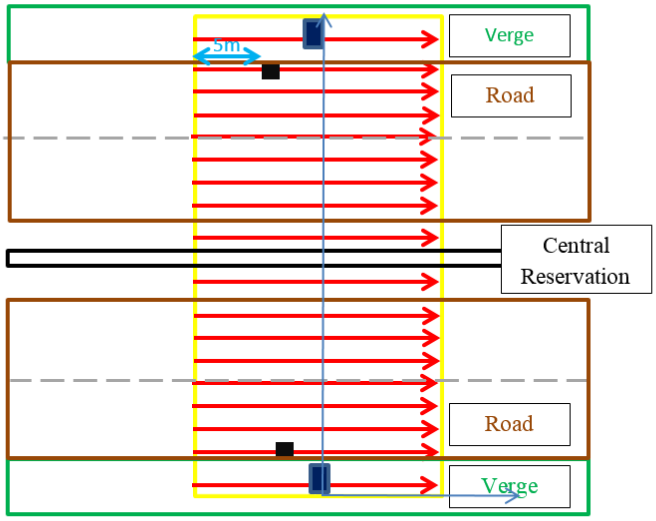

Fig. 4. Survey grid with location of scan lines on the road and verges. The red arrows indicate the scan carried out in the direction of the traffic flow (i.e., longitudinal scans).

It is worth noting that additional scans were performed at 90° or crossing the road exclusively with the 2000 MHz frequency antenna. These were purposely carried out to identify the presence of rebar in the concrete, which was assumed to be laid along the main (longitudinal) direction of the road.

V. RESULTS AND SHORT DISCUSSION

A. 2000 MHz Antenna System

The scans collected with the 2000 MHz antenna system on both the half-carriageways of the road are represented in Fig. 5 and Fig 6. This proved similarities in the road construction, although additional features were identified. For sake of clearness, the location of the scan within the investigation grid (i.e., Fig. 4) is indicated in the lower right part of the radargrams.

In addition to the scans carried out in the direction of the road (i.e., longitudinal scans in the grid of Fig. 4), further scans were performed across the road (i.e., transversal scans), in order to detect the possible presence of rebar in the orthogonal direction. It is worth noting that these transversal scans were performed with the 2000 MHz antenna system only, as the antenna wavelength was compatible with the expected dimension and depth of the target.

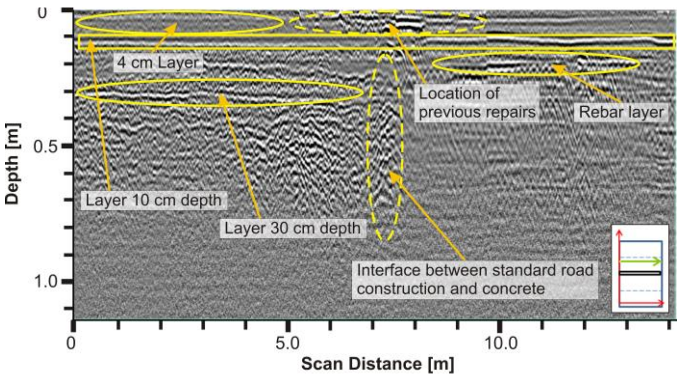

Fig. 5. Longitudinal scan (LID10013) carried out with the 2000 MHz antenna system.

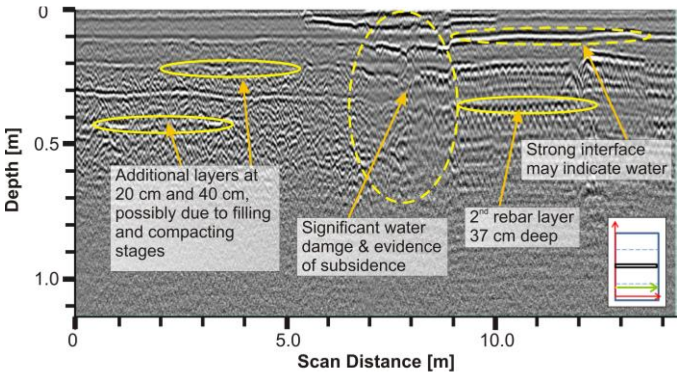

Fig. 6. Longitudinal scan (LID10003) carried out with the 2000 MHz antenna system.

The transversal scans were performed on both the half-carriageways of the road and provided similar results. The B-scan in Fig. 7 is representative of the main outcomes obtained from these investigations.

The results from the survey carried out with the 2000 MHz antenna system can be summarized as follows:

- 4cm asphalt wearing layer confirmed.
- The tunnel side road construction consists of an asphalt layer 10 cm thick on top of a reinforced concrete block with 2 layers of rebar mesh spaced between 16 cm and 19 cm.
- The road side construction consists of an asphalt layer 10 cm thick on top of a 20 cm thick base layer. Under the base layer is a further sub-base layer. These layers appear to have been constructed in 20 cm fills.
- There is no evidence of a second concrete block or a slip layer on the road side.
- A significant moisture damage and evidence of subsidence exist within the road at the interface between the standard road construction and the piled concrete construction.
- Possible water presence may be located at the interface between the reinforced concrete and the blacktop. It is worth to specify that this is not a certain target. It may be also possible that the strong reflection is due to a sharp contrast between the two materials.

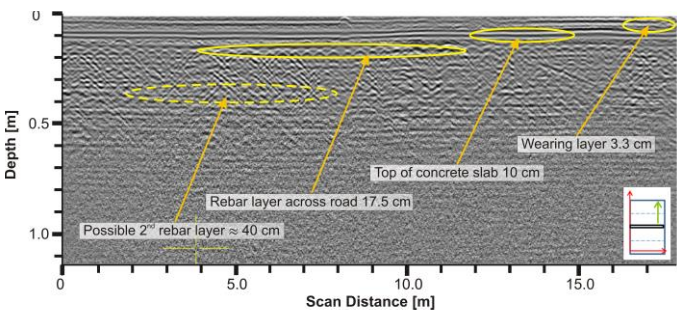

Fig. 7. Transversal scan (TID10019) carried out with the 2000 MHz antenna system.

The results obtained from the 2000 MHz investigation are represented in Fig. 8.

B. *900 MHz Antenna System*

The results from the 900 MHz antenna system confirm the outcomes from the 2000 MHz GPR, with layers clearly visible at same depths, approximately. In addition, the longitudinal scan reported in Fig. 9, shows a level of subsidence in the "wet" area and a deeper object. This object is not present in all the scans and does not develop in a straight line, although it appears consistently. Nevertheless, it was not possible to confirm if the object is an actual target or if it was due to noise in the B-scan.

C. *600 MHz and 200 MHz Antenna Systems*

Scans were also performed at lower frequencies to allow maximum penetration in order to investigate about the presence of an underground watercourse.

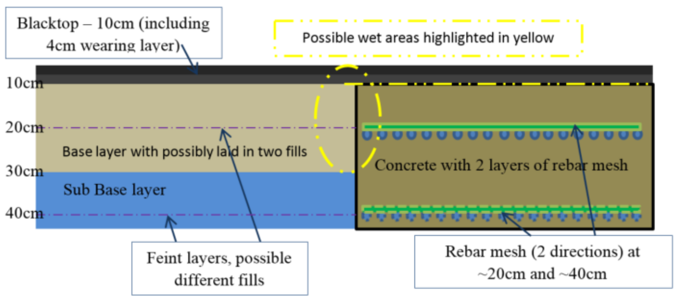

Fig. 8. Drawing of the road construction details based on the results from the 2000 MHz antenna system.

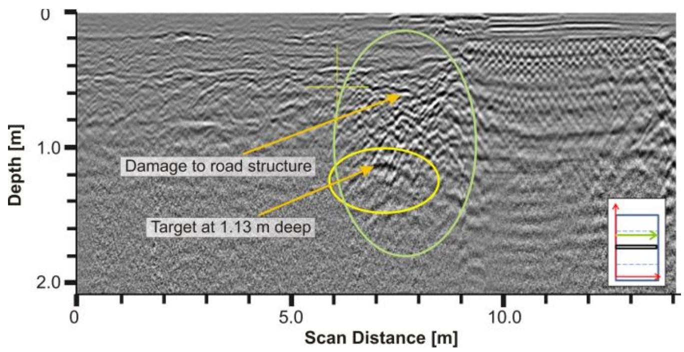

Fig. 9. Longitudinal scan (LID10014) carried out with the 900 MHz antenna system.

Representative outcomes from the 600 MHz and 200 MHz frequency antennas are reported in Fig. 10 and Fig. 11. To that effect, the survey did not identify or confirm the presence of any underground watercourse. This may be reasonably due to the interference caused by the rebar layers that did not allow to investigate at deeper distances.

VI. CONCLUSION

This paper reports on the assessment of the underground construction details of a road pavement using different frequency GPR antenna systems. In addition to this, the possible presence and location of an underground watercourse was investigated in this work. The results obtained using the 2000 MHz antenna showed that the road construction consisted of an asphalt layer of 10 cm thickness overlaying a reinforced concrete block with two layers of rebar mesh. A second reinforced concrete section (that allows movement at the joint) is missing with respect to the information provided. In addition, significant moisture damage and evidence of subsidence within the road were identified. The 900 MHz frequency antenna confirmed the above results as well as suggesting the existence of subsidence at the lower areas of the road foundation. Furthermore, results revealed the existence of an unidentified object at the deeper depth. This was not detected by the higher frequency antenna. The maximum depth of penetration was achieved by using the 600 MHz and the 200 MHz antennas (maximum of 3.5 m). To that effect this investigation did not identify or confirm the existence of any underground watercourse.

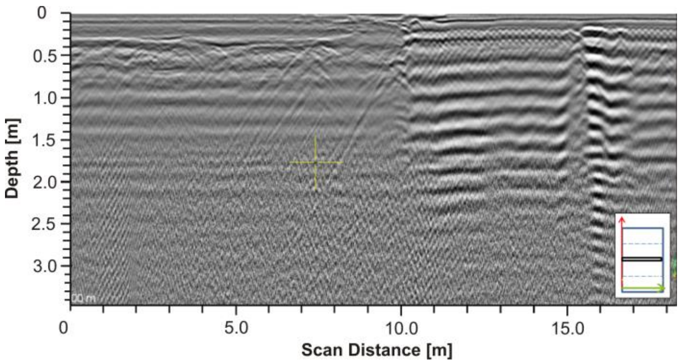

Fig. 10. Longitudinal scan (LID10001) carried out with the 600 MHz antenna system.

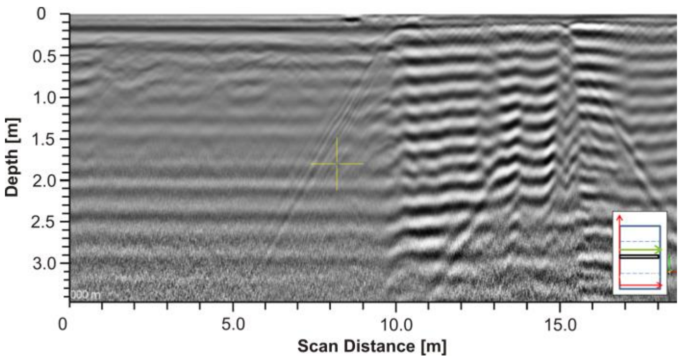

Fig. 11. Longitudinal scan (LID20011) carried out with the 200 MHz antenna system.

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