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Field observations and numerical models of GPR response from vertical pavement cracks

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ABSTRACT

High resolution ground-coupled GPR is useful for determining thickness, deterioration, jointing and cracks in pavements. Although only millimetres in width, vertical cracks can present a significant target in reflection profiles. On composite pavements, consisting of asphalt over concrete, we have observed responses at locations above joints in the underlying concrete that we attribute to cracks within the asphalt layer. On some asphalt pavement, we observed significantly stronger diffraction and waveguide effects responses at a 250 MHz centre frequency rather than at 1000 MHz, despite the small crack apertures. Using numerical modelling we show the importance of crack filling material, crack aperture, crack height, asphalt conductivity and the GPR centre frequency on the observed response. Our observations and models clearly show the potential of GPR to detect and characterise vertical cracks. We recommend a multi-frequency approach to GPR surveys of pavement: high frequency for crack characterisation and lower frequency for crack detection.

1. Introduction

The high spatial resolution possible with ground-coupled ground penetrating radar (GPR) has opened opportunities to provide pavement structural information beyond the traditional layer thickness obtained from typical commercial high speed road surveys performed with GPR using air-coupled horn antennas. Typical surveys provide thicknesses of Portland cement concrete (PCC), hot-mix asphalt (HMA) layers and underlying granular layers. These data are used for asset management, pavement structure inventory for pavement management systems and aid in engineering decisions related to pavement rehabilitation. In these applications, the client usually requires the pavement structural information at relatively low spatial resolution, with reporting intervals of 1 to 100 m.

A significant drawback of air-coupled horn antennas is their inability to clearly show hyperbolic scattering events and their inherent low lateral spatial resolution. In contrast, ground-coupled GPR can easily detect subtle structural features, such as cracks, joints, buried repair patches, individual steel reinforcement bars and buried utility cuts. To improve assessment of the pavement structure, it is important to understand these subtle GPR responses. Previous work on this subject has focused on road networks and runways to assess structural damage (Benedetto and Pensa, 2007; Birtwisle and Utsi, 2008; Hugenschmidt et al., 1998; Ranalli et al., 2007). The potential of high resolution GPR surveys to detect cracks in asphalt above joints in concrete and to locate buried repair patches has been previously demonstrated in a pavement condition survey for a rehabilitation programme (Popik and Redman, 2006).

Here we address the detection and characterization of vertical cracks, using ground-coupled GPRs, which often indicate deficiencies in the underlying pavement structure. Our objectives are to demonstrate, based on field observations, that GPR data can directly indicate vertical cracks and show the dependence of the scattering response characteristics (for example, peak amplitude) on media properties using numerical modelling. In a first study by Diamanti et al. (2010), we obtained good correlations between numerical modelling results and GPR data acquired on pavement. Here, we present a more in-depth analysis based on GPR data acquired on a variety of pavements that show characteristic crack responses. We then discuss numerical modelling results for some typical crack scenarios.

2. Methodology

2.1. GPR data acquisition

We collected GPR profiles on pavements using the cart-based multi-channel SPIDAR system, the Noggin SmartCart and the high speed ground-coupled multi-channel RoadMap system (Annan and Redman, 2006), produced by Sensors & Software Inc. The RoadMap profiles were collected at speeds of 60–100 km/h using 1000 MHz Noggin GPRs in the left wheel path (LWP) and right wheel path

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Fig. 1. Three-channel high-speed ground-coupled RoadMap system. The Noggin GPRs are within the striped covers at the back of the trailer. The antennas are 0.01 m above the pavement surface.

(RWP), and a 250 MHz Noggin in the centre of the lane. The three GPRs, separated by 0.90 m and placed at 0.01 m above the pavement surface, can be seen mounted at the back of the trailer in Fig. 1.

We used hand pushed carts to collect higher spatial resolution, multi-frequency data along the same path. The multi-channel SPIDAR system (Fig. 2) used two Noggin GPRs to collect data simultaneously at centre frequencies of 250 and 1000 MHz with no lateral separation between the profiles collected at the two frequencies. We also used the Noggin SmartCart, a single channel cart similar to the cart depicted in Fig. 2, to collect some of the data presented. An odometer and GPS synchronised with trace acquisition provided accurate trace positioning. Video data of the roadway were also acquired with the RoadMap system as an interpretation aid.

The time sampling intervals for the GPR systems were 100 ps for the 1000 MHz data and 400 ps for the 250 MHz data. We collected all GPR profiles along the direction of the roadway. The antenna polarisation direction was perpendicular to the profile direction. The spatial trace sampling interval, which varied depending on the GPR

Fig. 2. Two-channel SPIDAR Cart system with 250 and 1000 MHz GPRs. The 1000 MHz GPR is partially hidden behind the left front wheel. The antennas are ~0.01 m above the pavement surface.