Chapter 26
FDTD Simulation of the GPR Signal for Preventing the Risk of Accidents Due to Pavement Damages

Fabio Tosti
Roma Tre University, Italy

Andrea Umiliaco
Roma Tre University, Italy

ABSTRACT

It is well known that road safety issues are closely dependent on both pavement structural damages and surface unevenness, whose occurrence is often related to ineffective pavement asset management. The evaluation of road pavement operability is traditionally carried out through distress identification manuals on the basis of standardized comprehensive indexes, as a result of visual inspections or measurements, wherein the failure causes can be partially detected. In this regard, ground-penetrating radar (GPR) has proven to be over the past decades an effective and efficient technique to enable better management of pavement assets and better diagnosis of the causes of pavement failures. In this study, one of the main causes (i.e. subgrade failures) of surface damage is analyzed through finite-difference time-domain (FDTD) simulation of the GPR signal. The GprMax 2D numerical simulator for GPR is used on three different types of flexible pavement to retrieve the numerical solution of Maxwell's equations in the time domain. Results show the high potential of GPR in detecting the causes of such damage.

INTRODUCTION

Over the past decades, ground-penetrating radar (GPR) has been increasingly used in road network and runway surveys both for maintenance and for construction processes (Benedetto *et al.*, 2012a; Saarenketo and Scullion, 2000; Tosti and Benedetto, 2012). Many information on both physical and geometrical properties of pavement can be inferred through such non-destructive technique, thereby enabling more comprehensive detection of the main causes of road structural damages. GPR is widely used for the evaluation of layer thicknesses (Al-Qadi and Lahouar, 2004), voids detection un-

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derneath pavements (Lau *et al.*, 1992; Benedetto, 2013), reinforcing bars monitoring (Huston *et al.*, 1999), pipes location (Ayala-Cabrera *et al.*, 2011), asphalt stripping (Scullion *et al.*, 1994), and bridge inspections (Benedetto *et al.*, 2012b). Further applications in the area of pavement engineering have been addressed to the evaluation of the main causes of structural damages, such as the loss of bearing ratio of load-bearing layers (Benedetto and Tosti, 2013a; Diefenderfer *et al.*, 2005), even by other integrated non-destructive techniques, *e.g.* light falling weight deflectometer (Benedetto *et al.*, 2012c; Benedetto *et al.*, 2014). Several GPR-based methods have been developed for evaluating subsurface moisture in different soil types (Topp *et al.*, 1980; Huisman *et al.*, 2003; Grote *et al.*, 2010; Benedetto, 2010; Tosti, 2013). Water infiltration in clayey soils throughout the pavement section that causes the transport of fine-grained materials towards the outer surface, can be considered as one of the main issues affecting the loss of bearing capacity (Benedetto and Pensa, 2007). In this regard, many efforts have been recently devoted to the evaluation of clay content in soils using different radar instruments and techniques (Tosti *et al.*, 2013; Benedetto and Tosti, 2013b; Patriarca *et al.*, 2013).

At the same time, an effective strategy in pavement rehabilitation processes is represented by GPR-based decision support systems, that are increasingly developing also for improving asset management through the widening of pavement structures inventories for pavement management systems.

In addition, many efforts have been recently focused to improve air-coupled GPR systems for providing time-efficient inspections (Tosti *et al.*, 2014; Lambot *et al.*, 2006) along with the possibility to collect large-scale high resolution data (Benedetto *et al.*, 2013; Minet *et al.*, 2012).

Another major issue concerns the possibility to help decision makers in understanding the deeper observed mismatches in case of early-stage or unrevealed failures at the pavement surface level by using GPR-based numerical modeling (Diamanti and Redman 2012). Many researches have dealt with successful modeling attempts of ground-penetrating radar (Bergmann *et al.*, 1998, Giannopoulos, 1997; Bourgeois, 1996), and many approaches based on the finite-difference time-domain (FDTD) method have been proposed. It is well known that the use of such method is favored by the ease of implementation in a computer programme and its better scalability than other electromagnetic (EM) modeling methods (*e.g.* finite-element, integral) (Millard *et al.*, 1998). On the other hand, high computational requirements and stair-like stepped interfaces, due to the discretization of the volume of the problem (Giannopoulos, 2005b; Taflove, 1995), may be encountered.

Among the existing approaches on FDTD methods, Giannopoulos (2005a) and Giannopoulos (2005b) proposed one of the most versatile, namely, GprMax software tool for modeling GPR responses from arbitrary complex targets, in both 2D and 3D versions.

Despite such technological potential, visual inspections based on specific ingrained distress identification manuals (Consiglio Nazionale delle Ricerche, 1986; SHRP, 1993) are still much more preferred as traditional processes of pavement operability evaluation.

In particular, such manuals cover the entire range of basic pavement types, including reference drawings of distress types for the evaluation of their severity, as well as standard methods for measuring their geometric properties (*e.g.* size, shape) and assigning relevant severity levels. Notwithstanding the relatively large amount of technical instructions provided by using checklists, distress identification manuals have proved significant incompleteness of the evaluation processes, wherein the causes of faults can be only partially assessed.