Geophysical Research Abstracts
Vol. 13, EGU2011-7759, 2011
EGU General Assembly 2011
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Applications of GPR to road pavement: an overview

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Ground Penetrating Radar (GPR) has been using in the pavement engineering since almost twenty years. The traditional and mostly diffused application is the evaluation of the thicknesses of pavement layers. Such a measure can be done at traffic velocity unless disturbing safety and operability of the roads. Standards have been developed for this application (e.g. ASTM, 1999). The principles of using GPR reflections to compute layer properties have been determined by Maser and Scullion (1991).

In particular, by monitoring time delays between the peaks of the reflected signals, it is possible to evaluate layer thicknesses. Radar resolution depends on the wave length of the signal. If f is the frequency [GHz] and v the propagation velocity [mm/ns] of the signal, the wave length [U+F06C] is v/f [mm]. The propagation velocity depends on the dielectric characteristics of a low-loss materials as it follows: v = c/[U+F065]0.5 where [U+F065] is the dielectric permittivity and c the free space velocity of an electromagnetic wave (3x108 m/s). In dry asphalt [U+F065] is 2 to 4, in wet asphalt [U+F065] is 6 to 12 and v is 70 to 210 mm/ns. The theoretical resolutions of GPR are from about 90 mm, for a center frequency between 0.8 and 2.3 GHz, to 25 mm for f = 2.6 to 7.7 GHz.

At the state of the art two questions affect the evaluation of the thin layers: (1) the resolution of GPR, that is often comparable with the thickness and (2.1) the signal's analogical characteristics as (2.2) the signal's processing procedures to reduce the noise from antenna's "end reflection" (Delbò and alii, 2000; Benedetto and alii, 2004).

More recently GPR has been used to evaluate the pavement conditions. In the paper we present the methods (1) based on the electronic detection of pavement singularities as the ones (2) for moisture and bulk densities evaluation. Referring the first point, it is possible to identify three different categories of road damages (Benedetto and alii, 2004): point located singularity inside a homogeneous layer (i.e. void or water), long wave length singularity between two different layers (i.e. depressions), short wave length singularity between two different layers (i.e. pumping).

In addition, referring the second point, many authors measure the moisture content using GPR (for a review see Grote et alii, 2005; Benedetto and Pensa, 2007).

The relationship between the dielectric constant of a soil and its volumetric water content has been extensively studied in the past. Various empirical correlations have been proposed, like the commonly used theory suggested by Topp, which is supposedly valid for any type of soil (Topp, et al., 1980). Reviews of the various theoretical models are available (Friedman, 1998; Grote et al., 2002, 2003; Hubbard et al., 2002; Huisman et al., 2003; Robinson et al., 2003; Serbin and Or, 2003). Another theoretical approach uses the volume fractions and the dielectric permittivity of each soil constituent to derive an approximate correlation, using a self-consistent approximation that represents the medium with the multi-indicator mode (Fiori et al., 2005).

In some cases, the dielectric permittivity is estimated from the amplitudes of the transmitted and reflected signals (e.g. Al-Qadi et al., 2004).

A more efficient and self-consistent approach is based on the GPR processing in the frequency domain. Werts et al. (2001) observed that the dielectric permittivity is influenced by the frequency. Lambot et al. (2004; 2006) considered the dependence of the imaginary part of the dielectric permittivity from the frequency to investigate the subsurface electric characteristics. Relating to the water content estimation, they found very consistent results. Oden et al. (2008) have calibrated and validated a new model for measuring the electrical properties of soil. The algorithm estimates the shallow soil properties using the early-time arrivals, i.e. the arrivals recorded before subsurface reflections arrive (Pettinelli et al., 2007).

Finally a full signal processing in the frequency domain has been proposed very recently, basing on the theory of Rayleigh Scattering, for water content prediction in porous media (Benedetto, 2010).

Recently some researchers have also tested GPR for the analysis of the characteristics of bituminous materials (e.g. Aultman-Hall and alii, 2004; Liu and Guo, 2002, Benedetto et alii, 2006; Chazelas et alii, 2007). The investigated methods are generally based on empirical multi variables correlations among parameters, consequently they cannot be considered valid at a general level. The main parameters that have been investigated are: nature of aggregates, bitumen content, voids, compaction, maximum size of aggregate, continuity of the grading.

The new perspective in pavement management of using GPR for efficient, safe and effective diagnosis of damage has been firstly investigated at a methodological level (Benedetto and Angiò, 2002). More recently some very interesting contributions that demonstrate that this approach can be really effective appeared (Diamanti and alii, 2010). However the available experiences are actually sporadic and some additional research efforts are absolutely needed (Papi, 2010).

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