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Geophysical Research Abstracts
Vol. 15, EGU2013-3648, 2013
EGU General Assembly 2013

GPR-based evaluation of strength properties of unbound pavement material from electrical characteristics

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It is well known that inter-particle friction and cohesion of soil particles and aggregates deeply affect the strength and deformation properties of soils, exerting critical effects on the bearing capacity of unbound pavement materials. In that respect, considering that strength characteristics of soil are highly dependent on particle interactions, and assuming a relationship between electric properties (e.g. electric permittivity) and bulk density of materials, a good correlation between mechanical and electric characteristics of soil is expected.

In this work, Ground Penetrating Radar (GPR) techniques are used to investigate this topic. Two GPR equipment with same electronic characteristics and different survey configurations are used. Each radar operates with two ground-coupled antennae at 600 MHz and 1600 MHz central frequencies. Measurements are developed using 4 channels, 2 mono-static and 2 bi-static. The received signal is sampled in the time domain at *dt* = 7.8125 $\times$ 10^{-2} ns, and in the space domain every 2.4 $\times$ 10^{-2} m.

A semi-empirical model is proposed for predicting the resilient modulus of sub-asphalt layers from GPR-derived data. Basically, the method requires to follow two steps. Firstly, laboratory tests are carried out for calibration, with the main focus to provide consistent empirical relationships between physical (e.g. bulk density) and electric properties. The second step is focused on the in-situ validation of results through soil strength measurements retrieved by CBR tests and Light Falling Weight Deflectometer (LFWD). On the basis of traditional empirical equations used for flexible pavement design, the following expression is proposed:

$$E_i = \sum_{j=1}^{m} \alpha_j \cdot h_{j,i}$$

where E_i [MPa] is the i^{th} expected resilient modulus of the surveyed soil under the line of scan, $h_{j,i}$ [m] is the i^{th} thickness referred to the j^{th} layer, and α_j is a dielectric parameter calibrated as a function of the relative electric permittivity.

The experimental setting requires the use of road material, typically employed for subgrade and subbase courses. Different types of soil ranging from group A1 to A4 by AASHTO soil classification system, are analyzed. As regards the laboratory experiments, material is gradually compacted in electrically and hydraulically isolated test boxes. A large metal sheet supports the experimental boxes, so that the transmitted GPR signal is totally reflected. GPR inspections are carried out for any compaction step up to the maximum density value available. Moreover, in-situ tests are carried out on targeted types of soil, with grain size distribution and texture comparable to those analyzed in laboratory environment.

The results of this study confirm a promising correlation between the electric permittivities and the strength and deformation properties of the surveyed soils. Laboratory analyses show that the relationship between the relative permittivity and the bulk density is positive: the higher the density of the compacted soil sample, the higher the electric permittivity of the medium. Analogously, in-situ validation presents a good comparison between measured and predicted data. Percentage errors less than 20% demonstrate that a reliable prediction of Young Modulus using this GPR-based approach can be achieved.