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Time and frequency GPR waveforms analysis for clay content evaluation in soils

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The mechanical behaviour of soils is partly affected by their clay content, which exerts some considerable effects in many applications in the fields of civil engineering, geology and environmental engineering. This study focuses on pavement engineering, but the approach can be extended to other purposes.

The presence of clay in the bearing structural layers of pavements frequently causes damages and defects, such as transversal and longitudinal cracks, deformations and rutting. Consequently, the road safety and operability decrease, while the expected number of accidents increases.

In this work Ground Penetrating Radar (GPR) laboratory inspections are carried out in order to predict the presence of clay in pavement structural layers. Data are post-processed in the frequency domain, according to the Rayleigh scattering method based on the Fresnel theory. This new technique can be supported by other survey methods, improving the quality of the results.

Analysis are carried out using two different GPR systems.

A Radar is used with ground-coupled antennae in a bistatic configuration and common offset; the transmitter and receiver are linked by optic fiber electronic modules and operate at 500 MHz central frequency. The received signal is sampled in the time domain at time steps of 7.8125 x 10^{-2} ns.

A Vector Network Analyzer (VNA) acquires ultra-wide band data in a bandwidth from 500 MHz to 3000 MHz. The signal is sampled in the frequency domain with approximately 1.56 MHz frequency steps. A double-ridged broadband horn antenna is connected via a high-quality coaxial cable to the VNA pulse generator and illuminates the analyzed target in a monostatic off-ground configuration.

The experimental setting required the use of road material, typically employed for sub-grade and sub-base layers. Three kind of soils, classified as A1, A2, A3 by AASHTO are used and adequately compacted in electrically and hydraulically isolated boxes. Bentonite clay is gradually added from 2% to 25% in weight, according to mixing and compaction laboratory procedures. A metal plate supports the experimental boxes, so that the GPR signal is totally reflected.

GPR surveys are carried out for each clay content. The signals are analyzed in both time and frequency domains.

In the time domain the reliability of results is validated by the electromagnetic theory, in terms of signal amplitude, electric permittivity and time delay . In the frequency domain the results are highly consistent for all the investigated soils . Assuming a residual water content of the dry clay that is due to its hygroscopic capability, frequency spectra shift not linearly, as expected from the scattering theory. The modulation depends on the water content and, indirectly, on the clay content. The correlation between the central frequency values of the spectra and the clay content is negative: decreasing values of the central frequency correspond to increasing values in the clay content, from 0% up to 25%. A comparative analysis of the three soil spectra for different clay contents has shown a different behaviour of the clay, both for the ground-coupled radar and the broadband analyzer. In general, in fine grain size soils lower central frequency value intensities are registered.