BACKGROUND

In connection with the Department of National Defense (DND) sponsored Landmine Detection Project (LDLP) and related development and testing of integral sensor technologies, a test track was established at Defence Research Establishment Suffield (DRES), comprising approximately 30-50 km of normal grade aggregate placed directly over native prairie soils. Detailed characterization of soil electromagnetic properties is critical to a comprehensive study of time-domain reflectometry (TDR) and dielectric probes to reflect the measurement of fracture dependent soil dielectric constant.

Prior to analyzing DRES soil samples, system performance was assessed via temperature-dependent measurements on four polar liquid standards, including ethanol, methanol, propanol, and propylene glycol.

Following standardization, two soil grade aggregate samples (MLA-1, MLA-2) and single native-based soil (UNI) were analyzed for a range of moisture levels as specified by International Standards.

TIME DOMAIN REFLECTOMETER (TDR)

TDR measurements were acquired utilizing a specially developed test and reconfigured to fit the DRES AND TDR. In contrast with dielectric probe measurements, the TDR method builds on a broad band estimate of the effective dielectric constant by determining the effective propagation velocity Vₑ of a guided wave within the sample under test.

Like a propagation radar wave, the TDR pulse is partially reflected on encountering contrasts in electromagnetic impedance. The composite waveform variation is sensed in the uncompensated time with reference to a precise sampling time base. Subsequent analysis in a computer determines two-way transit time Δtₑ along the layers. Fitting and, consequently an effective propagation velocity Vₑ for the sample. Assuming that the soil is effectively dielectric over the TDR bandwidth, effective dielectric constant is estimated according to the relation

\[ n = \sqrt{\frac{V_e}{c}} \]

where n, the dielectric constant.

Given two-way transit time through the sample volume, the TDR method is usually line-monopole to local sample heterogeneity and presumably representative of bulk sample properties. However, accuracy of the method is limited by subsequent analysis and computation.

A range of techniques has been investigated to identify the data and sampling errors, including standard linear regression-based methods, local corrections and frequency point techniques. These various techniques were examined to be extensively validated. Although standard techniques yield very promising results, experience suggests development of full waveform inversion techniques.

RESULTS - DRES SOILS

Despite limitations of standard time-domain waveform analysis methods, there is surprisingly good agreement between TDR-derived dielectric constant and corresponding dielectric probe measurements at 100 MHz. TDR estimated dielectric constant is consistently higher and displays a marginally lower rate of increase with increasing moisture content.

In-situ validated best-fit exponential solutions for moisture-dependent dielectric constant facilitate approximate predictions of variable soil conditions. The results demonstrate excellent correlation between key properties of soil-based TDR and dielectric measurements.

CONCLUSIONS - TDR vs DIELECTRIC PROBE

In comparison with the characteristics of DRES soils, comparison of TDR and dielectric probe methods identified the following benefits and limitations of the two methods:

- Dielectric probe analysis is independent of bulk soil characteristics. Small sample volumes (1 cm) enable use of higher frequencies, enabling a more accurate characterization of soil parameters.
- TDR requires fewer measurements, leading to an overall reduction in measurement time and cost.

- Dielectric probe analysis is not affected by moisture content, making it suitable for high moisture content soils.
- TDR analysis is more sensitive to variations in soil properties, providing a more detailed characterization of soil properties.

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PUBLICATION DETAILS