TIME DOMAIN REFLECTOMETRY MEASUREMENT AND HIGHLY PLASTIC CLAYS

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Abstract: The use of latex paint to coat time domain reflectometry (TDR) probes was evaluated for use in highly plastic clay. The clay used for experimentation was taken locally from the Eagle Ford Group. The coating allows TDR signals, previously dissipated by conduction into the surrounding soil, to be returned for processing. A comparison between signals from coated and uncoated probes demonstrates the effect of the coating on TDR measurements in clay. Measurements taken with uncoated TDR probes in sand and silt are compared to measurements taken with coated probes in clay are shown to have similar calibration relationships. Finally, a calibration relationship specific to coated TDR measurements in Eagle Ford Clay is determined.

INTRODUCTION

The progression of wetting and drying fronts in highly plastic clay is being evaluated as part of ongoing research at The University of Texas at Austin. The goal of the project is to determine the movement of moisture in roadside embankments built with highly plastic clays in order to improve the current design methodology. The high potential for highly plastic clays to swell during wetting and crack during drying affects the rate of moisture movement within these embankments.

In order to evaluate the extent of these effects on moisture movement within the embankments, an experiment is being carried out to monitor moisture movement with alternate cycles of wetting and drying. A column of clay, 25 cm high and 23 cm diameter, is compacted in a clear polyvinylchloride cylinder. First, water is ponded at the top of the soil profile with a constant head of 2.5 cm. Once the wetting front reaches the base of the column and swelling ceases, the column is allowed to dry. When the drying front reaches the bottom and cracking has ceased, the process of wetting and drying is repeated.

The progression of wetting or drying fronts is monitored with a combination of visual observation and instrumentation. Time domain reflectometry (TDR) is used to measure the moisture content throughout the soil profile. TDR is advantageous because it is the only method that allows for water content measurement without disturbing the soil profile. Additionally, TDR responses depend on the electrical characteristics of the soil surrounding the length of the probe and thus provide the average water content at a given depth. However, lack of instrument response limits the use of TDR probes in highly plastic clays. This study demonstrates the effectiveness of coating the TDR probe for measuring moisture content in highly plastic clays, a subject previously unreported in the literature.

PRINCIPLES OF TIME DOMAIN REFLECTOMETRY

Electrical Concepts. TDR probes consist of a set of three parallel metal rods that come in various rod lengths, diameters, and spacings. The probes used in this study are 8 cm in

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length, 0.32 cm in diameter, and have a spacing of 2.5 cm between the outer rods (Figure 1). These probes are used in combination with a wave analyzer is used to measure the microvolt response that occurs over a period of 20 nanoseconds. Both probe and analyzer are manufactured by Soilmoisture Equipment Corporation out of Santa Barbara, California.

With TDR, an electrical pulse is sent down the length of a coaxial cable and into the TDR probe. During this process, the electrical pulse undergoes two reflections: the first, when it transitions from the coaxial cable to the metal rods; the second, when the signal meets the end of the metal rods. Figure 2 shows the TDR voltage responses for both an uncoated probe and one with a 0.01 cm thick coating of latex paint. The two reflections are apparent for the coated rod but are not present in the uncoated rod's response.

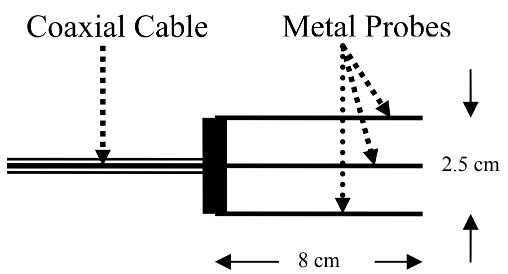

Fig. 1. Time domain reflectometry probe

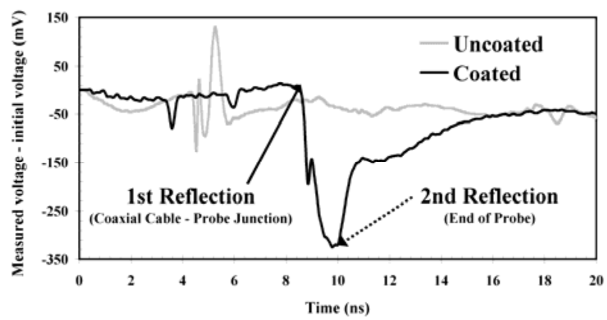

Fig. 2. Effects of coating on TDR response (Eagle Ford Clay, 26% volumetric water content)

The time between these two reflections depends on the dielectric constant of the surrounding medium. In this application the surrounding medium consists of soil, water, and air. Since the dielectric constant of water is at least ten times that of soil or air, a relationship between dielectric constant and the volume of water per volume of soil can be established. The volume of water per volume of soil is termed the "volumetric moisture content" and is expressed as a percentage. The relationship between the dielectric constant and the time between reflections can be derived as follows: The velocity, ν, of the electromagnetic wave traveling through the probe is equal to the length of travel (twice the length of the TDR probe, 2L) divided by the time between the two signals (Equation 1). The wave velocity is also equal to the speed of light in a vacuum (c) divided by the square root of the apparent dielectric constant of the insulating material, Ka (Equation 2). When Equation 1 and Equation 2 are combined, the apparent dielectric constant of the soil can be determined from the time of travel (Equation 3). Since the speed of light in a vacuum is a constant, and the length of a particular probe is constant, either the time of travel or the dielectric constant can be correlated to the volumetric water content of the soil.

$$\nu = \frac{2L}{t}$$

Equation 1

$$\nu = \frac{c}{\sqrt{Ka}}$$

Equation 2

$$Ka = \left(\frac{ct}{2L}\right)^2$$

Equation 3

CALIBRATION OF COATED TIME DOMAIN REFLECTOMETER PROBES

Materials. The highly plastic clay used for this experiment was taken from the Eagle Ford Shale outcrops in Round Rock, Texas. It was excavated from a depth of approximately ten feet from the embankment at the intersection of Hester's Crossing and Interstate 35 near

Round Rock. The Eagle Ford Clay has a liquid limit of 88% gravimetric water content and a plastic limit of 39% gravimetric water content.

Testing Equipment and Procedures. Soil was prepared at several different gravimetric water contents, mass of water per mass of solid, in order to measure the dielectric constant of the soil at several different volumetric water contents. The relationship between gravimetric water content, dry density, and volumetric water content for Eagle Ford Clay prepared at standard proctor compaction effort (ASTM D698) is shown in Figure 3. Specimens were compacted in a 4.8 inch high mold with a diameter of 5.9 inches. The specimens were compacted in three lifts and the TDR probes were placed in the center lift.

USE OF TDR IN HIGHLY PLASTIC CLAY

When the voltage versus time response acquired from the TDR is examined for a soil that is not problematic for TDR measurements (neither highly plastic, highly organic, at very high density or at very low density) the two reflections of the TDR signal are relatively clear. However, when the voltage versus time response is acquired for a high plasticity soil, the presence of two clear reflections may not be present. As such, no distinguishable reflections are present in the TDR measurement of Eagle Ford Clay with an uncoated probe (Figure 2). Empirical relationships between volumetric moisture content and the TDR measured dielectric constant of a soil have been developed, but do not yield accurate results for high plasticity clays (Roth et al.). Patterson et al. (1985) used a coating on their probes to reduce the interference caused by salts in the soil. They also noted that sensitivity is lost due to the coating and that the coating can wear, which affects the results. However, since uncoated probes do not return distinguishable signal for Eagle Ford Clay, the sensitivity loss with coating is a moot point. Future studies should investigate alternate coating thicknesses and materials to evaluate the loss in sensitivity. Wear to the coating in this experiment should be minimal since the probes will be free to move vertically as the soil might swell or shrink.

A linear relationship between the square root of the measured dielectric constant and the volumetric water content has been suggested (Roth et al.). The square root of the measured dielectric constant is plotted versus the volumetric water content for a sand, a silt, and the Eagle Ford Clay are plotted in Figure 4. The silt and sand nearly fall on the same linear trend. The Eagle Ford Clay falls close to that linear trend but diverges slightly at very low water. Considering that the measurements taken on Eagle Ford Clay utilize a coated probe and the measurements on silt and sand did not, it is surprising how close calibration relationships are.

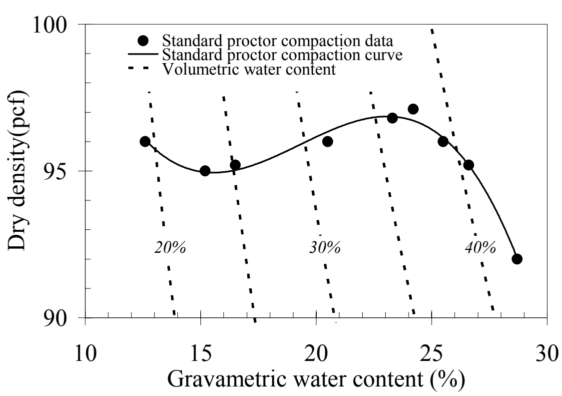

Fig. 3. Standard proctor compaction curve for Eagle Ford Clay

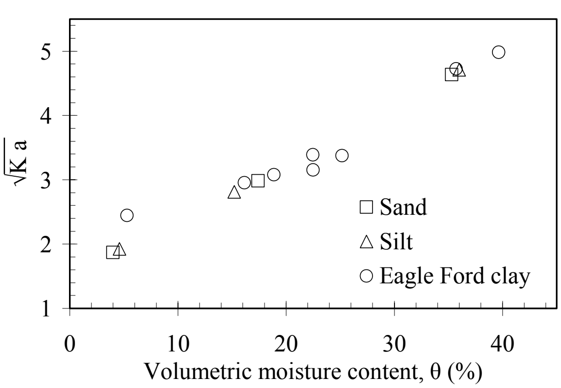

Fig. 4. The square root of Ka versus volumetric water content for three soils

RESULTS AND CONCLUSIONS

The TDR responses for three different volumetric water contents are shown in Figure 5. By referring to Equation 3 it is apparent that suggesting a linear trend with the square root of the measured dielectric constant is the same as a linear trend with the time between reflections. Figure 5 illustrates this linear trend as the time between reflections increases with increase with increasing volumetric water content. It may also be noted that the intensity of the signal decreases with increasing water content as more energy is dissipated by the increasing conductance of the soil-water-air medium. A calibration curve and a corresponding calibration equation (Figure 6) have been determined for coated probes used in Eagle Ford Clay.

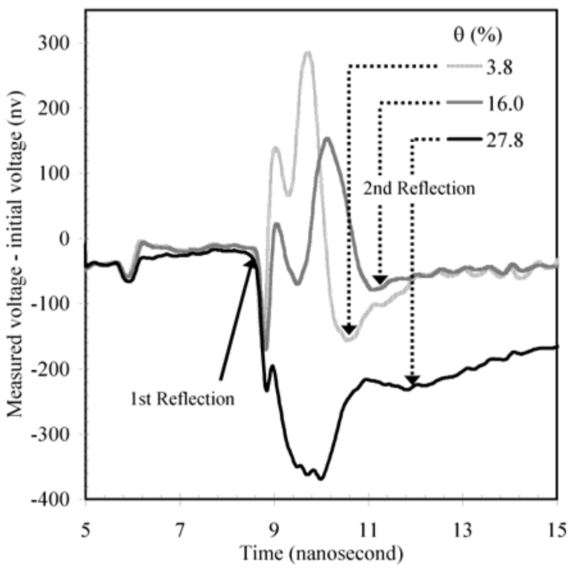

Fig. 5. Voltage versus time for various water contents

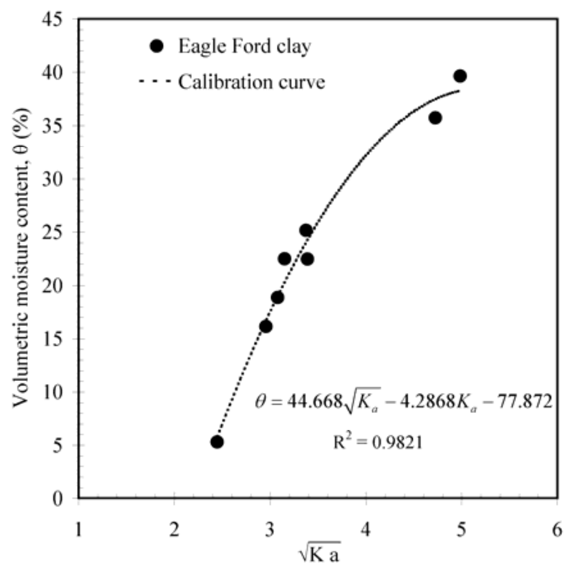

Fig. 6. Volumetric water content versus the square root of Ka

Coating of TDR probes has permitted measurement of volumetric water content in Eagle Ford Clay. At this point, the results also suggest a nonlinear relationship but further measurements are needed to establish a firmer calibration curve. The testing outcome suggests that similar calibration relationships for other highly plastic clays can be determined. Future investigations of TDR coating for use in highly plastic clays should also consider alternate coating thicknesses and materials.

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