Instrumentation for Improved Pavement Design

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The Minnesota Road Research Project (Mn/ROAD http://mnroad.dot.state.mn.us) provides a unique opportunity to test new and existing technologies for application in the area of pavement design. Mn/ROAD consists of approximately 40 pavement test sections, each with extensive instrumentation. Laboratory and field experiments were conducted at Mn/ROAD to investigate the use of Time Domain Reflectometry methods for measuring water table depth and frost penetration below the pavement surface. Two papers reporting on the feasibility of the methods and their application in pavement design research are published in the proceedings of the Second International Symposium and Workshop on Time Domain Reflectometry for Geotechnical Applications held at Northwestern University, September 5-7, 2001 (http://www.iti.northwestern.edu/tdr/tdr2001/preceedings). The following is a summary of those papers.

Measuring Water Table Elevations Using Time Domain Reflectometry

Measuring and monitoring the depth of the ground water table is important in a variety of geotechnical applications, and is routinely practiced in such areas as embankment stability and dam seepage applications. Locating the depth to the water table is also important in the field of pavement engineering, both for structural and drainage design purposes. Ongoing improvements in the pavement design process involve new methods for measuring variables such as water table depth. The Minnesota Department of Transportation's implementation of a mechanistic-empirical (ME) design procedure for flexible pavement brings to the forefront the need for improved methods for monitoring and characterizing environmental and subsurface parameters in and around the pavement structure. ME design procedures incorporate environmental effects and subsurface conditions, i.e. climate and water table depth into pavement layer design. Therefore, there is a need to locate the water table for improved calculation of layer moduli, thus improving the overall pavement design. The primary objective of this study was to compare the use of traditional methods of measuring water levels with that of Time Domain Reflectometry (TDR) methods. A secondary objective was to develop an algorithm for automating TDR waveform interpretation.

Field Installation

An electronic pressure transducer and an air dielectric coaxial cable were both installed in two monitoring wells below the centerline of the pavement structure. Transducer and coaxial cables were run horizontally across the top of the subgrade to a datalogger located at the pavement shoulder. Monitoring wells were capped at the top of the subgrade prior to placing the base course. Manual data was collected from existing wells located on the shoulder.

There was good agreement between the manual, transducer, and TDR measurements. Differences between the manual data compared to the transducer and TDR data were explained by the proximity of the monitoring wells to one another. The distance between the original wells located in the shoulder and the wells located beneath the pavement were 252 feet and 63 feet for the two test sections.

Conclusions

TDR technology in conjunction with air dielectric cable works well when used to locate the air-water interface in monitoring wells located beneath the pavement structure. The system described requires less maintenance, is less susceptible to power surges, has been automated to eliminate the need for labor intensive manual measurements, and can be located directly below the pavement centerline. The use of TDR methods for tracking seasonal and short-term changes in water table elevations below the pavement structure improves the ability to estimate critical design parameters. TDR methods used in conjunction with automated waveform analysis provide a less expensive and more durable alternative to pressure transducers or manual readings.

Frost Depth Measurements Using Time Domain Reflectometry

Determining frost depth below the pavement is important for timely implementation of winter and spring load limits. Existing instruments such as resistivity probes, frost tubes and moisture blocks are limited both in terms of data acquisition (automated and continuous measurements) and data interpretation. Consequently a delay between data collection, interpretation, and dissemination of information occurs. A laboratory study was conducted by the Minnesota Department of Transportation investigating the use of the Moisture Point probe as an instrument for locating the depth to the freezing front. The Moisture Point probe combines Time Domain Reflectometry with remote diode switching to provide a profile of the aggregate base and subgrade dielectric properties. From this the frost depth can be estimated. The Moisture Point probe works well in locating the frost depth and improves the ability to successfully implement spring and winter load limits. This method also provides the opportunity to validate air temperature-based models currently used to determine when to begin spring and winter load limits. Integrating the Moisture Point probe into Minnesota's Road and Weather Information System (R/WIS) communication architecture will significantly improve pavement life in Minnesota by providing additional critical data in a timely and convenient format. The objectives of this study were to 1) evaluate a multi-segment TDR probe for improved frost depth measurements below the pavement and 2) implement field testing at designated Road and Weather Information System (R/WIS) sites around Minnesota.

Comparison of Current Methods

Methods currently used to estimate frost penetration are limited in a variety of ways. Table 1 provides a summary of current methods for measuring frost depth within the pavement structure. Frost tubes (plastic fluorescein dye tubes) undergo a color change as a result of freezing. Frost tubes readings are taken manually, can be subjective, and often result in slow dissemination of critical information. Resistivity probes utilize the resistance change between frozen and unfrozen soil to determine the depth of frost penetration. Data analysis can be subjective and may require the use of thermocouple data in conjunction with probe data to determine frost depth. Data is usually collected manually, but in some cases has been automated. Recently moisture blocks, another type of electrical resistance sensor, have been used to estimate frost depth below pavements. Data from the moisture block sensors is analyzed by monitoring the measured resistance in the soil as it increases above normal summer values when the water freezes. Since this analysis is somewhat subjective, thermocouples are usually installed next to the moisture block so that temperature data can be used to verify frozen conditions. To date the results are inconclusive, with additional concern as to the long-term stability of the moisture block's gypsum core.

	Frost Tube	**Resistivity Probe**	**Moisture Block**	**Thermocouple**	**TDR Probe**
Data Collection	Manual	Primarily Manual	Automated	Automated	Automated
Data Interpretation	Subjective	Subjective, requiring temperature data.	Subjective, requiring temperature data.	No accounting for freezing point depression	Potential for developing algorithm for automated analysis.
Installation	Labor intensive. Soil disturbance is extensive.	Labor intensive. Soil disturbance is extensive.	Labor intensive. Soil disturbance is extensive.	Labor intensive. Soil disturbance is extensive.	**Not** labor intensive. Minimal disturbance to soil.

Table 1: Comparison of methods currently used for measuring frost depth within pavement system.

Conclusions

The multi-segment TDR probe shows promise as an instrument for measuring the frost depth within pavement systems. Measured changes in the dielectric during a freeze-thaw cycle gave a good indication of the frost depth. Rapid freezing and thawing, as well as high initial moisture content, produce a distinct and measurable change in the dielectric. Whereas, slow rates of freezing and low initial water contents can make data interpretation difficult. These factors should be considered as automated interpretation techniques are developed. The benefits of integrating the Moisture Point probe into the R/WIS system architecture hold promise that could be realized statewide. By accurately determining the frost depth and effectively disseminating the information to decision makers there is a reduction in damage to the pavement structure due to increased winter loads and spring-thaw weakening. By reducing the damage during these critical periods a significant reduction in maintenance costs will be realized.

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