National Cooperative Highway Research Program

RESEARCH RESULTS DIGEST

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Development of Prototype Soil Moisture Sensors

An NCHRP staff digest of the essential findings from the final reports on the sensor development phases of NCHRP Projects 21-2 and 21-2(2), "Instrumentation for Moisture Measurement--Bases, Subgrades, and Earth Materials," by C. G. Gardner, G. A. Matzkanin, and J. R. Birchak, Southwest Research Institute, San Antonio, Texas (Project 21-2); and E. T. Selig, D. C. Wobschall, S. Mansukhani, and A. Motiwala, State University of New York, Buffalo, New York (Project 21-2(2)).

THE PROBLEM AND ITS SOLUTION

Water in its various states, when insufficient or in excess in the components of highway systems, adversely affects their service behavior. Despite recognition of the importance of the relationships between the presence of water and service behavior, engineers have been hampered in efforts to predict performance by the lack of instrumentation and techniques for in situ water or moisture measurement. Current techniques are generally insufficient because of questionable accuracy, time requirements, disturbance of the site, long-term instability, or a combination of these factors. The objective of Projects 21-2 and 21-2(2), conducted independently by Southwest Research Institute (SwRI) and the State University of New York at Buffalo (SUNYAB), was to develop new and innovative sensors for the in situ measurement of moisture in aggregate base and soil subgrade layers of pavements.

Research has been completed with the development and laboratory evaluation of two prototype moisture sensors--one by SwRI researchers based on nuclear magnetic resonance (NMR) technology, the other by SUNYAB researchers using dielectric constant technology. Both the NMR and dielectric sensor types were found to be potentially applicable to highway soil moisture measurement problems. Each sensor measures the amount of water in the effective volume of a soil sample and is somewhat influenced by soil type. For a particular soil of known dry density, the percent water on a dry weight basis can be determined by empirical calibration.

Under Project 21-2(3), "Instrumentation for Moisture Measurement--Bases, Subgrades, and Earth Materials (Sensor Evaluation)," the NMR and dielectric sensors are undergoing (1) refinement and development of ancillary readout equipment; (2) simulated field evaluation over a range of soil, compaction, moisture, and contamination conditions; and (3) field installation and practical evaluation in two different climatic regions. The contract research agency is SwRI, with a substantial subcontract under the responsibility of SUNYAB. The field evaluation effort is scheduled for completion in December 1976. Information contained in the agency reports for Projects 21-2 and 21-2(2) is expected to be published ultimately in the Project 21-2(3) report. In the meantime, the technology on which each of the prototype sensors is based is described in papers by Gardner and Matzkanin and by Selig, Wobschall, Mansukhani, and Motiwala, published in *Transportation Research Record 532*. Researchers and others interested in more detailed information may obtain loan copies of the uncorrected agency reports for Projects 21-2 and 21-2(2) from the Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

FINDINGS

A prototype NMR sensor, based on the spin echo approach, was designed, fabricated, and subjected to laboratory evaluation. The response of the sensor as a function of moisture content was determined for bentonite clay, silica flour, and a local organic silty clay. The influences of soil density, organic matter, and dissolved salts were investigated. An accuracy of ±1 percent moisture over a moisture range of 6 to 25 percent was shown with silica flour. With bentonite clay, moisture determinations were less accurate. As a result, sensors must be calibrated for each soil type. The presence of sodium chloride (up to 2,000 ppm) was found to have no significant effect on sensor response. Sensor configuration is approximately 4x4x3in. with an effective soil cavity of about 1 cubic inch. Practical use in the present configuration is limited to fine-grain soils. However, development of alternate configurations is considered feasible if the technique is shown to be an effective method of in situ moisture measurement.

The dielectric sensor is based on the relationship between the amount of water in a material and its dielectric constant. The usual laboratory methods for measuring dielectric constant are not suitable for remote readout of a sensor buried in the ground for long periods of time. Therefore, in the prototype model the sensor electrodes are incorporated as part of a resonance circuit whose frequency of oscillation circuit is contained within the buried sensor; a coaxial cable connects the sensor to the external power supply and readout instrument. The measured output is the oscillation frequency difference with and without the soil in the circuit. This difference is a function of both the capacitance and the electrical conductance. Research was performed to determine the optimum circuit design to minimize the unwanted conductance effects while providing adequate capacitance sensitivity to moisture change. A wide range of sensor configurations can be constructed to accommodate different application needs. Empirical calibration is required to relate frequency change to moisture defined as weight of water per unit volume of soil.

APPLICATIONS

The findings of these projects -- development and limited evaluation of prototype NMR and dielectric moisture sensors -- are of primary interest to researchers in the moisture measurement field. Ultimate implementation is dependent on the outcome of the field evaluation phase currently in progress as NCHRP Project 21-2(3). A primary prospect for future implementation is use of the sensors for in situ determination of soil subgrade moisture conditions under pavements at time of construction and subsequent to construction as input to mechanistic methods for predicting pavement performance.

In addition, the researchers are hopeful of applying the technology to the development of laboratory instruments for almost instantaneous measurement of moisture in soil samples without the need for drying. This would involve placement of the soil sample in a chamber of known volume, measurement of the weight of water in the sample, determination of the wet weight of the sample, and computation of the soil dry weight and moisture content on dry weight basis.

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