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16. Abstract

The pilot implementation of the new system to calculate IRI used for pavement design purposes and applied to the design of pavements on expansive clays subgrades was conducted successfully. Six training sessions were conducted in three Districts: three for design engineers and three for laboratory technicians. Three sets of testing equipment were received, set up, calibrated, and made operational in the three district labs. Two computer programs, one for design and the other for the analysis of a pavement cross-section, to determine the expected performance of expansive clay roughness countermeasures were delivered to the three districts. User guides for each of the programs were provided to each of those in attendance.

It is recommended that statewide implementation should now proceed to make this capability available to other districts within the state that have pavement performance problems caused by expansive clay roughness. The statewide implementation effort should include the monitoring validation described above, technical support of the computer programs and laboratory testing, additional training sessions in at least six more districts, and involvement of consulting engineers in the training sessions.

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The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation. The researcher in charge of the project was Robert L. Lytton.

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REPORT 5-4518-01-1

Introduction

Swelling and shrinkage of subgrade soils are critical factors contributing to an increase in roughness and degradation of serviceability of highway pavements. Existing procedures for predicting swell are largely based on the potential vertical rise (PVR) procedure developed by McDowell in 1956. A recently completed research project 0-4518 reviews the basic assumptions of the existing PVR procedure and identifies likely sources of the questionable predictions that have arisen in the past.

The analysis and design studies conducted in the research project showed that the PVR method is generally too conservative. Acceptable performance can be achieved at a high level of reliability with both flexible and rigid pavements while using smaller amounts of subgrade treatment than are required by the presently used PVR criterion. Reports produced by that project present an alternative approach that features rigorous modeling of both the moisture diffusion process that induces changes in suction within a soil mass and the deformations that occur in response to the changes in suction. The use of the predicted present serviceability index (PSI) or the international roughness index (IRI) or both is a more reliable indicator of acceptable performance and is shown in the reports from 0-4518 to be related to the total movement beneath the pavement, including both swelling and shrinking, rather than the swelling movement alone.

The test methods developed in the project 0-4518 work well and are repeatable, efficient, and accurate. The test methods include the measurement of suction with filter paper and with a transistor psychrometer laboratory apparatus and the measurement of the diffusivity of the soil using a Shelby tube sample taken directly from a boring. A pavement design program was developed in the project that is capable of predicting the PSI and the IRI of a pavement due to the effects of both traffic and the underlying expansive soil. Pavements can be asphalt, jointed concrete, or continuously reinforced concrete. A pavement analysis program was also developed to predict the transient changes of suction and vertical and horizontal movements of a pavement cross-section.

Both the analysis and design programs permit the use of various expansive clay roughness countermeasures such as vertical and horizontal moisture barriers, lime or cement stabilized layers, or inert layers. Application of these two programs and the testing techniques to three case study sites in the Texas Department of Transportation (TxDOT) Atlanta, Austin, and Fort Worth Districts showed that the new methods matched the observed differential movements in the field in all three sites. The case study predictions and the field observations showed the importance to design of not only the expansive nature of the subgrade soil, but also the initial moisture condition, the presence of roadside vegetation including both grass and trees, and slopes and drainage. The project produced two user-friendly programs, the design and the analysis programs, and their corresponding user's guides and test protocols for the test methods that were developed and used in the project.

It was expected that the implementation of the results of the earlier research project through this implementation project would provide designers with tools that are capable of evaluating the effectiveness of a variety of treatments that may be applied to restrain the development of expansive clay roughness on highway pavements. This report describes the four-part implementation effort completed in 2006 as part of project 5-4518-01.

The first part involved the procurement, assembly and calibration of the laboratory equipment for the three laboratories that participated in this implementation project. The second part was the preparation of presentation materials and the actual presentation of six training sessions that were held in Bryan, Austin (Cedar Park), and Fort Worth. Three of the sessions were about the design and analysis programs and were presented to design engineers. The remaining three sessions were presented to technicians on the proper methods of performing the tests. The third part was the revision and improvement of the laboratory testing protocols, computer programs, and the user manuals based upon the feedback from the training sessions. The fourth part was the preparation of a monitoring procedure for validating the predictions of the PSI and IRI on pavements built on expansive clay subgrades.

Implementation Task Summary

A total of seven tasks were performed in completing the implementation requirements. The first three tasks were directed at acquiring, assembling, calibrating, and setting up the laboratory testing equipment in three TxDOT laboratories. Three other tasks were related to setting up and providing the six training sessions. The seventh task was to prepare a procedure for validating the prediction procedure used in the design program for predicting the PSI and IRI of pavements on expansive clay subgrades. Each of these seven tasks is described below.

Task 1. Acquire, Assemble, and Calibrate Three Sets of Laboratory Equipment
In this task three sets of laboratory testing equipment were purchased or built. The laboratory equipment included three filter paper suction test setups, an eight-probe transistor psychrometer suction test cabinet, and three eight-sample diffusivity test cabinets. Each filter paper suction test setup is capable of measuring both total and matric suction. The key to accurate and repeatable measurements of suction with any method, including the filter paper method, is temperature control. One set of filter paper suction test equipment includes the following:

- an electronic balance that is sensitive to 0.0001 gram accuracy;
- an oven to dry the filter paper samples at slightly above the boiling point of water;
- Schleicher and Schuell no. 589 filter paper supply or their equivalent. They are chosen for the consistency in their manufacture;

- protective filter papers used in measuring the matric suction;
- glass jars to hold the soil sample while the filter papers are coming to equilibrium with the soil;
- moisture tins for measuring the moisture content of the filter paper;
- two Styrofoam ice chests in which to hold the glass jars while the filter papers are coming to equilibrium;
- tweezers;
- rubber gloves for handling the soil and filter papers;
- electrical tape to seal the jars against the loss of moisture;
- PVC O-rings on which to rest the filter papers that are used to measure the total suction;
- aluminum block to act as a heat sink prior to weighing the moisture tins and the oven-dried filter papers.

The eight-probe transistor psychrometer suction test cabinet with a built-in datalogger is manufactured in Australia. It was imported and calibrated and tested at Texas A&M University prior to its delivery to the TxDOT at the Cedar Park CST site. The soil diffusivity test equipment consisted of a cabinet with a water bath and temperature controller, eight wells for Shelby-tube samples of soil, and a CR7 datalogger for recording the measurements made by thermocouple psychrometers embedded in each of the samples. The diffusivity equipment was designed and built at the Texas Transportation Institute.

Task 2. Assist TxDOT with Soil Sampling Techniques
Each training session used actual soil sampled from the district within which the training was conducted. All of the required laboratory testing is conducted on Shelby tube samples. TxDOT personnel selected a pavement site in each district to serve as a subject for the training sessions and made a boring on that site to a depth of 20 feet. The week before the training sessions were held, the soil was sampled and test samples were prepared for both filter paper suction and diffusivity tests.

Task 3. Install Testing Equipment in TxDOT Laboratories
In addition to acquiring soil samples for testing, in the week before the training sessions the test equipment was set up and checked to make sure that everything was working properly. District laboratory personnel assisted in setting up the equipment and this served as a valuable part of their training.

Task 4. Training Sessions for Laboratory Test Protocols
Laboratory test protocols and data recording sheets were prepared for each of the three pilot implementation sites and the training was conducted over a period of two or three days. The test samples that were set up the previous week were used to make the filter paper suction and diffusivity measurements. Companion samples that were held in moisture-controlled storage were used for sample preparation practice.

Task 5. Training Sessions for Laboratory Test Computations

Interpretation of the laboratory test data for each of the items of test equipment requires some calculation to arrive at the desired result. At each of the three pilot implementation sites, calculations were made of the matric and total suction from the filter paper measurements and calibration curve. Calculations were also made of the diffusivity using both the data reduction software for that test and the graphical method for determining the diffusivity. In the Austin training session, the technicians were shown how to perform the calculations of total suction using the data from the transistor psychrometer cabinet.

Task 6. Monitoring Plan for the Validation of Pavement Roughness Models

The design software that was prepared in the 0-4518 project uses models of roughness due to traffic and to expansive clay subgrade. The models predict both the Present Serviceability Index and the International Roughness Index due to both causes. The traffic roughness model was taken from the AASHO Road Test models for both asphalt and concrete pavements. The expansive clay roughness model was developed at Texas A&M University based upon decades of monitoring of pavement test sections at various locations across the state of Texas. No independent validation of the expansive clay roughness model has been undertaken since the formulation of the model. The monitoring validation plan that is presented subsequently in this report lists the number and types of test sections that will need to be included in order to have a broad-based validation of the roughness models.

Task 7. Training Sessions for Design Engineers

Design engineers were given practical explanations and hands-on applications of the underlying concepts and capabilities of the design program (named WinPRES) and of the analysis program (named FLODEF). Handout materials and PowerPoint® presentations were prepared to assist in presenting the material on both of the two programs. To the extent possible, the soils data that were used in both the design and analysis training sessions by the design engineers were provided by the laboratory tests being run at the same time by the laboratory technicians in their training sessions.

The separate training sessions for engineers and technicians were conducted concurrently in the Bryan District Office (February 9-10, 2006); Cedar Park Office (April 18-20, 2006); and in the Fort Worth District Office (July 31-August 1, 2006).

The typical training session for design engineers began on the first day with an introduction to some practical fundamentals concerning the mechanics of unsaturated soils, pavement design, the two kinds of roughness, reliability, and the boring, sampling, testing, interpretation, and use of the soils data. Following the introductory material, there were practical exercises using the design program WinPRES. The first exercises were focused on the design of flexible pavements on expansive clays using soils data that were generated by the laboratory technicians. In the afternoon, practical exercises were undertaken on the design of jointed and continuously reinforced concrete pavements. Throughout all of these exercises, trials were made of the various design alternatives that are provided in the design program including the effects of tree-size vegetation, vertical and horizontal moisture barriers, and inert and stabilized layers. The output of the program showed graphically the time history of the IRI and/or the PSI that is expected on the selected wheel path(s).

The second day of the training session for design engineers was devoted to the analysis program, FLODEF. Because this is a two-dimensional finite-element program that computes the changes that occur over a designated time period of up to 20 years, the time period was restricted to 5 years for the purpose of the practical exercises. This required about three minutes of running time and provided sufficient information for the engineers to see what can be produced by the program. The 20 year time period can be computed in about 12 minutes.

The morning was spent in familiarizing the design engineers with the input and output capabilities. One of the most dramatic capabilities is the ability to plot contours of vertical and horizontal movement within the entire pavement and subgrade cross-section. The ability to put in both trees and grass to the side of the paved area and see what their effects are on the horizontal and vertical movement of the pavement was of considerable interest to the participants. One interested participant remarked that he did not realize that the horizontal movement beneath a pavement could be on the order of several inches, easily sufficient to explain the longitudinal cracking of the shoulders and travel lanes of a paved area built over expansive clay.

The afternoon was spent with the training session participants trying out various investigations of their own and comparing their results with the results by the instructor and other participants. Of particular interest was the effectiveness of the various roughness countermeasures such as vertical and horizontal moisture barriers, and inert and stabilized layers. Also of interest was how the effectiveness of these countermeasures changed with the climate in which the pavement was built, the presence of elevated water tables, and the patterns of horizontal and longitudinal drainage.

The third day of the training session for design engineers familiarized them with the laboratory measurements of diffusivity and the various methods of computing the diffusivity from the laboratory measurements. In the final training session in the Fort Worth District, this was conducted in the last two hours of the second day.

At the conclusion of the six training sessions, a CD with the two programs and their user's guides, the PowerPoint presentations, and the handouts that had been used in both the laboratory technicians and the design engineers training sessions were delivered to the TxDOT.

Computer Programs

The Design Program, WinPRES

The design program is set up to make very rapid calculations of the Present Serviceability Index (PSI) and the International Roughness Index (IRI) with time for both asphalt and concrete-surfaced pavements and to display the results graphically. This allows the designer to try a number of design strategies and evaluate the long-term consequences of each of the alternatives considered. A typical run presents its results within 5 seconds when the RUN button is pressed. The entire user's guide to this program was provided to each of the participants of the design engineer training sessions and the details of the inner workings of this program are found in Volume 3 of the final report of Project 0-4518, of which this project is a pilot implementation effort. Several of the unique features of this program are discussed below.

One of the unique features of expansive clays is that they crack, and the cracks allow water to diffuse throughout the soil mass at a rate that approaches 100 times the rate of water diffusion in intact soil. This is an important feature of expansive clay masses and one that governs the rate at which roughness develops in pavements. The design program provides two options for taking into account the cracked nature of the soil:

- an empirical relation based upon the field observations made previously in the monitoring study that was conducted by the combined efforts of Texas A&M, Texas Tech, and University of Texas at El Paso and

- a theoretical relationship between laboratory measured diffusivity and the field diffusivity because of the depth of cracks in the soil mass. The two methods produce practically the same field diffusivity result.

The expansion characteristics of the subgrade soil are based upon relationships that were published in the American Society of Civil Engineers *Special Geotechnical Publications* No. 40 and 115 and derived from the soil data base that is maintained by the Natural Resources Conservation Service of the U.S. Department of Agriculture. The chart method presented makes realistic estimates of the volumetric activity of the soil based upon measured Atterberg Limits and the -#200 and -2 micron fractions of the soil.

The design engineer must specify the equilibrium moisture condition of the subgrade soil at a depth where stable moisture conditions are present. The engineer has two options for doing so:

- using an empirical relationship between the Thornthwaite Moisture Index and the equilibrium moisture condition at the stable moisture depth or

- measuring it using the filter paper or transistor psychrometer methods of measuring total suction.

The level of this equilibrium suction has been found to significantly affect the choice of the best roughness countermeasure to use at a given pavement site.

The roughness countermeasures that may be considered by the design engineer include vertical and horizontal moisture barriers, inert layers and layers stabilized by either cement or lime. The program has a feature that computes the depth of vertical moisture barrier that will satisfy a prescribed level of reliability in a designated wheel path.

The effect of tree-sized vegetation, the depth of its root zone, and its proximity to the edge of the pavement are taken into account within the design program.

The designer can require a different level of reliability of the pavement design for traffic and expansive clay-related roughness.

The new design method has been found in the previous project 0-4518 to require less conservative roughness countermeasure treatments of the pavement than the Potential Vertical Rise method that was developed and published in 1956.

The Analysis Program, FLODEF

The analysis program, FLODEF, was developed primarily to provide the designer with a method to review in detail the effects of a design countermeasure for specific site conditions. These site conditions include an inclined stratum of subsoil or rock, high water table, tree root zones and grass in the vicinity of the paved area, and horizontal and vertical movements of the expanding and shrinking subgrade layers. This capability to predict movement is especially useful in anticipating the amount of horizontal movement that is latent in the subgrade that causes longitudinal cracking in the shoulder and travel lanes.

The program is a two-dimensional finite-element program that computes the transient movement of moisture and vertical and horizontal movement of the layers in a pavement cross-section. It has all of the same input capabilities as the design program but, in addition, is capable of demonstrating graphically how the movements of both moisture and soil in various parts of a pavement cross-section are affected by a roughness countermeasure that is being considered for design. The program has the capability of representing both trees and grass as they pump water from their root zones at different rates during the year. The program can compute the behavior of a pavement cross-section every month for 5 years in about 3 minutes of running time on a desktop personal computer. Twenty years requires about 12 minutes of running time.

Surface weather boundary conditions are provided for nine sites distributed entirely across the state of Texas so that the analyst can choose the one that is closest to the site of interest. These surface boundary conditions are based upon several decades of weather data records for these nine sites and upon monitoring data that were measured in the field in most of these locations.

The program does not predict the Present Serviceability Index or the International Roughness Index as does the design program, nor does it consider the effects of traffic on the service life of the pavement.

Monitoring Validation Plan

The prediction of the pavement roughness due to expansive clays is based upon monitoring measurements that were made over a period of time up to two decades on some of the pavement test sections that were monitored. The empirical relationship between the rate of roughness increase and the total movement in any given wheel path needs to be validated by measurements made on other sections of pavement than those on which the original data were collected. The elements of a Monitoring Validation plan are to identify the monitoring variables and the monitoring measurements that need to be made and the analyses of the data that need to be conducted in order to validate the currently used empirical roughness relationship.

Monitoring Variable

The state of Texas has been found by several statistical studies of climatic variables to have five unique climatic zones. There should be a complete set of monitoring measurements made in each of these five zones. Measurements of pavement roughness should be made on asphalt-surfaced, jointed concrete, and continuously reinforced concrete pavements in each of the climatic zones. Each pavement should have an expansive soil subgrade. The pavement test sections should be chosen to have three different ages after construction in order to observe the effect of age on the rate of increase of roughness within the time frame of the validation study. This set of variables results in a total of 45 different pavement sections to provide the data for validation.

Monitoring Measurement

The measurements that should be made on each pavement section include pavement profiles, soil profiles, and site conditions.

The pavement profiles should be measured with a profilometer in all of the wheel paths in both directions for a minimum of one mile. The Texas Transportation Institute possesses profile analysis programs that have been used in previous studies to determine the Present Serviceability Index and the International Roughness Index from the profile data.

Soil borings on each site should be made at two locations within each site to ascertain how variable the soil conditions are within the site. Each boring should be made to a depth of 20 feet and samples should be taken from each distinctive soil layer. Measurements of the Atterberg Limits, -#200 and – 2 micron fractions should be made of each layer. In addition, the total and matric suction should be measured in each layer and the laboratory diffusivity should be measured in one or two of the upper layers of the subgrade soil. Each boring should be logged for root fibers to aid in determining the depth of soil cracking in the field.

Site conditions should be recorded along the length of each test section, making note and taking photographs of the longitudinal and lateral drainage, vegetation, and distressed conditions, especially in the vicinity of the boring locations.

Monitoring Analysis

Validation of the relationship between the measured PSI and IRI and the total movement in any given wheel path requires five separate analyses. The first analysis is an analysis of the profile of each wheel path to produce the PSI and IRI for each quarter-mile of the test section in each wheel path. The second analysis would be made of the laboratory measurements. Ideally, the measurements should be made in the district labs but if that is not possible for some reason, the lab at Texas A&M University can make the necessary measurements. The third analysis is with the design program, WinPRES, to determine the predicted maximum movements and PSI and IRI histories on each of the pavement sections and in the monitoring validation study. The fourth set of analyses is with the analysis program FLODEF to determine the predicted transient movements in each wheel path to determine the maximum total movement in each wheel path. The fifth and final analysis is to determine the relationship of the total movement observed in the monitoring validation study to the rate of change of the PSI and the IRI as measured on the same sets of test sections. The two empirical relationships can then be compared and revised as needed.

Conclusions

The pilot implementation of the new system to calculate IRI used for pavement design purposes and applied to the design of pavements on expansive clays subgrades was conducted successfully. Six training sessions were conducted in three Districts: three for design engineers and three for laboratory technicians. Three sets of testing equipment were received, set up, calibrated, and made operational in the three district labs. Two computer programs, one for design and the other for the analysis of a pavement cross-section, to determine the expected performance of expansive clay roughness countermeasures were delivered to the three districts. User guides for each of the programs were provided to each of those in attendance.

It is recommended that statewide implementation should now proceed to make this capability available to other districts within the state that have pavement performance problems caused by expansive clay roughness. The statewide implementation effort should include the monitoring validation described above, technical support of the computer programs and laboratory testing, additional training sessions in at least six more districts, and involvement of consulting engineers in the training sessions.