INVESTIGATION OF AN UNSATURATED, FINE-GRAINED PAVEMENT SUBGRADE SOIL

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Abstract

This paper describes preliminary findings from research on a fine-grained subgrade soil. Laboratory soil-water characteristic and permeability tests were conducted on recompacted soil samples from a site where test pavements were instrumented with seasonal instrumentation. Predictions from a computer program that models one-dimensional coupled heat and moisture flow are compared to measured variations of temperature and moisture obtained from the seasonal instrumentation. Recommendations are made for testing of unsaturated fine-grained soils and for modeling climatic effects on pavements.

Introduction

The moisture content of pavement bases and subgrade soils varies seasonally depending on the climatic conditions. The moisture variation causes significant changes in the soil moisture suction, particularly if the subgrade soils are fine-grained. Research has shown that the resilient modulus of subgrade soils decreases with decreases in moisture suction [1,2]. Efforts to investigate the long-term performance of pavements include seasonal instrumentation and monitoring of pavements [3] and the development of a computer program to model climatic effects on pavements [4]. This paper describes preliminary conclusions from laboratory testing, seasonal instrumentation and climatic modeling of a fine-grained pavement subgrade soil [5].

Advances in laboratory testing have significantly improved understanding of unsaturated soil behavior. It is possible to vary the soil matric suction to observe the variations in soil moisture, hydraulic conductivity, shear strength, resilient modulus and volume change using the axis translation technique. Triaxial shear equipment can be fabricated to accommodate the testing. However, special procedures discussed in this paper are required to test fine-grained soils.

Test pavements with seasonal instrumentation were constructed in Delaware, Ohio [6] as part of a national research effort to investigate the long-term performance of pavements [3]. The instrumentation is monitored regularly to determine the seasonal variations of moisture, temperature and frost penetration. Temperature and moisture profiles predicted using the computer program were compared to measured values. Additional laboratory testing and modifications to the program are required to improve the predictions.

Laboratory Testing

It was necessary to purchase or fabricate apparatus to enable all of the tests mentioned previously. Triaxial shear cells were modified with two additional outlet ports through the base to enable application of the pore air pressure. An electronic load transducer was built into the loading piston inside the cell. Volume change indicators (VCI) and diffused air volume indicators (DAVI) were constructed. The triaxial pedestals and caps were machined with a grooved water compartment below the high air entry disk. High air entry disks were epoxied into recesses in the end caps to prevent air leakage from the soil to the water compartment. An acrylic cylinder was machined to fit over the pedestal for one-dimensional testing. Design details were obtained from the reference by Fredlund and Rahardjo [7].

Tests were conducted on bag samples taken from the site of instrumented test pavements located near Delaware, Ohio. Samples were hand compacted and statically compressed in the acrylic cylinder to the maximum dry density at 3% above the optimum moisture content, based on the standard Proctor procedure, in order to simulate roadway embankment compaction. A small head of water was applied to the bottom of the soil samples for several days and inflow measured until the computed degree of saturation exceeded 100%. Soil water characteristic curves obtained from the triaxial apparatus and from pressure plate extraction testing are shown in Fig. 1. The apparent error between the two drying curves may be within the accuracy of the measurements. As discussed in the following section of this paper, attempts to determine the unsaturated hydraulic conductivity using a steady-state method were unsuccessful.

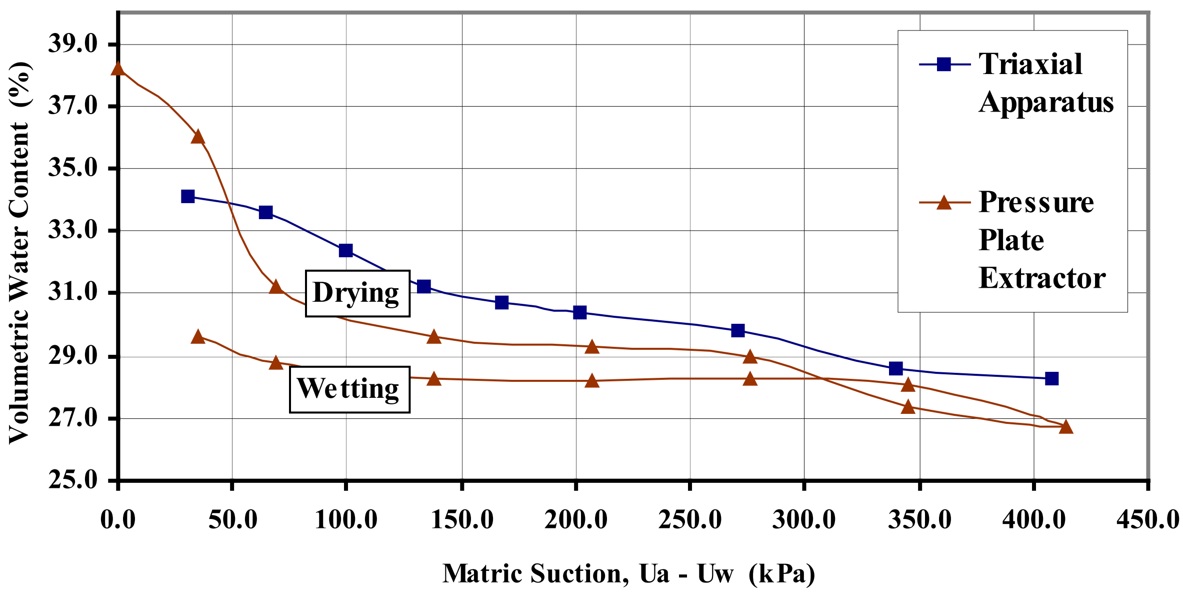

Figure 1 - Soil Water Characteristic Curves

Recommendations for Testing Fine-Grained Soils

Fine-grained soils are difficult to test for a variety of reasons. Soil saturation is not reached using the manner described above. It is necessary to prepare specimens from a slurry or to use back pressure saturation techniques to effectively saturate fine-grained soils. It takes several hours or days to achieve equilibrium after application of the applied air pressures depending on the sample height. The time for soil-water characteristic, permeability and volume change testing could be reduced by decreasing the sample height. However, it is more difficult to obtain representative samples and the error increases when computing volumetric relationships. Additionally, it is difficult to determine when equilibrium is reached because of the low flow volumes. A procedure described by Fourie and Papagerorgiou [8], in which the volume of flow from the samples is controlled and the pressures are measured, is recommended herein for testing fine-grained soils. Triaxial equipment typically is designed to withstand 700 to 1000 kPa of pressure. High matric suctions are required for fine-grained soils in order to define the complete drying and wetting bounding curves. For permeability testing, steady-state conditions are not reached for unsaturated fine-grained soils. Unsteady-state methods by direct measurements [7] can be used but they require costly equipment. Indirect methods can be used without permeability tests [7, 8]. Soil samples can be tested at different matric suctions to investigate shear strength and resilient modulus behavior using the axis translation technique. Alternatively, samples can be prepared at different molding water contents and cured for a period of time to allow for thixotropic effects prior to testing [9]. The relationship can then be expressed in terms of water content or degree of saturation or can be related to the matric suction using soil-water characteristic data.

Seasonal Monitoring

Seasonal monitoring program (SMP) instrumentation was installed in test pavements at the site as a part of the United States Federal Highway Administration (FHWA) Long-Term Pavement Performance (LTPP) testing program [3]. The instrumentation includes time-domain reflectometry (TDR) soil moisture probes, thermister probes for temperature and electrical resistivity probes to measure the depth of frost penetration. The test pavements are monitored at least one each month except for the thermister probes which are monitored continuously. Automated weather stations were also installed at the SMP test sites.

The seasonal variations of the soil moisture are shown in Fig. 2 for one test pavement. As can be seen from the figure, the seasonal variations of moisture content are significant. The weather during the monitoring period was unusually wet during the summer and dry during spring. Therefore, higher water contents were measured during summer (August) and the lower water contents during spring (March - April), which was unexpected. The TDR probes are sensitive to the apparent dielectric constant of the soil surrounding the probe. The low water contents measured during January indicate that some of the soil moisture was frozen. The water contents increase with depth at this site because the water table is shallow. The water contents were computed using Topp's equation [10]. Values of volumetric water content greater than 40% are too high since the calculated soil porosity is 38 to 40%. An improved equation should be used for calculating the water contents [11].

The seasonal variations of temperature, shown in Fig. 3 and discussed in the next section, were obtained from the same test pavement.

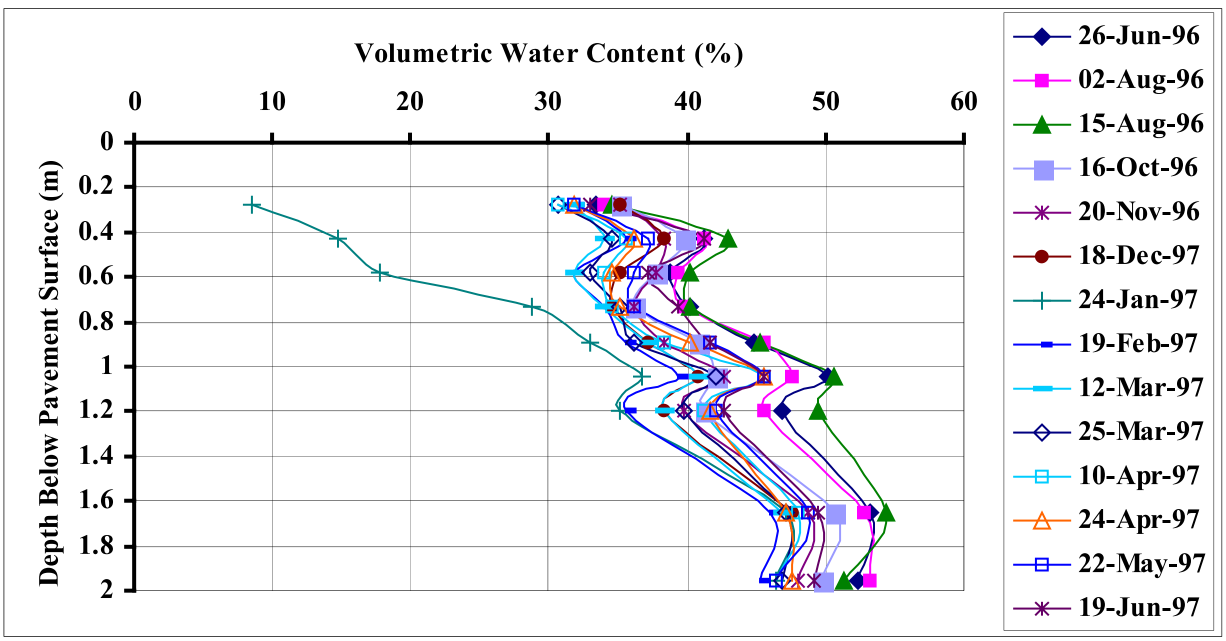

Figure 2 - Seasonal Variation of Volumetric Water Content below Test Pavement

Climatic Modeling

A one-dimensional finite element program that models coupled heat and moisture flow to predict subgrade conditions and pavement material properties over time was developed for the FHWA [4]. The program uses actual weather information to compute infiltration of the pavement and performs a drainage analysis of the pavement base. Frost heave and thaw settlement are also modeled. The program input requires climatic data as well as pavement and subgrade properties. The Gardner equations [12] are used for approximating the soil moisture and hydraulic conductivity functions for unsaturated soils. Default values included in the program were used for the thermal properties of the pavement materials and the soil. The program output includes predicted subgrade temperature, moisture suction, moisture content and frost penetration profiles.

Preliminary results for the seasonal variation of temperature at one of the test pavements are shown in Fig. 3. There is reasonable agreement between the predicted and measured temperature variations except during the cold months when the ground temperature was significantly lower than the mean temperature. The predictions can be improved by increasing the depth to the lower boundary where constant temperature is assumed.

The predicted volumetric moisture contents were consistently lower than the measured TDR values. There apparently was some problem with modeling the upper boundary condition. The hydraulic conductivity function was not approximated well. Also, as mentioned previously, the measured volumetric water contents are high. Additional research is underway to improve the predictions. It is more difficult to model moisture flow than heat flow because the soil hydraulic conductivity is very sensitive to changes in moisture condition.

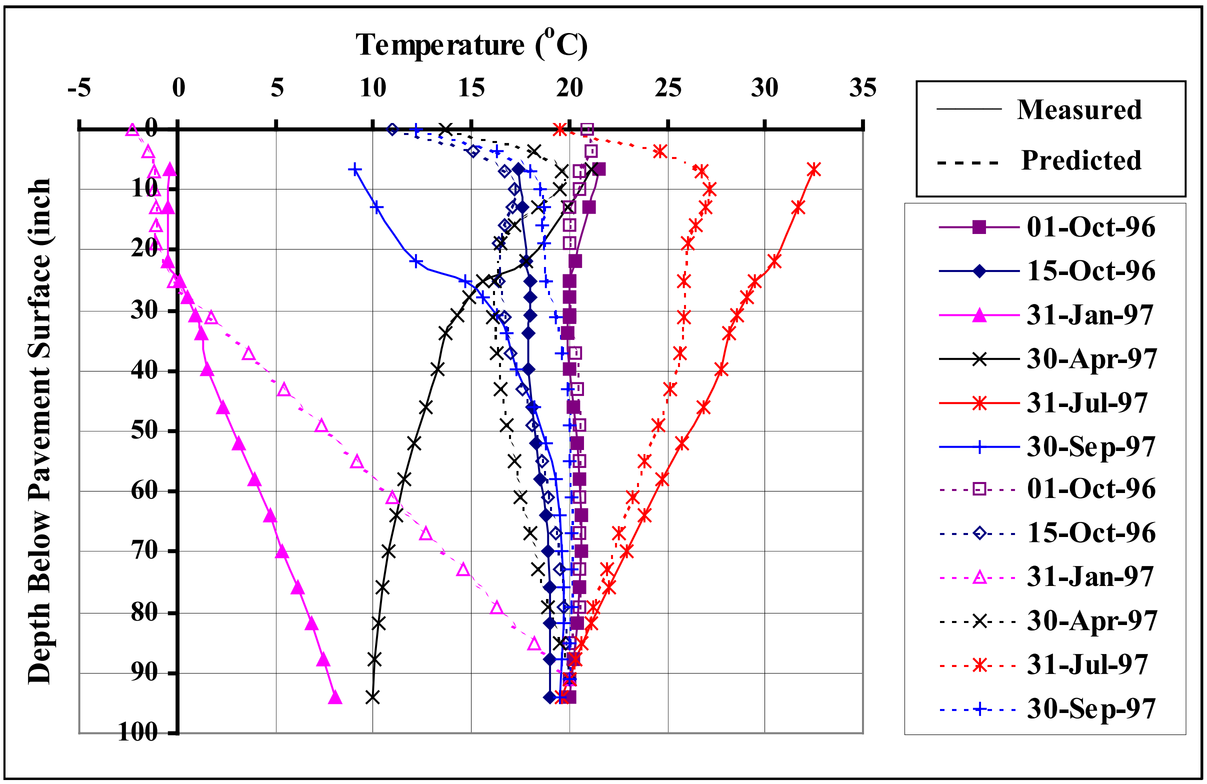

Figure 3 - Seasonal Variation of Temperature below Test Pavement

Conclusions

The long-term performance of pavements is highly dependent on the properties of the subgrade soils which vary significantly because of climatic effects. The wealth of information that has been gained from recent research on unsaturated soil behavior will improve understanding of the climatic effects on pavements. Continued monitoring and modeling of climatic effects is required in order to incorporate climatic effects into pavement design. Modeling of unsaturated soils could be improved through the use of a large, comprehensive database on unsaturated fine-grained soil properties.

Acknowledgement

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