2007-11TS
Published April 2009

RESEARCH
SERVICES SECTION

TECHNICAL SUMMARY

Technical Liaison:
John Siekmeier, Mn/DOT
john.siekmeier@dot.state.mn.us

Administrative Liaison:
Dan Warzala, Mn/DOT
dan.warzala@dot.state.mn.us

Principal Investigator:
Satish Gupta, University of Minnesota

PROJECT COST:
$195,500

Researchers tested soils in the laboratory to correlate suction (how tightly water is held between soil particles) with properties like shear strength.

Pavement Design Using Unsaturated Soil Technology

What Was the Need?

Pavements are constructed on compacted soils and aggregate materials that are typically unsaturated; this means that some of the pores between particles are filled with air instead of water. Keeping these materials unsaturated helps maintain subgrade stiffness and strength. However, soil suction changes as water content changes, and this has a significant effect on the shear strength of a pavement foundation.

Design and maintenance measures that maintain a pavement foundation's unsaturated condition have been largely based on empirical tests and previous experience. These empirical data do not directly account for the variations in soil suction that affect subgrade strength. Without data based on principles of unsaturated soil mechanics that consider the effects of soil suction, pavement designers cannot easily quantify when favorable engineering properties—for example, high shear strength—have been achieved; unnecessary measures may be taken that result in costly overengineering.

Establishing soil suction resistance factors that predict the mechanical properties of unsaturated soils will help Mn/DOT design cost-effective pavement foundations that more closely approximate actual field conditions during construction and throughout the road's service life.

What Was Our Goal?

The goal of this project was to improve Mn/DOT's understanding of how moisture content, or more precisely the surface tension forces exhibited by water between soil particles, contributes to the increase in pavement subgrade stiffness (as measured by resilient modulus) and shear strength. These results should provide a theoretical framework for developing models that predict the mechanical properties of unsaturated soils. Specific objectives included:

- Developing methods for predicting the shear strength of unsaturated soils based on saturated shear strength and water retention characteristics.
- Determining the resilient modulus of fine-grained subgrade soils, taking into account the influence of soil suction.
- Determining the relationship between resilient modulus and shear strength.
- Generating a framework for predicting seasonal soil suction resistance factors for use in mechanistic pavement design.

What Did We Do?

Researchers tested soils from four different regions of Minnesota that displayed a wide range of textural differences: silty soil from Red Wing, silty clay loam soil from Red Lake Falls, loam soil from MnROAD facilities near Monticello, and clay soil from TH 23 near Duluth.

Shear strength and resilient modulus measurements were taken for each soil at several suction levels and two densities. These tests allowed researchers to plot water retention characteristics curves and to note the relationships between shear strength and suction, and between resilient modulus and suction. They then used the four representative soil samples to create a matrix of soil types and interpolate the range of moisture conditions found in Minnesota.

continued

"The constitutive models help us understand the effects of moisture we see during field tests. This allows us to be more confident that our pavement performance estimates are reasonable, and we can now better quantify the effects of moisture during construction quality assurance."

–John Siekmeier,
Mn/DOT Senior Research Engineer

"Knowing how unsaturated conditions affect soil strength and stiffness allows us to design pavements based on the actual field conditions. This new design approach helps optimize limited resources and provide better value."

–Satish Gupta,
Professor, University of Minnesota Department of Soil, Water and Climate

Produced by CTC & Associates for:
Minnesota Department of Transportation
Research Services Section
MS 330, First Floor
395 John Ireland Blvd.
St. Paul, MN 55155-1899
(651) 366-3780
www.research.dot.state.mn.us

To bring soil specimens to a given level of soil suction, the specimens were placed in rubber sleeves and put in a pressure chamber.

Using this matrix with data from the soil tests, researchers then developed two constitutive models that use mathematical equations to describe a soil's material properties by predicting the effects of soil suction on resilient modulus and shear strength. They considered the relationship between suction and water content when constructing their models. Suction defines how tightly water is held between soil particles. Once the suction present in a soil is known, the stiffness and strength of the soil can be predicted given a specified degree of saturation.

What Did We Learn?

The new models allow pavement designers to take any soil encountered in the field, with any moisture content, and predict its stiffness and strength. Predictions generated by these models will be particularly helpful in the predesign phase of pavement construction.

Use of these models does not mean that field testing of soils will no longer be required. While the predictions derived from the constitutive models may be adequate to provide target values, actual soil samples taken during construction will be needed to validate the models' predictions in the field.

What's Next?

The results of this study are now being implemented as described in Report 2009-12, which developed specifications for using the dynamic cone penetrometer and light weight deflectometer for construction quality assurance. The DCP test is used during construction quality assurance to estimate strength, and the LWD field test is used to measure deflection.

Further application of the results of this study includes the development of a framework for incorporating the effects of suction into the resistance factors used in MnPAVE, Mn/DOT's software program that supports computer-based mechanistic-empirical pavement design. Though MnPAVE has not yet been updated to reflect the adjusted resistance factors, pavement designers can continue to use the study's constitutive models in their predesign work to predict the strength and stiffness of pavement foundations and provide the basis for validation in field tests.

This Technical Summary pertains to Report 2007-11, "Pavement Design Using Unsaturated Soil Technology," published May 2007. The full report can be accessed at http://www.lrrb.org/PDF/200711.pdf.

The current implementation project mentioned under "What's Next?" is the LRRB-funded report "Using the Dynamic Cone Penetrometer and Light Weight Deflectometer for Construction Quality Assurance," published February 2009. The full report can be accessed at http://www.lrrb.org/PDF/200912.pdf.