RESEARCH ADMINISTRATION
Bureau of Field Services
Michigan Department of Transportation

Research Spotlight

Project Information

REPORT NAME: Predictive Modeling of Freezing and Thawing of Frost-Susceptible Soils

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TOTAL COST: $184,443

COST SHARING: 20% MDOT, 80% FHWA through the SPR, Part II, Program

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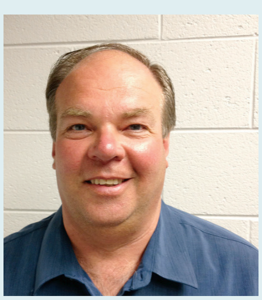
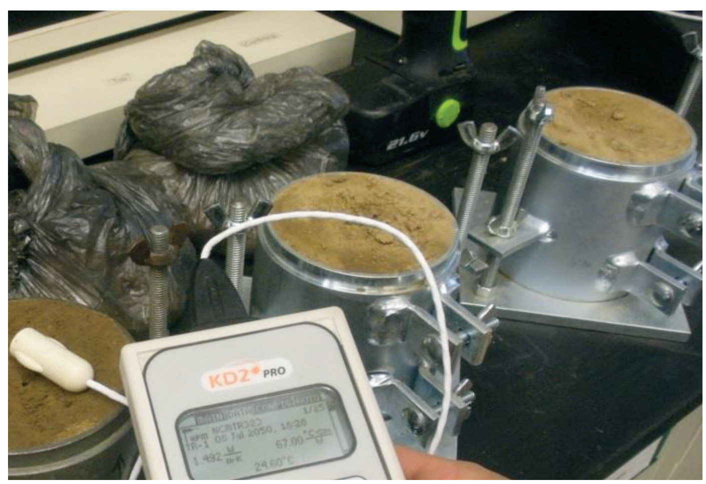


Better soil freezing model may help reduce infrastructure damage

When ice forms in soil, it can cause frost heave, where the ground swells upward. Frost heave, and the subsequent settlement during thaw, can cause premature damage to pavements and other transportation infrastructure. While design processes such as increased subbase thickness and partial removal of frost critical subgrade soils can mitigate the impact of frost heave, effective application of these measures requires an understanding of how often frost heave cycles below the pavement. This information is critical in determining when seasonal load restrictions (SLRs) should be enacted.

Problem

Traditionally, MDOT has measured soil freezing manually using frost tubes installed at several locations throughout the state. Frost tubes are embedded in the ground and filled with a solution that changes color when it freezes. The color is checked manually to determine how deep freezing temperatures have penetrated into the soil.



This project showed that thermal conductivity, which is easy to measure, could be used to accurately model the impact of a soil's properties on its freezing behavior.

Traveling to these locations and manually reading the frost tubes are time-consuming. MDOT has invested in a a select number of Road Weather Information System (RWIS) stations to reduce staff time and associated expense required for manually determining frost depth. MDOT wanted to develop a statistical model that could estimate frost depth from available weather data.

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"In many winters, freeze and thaw cycles don't neatly follow the calendar year. Having the ability to model frost below pavements using climate data and soil type can help to reduce the pavement distress caused during thaws."

Richard Endres, P.E.
Project Manager

Research

Researchers conducted a literature review to identify existing frost depth models and evaluate their accuracy and feasibility for use in Michigan.

Next, they developed a statistical model that related the frost depth data measured in Michigan to calculated cumulative freezing degree days (CFDDs), which measure how far below freezing the air temperature has fallen and for how long. CFDD is calculated easily using air temperature data. To improve this model's accuracy, researchers incorporated soil type into the calculations, producing separate models for clayey and sandy soils. These separate models were recombined into a single model by incorporating a soil's thermal conductivity as an input.

Researchers assessed the accuracy of the combined statistical model using frost depth data measured in Michigan and Minnesota.

Results

Existing frost depth models include the Pacific Northwest National Laboratory's UNSAT-H, a one-dimensional finite difference heat and mass balance model that requires extensive information about hydraulic and thermal properties, two mechanistic-empirical models and one empirical model. However, none of these models calculated frost depths that closely matched measured results in Michigan. The differences between the measured and the estimated frost depths may be because most models require data that are not readily available and were estimated for the purposes of evaluation.

The initial frost depth model created for this project included only CFDD as an input. This model predicted frost depths in Michigan accurately, but it over-predicted reported frost depths in Minnesota by up to 40 inches. When researchers created separate models for clayey and sandy soils, still using only CFDD as an input, accuracy improved significantly in both states. However, the model for sandy soils was less accurate than the clayey soil model because of greater variability in the sandy soil's grain size and grain size distribution.

The final frost depth model uses a soil's average thermal conductivity in addition to CFDD as inputs. Comparisons of the model's predictions to actual frost depths produced accurate results for all soils in both Michigan and Minnesota. This suggests that thermal conductivity can express the impacts of a variety of soil parameters adequately.

The simplified frost heave model produced accurate predictions of frost heave under shoulders and pavements at five sites in Oakland County, Michigan. However, the accuracy of calculations of heave pressure due to frost heave could not be evaluated due to lack of field data.

Value

The primary benefit of this project was the development of an accurate model for frost depth using easily obtained thermal conductivity data rather than a large number of data points that are currently unavailable for Michigan.

Researchers recommend that the developed frost depth model be used in conjunction with a thaw model (to be developed) to foster procedures and policies for predicting the times when seasonal load restrictions should be imposed and removed. Such procedures would provide better protection of the pavement infrastructure and would save the industry from unwanted expenses.

Research Administration

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