Design Spreadsheet Offers Alternatives to Protect Pavements from Frost Damage

What Was the Need?
Research has shown that frost action is the most severe environmental force to impact pavement performance. When water penetrates road bases and subbases and then freezes, it causes frost heave, the expansion of materials that triggers transverse forces up through pavement structures. Frost heave can reduce subgrade strength during spring thaw, impacting pavement surface smoothness and leading to cracks and potholes.

MnDOT’s pavement design procedures focus on expected traffic levels, environmental factors and potential damage forces, and address subsurface drainage and subgrade preparation. However, design standards do not characterize subgrade susceptibility to frost, potential frost heave or deleterious effects of frost on ride smoothness.

Since 1995, MnDOT has required the use of frost-free materials (FFM) in subgrade depths of 30 to 36 inches for asphalt pavements, based on traffic load requirements. It is not clear that such FFM requirements are effective. In some areas, 30 inches may be excessive and, therefore, unnecessarily expensive; in others, 36 inches of FFM may not be enough, leading to costly pavement failure and repair. MnDOT needed a research-based pavement subgrade design procedure for resisting frost damage in pavements.

What Was Our Goal?
The goal of this project was to develop a procedure for optimizing subsurface materials and thicknesses based on existing subgrade soils and geographic areas in Minnesota in order to resist pavement damage from frost action.

What Did We Do?
Researchers first reviewed existing literature on frost action and frost susceptibility. They synthesized national and international research and looked at practices and standards for mitigating frost action in states and countries with climates similar to Minnesota’s. Then they reviewed MnDOT’s current and historical policies and practices.

The central effort in this research was to examine existing pavements in Minnesota to characterize pavement performance and winter profiles. Researchers and the Technical Advisory Panel selected 72 pavement sites for study based on soil types (such as glacial till, clay, silt, sand and peat); pavement types (including concrete, asphalt and composite); subsurface materials and thickness; and weather conditions. The team evaluated construction logs, project plans, management data and subsurface investigations, and they augmented Minnesota-specific data with performance and soil data from the Federal Highway Administration’s (FHWA’s) Long-Term Pavement Performance (LTPP) program. Researchers created winter pavement profiles of most of the sites and compared them with roughness and ride quality data collected the previous summer.

Researchers studied records on Minnesota roadways, subgrades and regions for frost susceptibility and performance. After conducting pavement profiles in summer and winter, investigators correlated findings with FHWA data to develop a simple design tool for determining the amount of frost-free materials needed for a specific site’s subgrade to prevent frost and freeze-thaw damage to pavements.
Finally, the team analyzed performance trends and design and construction details to assess the effect of frost heave on ride quality. Using the findings from this effort, the team built a design tool for determining what pavement structures require of subgrades to resist environmental effects based on project location, projected frost depth and soil type.

**What Did We Learn?**

The initial evaluation did not produce strong correlations between winter ride quality and factors like FFM depth, grading soil depth and region. Winter ride quality measurements were poorer than summer measurements, but the role of FFMs remained unclear. Insufficient data, outliers and other questionable information were culled from the records, which were then amplified with data from other pertinent historical sources. Results from this effort suggested that FFM depth may improve pavement performance by incrementally reducing ride deterioration, particularly at depths of 25 inches or greater.

Review of relevant LTPP data established that shallower FFM depths and greater silt content in subgrades correlate with poor pavement ride quality. Silty soils, which have low permeability and produce high capillary effects, have long been considered susceptible to frost damage.

Researchers avoided thermodynamic modeling and analysis—and kept the design tool simple—by selecting subgrade silt content as a proxy for frost susceptibility. The spreadsheet tool uses project location (latitude and longitude), predicted frost depth and subgrade soil silt content as the key factors in frost susceptibility of pavements. The tool recommends frost treatment ranges from about 30 percent of predicted frost depth for soils with zero silt to over 80 percent of predicted frost depth for soils with 100 percent silt. The spreadsheet requires limited laboratory testing of subgrade soils, is simple and inexpensive to implement, and produces results similar enough to MnDOT’s practices that they will not require dramatic change in construction needs.

**What’s Next?**

Researchers produced four spreadsheets, each employing a different combination of frost depth prediction and soil type characterization. Once MnDOT selects its preferred spreadsheet and determines if additional subsurface tests should be included as inputs, pilot implementation will begin. Additional study to enhance the tool could include investigating MnROAD cells further, collecting more winter ride quality data, developing uniform frost depth prediction methods and tracking more information from new construction.

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