Climate Research at MnROAD
MnROAD Lessons Learned – December 2006
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1 Abstract

From the beginning, MnROAD was imagined by its planners as a cold-regions research facility for pavements. In its first decade of operation, MnROAD was the site of numerous experiments whose main aim was to observe the effects of a Minnesota winter (or more than one winter) on the pavement system, from the materials in the surface course to the soils in subgrade. In holding to its goals as a cold-regions research facility, MnROAD engineers developed an extensive knowledge of pavement construction, design, and maintenance in cold-regions climates. In many areas, MnROAD engineers were pioneers in their particular cold-regions study: for instance, MnROAD engineers were some of the first in the United States to closely observe low-temperature cracking in pavements. Furthermore, MnROAD has gathered a significant amount of environmental data and data related to cold-regions phenomena such as low-temperature cracking. This brief details some of the MnROAD products dealing with MnROAD's experience in cold-regions pavements.

2 Background

Thanks to Minnesota's harsh winters, MnDOT engineers and administrators involved in the early planning of MnROAD were aware of the importance of environment in pavement performance. These planners recognized the need for and benefit of research in the effects of cold region climates on pavement systems. Furthermore, these planners also realized the benefit this research would have to pavement engineers outside of Minnesota. As a result, using a combination of federal and state funds, the Cold Regions Pavement Research Test Facility, later to be known as the Minnesota Road Research Project, was constructed starting in 1991 and opened to live traffic in 1994.

Almost all of the original research objectives for MnROAD were then informed by the desire to position MnROAD as a cold-regions research facility. Though only one of the fourteen deals directly with cold-regions research (frost action prediction), all of the objectives were composed with an understanding that MnROAD's contribution in each case would be distinguished by the regular seasonal changes (and their extremes) that accompany Minnesota's climate.

While MnROAD's planners recognized Minnesota's unique climate, with relative temperature extremes in both the winter (-20˚F) and the summer (100˚F), as a resource that could be exploited by the pavement community in pavement research, the first batch of test sections constructed at MnROAD were mainly concerned with investigating thickness for the sake of existing pavement designs. It was not until the failure of some of these sections due to environmental factors that MnROAD engineers quickly shifted MnROAD's primary focus from thickness to environment.

Since setting its aim on environment and environmental effects on pavements, MnROAD has accomplished even more work dealing with the response and performance of pavements to environment. One of the foremost concerns of MnROAD as a cold-regions facility has been the collection of a wide variety of climatic data, which derives from instrumentation that includes and is not limited to:

- Temperatures sensors in the pavement, base, and subgrade layers
- Moisture sensors in the underlying base and subgrade layers
- Piezometers that provide water table elevations under each cell
- Frost penetration depth surveys, and
- Precision surface elevation changes measured periodically to monitor the effects of frost heave or other factors that result in changes in pavement elevations.

Given MnROAD's unique position as the leading full-scale pavement facility in a cold-regions environment in the United States, MnROAD has conducted and contributed to a number of cold regions projects, some of which will be discussed in the following sections.

3 MnROAD Cold-Regions Research and Data

The following selection of topics characterizes the first ten years of MnROAD as a cold-regions research facility. These topics present significant uses of MnROAD data and expertise in cold-regions research.

3.1 CRREL Materials Tests and Frost Depth Modeling

Some of the earliest work in cold-regions research done using MnROAD data and materials was that of the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). From January 1990 to December 1994, as part of a research project between MnDOT and CRREL, engineers at CRREL participated in two main research topics: the testing of base and subgrade materials from MnROAD and the use of the CRREL Mechanistic Pavement Design and Evaluation Procedure to predict the performance of MnROAD test sections. This brief will discuss the material tests conducted, while the pavement design and modeling portions of CRREL's work are discussed in the Lessons Learned brief on mechanistic-empirical design.

In MnDOT Reports 1996-21 and 1996-23, CRREL researchers describe the resilient modulus tests conducted on materials from MnROAD. Many of these materials were tested in both frozen and thawed conditions, and the results of these tests were used to create equations to predict the modulus of a given material in a frozen state based on that material's degree of saturation and density. CRREL conducted these tests mainly to provide inputs for its pavement design procedure, which is described in the Lessons Learned brief on mechanistic-empirical design.

Later work by Berg in MnDOT Report 1997-21 calculated maximum frost penetration depths, using the modified Berggren equation, for the test sections at MnROAD over three winters. These calculated depths were then compared against the measured frost depths for the same period of time and discussed. Berg found that the calculations overestimated frost depths substantially. As the author suspected that some of this error might have been due to measurement error, Berg recommends that MnROAD reevaluate its measurement data from the test sections that were particularly divergent from the expected frost depths. Berg also found, however, that by adjusting certain inputs (thermal conductivity of materials and mean annual soil temperature), he was able to obtain calculations that better agreed with MnROAD measurements. Berg's study, as an appendix to the CRREL reports, concludes by providing MnROAD with more directions for research and environmental measurements.

3.2 Seasonal Variation in Pavements

One of MnROAD's most publicized benefits to the state of Minnesota has been in the field of seasonal variations in pavements, and this topic was covered in a number of thorough reports in 1999-2000. Using data from MnROAD, Ovik et al. in MnDOT Report 2000-35 were able to conduct a close analysis of the moduli in various layers of a flexible pavement system. In doing so, the researchers divided the calendar year into five distinct seasons for the purposes of a mechanistic-empirical design method specific to Minnesota.

The so-called fifth season results from splitting the spring season to reflect the effects of spring thaw. Thus, in the early spring the aggregate base contains a large amount of moisture, while the subgrade is still frozen, and in the late spring the aggregate base is mostly drained but the subgrade has now thawed and thus less stiff. Hence, the fifth season, when incorporated into a mechanistic empirical design, allows the designer to account for the fact that through one full season different layers of the pavement system will contribute structurally to the system in a highly variable manner.

One of the most publicized benefits of this approach to pavement and environment was legislation concerning load limits for Minnesota's roadways, as detailed in MnDOT Report 2000-18 by Ovik et al. and MnDOT Report 2004-25 by Ovik and Siekmeier. These benefits are those of spring load restrictions and increased winter load limits, and they are well known to pavement engineers in the state of Minnesota for their contributions to savings in road maintenance budgets. The reports in seasonal variation have been one of the most heavily promoted MnROAD products, and in that role they have informed both public policy on Minnesota's roadways and the pavement design for Minnesota's roads (in the form of ROADENT and later MnPave). For more details on the influence of MnROAD work in seasonal variation of pavements, consult the Lessons Learned brief on mechanistic-empirical design.

3.3 Integrated Climatic Model

As part of the AASHTO Mechanistic-Empirical Pavement Design Guide, the user the designer executes the Enhanced Integrated Climatic Model (EICM), which is incorporated into the MEPDG software. This software includes multiple seasons of hourly weather data from weather stations across the United States. Among these weather stations is that of the MnROAD site.

However, MnROAD's climatic data obviously does not end with that collected by its weather station. As detailed in the Background section, this data is quite extensive and covers changes in moisture and elevation to changes in temperature through the entire pavement system, as typified by Figure 1.

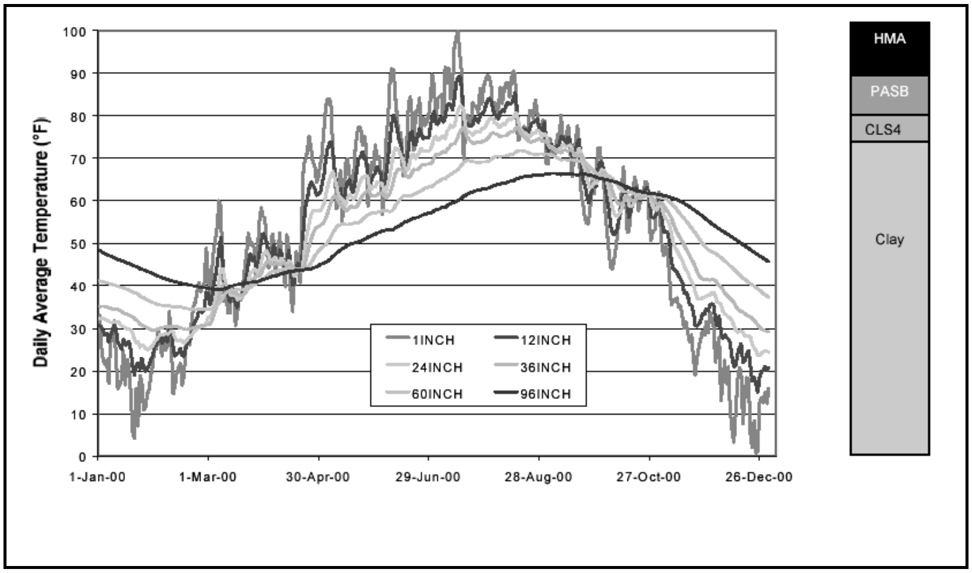

Figure 1. Seasonal variations of temperature for several depths of a test section at MnROAD.

The extent and quality of this data has made MnROAD data very attractive to those professionals modeling pavements and needing data for verification and calibration efforts. For this reason, the creators of EICM, the climatic model incorporated into MEPDG, looked to MnROAD for data in developing EICM. Temperature profiles through the slab thickness for several of the MnROAD concrete pavement sections were used for verification of the EICM temperature predictions for concrete pavements. Furthermore, the developers of MEPDG expect that the data collected at MnROAD for both asphalt and concrete pavements will be used for further validation of the EICM predictions, especially to predict the moisture content of unbound materials and the variation of asphalt temperature throughout the asphalt surface thickness.

3.4 Low-temperature Cracking

MnROAD engineers detected the first signs of thermal cracking in January 1994 in five test cells (Palmquist 1999). As MnROAD immediately began making close observation of low-temperature, or thermal, cracking in the HMA test sections, thermal cracking is a phenomenon that MnROAD engineers have closely studied for all of MnROAD's first ten years of operation. Figure 2 illustrates different types of thermal cracking observed at MnROAD.

Figure 2. Typical thermal cracking patterns on PG 58-28 (top) and PG 64-22 (bottom) test cells at MnROAD (Clyne et al. 2006).

In addition to noting important environmental and material data along with their observations, from the outset MnROAD engineers have recorded these observations in light of possible research topics: for instance, MnROAD proposed the necessity of load-related inputs for thermal cracking models by observing that in many cases more thermal cracks developed in the right (driving) lane than in the left (passing) lane in the mainline sections. A number of test section assessment reports by Palmquist, Worel et al., Palmquist et al., and Zerfas describe in detail the damage done by the Minnesota's climatic extremes.

While there was not a significant amount of modeling done with MnROAD data throughout the first ten years of MnROAD, toward its later years work on thermal cracking involving MnROAD data became more prevalent. The first example of researchers using MnROAD material and thermal cracking data to evaluate or develop thermal cracking models is that of Waldhoff et al. (2000). Waldhoff described the use of MnROAD data to verify the predictions of the Superpave Indirect Tensile Test, but more importantly, using MnROAD's as-built and material properties, Waldhoff compared the predictions of the Superpave thermal cracking model (TCMODEL) with observed cracking at MnROAD to suggest revisions for TCMODEL.

Near the conclusion of MnROAD's first ten years of research, Marasteanu et al. in MnDOT Report 2004-23 conducted the first major research for MnDOT that uses

MnROAD data to attempt to model and account for the thermal cracking observed at MnROAD. This report discusses in depth two important topics: experimentation and modeling. The experimental portion consisted of developing a semi-circular bend test to determine the stress intensity factor for various asphalt mixtures at low temperatures. This test allows for the selection of materials that perform better in cold-region pavements.

The modeling portion of the study involves two separate models to predict the performance of asphalt pavements under thermal cracking: the first is fictional restraint crack spacing model that predicts thermal crack spacing, while the second model accounts for the cumulative damage due to the crack and the propagation of the crack through the asphalt layer. In addition, the work in Marasteanu et al. addresses the thermal cracking component of the AASHTO Mechanistic-Empirical Pavement Design Guide and finds many inadequacies of this model based on the analysis done using MnROAD data. The report concludes with recommendations for the testing of materials and modeling of phenomena in understanding low-temperature cracking.

In addition, MnROAD's interest in preventing thermal cracking has led to experiments with new materials such as emulsified oil-gravel surfaces. This material is detailed in the Lessons Learned technical brief on low-volume roads.

4 MnROAD Contributions to Pavements in Cold-Regions Research

MnROAD's main contribution to cold-regions research is its database. As detailed above, this database consists of a wide spectrum of climatic data. Furthermore, this data has been used for a variety of projects by researchers in pavements. One of the more influential uses of MnROAD data has been that by the developers of models for pavements. These uses of MnROAD data have been to predict frost depths, thermal cracking, and other climate-related phenomena. The most noticeable uses of MnROAD data has been in the calibration and verification of a number of pavement design methods, including the CRREL procedure for freezing climates and the MEPDG. In particular, MnROAD data has been used extensively in calibrating and verifying EICM, a component of MEPDG.

One of the most important contributions of MnROAD on a national level is MnROAD's effort in observing and documenting thermal cracking on its test sections. MnROAD's experience with thermal cracking brought this topic to prominence in the pavement community. Many subjects of surveys and interviews for the MnROAD project felt that MnROAD's work in thermal cracking, considered by itself, was significant enough to warrant the cost of MnROAD versus its impact on pavements. MnROAD's data on thermal cracking will continue to be the main source of thermal cracking data in the United States for many years to follow.

The benefit that most state and local pavement engineers would point to if asked to justify MnROAD would be that of the work in the seasonal variation of pavements. Early estimates put the savings of spring load restrictions to road maintenance costs in Minnesota in the millions of dollars per year. Though current estimates are unavailable, many MnDOT officials feel that the money saved by spring load restrictions effectively "paid for" the entire Minnesota Road Research project.

5 Recommendations

While MnROAD provided much data to climate models and has been the site of a number of cold-regions experiments, many of MnROAD's endeavors in cold-regions research have suffered from a lack of exposure to the larger pavement community. As the quality of its facility, its database, and its engineers already position it as the premier cold-regions test track in the world, the only remaining task for MnROAD is to publicize these facts.

Quite simply, MnROAD needs to increase its profile, but more importantly increase its profile as the main source for cold-regions data and expertise in pavements. While some may feel that MnROAD has already established itself as the premier cold-regions research facility for pavements, the Lessons Learned research team has found through interviews, surveys, and literature searches that a surprising number of pavement professionals are either unaware of MnROAD or unaware of MnROAD data when it is being utilized in research. MnROAD must make an honest attempt to formally publish its research in as visible a manner as possible. Posting unpublished and unfinished reports to a URL on the MnROAD website is not a form of publishing. Furthermore, MnROAD needs to standardize its data releases and its guidelines for data usage so that pavement professionals know how MnROAD would like to be cited when MnROAD data is used for research.

6 References

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